SIMULATION OF MIXED-FEED LIME SHAFT KILN : PERFORMANCE ANALYSIS AND OPTIMAL DESIGN

A THESIS

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By

CHAMAN LAL VERMA

DEPARTMENT OF CHEMICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled 'SIMULATION OF MIXED-FEED LIME SHAFT KILN: PERFORMANCE ANALYSIS AND OPTIMAL DESIGN' in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy submitted in the Department of Chemical Engineering of the University is an authentic record of my own work carried out during a period from July, 1979 to December, 1986 under the supervision of Dr. S.K. Saraf and Dr. N.G. Dave.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree.

(CHAMAN LAL VERMA)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(NATWAR G. DAVE)
Scientist (Building Materials)
Central Building Research
Institute, Roorkee (U.P.) 247 667
India

(SHANT KUMAR SARAF)
Professor of Chemical Engineering
University of Roorkee, Roorkee
(U.P.) 247 667 - India

DATE : 20 DECEMBER, 1986

ABSTRACT

The process of endothermic decomposition of calcium carbonate (limestone) to calcium oxide (quick lime) is brought about at elevated temperatures usually exceeding 1173 K under atmospheric pressure conditions. A mixed feed lime shaft kiln is basically a solid fuel-fired moving bed reactor with the upward-flow of hot gases counter-current to the down-flow of a mixed-charge of limestone and fuel particles undergoing calcination and combustion, respectively. A kiln basically has three operating sections, namely, the preheating, the burning and the cooling zones. The feed consisting of limestone and fuel particles is loaded into the kiln at the top, and the calcined product is withdrawn from its bottom. Air at ambient conditions enters at the bottom and the hot kiln (exhaust) gases leave from the top of the kiln.

The literature survey revealed that although the most sophisticated lime shaft kilns have been developed to obtain high productivity, lime quality and thermal efficiency, yet the design of a suitable kiln for a new situation using the basic princip les involved in lime burning remains uncertain owing to the complex nature of the process and the uncertainties involved in the operating practices. No published information is available on mathematical modelling and simulation of the mixed-feed limeshaft kilns.

A field survey conducted for the study of lime kilns in India revealed that a major fraction of lime is being produced in the mixed-feed lime shaft kilns in the building and small scale process

industries for capacities generally in the range of 5 to 15 tonnes of quick lime per day. Presently these kilns are designed using thumb rules, based on past experience. For example, the relevant Indian Standards suggest a height-to-diameter ratio in the range of 3 to 4 corresponding to a superficial lime output rate of 2.5 tonnes/(m^2) (day) for an efficient mixed-feed vertical lime shaft kiln.

In view of the importance of the mixed-feed lime shaft kilns for lime manufacture in India, the present investigation was undertaken to develop a detailed mathematical model for simulating the performance of such kilns. The effect of different design and operating parameters on the performance of these kilns was then studied to establish optimal design and operating criteria.

Initially an attempt was made to evolve some state-of-the-art process engineering correlations for the mixed feed lime shaft kilns based on published information and the experience gained during the field survey and investigations on some commercially operating kilns. The energy requirements for the preheating and calcination of limestones were correlated with their chemical compositions. For a continuously operated kiln the times required for the preheating of limestone particles, their calcination and cooling of the product quick lime were correlated in terms of the particle diameters and the superficial lime output rates. The heights of the three zones of the lime kiln were estimated through the knowledge of the retention times for the respective zones. On account of the generalized practice

of semi-continuous kiln operation followed for these types of low capacity mixed-feed kilns, a correlation was evolved to estimate the increase in the overall retention time by duly accounting for the time lag of manual over mechanized operation, working (8-hourly) shifts per day, the number of charges or discharges effected per shift, and the average time for each charge or discharge.

Simulation of the mixed-feed lime shaft kiln required a detailed study of the phenomenological behaviour of the process and careful analysis of the design and operating parameters. The important design parameters identified are : Nominal lime production rate, Superficial lime output rate, wall thickness of brick masonry shaft and the exhaust gas temperature. The operating parameters of significance are : the size of limestone particles, the size and composition of the fuel particles, limestone-to-fuel ratio in the mixed-feed (input) and excess air fraction.

The shrinking core model has been assumed for the decomposition of a limestone sphere undergoing calcination. At a given instant, there is a central core of undecomposed calcium carbonate surrounded by a shell of calcium oxide with the reaction occurring at the interface between the core and the shell. Rate of conduction of heat through the lime layer to the limestone core boundary has been taken to be the calcination rate controlling mechanism. The surface of stone exchanges heat with the fuel and

gases by conduction, convection and radiation mechanisms. The undecomposed limestone core is assumed to remain at the calcination temperature (1173 K) after the commencement of the calcination process irrespective of the core size. The net heat received at the surface of the limestone-lime particle is consumed for the dissociation of calcium carbonate and partially for the heating up of the lime layer. The stone particle conduction equation was solved using the usual quasi-steady state assumption for any specified surface temperature and limestone conversion. Development of the model equation with due consideration for the sensible heat accumulation in the lime layer, and accounting for variations in surface temperature and fractional conversion along the axial position in the kiln are the novel features incorporated in the proposed model.

The proximate analysis of coal provides a basic framework for describing its combustion behaviour in a mixed-feed lime shaft kiln. The coal particles get preheated initially to 373 K and thereupon the demoisturization starts. The volatile matter is assumed to be driven off linearly with temperature when the fuel temperature lies in the range of 673-1173 K. Instantaneous combustion of the volatile matter is generally assumed when the fuel temperature becomes equal to greater than 948 K, the assumed value of auto-ignition temperature for the volatile matter. The volatile matter released in the fuel temperature range of 673 to 948 K is assumed to escape unburnt resulting in the partial loss of thermal efficiency.

The ignition of the fixed carbon content of a coal particle has been assumed to commence only after the process of devolatilization is completed. The kinetics of shrinking particle size model has been assumed for combustion of the fixed carbon content of the fuel alongwith simultaneous segregation of ash from the fuel particle. An equation to describe the combustion behaviour of the fixed carbon content of the coal particle was used which accounts for the surface reaction rate and oxygen mass transport resistances.

When the fuel temperature reaches 1173 K (assumed ash fusion temperature) and above, the fusion of the ash particles is assumed to result in the formation of a porous ash layer around the shrinking core of fixed carbon interspersed with the fine ash particles. The necessary changes in particle surface areas before and after the ash fusion and increase in the density of the ash layer on account of its shrinkage with increase in the fuel temperature are also incorporated in the model.

Detailed analysis and modelling of the preheating, burning and cooling zones of the coal fired lime shaft kiln are carried out with some realistic assumptions. Comprehensive material and energy balances have been written for a differential volume element of axial width ΔZ at a given axial position (Z) of the kiln in due cognizance of the conditions prevailing in a particular zone of the kiln under

consideration. The complicated interphase modes of the heat and mass transfer processes with or without chemical reactions, the relevant heat transfer coefficients, effectiveness factors for estimating active heat exchange surface areas, variations in specific heats with temperature and composition, variations in gas emissivities for gas-solid radiant heat exchange, etc., are properly accounted for in the analysis of a particular zone. In addition, the bulk movement of gaseous components from one phase to another at appropriate temperatures and their contributions in the energy balances are properly incorporated in the proposed models. The temperatures of bulk gas, limestone and the fuel particles, fractional degree of combustion of the fuel and fractional degree of calcination of the limestone particles are the important output parameters obtained from the solution of the simulation model after applying suitable convergence criteria. Thus, a rigorous, uniquely stable and efficient system has been developed for analyzing the behaviour of a coal fired lime shaft kiln.

The important design and operational parameters investigated, their average values for the base conditions, and their ranges of variation are given in Table-6.1 (Chapter-6).

The effect of variations in the design and operational parameters on the performance of the kiln are extensively discussed. Temperature and conversion profiles pertaining to the base conditions are carefully analyzed. Only one parameter is varied at a time for

parametric sensitivity analysis by choosing the maximum and the minimum values of the ranges investigated apart from the base conditions, maintaining all the other parameters at the values corresponding to the base conditions. The results of the senstivity analysis are presented in Tables-6.4 through 6.6 (Chapter-6).

The aim of the present investigation was largely to develop a comprehensive, uniquely stable and an efficient simulation system for the mixed feed lime shaft kiln, a stupendous task in itself, and not to carry out rigorous optimization studies for such kilns. But parametric sensitivity analysis le d to the identification of the following optimum and most appropriate design and operating conditions from the thermal performance point of view for a nominal lime production rate of 10 tpd :

(i) Partical size of limestone (d_{p_s}) =0.100 m

(ii) Ratio of particle size of fuel to size of limestone (d_{p_f}/d_{p_s}) = 0.5

(iii) Superficial lime output rate (P_s) = 3.0 t/(m^2) (day)

(iv) Limestone to fuel ratio (X_r) =5.8

(v) Fractional content of volatile matter in fuel (X_{fv}) = as low as possible, but not exceeding 0.25

(vi) Excess air based on total combustion of fixed carbon and total volatile matter (X_{ea})

= - 10 percent

(vii) Wall thickness of masonry shaft (W_{rb}) excluding fire bricks = 0.46 m

(viii) Exhaust gas temperature (T_{g_o}) = = 813 K

For the above conditions the effective kiln height-to-its-internal diameter ratio in around 6.5.

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NOMENCLATURE

a	Constant as defined
a_s	Specific interfacial area of limestone particles, m^2/m^3 of bed volume
a_f	Specific interfacial area of fuel particles, m^2/m^3 of bed volume
$A_{l/c}$	Fractional time lag allowance for manual kiln operation over mechanised operation
C, C_p	Specific heat, Kcal/(Kg)(K)
d_p	Average particle diameter, m
D	Diameter, m
E	Energy, specific energy, Kcal/Kg
E_a	Fractional excess air
E_s	Endothermic heat of dissociation of limestone, Kcal/Kg
G	Superficial gas mass velocity based on empty kiln cross-sectional area, $Kg/(m^2)$ (hr)
h	Heat transfer coefficient, $Kcal/(hr)(m^2)$ (K)
H	Height (Length) of zone, m
H_f	Heating value of fuel, Kcal/Kg
H_l	Heat loss, Kcal/hr
k	Thermal conductivity, Kcal/(hr)(m)(K)
k_s	Surface rate constant, $Kg/(m^2)(hr)(atm)$
k_d	Diffusional rate constant, $Kg/(m^2)(hr)(atm)$

$\bar{K}_s$	Rate constant for combustion of carbon due to combined effect of surface as well as diffusional resistances, $Kg/(m^2)(hr)(atm)$
L	Length,m
m	Mass, Kg
$\dot{m}$	Mass flow rate (Kg/hr)
n	Number of particles
Nd	Number of discharges effected per shift in semi-continuous kiln operation
N_s	Number of working shifts per day employed in semi-continuous kiln operation
Nu	Nusselt number
p	Partial pressure, atm
P_n	Nominal lime production rate, tonne/day
P_s	Superficial lime output rate based on inner cross-sectional area of empty kiln, $tonne/(m^2)(day)$
P_v	Superficial lime output rate based on inner volume of kiln $tonne/(m^3)(day)$
Pr	Prantl number
Q	Rate of heat transfer, Kcal/hr
r	Radius, m
r_c	Radius of calcium carbonate core, m
r_p	Radius of particle, m
R	Radius of of kiln, m
R	Gas constant
R_t	Retention time, hr

Re	Reynolds number
s	Surface
S	Sensible heat, Kcal
S_{hl}	Sensible heat content of the lime layer, Kcal
t	Time
t	Tonne (metric)
T	Temperature, K
T_{dm}	Temperature of demoisturization, K
T_{ff}	Incipient ash fusion temperature of coal, K
T_{vmc}	Auto-ignition temperature for VM combustion, K
U_i	Overall heat transfer coefficient based on inner wall area, Kcal/(hr)(m^2) (K)
v_{sf}	Volumetric flow rate of stone and fuel, m^3/hr
V	Volumetric flow rate, m^3/hr
V	Fractional volatile matter of fuel on dry ash free basis
W	Wall
W_{fb}	Fire bricks wall lining thickness
W_{rb}	Red bricks (clay) wall lining thickness, m
W_t	Wall thickness of the kiln shaft, shaft
x,X	Fractional conversion, weight fraction, fractional content by weight
x_f	Fuel conversion based on original unit mass of fuel
x_s	Fractional degree of calcination of limestone
x_{ff}	Fractional fuel conversion at incipient ash fusion point
X_r	Limestone to fuel ratio by weight

Z	Distance along the axis taken as positive from top/upper section of kiln/zone, m
Δ	Forward finite difference operator
ΔH_l	Wall heat losses, Kcal/hr
ΔZ	Width of differential element along the axis of kiln, m
α	Constant as defined in text
β, γ	Constant as defined in text
θ	Time, hr
θ_d	Average time of each discharge effected in manual kiln operation, hr
$\theta_{r/z}$	Retention time for an operating zone of kiln under semi-continuous operation, hr
$\theta_{t/c}$	Retention time for continuous operation, hr
ϕ	Sphericity of solid particles
η	Effectiveness factor (fraction)
η_l	Fractional thermal efficiency of lime kiln
μ	Viscosity, Kg/(m)(hr)
ρ	Density, bulk density, Kg/m^3
ρ_{ff}	Density of fuel at incipient ash fusion point
λ_w	Heat of desorption of water, Kcal/Kg
λ_{vm}	Heat of devolatilization, Kcal/Kg
σ_λ	Radiation constant, $Kcal/(m^2)(hr)(K^4)$
ϵ	Emissivity
ϵ_b	Bed porosity

SUBSCRIPTS

a	air, ash
av	average
b	burning
c	conduction, convection, cooling, core, coke, fixed carbon
d	decomposition, diffusion, discharge, dissociation
dm	demoisturization
dv	deveolatilization
e	effective, excess
ea	excess air
eff	effective
ex	external
f	fuel
fa	fuel ash
fb	fire bricks
fc	fixed carbon
ff	ash fusion condition
fg	fuel to gas
fm	fuel moisture
fs	fuel to stone
fv	fuel volatile matter
g	gas
gf	gas to fuel
gs	gas to stone
gls	general lime stone
gw	gas to wall
hl	heat of lime layer

i	inner
l	lime, loss
m	mixture (of limestone and fuel), mean
max	maximum
mf	mixed-feed
min	minimum
n	nominal
o	outer, kiln inlet condition (top)
p	particle, preheating, purity
pl	product lime
r	radiation, ratio, reference, room
rb	red (burnt clay) bricks
s	stone, specific, surface
sg	stone to gas
t	thickness, time, temperature, tube
vc	volatiles combustion
vm	volatile matter
wa	wall to air
wg	water vapour (gas)
u	under burning
w	wall, water
∞	ambient air

CHAPTER-1

INTRODUCTION

Chapter - 1

INTRODUCTION

Lime is a basic industrial chemical which is known to mankind, as a building material, since times immemorial. It finds extensive applications in the building, chemical, paper, sugar, pharamaceutical, iron and steel, and numerous other industries. The chemical grade lime is of highest purity and is used, by and large, as captive lime in the soda ash, precipitated chalk, carbide, synthetic rubber, glass, aluminium, magnesium and the aforesaid industries. Building lime has been classified in different grades depending upon its quality and composition (I.S.I., 1973). This material is mostly harnessed in preparation of mortars, plasters, pozzolanas, sand - lime bricks, and for purposes of whitewashing and soil stabilization, etc.

Manufacture of lime is effected by the burning of limestone rocks having significant percentage of calcium carbonate at controlled operating conditions and thus, in the process, driving off carbon dioxide from the parent stone. The impurities present (primarily silica, alumina, iron oxide, etc.) in the stone are non-volatile in nature and remain as contaminants in the lime produced. Limestones generally contain some quantities of magnesium carbonate also, and depending upon the relative proportions of calcium and magnesium carbonates in the stone, different nomenclatures are used to classify the limestone, but two basic types are of commercial importance, namely, calcite and dolomite (Boynton, 1967). The calcitic stone usually contains calcium carbonate exceeding 95 percent and the dolomitic

stone has the magnesium carbonate content of 35 - 40 percent by weight. During the burning operation both the carbonates are converted to their corresponding oxides. Dolomitic lime is used largely in the refractories where a high MgO content is essential.

The endothermic process of decomposition of pure calcium carbonate (limestone) to calcium oxide (quick lime) is represented by the reaction as:

$$CaCO_3 + \text{Heat} \longrightarrow CaO + CO_2 \qquad (1.1)$$

Similarly the representative reaction for the calcination of dolomitic limestone ($CaCO_3.MgCO_3$) to dolomitic quick lime (CaO.MgO) is:

$$CaCO_3.MgCO_3 + \text{Heat} \longrightarrow CaO.MgO + 2\ CO_2 \qquad (1.2)$$

The average dissociation temperatures for the above two types of limestones under normal atmospheric pressure conditions are $900^{o}C$ and $725^{o}C$, respectively. Associated with the reaction (1.1) and (1.2) are other undesirable side reactions, viz., the sulphur dioxide present in the stone or fuel tends to react with lime and oxygen to form calcium sulphate which is unstable at high temperatures. So for the production of sulphur free lime it is necessary that the lime remains very hot while in contact with the products of combustion. Alumina and silica combine with both CaO and MgO to form silicates and aluminates at very high temperatures. These compounds are water insoluble and are generally undesirable in lime since they represent a loss of not only the oxide values, but also coat the lime particles with a water impervious layer and so reduce its reactivity.

The reactivity of quick lime is also affected by the higher operating temperatures and retention times. It is well known that temperature has a predominant effect on the rate of dissociation of limestone (Boynton, 1967 and Knibbs and Gee, 1959). With the increase in temperature the rate increases and consequently the reaction time decreases. However, maintenance of higher temperatures beyond an optimum limit for extended periods of time leads to overburning of lime. The process of overburning causes sintering, with a consequent increase in density, decrease in surface area and, therefore, the loss in its reactivity. The optimum temperature for maximum kiln efficiency varies with composition for different limestones.

The physical and chemical properties of the limestones and the fuels employed in calcining them play an important role in determining the material and heat requirements of the process for a given type of firing system and draft employed in the kiln. Thus the process engineering design for the manufacture of quick lime involves careful analysis and accurate estimation of raw material properties and optimisation of important variables, which influence the kiln design and its production efficiency. The major parameters to be controlled in the design and operation of a lime burning kiln are the temperature,feed particle size, retention times, kiln draft, feed input rate, the physical properties and chemical compositions of raw materials, lime to fuel ratios, and heat losses.

A mixed feed vertical lime shaft kiln is basically a moving bed reactor with the upward flow of hot combustion gases, counter-current to the downflow of a mixed charge of limestone and fuel particles undergoing calcination and combustion, respectively. A kiln basically has three operating zones, namely the preheating, burning and cooling. The feed is loaded into the kiln at the top and the calcined product is withdrawn from its bottom.

Even though the most sophisticated lime shaft kilns have been developed to obtain high productivity, lime quality and thermal efficiency, yet the design of a suitable kiln for a new situation using basic principles involved in lime burning remains uncertain owing to the complex nature of the process and the uncertainties involved in the operational practices. Some fundamental and empirical design correlations have been proposed by some investigators for typical kiln designs, especially for oil or gas firing systems. However, no published information is available on mathematical modelling and simulation of mixed-feed lime shaft kilns.

In India a major fraction of lime is being produced in the mixed-feed lime shaft kilns. Presently these kilns are designed using thumb rules based on past experience. For example, the Indian Standards (ISI, 1961 & 1967) suggest a superficial lime output rate of 2.5 tonnes/(m^2)(day) based on empty cross-sectional area and correspondingly height-to-diameter ratio in the range of 3 to 4 for an efficient mixed-feed vertical lime shaft kiln.

In view of the importance of mixed-feed lime shaft kilns for lime manufacture in India, the present investigation was undertaken to develop a detailed mathematical model for simulating the performance of such kilns. The effect of different design and operating parameters on the performance of such kilns was then studied to establish optimal design and operating criteria.

CHAPTER-2

REVIEW OF LITERATURE

Chapter - 2

REVIEW OF LITERATURE

2.1 LIMESTONE CALCINATION AND MECHANISM STUDIES

Studies on the calcination of limestones and the mechanism of calcination have been reported by several investigators, viz., Azbe (1941), Fishwick (1970), Gibbs (1942), Hills (1968), Koloberdin et.al (1972 and 1975), Narsimhan (1961), Satterfield and Feaks (1959), Transtel and Ulrich (1965), and Lee (1976). The decomposition of a limestone sphere, when exposed to high temperatures in a furnace, starts at the surface of the particle and proceeds inwards towards the centre as shown in Fig. 2.1. Temperature gradients develop between the surrounding and the surface of the limestone and between the surface and centre of the lump. At a given instant there is a central core of undecomposed $CaCO_3$ surrounded by a shell of CaO with a relatively thin reaction front between the core and the shell. The rate of reaction could possibly be controlled by the three simultaneously occurring processes:

(i) Heat transfer to the surface of the stone by radiation and convection and thence to the reaction front through the CaO shell by conduction.

(ii) Initiation of chemical reaction at the surface with the evolution of CO_2 and the movement of reaction front radially inwards as the reaction progresses.

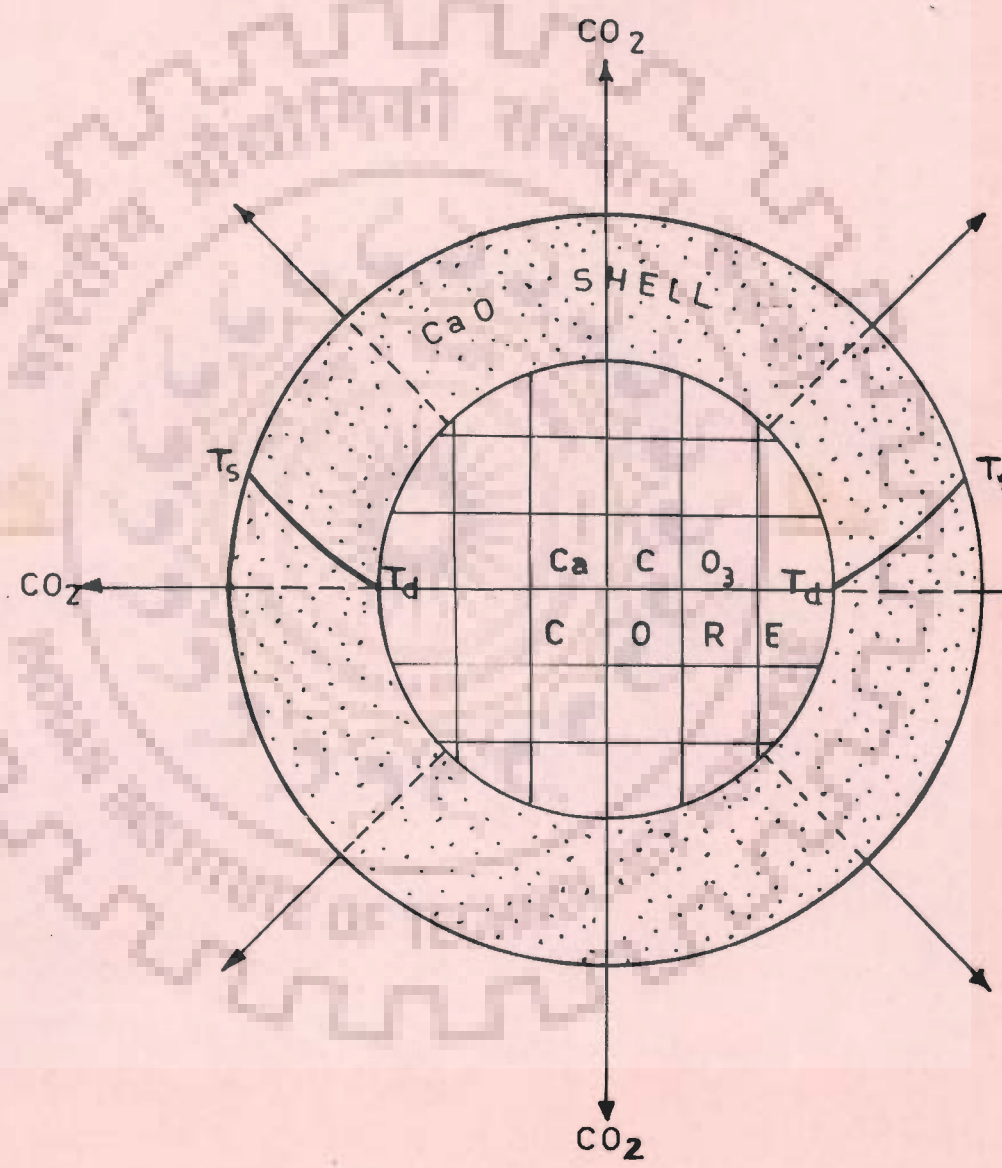


FIG. 2·1— A DECOMPOSING PARTICLE OF CALCITE SHOWING RADIAL TEMPERATURE PROFILE IN CaO LAYER.

(iii) The transfer of CO_2 evolved at the interface by diffusion through the pores of the reactive lime shell covering the unconverted limestone core.

Furnas (1931) studied the rates of calcination by passing streams of hot gases through a sized limestone charge in a furnace. He found that, within a lump of limestone undergoing calcination, (i) the boundary layer between the $CaCO_3$ core and the surrounding CaO shell is clearly visible, (ii) the boundary layer is sharp and thin, and (iii) its rate of travel inwards from the surface is roughly linear with time, independent of lump size and shape. He observed the rate of travel of the decomposition zone to be a temperature function as :

$$\log R = 0.003145\ t - 3.3085 \qquad (2.1)$$

where R is the rate of advance in cm/hr, and t is the temperature in ^{o}C. This equation may be treated as a rough approximation only as it does not fit the results of Satterfield and Feakes (1959).

Satterfield and Feakes (1959) measured the actual temperatures of the decomposing calcium carbonate samples. They observed that the calcination temperature was considerably lower than that of the surroundings, and remained constant during the reaction. Their experiments were conducted in pure CO_2 at one atm pressure and very high temperatures were therefore involved. They concluded that heat transfer was important in controlling the reaction rate at high temperatures. Satterfield and Feakes brought forth the possibility of a chemical control mechanism which involved the cracking of the

original carbonate lattice. They concluded that the effects of CO_2 partial pressure and temperature on reaction rate acted as confirmatory evidence for the proposed mechanisms. According to them a considerable number of previous workers, who proposed a chemical control mechanism suggested the following rate equation for calcination of limestone:

$$M = k\, e^{-E/RT} \qquad (2.2)$$

where M is the reaction rate, expressed as moles/(hr) (sq cm) of reaction area, k is the raction rate constant, E is the activation energy per g. mole, R is the gas constant and T is the absolute temperature in ^{o}K. Accoring to Satterfield and Feakes, the earlier workers who assumed the reaction to be a chemical controlled mechanism found the Arrhenius activation energy for the reaction to be about 40 K cal/g mole - approx. equal to the heat of calcination reaction, whereas, they found a much larger activation energy of the order of 360 K cal/g mole. Thus their investigation did not yield any quantitative information on the kinetics of the chemical reaction.

Gibbs (1942) calculated the rate of heat penetration in the stone through the concept of concentric spherical layers assuming that, the specimen is homogenous in structure and composition, the portion of the specimen undergoing active calcination can be considered as a concentric layer in the sphere, this layer penetrating deeper and deeper as the calcination proceeds. Although this zone of active calcination undoubtedly has some depth or thickness, he merely

considered it as a spherical surface. Consequently he interpretedthe weight loss during the calcining process as that lost by the volume between the active calcining surface and the surface of the 2 in. sphere used by him in the experiment. The furance temperature was varied between $1050^{o}F$ and $2100^{o}F$. Gibbs developed an empirical relation between time and penetration which, he professed, could be approximately used for practical purpose:

$$P = a\,T^{2} + b \qquad (2.3)$$

where P is the penetration in inches (i.e. distance of the actively calcining surface from the surface of the sphere, T is the time in minutes, a is a constant of value 0.00002875 and b is a constant of value 0.0125.

The rates and activation energies for the decomposition of limestones have generally been determined from a series of isothermal decomposition experiments, but Bijawat (1957) showed that these can be obtained from a single nonisothermal decomposition experiment also. Good agreement was observed for the values obtained by the two methods. The results presented by him are based on the experimental data of Azbe (1942). The movement of the calcination boundary is given by the equation :

$$P = r\,(1-F^{1/3}) \qquad (2.4)$$

where P is the penetration at any time Θ in inches. F is the fraction

of CO_2 left at any time in the decomposing specimen, and r is the radius of the sphere.

Transtel and Ulrich (1965) have discussed the reaction processes when limestone is burnt within the temperature range 900 - 1200°C using various slab stone dimensions and CO_2 contents of the furnace. A mathematical analysis of the reaction process has been made in which it is assumed that the heat requirement of the calcination reaction is provided by conduction in the CaO layer, but is hindered by the outward flow of CO_2. The equations developed by the theoretical approach can be used to determine the kiln conditions required to produce a given quality of lime. The speed of calcination can be calculated for a given set of conditions. However, they point out that the correction factors must yet be determined which will allow the equations to be applied to pieces of limestones packed closely within the confines of a kiln.

Narsimhan (1961) has advanced theoretical treatments for the calcination of limestones assuming the reaction to be heat transfer, mass transfer, and simultaneous heat and mass transfer controlled. It is assumed that the surface chemical reaction is very fast and as such does not interfere in the determination of the overall decomposition rate. He has derived rigorous expressions based on heat transfer rate and system properties for the prediction of decomposition times for definite geometrtic shapes such as spheres and cylinders. While deriving his mathematical model for a sphere of calcium carbonate, Narsimhan assumed that the temperature in

the centre of the sphere levels up with the decomposition temperature within a very short time. This assumption has been justified in view of the large magnitude of the thermal diffusivity of calcium carbonate. On this basis there is no internal temperature gradient and all the heat reaching the decomposition plane is used up for the endothermic reaction. The good agreement observed between the actual and predicted values for the burning times bears out the soundness of the decomposition scheme envisaged by him.

The complex theoretical expressions derived by Koloberdin and associates (1972 and 1975) for the thermal decomposition of carbonates could not be experimentally verified. They have derived an equation based on heat transfer to the surface of the limestone particle, thermal conduction through the layer of calcium oxide formed, and on the rate of reaction itself.

An interesting investigation on the subject has been carried out by Hills (1968). His experiments, substantiated with theoretical approach, revealed that the rate of decomposition of limestone spheres is exclusively controlled by heat and mass transfer alone. The definite spherical boundary, that exists between the undecomposed carbonate and a layer of reacted porous lime, maintains its spherical shape and the rate of reaction is solely controlled by the heat transfer to this boundary and by the transfer of CO_2 away from it. He developed a mathematical model of the decomposition process and it was shown to compare favourably with his experimental data. The rate of decomposition of limestone is given as:

$$\text{rate} = 4\pi r^2 \quad \rho_{co_2} \quad dr/dt \text{ , moles/time} \qquad (2.5)$$

where ρ_{co_2} is the molar density of carbon dioxide. If dr/dt is constant then according to this identity the rate per unit area of reaction interface is also constant. Hills observed that the approximate constancy of dr/dt had led many a previous worker to propose that the reaction is controlled by a chemical step at the reaction interface. However, he points out that transport controlled reactions can also display some characteristics, symptomatic of chemically controlled reactions, and so they do not provide any evidence to the mechanism controlling the reactions. He developed some mathematical models based on heat and mass transfer for prediction of the rates of decomposition of the limestone particles which were shown to compare very well with the experimental data. According to him the existing theoretical treatments for packed bed processes do not apply to these reactions since their mathematical formulations involve strongly non-linear equations. As manifested by Hills, the equations derived in his paper should enable one to predict the decomposition of calcium carbonate in packed bed conditions.

Li and Coworkers (1976) investigateed the rates of decomposition of limestones obtained from four different mines. An empirical formula given for the thermal decomposition of limestone is :

$$Y = a \; e^{-bt} \qquad (2.6)$$

where Y is the percent of limestone remaining undecomposed, t is the decomposition time in minutes, and a and b are constants (a =

99.609 - 100.120, b = 0.066 - 0.0081) under the conditions of their experiments. The decomposition temperatures of 800 - 900^{o}C have only been reported.

2.2 MANUFACTURE OF LIME IN SHAFT KILNS

The burning of limestone is carried out in what is known as lime kiln. Several types of kilns, such as the shaft, rotary, fluosolids, the calcimatic, etc., are presently being employed for the manufacture of quick lime, but the present review restricts itself to the shaft kilns only. The general details of the manufacturing process have been reported by some investigators, e.g., Azbe (1947), Beckenbach (1971), Flachsenberg (1975), Middlemas (1964), Schwarzkopf (1970) etc. Recent developments in lime shaft kilns have been reviewed by several workers viz. Dandois and Smithwick, 1973; Das, 1974; Fiedler, 1976; Gribbin, 1970; and Verma and Saxena, 1978. Although the manufacturing technique appears to be simple yet the actual process in a lime kiln is extremely complicated.

The mixed-feed lime shaft kilns have been widely used in the European and oriental countries, but they appear to be comparatively less popular in the U.S.A. These kilns exhibit good thermal efficiency and produce effluent gas with high carbon dioxide concentration. Thus industries using both lime and CO_2, such as sugar, refining plants, basic magnesia plants and alkali industry depend entirely

on such kilns. Small scale production for building lime is also carried out in the mixed-feed kilns in many developing countries.

A schematic diagram of a typical mixed-feed lime kiln has been shown in Fig. 2.2. It is usually a tall cylindrical structure lined inside with refractory and insulating bricks. The fuels employed in burning limestone may be coal, coke, charcoal, cinder, or wood. A unformly mixed-proportion of limestone and fuel is lifted by a skip hoist to the top of the kiln and thence loaded into the kiln. As the burning progresses the charge travels down through the kiln to a rising stream of combustion products. The lime produced is removed from the bottom of the kiln by some suitable means. Generally, the kiln operates in three zones, namely, the preheating, calcining and the cooling zones. The middle calcining zone operates at elevated temperatures in the range of 900-1200^{o}C for obtaining soft burnt lime, and the upcoming gaseous products from this zone preheat the mixture of limestone and fuel. Air for combustion is introduced at the bottom of the kiln and gets preheated while cooling the quick lime in the cooling zone near the bottom. There is always some amount of unavoidable crushing of lime during its downward movement into the kiln, and the material discharged from the kiln consists of lime lumps and powdered lime contaminated with fuel ash and clinkers from coal and coke.

The gas fired vertical shaft kilns are also, in general, cylindrical structures with suitable arrangements for burning the limestone with

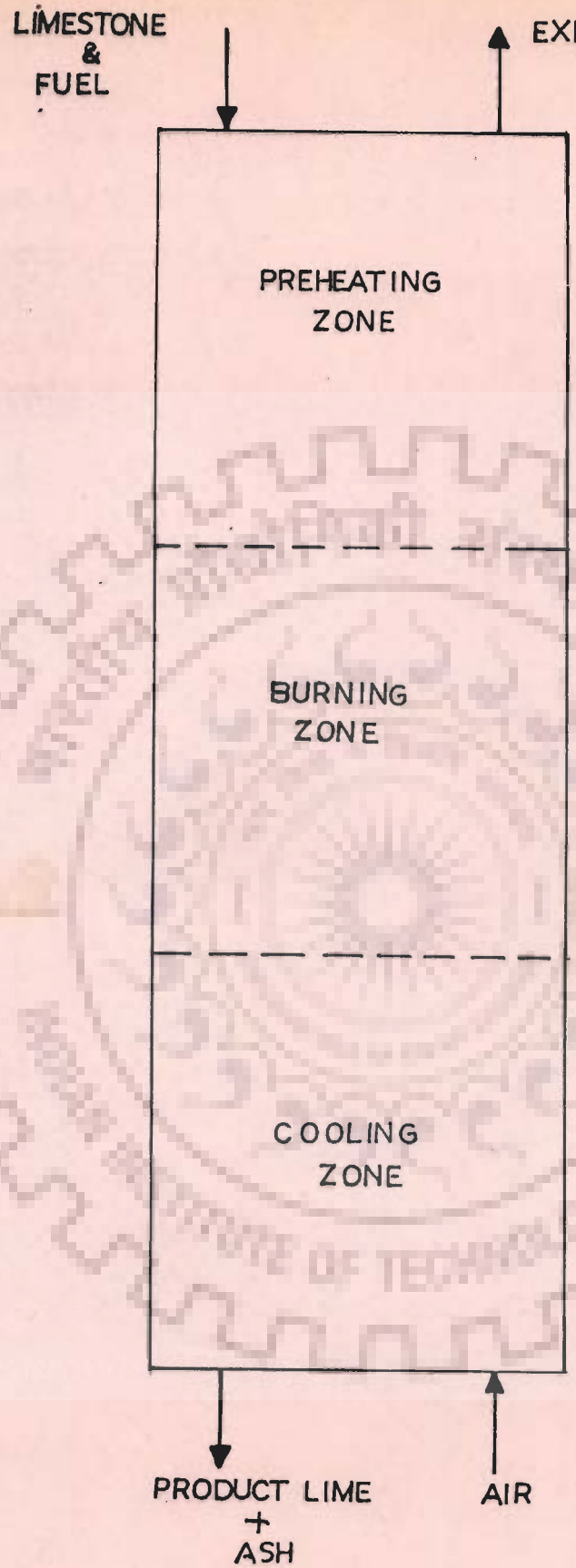


FIG. 2·2 – SCHEMATIC DIAGRAM OF A MIXED-FEED LIME SHAFT KILN

gas. Any fuel gas, such as, natural, blast furnace, or coke oven gas can be used. Similarly in the oil-fired kilns a suitable fuel oil is employed for firing the kiln. The oil is sometimes first gasified by injection into a hot stream of recirculated gas from the kiln top. Combustion of the oil can be effected either in the external combustion chambers or within the kiln body itself, but the heat consumption per Kg. of lime has been reported to be comparatively less in the latter case (Hoffman, 1963). The main advantages of these kilns over the mixed-feed kilns are : higher capacity, better quality and non-contamination of the product lime with fuel ash.

According to Azbe (1945) certain fundamental requirements for obtaining good quality and low cost lime are : (i) proper combustion of fuel and steady supply of heat to the kiln, (ii) proper heat distribution in the kiln, (iii) uniform drawing of lime through the different shaft sections, (iv) complete cooling of lime and recovery of heat, (v) temperature control of the hot zone by economical means, (vi) ample draft to obtain high capacity and (vii) arrangements to faciiitate operation. Parson (1964) has reviewed some of the advantages obtained in the vertical shaft kiln. These are : (i) its simplicity of construction and operation, (ii) low first cost, (iii) high thermal efficiency (because of convective heat transfer rather than radiative as in rotary kilns), (iv) high volumetric efficiency, (v) possibly minimum decripitation of solid products & (vi) erosion of refractory

due to slight movement of particles relative to each other. He points out that the gas kiln popular in America has never matched the efficiency of the mixed-feed kiln used in Europe. According to him all the defects of the vertical kiln, namely, irregularity of operation, prevalence of core, overburning, deterioration of refractories, etc., can be blamed on one common characteristic, i.e., channeling. Channeling is the tendency of some parts of lthe kiln shaft to run at higher temperatures than others. It is a combustion phenomenon that results from the combination of fuel and air in the voids in the kiln charge. He logically deduced that an excess amount of fuel could help in reducing channeling.

Azbe (1941) has briefly described his patented design of a centre burner gas-fired vertical shaft lime kiln with provisions for the control of zonal temperatures, distribution of heat, rate of draw and location of draw. He has divided the lime kiln into six zones, namely, (i) storage and drying zone, (ii) preheating zone, (iii) upper calcining zone, (iv) lower calcining zone, (v) finishing zone, and (vi) cooling zone. Division of the kiln into these zones, he suggests, makes it amenable to effective control that greatly enhances quality, quantity and efficiency.

The annular shaft kilns (Beckenback, 1971 and Flachsenberg, 1970) with nominal outputs in the range of 100 - 300 tpd, came into existence in West Germany in the sixties owing to more exacting demands in regard to reactivity, low ash content, and sulphur content of quick lime. This kiln can be operated either by induced draft or by forced draft and is equally suitable for oil or gas firing. Some

other kilns have also been developed which lend themselves to convenient firing with oil and gas (Middlemas, 1964). A new design of an oil-fired lime shaft kiln based on the 'catagas' system of oil gasification has also been reported by Middlemas (1963). This kiln is basically a conventional gas fired design with catagas units fitted at the bottom of the burning zone.

2.3 DEVELOPMENT ON LIME KILNS IN INDIA

In a recently conducted field survey it was observed that building lime is being produced in India in the small scale and cottage industries. Several types of lime kilns are in vogue, namely, the stack or heap kilns and the intermittent kilns of the batch type (Dave and Masood, 1972; Dave and Coworkers, 1977; Macedo, 1958; Rai and Sharma, 1966; and Verma and Saxena, 1978). These kilns being of the primitive type are highly inefficient and produce lime of unpredictable quality. The improved vertical shaft kiln, constructed in masonry and lined inside with fire bricks in rather a recent development in the country. The use of this type of kiln is being advocated by the Khadi and Village Industries Commission, Bombay and the Central Building Research Institute, Roorkee for the manufacture of building lime for smaller capacities of production. The other advanced type of shaft kilns, the rotary or the fluo-solids kilns have yet to be used on a large scale in the country to achieve much larger capacities of production of the building lime, say exceeding 25 tonnes of quick lime per day. These vertical shaft kilns are of the mixed-feed type generally operating on natural draft. The survey

further indicated that lime for use in the chemical and metallurgical industries is also being produced in the rotary, fluo-solids and cross-flow kilns to some extent in the country. But their designs are proprietory in nature and the know-how is generally being imported.

A symposium was organised by the National Buildings Organisation on the 'Manufacture and Use of Building Lime in India' at Rewa (M.P.) in March, 1958, in which Macedo (1958) presented a paper on the factors in the design and economic operation of a lime kiln . The paper is a general review on the subject. The specific design criteria for any of the kilns based either on theory or practice, are not mentioned in his paper. Macedo remarked that the mixed -feed vertical kiln was a highly heat efficient lime kiln and it was best suited to the Indian conditions.

After a careful analysis of the existing practices of lime burning, Macedo (1967) later observed in another symposium held in New Delhi that most of the building lime produced in the small and cottage scale sectors was costly and the quality of the product was uncertain.

Dave and Masood (1972) presented a paper on the study of existing lime kilns in India in another seminar on 'Lime Manufacture and Uses' held at New Delhi. They reported the construction and operational features of some typical kilns, such as, the country batch

type, the Vindhyan Kiln, the Rajasthan kiln, and the fire-brick lined kiln. They concluded that most of the lime kilns in operation in India were following the age old uneconomic operational practices and needed considerable improvements for efficient operation. These investigators further observed that lime burning is characterised by a large number of operating variables, and optimum performance is achieved by trial and error methods only. The author believes that this degree of uncertainty to obtain optimum kiln performance can be eliminated by a considerable extent if the analysis of design and operation of lime kilns for optimum performance is undertaken to investigate and correlate the effect of numerous parameters which affect the productivity thermal, efficiency and product quality.

Describing the manufacture of lime in India Robin Spence (1974-75) observes that great improvements in efficiency of the lime kilns are possible with the present days' scientific understanding of the fundamental process. In view of the general scarcity of cement in India from time to time, the labour intensive lime industry has been predicted as the hope of the future.

Verma and Saxena (1978) carried out some preliminary studies of the low capacity mixed-feed kilns producing less than 5 tonnes of lime per day. The study revealed that there were significant variations in the design and performance characteristics of these kilns. The prevalent methods of operation were quite inefficient and heat wasteful. They concluded that the performance of the semi-continuously operated kilns in respect of obtainable productivities

could be enhanced by lowering down the retention times under local operating conditions, such as, incorporating frequent charging and discharging schedules at regular intervals of time, contrary to the existing practices of once-a-day charging of the raw material and withdrawal of the product lime.

Dave and Coworkers (1977) have also reported some recent investigations on the design and performance of Indian lime kilns. They observe that the lime industry still works mostly on traditional lines and little improvements in the designs and operational practices have been effected. In order of eliminate the colossal wastes of energies and the loss in productivities they consider it imperative that steps be undertaken to investigate the ways and means of carrying out the necessary improvements.

Gobindakrishnayya (1958) has outlined the salient features of the oil fired lime shaft kilns. The operational advantages of oil firing over solid-fuel firing were outlined. He concluded that for the manufacture of lime as a building material in comparatively small sized shaft kilns, the oil firing system is neither practical nor economical.

Adhia (1952) has reported a nomograph to determine the performance of a mixed-feed coke fired lime kiln used in the chemical industry, such as the alkali and sugar industries where lime and gas

both are used. The nomograph is a general presentation of material balances in a lime kiln. It takes into consideration excess air upto a maximum of five percent, whereas excess air to an extent of about 25 percent and higher is not uncommon for such kilns. No attempt was made to predict important kiln design characteristics such as the thermal efficiency and product quality.

In a recent seminar held at New Delhi, Chopra (1985) has advocated the designing and installation of coal fired mixed-feed vertical shaft kilns in the country for capacities of 50-60 tonnes of quick lime per day. Verma and others (1985) delved on the subject of lime manufacture, fuel utilisation patterns and problems. They have described the modern kilns of high capacities which could be potentially used by the indigenous lime manufacturers with a view to effecting further economies in the consumption of fuels. The technologies mostly being adopted by the indigenous iron and steel industry are of foreign origin.

2.4 OPERATIONAL PARAMETERS AND THERMAL EFFICIENCIES

Azbe (1953-54) has given the effect of temperature on the calcining time, as reported by several investigators, for a 150 mm limestone. Wide variations in the calcination time corresponding to a given firing temperature were observed. Different calcining times

could be obtained by varying the gas velocity, the radiation characteristics, surface orientation of limestone, etc. An increase in temperature enhances the calcination rate by lowering the calcining time and vice versa. The burning of limestone at higher temperature for extended periods of time tends to overburn the product, causing lime shrinkage with consequent reduction in lime reactivity, and thus impairing the product quality.

The draft employed in a lime kiln exerts a tremendous influence on the operation and productivity of the kiln (Azbe, 1941 and Holman, 1950). Azbe (1945, 1953-54) recommended the use of Fanning's equation to estimate the draft loss:

$$\frac{\Delta P}{\rho} = \frac{(4\ f)LV^2}{2\ g_c\ D} \qquad (2.7)$$

where ΔP is the pressure drop, f is the friction factor, ρ is the the density of gas, L is the height of bed, V is the gas velocity based on empty cross-section, g_c is the gravitional constant and D is the diameter of passage. The friction factor, f, is governed by Reynolds Number. The gas velocity is directly proportional to the cross-sectional capacity of the kiln, P_s, in $t/(m^2)$ (day) i.e.

$$P_s \propto (\Delta P)^{0.5} \qquad (2.8)$$

Thus the production capacity of a kiln can be enhanced by the judicious application of a draft system. On this basis Azbe investigated the effect of various mechanical draft systems, namely, forced, induced and the balanced draft on the kiln capacity. He inferred that the capacity of an existing kiln could be increased two to four times

by proper application of such draft systems, the maximum effect being realized by the combined application of the induced and the forced drafts in the balanced form.

The size, shape and composition of limestone affect the time of preheating, calcining and cooling (Azbe, 1944; Eigen, 1957 and Koloberdin and others, 1976). The physical properties of the limestone such as its specific heat, thermal conductivity, etc. depend to a great extent upon its chemical composition. The passage time in the kiln varies from about 10 hours in modern kilns to as much as 100 hours or even more in some of the older type kilns. Azbe concluded that the heating and calcining times are directly related to the square of the stone size. Because of the requirement of lower calcining time for smaller size of limestone, higher capacities could be achieved through the use of smaller stone sizes. Eigen (1957) has considered the burning of small sized limestone in a cross-current shaft kiln and concluded that small sized limestone in a high coke fired shaft kiln calcines more economically than in the cross-current kiln.

During the operation of a lime kiln, the feed input vis-a-vis product output rates are to be regulated and synchronized with the designed capacity and quality of product keeping in view the retention times in the various zones. Sophisticated kilns have been developed with elaborate arrangements for materials feeding and product withdrawal (Verma and Saxena, 1978). Azbe (1941) has indicated that a kiln with automatic draw to loosen the charge and move the fines

will give about 16 percent higher production over the same kiln, if discharged manually.

The type of fuel used and its method of burning wield a significant influence on the operation and performance of a lime shaft kiln. A gas or oil fired kiln for a unit volume obviously produces greater quantity of lime than the solid fuel fired kiln. The performance of pulverised coal firing over coke firing has been reported by Eigen (1957). High output, low fuel costs, availability of 93 percent free CaO soft burned lime, and eash of separation of flyash by screening have been described.

Reporting his findings on the coke fired lime shaft kilns, Eigen (1957 and 1959) observed that the lime output in tonnes per square meter of cross-section is directly proportional to the depth of the burning zone and intensely proportional to the true burning time. High burning efficiency is achieved for small grained limestone with relatively coarse coke free from fines especially if the limestone and coke are closely classified and effective height is relatively large.

The thermal efficiency of a lime shaft kiln has been defined as the ratio of theoretical heat requirement based on unit weight of lime to that of the total heat supplied into the kiln based on the unit weight of the product (Boynton, 1967; Balazsovics, 1970; and Eigen, 1958). According to Brzakovic (1975), the theoretical heat requirements in lime calcination vary between 690 and 835 Kcal per Kg. of lime and the value of 760 Kcal/Kg is being accepted as the nearest true value. According to Tanskii (1962) kiln efficiency

is primarily a combination of fuel efficiency, refractory life, operating labour, and supply costs and last but not the least, down time. Vertical kilns are practically maintenance free and do not ordinarily have any down time except perhaps for occasional relining with refractories. He suggests that in order to obtain maximum fuel efficiciency in a vertical kiln, the requirements to be met are: (i) appropriate size grading of limestone, (ii) availability of adequate draft, (iii) stone to be preheated properly, (iv) proper mixing of combustion gases and air, (v) adequate volume and pressure for introduction of combustible gases and air into the centre burner, (vii) effective cooling of lime and reintroduction into the kiln of the preheated air and (vii) adequate instrumentation to balance out the kiln operation.

Weisz (1952) has given exclusive charts for determining the thermal efficiencies of the lime shaft and cement kilns from studies of gas analysis. He has defined terms like 'equivalent CO_2' and 'A' factors which take into account the combustion characteristics, and quality of limestone and burnt lime respectively. Several types of fuels, such as, nonresinous wood, metallurgical coke, bituminous coal, natural gas, blast furnace gas, etc., have been accommodated in his charts.

For obtaining an efficient operation of a lime kiln, the role of instrumentation and control has been emphasized by Azbe (1946) especially for modern kilns incorporating complex design features. He has suggested hot zone recirculation of gases for the temperature control. Separate draft controls are described for kiln fan motor and producer fan motor in a gas fired kiln. The significance of measurement and control engineering has been highlighted by Ruch

(1973). He has enumerated several variables which should be measured by direct or indirect means to execute the process for an optimal operation.

2.5 PROCESS ENGINEERING IN KILN DESIGN

The process engineering problems of lime shaft kilns have been elucidated by Jeschar (1971) who observed that although considerable improvements could in fact be achieved in some plants, yet it is not possible to predict the behaviour of a particular kiln in all respects. He has considered a hypothetical kiln in which the fuel is fed into the region of decarbonation zone, no wall losses take place and the system properties in the gas and solid phases remain the same over the entire cross-section of the kiln. For such an idealized kiln he has obtained the equation to predict the solid and gas temperatures in the preheating and cooling zones of the lime kiln. He has reviewed some equations for the calculation of heat transfer coefficients in bulk materials and presented an approximate equation for computing the length of the decarbonation zone.

Balazsovics (1959) has vividly described the importance of thermotechnical problems in lime burning kilns. The attainable maximum productivity is affected by the formation and operation of the burning zone of a lime shaft kiln. He has investigated the effect of different factors on heat transfer and also on the output

of the lime shaft kiln, and observed that the heat transfer coefficient in the burning zone is proportional to the square-root of the superficial velocity of the exhaust gases based on the empty cross-section of the kiln. Since the gas velocity is directly related to the cross-sectional capacity, the heat transfer coefficient, h in (Kcal) (hr) (m^2) (^oC), is related to the capacity, P_s in $t/(m^2)$ (day), by the correlation :

$$h = K (P_s)^{0.5} \qquad (2.9)$$

where K is a constant. Balazsovics recommends that the above heat transfer coefficient must be multiplied by a factor of 0.75 to account for the surface irregularity of limestone and the decrease in available surface for heat transfer under the conditions of packed beds. The time period of burning for the practical shape of stone has been given by the equation

$$t_b = \frac{W \rho_s}{\Delta T_m} \left(\frac{d_p}{6.0 \times 0.75\ h} + \frac{d_p^2}{24\ k} \right) \qquad (2.10)$$

where, W (quantity of heat in K cal/Kg required for the decomposition of 1 Kg limestone), ρ_s (bulk density of limestone, Kg/m^3), ΔTm (mean temperature difference between exhaust gas and dissociation layer of the stone in ^oC), d_p (diameter of the stone, m), K(thermal conductivity of stone Kcal/(m) (hr) (^oC). He has further observed that for large lumps of stones, the thermal conductivity of the stone decisively affects the kiln output and the mean temperature difference between the exhaust gas and the dissociation layer of stone is very important. He has also reported an equation relating to the behaviour

of burning zone with recycling of the exhaust gas, and concludes that recycling of the exhaust gas in the burning zone is justified only when an overburning of the lime cannot be avoided by other means.

Wuhrer (1963) has discussed the essential requirements for obtaining soft burned lime in coal fired lime shaft kilns. These are: low heat consumption, a continuous and uniform kiln feeding, a good grading of the stone and coal, mixed firing, proper coal size matching the stone size, and a limited mass temperature in the decarbonation zone. The capacity of a kiln is dependent upon the length of the zone of heat exchange i.e. the oxidation zone of coal in the kiln. He has proposed the following thumb rule, duly confirmed by his experiments, for the height of the oxidation zone of lime kiln :

$$Ho = d_c \cdot V_f \cdot 5 \qquad (2.11)$$

where Ho is the height of the oxidation zone, d_c is the average diameter of coal particles and V_f is the dilution factor of coal in the poured material. For a coal content of 13 percent V_f is about 6. Values of the burning times for single limestone particles were observed to tally with those obtained by some other workers as claimed by him. The influence of production rate and stone diameter on the residence time has been correlated.

2.6 CRITICAL APPRAISAL

A perusal of the available literature reveals that although some of the most sophisticated lime shaft kilns have been developed

to obtain high productivity, lime quality and thermal efficiency, yet the design of a suitable kiln for a new situation using basic principles involved in lime burning still remains uncertain owing to the complexities of the process and operational behaviour of a lime shaft kiln. Some serious efforts to develop the fundamental or empirical design correlations have been made by some investigators for typical kiln designs, especially for gas or oil firing systems.

Most of the lime production in India is carried out in vertical shaft kilns as per the literature surey and field studies carried out recently. The building lime, by and large, is being produced in the mixed-feed shaft kilns. The design of such kilns is apparently based on thumb rules deduced from the operational behaviour of these kilns (Wuher, 1963). The trial and error procedures are still employed in India after commissioning the kiln to obtain desired capacity and product quality from the building lime kilns. The available Indian Standards (I.S.I., 1961 and 1967) on mixed-feed lime shaft kiln also reflect similar thumb rules.

Process design correlations, based on theoretical and detailed performance analysis have not been evolved nor any kind of simulation studies have been conducted for the mixed-feed coal-fired kilns. It was, therefore, considered essential to analyse the performance of these kilns and develop appropriate design and performance correlations for efficient utilization of these low cost kilns in developing countries, and that some experimental investigations be conducted for estimation of performance vis-a-vis optimal design and operation of the vertical mixed-feed lime shaft kilns.

CHAPTER-3

PERFORMANCE ESTIMATION OF SOME MIXED-FEED LIME KILNS

Chapter-3

PERFORMANCE ESTIMATION OF SOME MIXED-FEED LIME KILNS

3.1 FIELD SURVEY

For the purpose of the present investigation, the studies have been restricted to the mixed-feed lime shaft kilns operating on natural draft. Design and performance data in respect of a few masonry kilns spread over some important lime manufacturing centres were obtained by visiting plant sites. The major data collected in respect of the physical features of kilns, nominal production rates, size of limestones, size of fuel particles, fuel consumption, etc., are given in Table-3.1, where P_n denotes the nominal production rate in tonnes per day, L_e in the effective height of the kiln (m), D_{av} is the average inner diameter (m), d_{p_s} is the size of limestone particles (m); d_{p_f} is the size of fuel particles (m), W_t is the average wall thickness including firebricks lining (m), etc.

3.1.1 Design Features

The nominal production capacities of the kilns ranged between 3 and 20 tonnes of quick lime per day. The kilns were constructed in ordinary brick masonry lined inside with 23 mm thick lining of fire bricks. The heights of the kilns varied from about 3 to 15 meters and the inner diameters ranged from 1.5 to 4.0 meters. The thickness of the kiln shafts varied between 0.75 and 2.00 meters.

Four outlet doors of suitable sizes (generally 60 cm wide x 75 cm high) having arches at the top were provided for the discharge of the burnt lime. In some of the kilns poke holes were provided for the measurement of operating temperatures as well as for observing the conditions of firing. Suitably graded pieces of limestones (50 - 125 mm) and coal particles (20 - 50 mm) were taken in stipulated ratios by weight or by volume and were charged into the kilns. Usually the mineral limestones of building or chemical grades were calcined.

3.1.2 Operational Features

The kilns were operated semicontinuously on the natural draft, the air for combustion being induced through the doors at the bottom, usually in one 8 to 12 hours shift per day with twice a day charging and discharging schedules varying from 2 to 4 hours for each schedule. The product consisted of burnt pieces of quick lime, some dust lime containing the ash of the fuel, underburnt and overburnt pieces of limestones, and some ash clinkers or unburnt pieces of coal. Usually the steam coal of grade II or III with gross calorific values ranging between 5,000 and 6,000 Kcal/Kg was used in these kilns. Limestone-to-coal ratio by weight in input feed varied from 4-6.

The kilns were not loaded and discharged during the late evening and night hours with the result that the fire in the kiln travelled to its top surface during the early morning hours resulting in the elimination of the preheating zone altogether. The first morning

TABLE-3.1

INITIAL DATA ON SOME MASONRY MIXED-FEED LIME SHAFT KILNS

Kiln N0.	Identification (Plant, site)	P_n (t/d)	L_e (m)	D_{av} (m)	D_{p_s} (m)	d_{p_f} (m)	X_r (w/w)	W_t (m)	Remarks
1.	KVIC,DDN	3.0	5.50	1.98	.050-.100	.025-.050	4.5-5.5	0.75	Mineral Lime stone (building/ chemical grade) and steam coal (grade II/III) employed
2.	KVIC,DDN	5.0	8.00	1.75	.075-.125	.025-.050	4.5-5.5	0.75	
3.	CBRI,RKE	4.5	4.58	1.54	.075-.100	.040-.050	5.0-6.0	0.85	
4.	PSLW,MRT	3.5	2.95	2.22	.050-.075	.025-.040	4.0-5.0	1.50	-do-
5.	M&C,DDN	9.0	9.15	2.74	.075-.125	.025-.075	4.5-5.0	2.00	-do-
6.	VP,DDN	10.0	10.10	2.74	-do-	-do-	-do-	1.37	-do-
7.	HML,NRNL	15.0	12.00	3.25	.100-.150	.050-.075	5.0-5.5	1.20	-do-
8.	GHLI,RPR	20.0	14.50	4.00	.075-.150	.040-.075	5.5-6.0	1.25	-do-
9.	TLI,MZFNR	10.0	9.50	2.40	.075-.100	.040-.050	-do-	0.95	-do-
10.	HC,PNTSHB	10.0	11.00	2.37	.075-.125	.040-.065	5.0-5.5	1.35	-do-
11.	RC,KLMB	10.0	11.00	2.52	-do-	.040-.060	5.0-5.5	1.35	-do-
12.	PC,MDDN	8.5	11.50	2.50	-do-	-do-	5.0-6.0	0.95	-do-

discharge accounted for a major part (about 60 to 70 percent) of the daily produce which was hand picked (manually) by semi-skilled workers for lumps of quick lime.

3.1.3 General Observations

The superficial lime output rates based on empty kiln cross-sectional areas were computed and observed to lie in the range 1.0 - 2.5 t/(m^2) (day). The specific energy consumption was estimated to be in the range of 1,750 - 2,500 Kcal/Kg of lime. The degree of underburning of limestone varied from 10 to 40 percent. The maximum bulk operating temperatures in the burning section of the kilns ranged between 1173 K and 1573 K.

The data obtained for the mixed-feed lime kilns are only indicative in nature as the same are based on the pieces of information supplied by the kiln operators, onwners or lime manufacturers. The wide variations in the designs and operational practices of these kilns necessitated performance studies of a few selected kilns in some detail both in the field and in the laboratory.

3.2 IN-SITU INVESTIGATION

3.2.1 Experimental

Two low capacity masonry mixed-feed kilns were investigated at site under the existing field conditions of operation. The general design features of these cinder (waste fuel from steam boilers) fired kilns are indicated in Table-3.2.

Limestone particles of size 15-150 mm and cinders of size 5-25 mm were burnt in the kilns. Samples of representative limestones were analysed for their chemical compositions and the results are reported in Table-3.3. The proximate analysis of cinders as determined in the laboratory are reported in Table-3.4.

The heat values of the fuels were estimated from their proximate analyses using Goutal's Formula (Brame and King, 1955) and the same were computed to be about 3,115 and 2,420 Kcal/Kg for the fuels used in the two kilns respectively.

Temperature measurements were carried out at different time intervals to locate the preheating, calcining and cooling zones using stainless steel sheath type chromel-alumel thermocouples alongwith indicating pyrometers. The bulk averaged operating temperatures were measured along the height of the kiln at appropriate locations in the different zones and the representative curves are given in Figs. 3.1 through 3.3.

Flue gas samples were withdrawn at different times from just above the calcination zone by means of rubber bladder type gas samplers. These gases were analysed with the help of Orsat's apparatus. The representative time averaged analyses of gas samples collected from the two kilns are reported in Table-3.5.

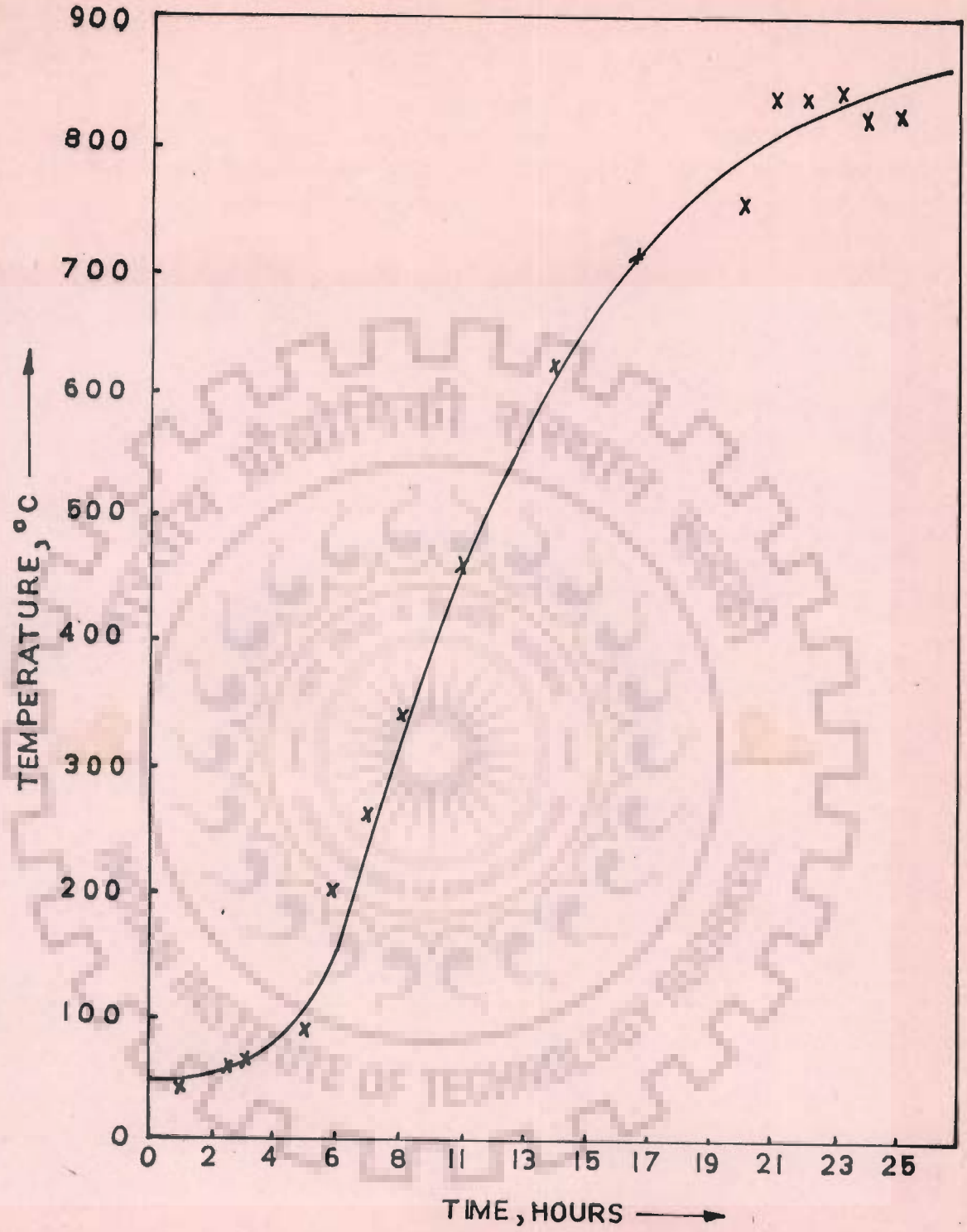
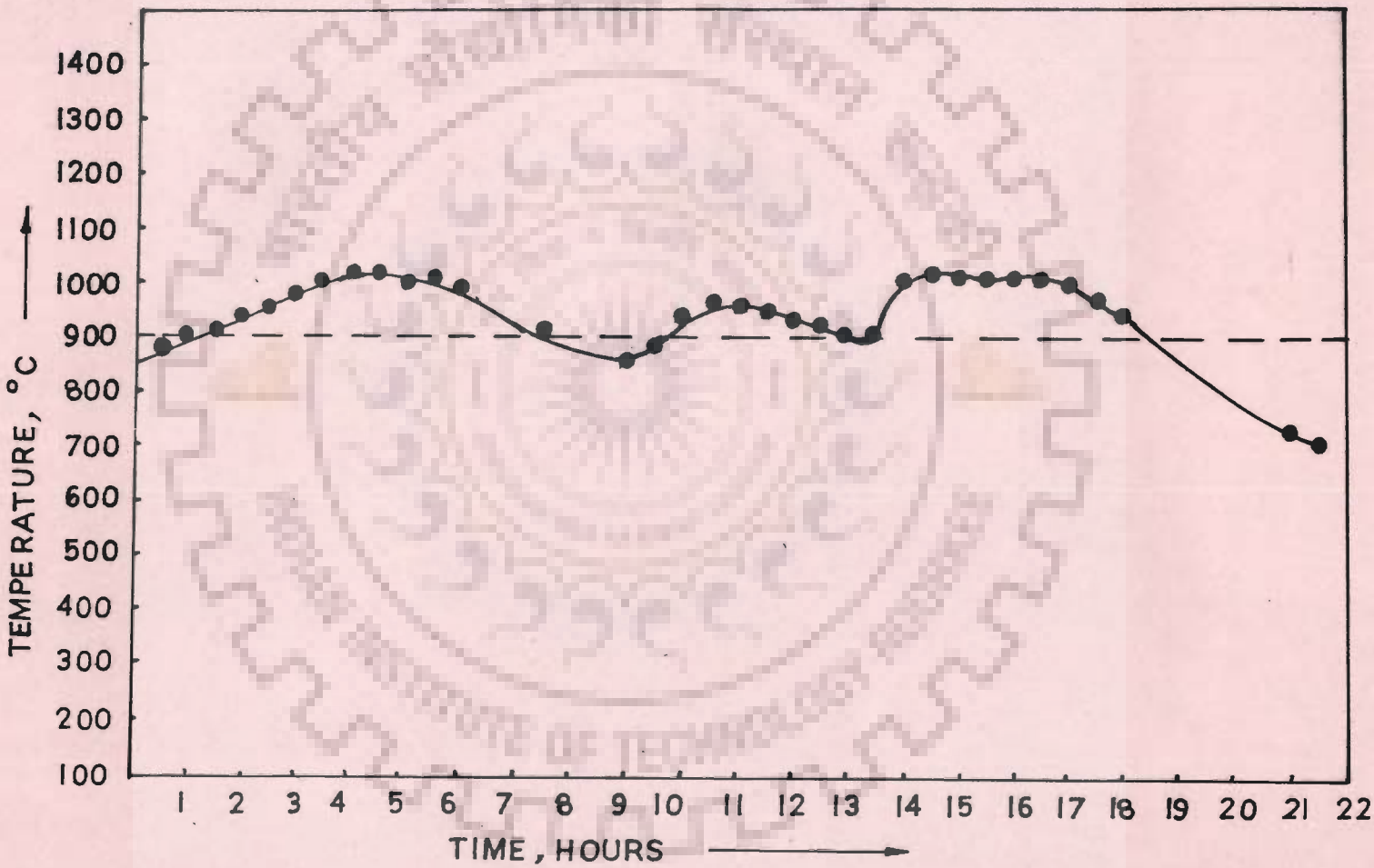


FIG. 3·1 – REPRESENTATIVE TIME-TEMPERATURE GRAPH AT PREHEATING SECTION OF CINDER FIRED KILN



FIG·3·2— REPRESENTATIVE TEMPERATURE VARIATIONS AT CALCINATION SECTION OF CINDER FIRED KILN

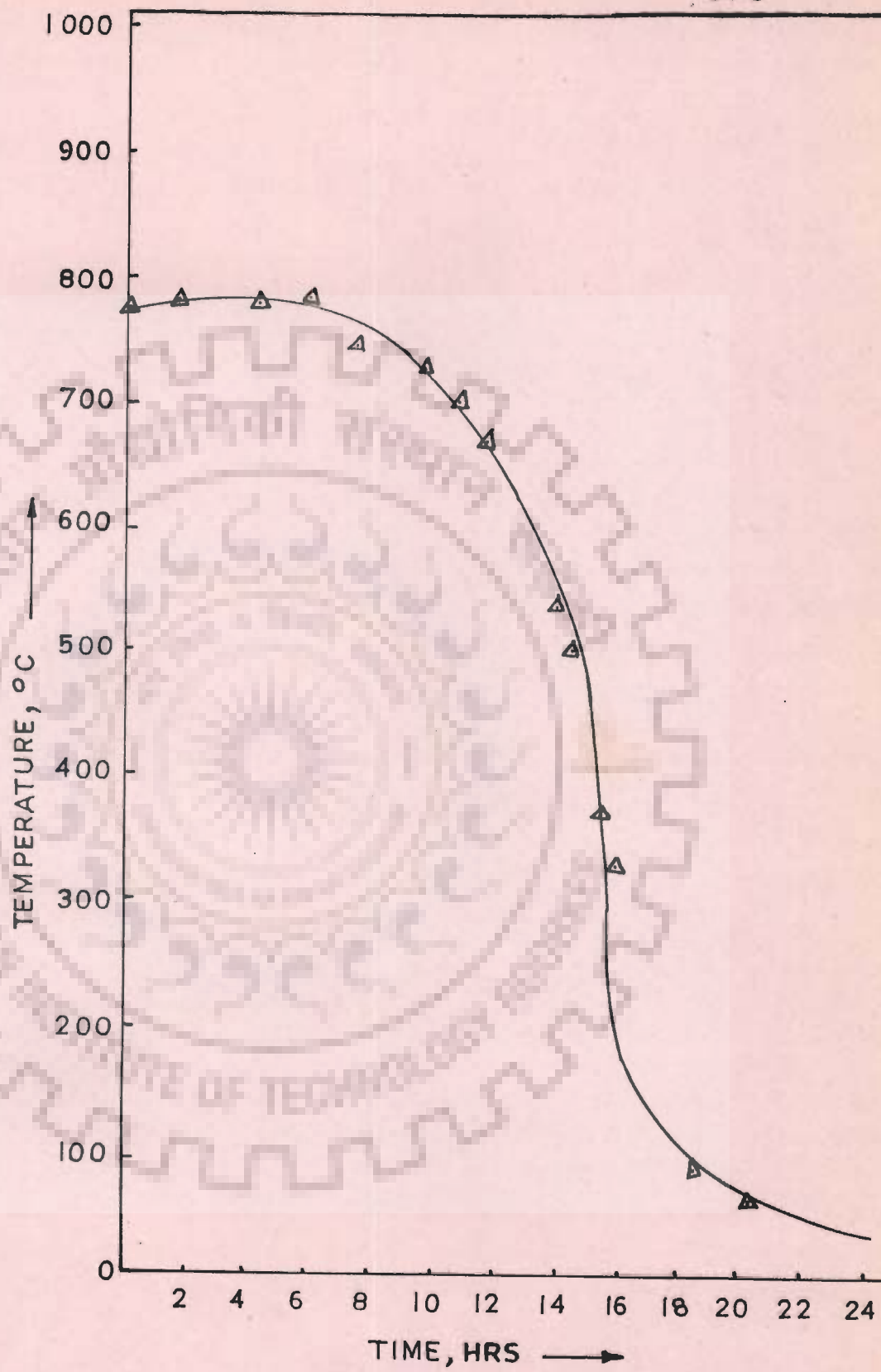


FIG. 3·3 - REPRESENTATIVE TIME-TEMPERATURE GRAPH AT
SECTION OF CINDER FIRE KILN

TABLE-3.2

General Design Specifications of the Kiln Investigated

Kiln No.	Average Cap. (t/d)	Height (m)	Av. Inner Dia. (m)	Av. Wall Thickness (m)
1.	1.0	3.05	1.85	1.10
2.	2.0	4.17	2.04	1.33

TABLE-3.3

Chemical Analysis of Limestone Samples

Sl. No.	Constituent	Quantity (percent by weight)	
		Kiln No.1	Kiln No.2
1.	Loss on Ignition	39.29	42.40
2.	SiO_2	11.15	1.45
3.	R_2O_3	1.58	0.65
4.	CaO	42.54	53.40
5.	MgO	5.11	1.20
6.	Others	Tr.	Tr.

TABLE-3.4

Proximate Analysis of Cinders

Sl. No	Constituent	Quantity (W/W percent)	
		Kiln No. 1	Kiln No. 2
1.	Moisture	0.00	0.00
2.	Volatile Matter	0.00	0.00
3.	Fixed Carbon	38.00	29.50
4.	Ash	62.00	70.50

TABLE-3.5

Representative Time Averaged Analyses of Gas Samples

Sl. No.	Constituent	Quantity (percent by volume)	
		Kiln No. 1	Kiln No.2
1.	CO_2	25.3	22.9
2.	O_2	3.9	5.9
3.	CO	1.6	2.3
4.	N_2(by difference)	69.2	68.9

The limestone to fuel ratios in the feed and productions obtained from the two kilns were determined over a period of three days and the average values for the same were estimated. The representative products from the kilns were carefully sampled in sufficient quantities and the lump lime pieces, the unburnt stones, overburnt lime, powdered lime (contaminated with fuel ash) and unburnt fuel pieces were hand picked separately and weighed to assess the product distribution. The data collected on the kilns are reported in Table-3.6.

3.2.2 Performance Results

The performance data obtained from the studies carried out on the two cinder fired lime kilns were analysed and the results are reported in Table-3.7.

The initial four columns of the table represent the relevant productivity data obtained for the two kilns, where P_s is the superficial lime output rate based on cross-sectional area of the kiln, $t/(m^2)(day)$, and P_v is the output rate based on the inner kiln volume, $t/(m^3)(day)$. R_t is the average kiln retention time in hours. It is seen that kiln No. 1 yielded lower sectional and volumetric outputs than those obtained from kiln No. 2. This is on account of (i) the higher retention time of labout 90 hours imposed in kiln No. 1 compared to that of about 80 hours in kiln No. 2, (ii) the operational lapses, and (iii) the

TABLE-3.6

Quality of Product in Cinder fired Lime Kilns

Kiln No.	Average Production (tpd)	Stone:fuel by weight (X_r)	Product Distribution (% W/W)				
			Lump Lime	Kiln Dust (Lime + Ash)	Under burnt Stone	Over burnt lime	Unburnt Fuel
1.	1.0	2.5	39.5	52.6	6.6	0.7	0.6
2.	2.0	2.0	39.6	50.2	8.5	0.6	0.7

design of the kiln in respect of geometrical height to average diameter ratio. The greater height of kiln No.2 resulted in increased draft compared to kiln No. 1. Thus it is inferred that maximum attainable output from a kiln can be obtained by an experienced burner through regulation of retention times to an optimum lower limit, i.e., by operating the kilns in as continuous a manner as feasible.

The data on the average quality of the produce obtained from the two kilns are reported in Table-3.6. It is observed the the product is highly contaminated by as much as about 50 percent of kiln dust consisting of powdered lime and fuel ash which is basically attributable to the high amount of ash content in the cinder (Table-3.4). The lime lumps obtained were of the order of about 40 per cent only, but the degree of underburning and overburning was observed to be less than 10 per cent and, therefore, within reasonable limits.

The thermal performance of the lime kilns has also been elucidated in Table-3.7, where E_s is the specific energy consumption in terms of Kcals per Kg. of lime and F_s represents the fuel consumption in tonnes per tonne of lime produced. The average E_s and F_s values were computed to be of the order of 2,450 Kcals/Kg and 0.9 tonne of fuel per tonne of lime, respectively, which are quite high.

-The thermal losses are accounted for by the cumulative effect of several operational interactions. Firstly, the traditional method of

TABLE-3.7

Performance Data for the Cinder-Fired Lime Kilns

Kiln No.	L_e/D Ratio	P_s $t/(m^2)$ (day)	P_v $t/(m^3)$(day)	R_t (hrs.)	E_s (Kcals/ Kg lime)	F_s (t cinder)
1.	1.43	0.28	0.09	90	2,500	0.8
2.	1.95	0.55	0.13	80	2,420	1.0

TABLE-3.8

Chemical Analysis of Limestone Used in Bench Scale Kiln

Sl.No.	Constituent	Quantity (% W/W)
1.	LOI	41.60
2.	$Si\ O_2$	4.25
3.	$R_2\ O_3$	0.98
4.	CaO	51.57
5.	MgO	1.20
6.	Others	0.40

kiln operation with once-a-day charging and discharging schedule made an allowance for the fire zone to reach the top of kiln usually from midnight onwards, and thereby resulting in tremendous sensible heat losses through the flue gases. The temperature of the flue gases was observed to rise, with the upward movement of the fire zone, to as much as 700°C representing significant heat losses. This observation is also corroborated by the findings of some earlier workers (Dave and Masood, 1972). The temperature of the withdrawn lime going to as much as 400°C for the latter half portion of the product withdrawn from the kilns also accounted for the loss of sensible heat. Incomplete combustion of fuel indicated by the presence of CO in the flue gases also contributed to some heat loss as according to an estimate (Boynton, 1967) the presence of one per cent CO in the exhaust gases amounts to a loss of about 55-65 Kcals per Kg. of lime.

3.3 LABORATORY INVESTIGATION

A bench scale prototype kiln, constructed in brick masonry, was set up in the laboratory. The details of this model are shown in Fig. 3.4. Two discharge doors located diametrically opposite to each other were provided. The chemical analysis of limestone and proximate analysis of coal particles burnt in this kiln are given in Tables-3.8 and 3.9 respectively. The kiln was operated by using a predetermined optimum proportion of limestone to coal for the conditions of the experiment.

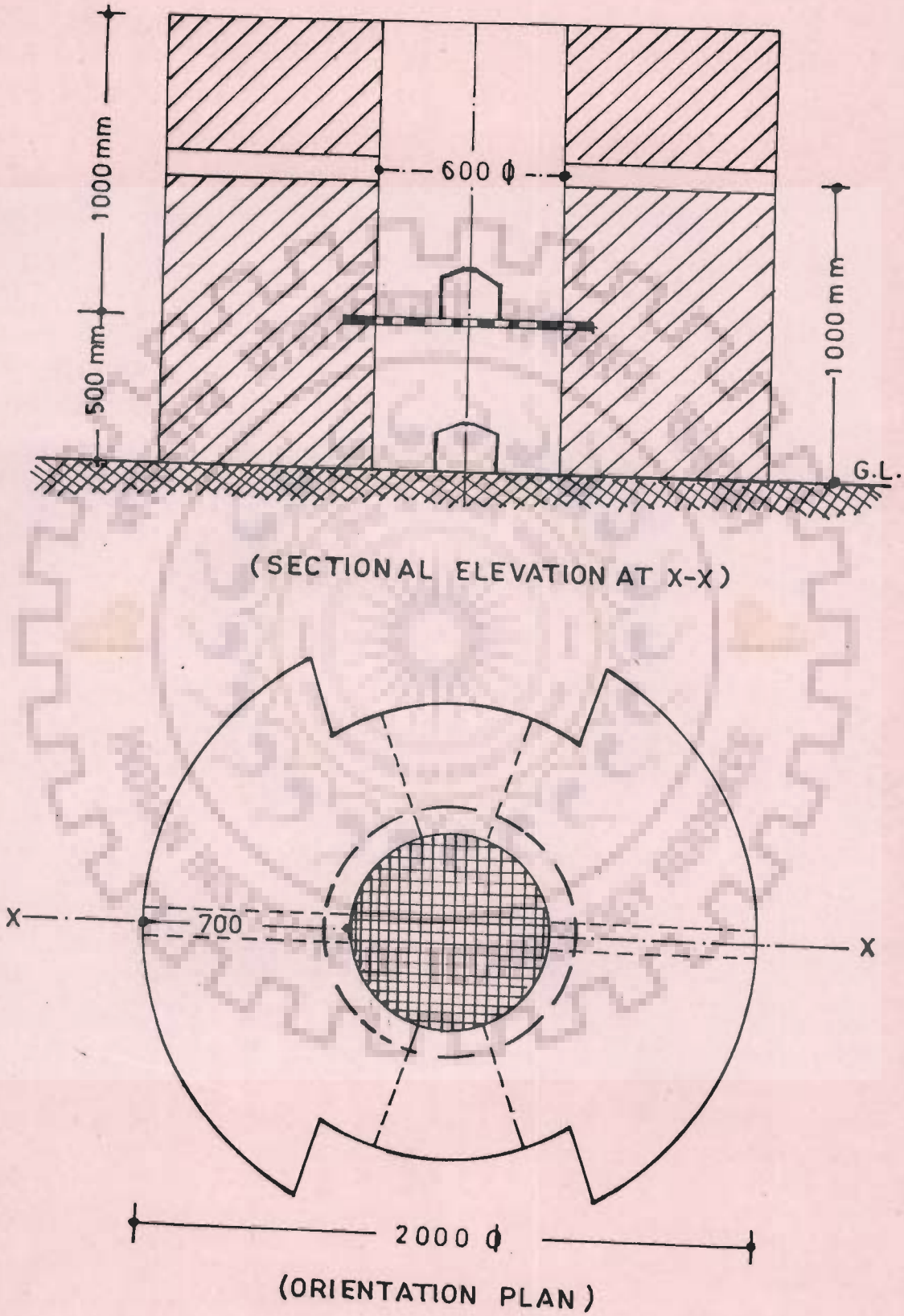


FIG. 3.4 DETAILS OF BENCH SCALE EXPERIMENTAL LIME KILN
(ALL DIMENSIONS IN MM)

TABLE-3.9

Proximate Analysis of Coal Used in Bench Scale Kiln

Sl. No.	Constituent	Quantity (% W/W)
1.	Moisture	5.33
2.	Volatile Matter	14.95
3.	Fixed Carbon	48.12
4.	Ash	31.60

TABLE-3.10

Operating Data on the Bench Scale Kiln

Sl.No.	Operational Feature	Characteristic Data
1.	size gradation of limestones	40 - 60 mm
2.	Size gradation of coal particles	25 - 50 mm
3.	Feed rate of total charge	25 - 30 Kg/ hr
4.	Limestone to coal ratio (W/W)	3.5 - 3.7
5.	Maximum bulk operating temps.	1020 - 1160 ^{o}C
6.	Temperatures of exhaust gases	300 - 600^{o}C
7.	Temperature of lime withdrawn	200 - 350^{o}C
8.	Kiln retention time	8 - 10 hrs

The operational data for the kiln is given in Table-3.10. The productivity of the kiln was estimated under pseudo-steady state conditions. During the progress of operation, samples of the produce withdrawn from the kilns were collected and separated to estimate the product distribution. From a knowledge of the burnt (quick) lime obtained and the fuel consumed specific fuel/energy consumptions were determined. The bulk operating temperatures were measured using chromel alumel stainless steel sheaths type thermocouples and consistent controls were exercised throughout the duration of the experimental run.

The exhaust gas samples were collected from the top of the experimental kiln and the same were analysed with the help of Orsat's Apparatus. The time averaged data are indicated in Table-3.11.

Average lime production rate of about 10 Kg/hr with specific energy consumption of the order of 3,500 Kcal/Kg of quick lime were obtained. The distribution of product obtained is outlined in Table-3.12.

The data obtained from the bench scale operation of the lime kiln are only indicative type demonstrating the flexibility in operation of the mixed-feed lime kilns even in the cottage scale industries. The low level of production, however, adds to the operating expenses in terms of higher energy costs.

TABLE-3.11

Average Analysis of Flue Gas Samples from Bench Scale Kiln

Constituent	Quantity (% V/V)
Carbon dioxide	26.6
Oxygen	3.8
Carbon monoxide	0.1
Nitrogen (by difference)	69.5

TABLE-3.12

Product Distribution Data in the Bench Scale Kiln

Sl. No.	Product Constituent	Percent (W/W)
1.	Quick (lump) lime	63.8
2.	Underburnt	11.1
3.	Dust lime (Produced lime + Coal ash)	25.1

3.4 PROCESS ENGINEERING CORRELATIONS : STATE-OF-THE-ART

Initially an attempt was made to evolve some process engineering correlations for the mixed-feed lime shaft kiln based on published information, the experience gained during the field survey and investigation on commercially operating kilns and the bench scale laboratory kiln.

3.4.1 Energy Requirements in Lime Burning

The energy required for the calcination of limestones at a given temperature consists of the heat required for preheating a given sample of limestone from the room temperature to the threshold calcination temperature and the heat of dissociation of the stone for conversion to quick lime. Generally limestones of variable compositions are obtained from various sources. It was thus considered appropriate to evolve correlations for estimation of energy requirements for different types/grades of limestones, notably the calcite, dolomite, magnesian, hydraulic, etc. with a view to providing useful information on state-of-the-art kiln design computations.

3.4.1.1 Preheating of Limestones

The representative composition of a generalized sample of limestone could be represented by the weight fraction of its different

constituents. Ignoring the traces, let x_1, x_2, x_3, x_4 and x_5 be the weight fractions of calcium carbonate, magnesium carbonate, silica, alumina and iron oxide, respectively. Using the specific heat data for the different components (Murray, 1947; Perry and Chilton, 1968), the specific heat of a generalized sample of limestone ($c_{p_{gls}}$) was evolved from the equation :

$$C_{p_{gls}} = x_1 C_{p_{CaCO_3}} + x_2 C_{p_{MgCO_3}} + x_3 C_{p_{SiO_2}} + x_4 C_{p_{Al_2O_3}} + x_5 C_{p_{Fe_2O_3}} \quad \text{, Kcal/(Kg) } (^oC) \qquad (3.1)$$

substitution of the specific heat data leads to

$$C_{p_{gls}} = \alpha + \beta T - \gamma/T^2 \qquad (3.2)$$

where T is the temperature in K and

$$\alpha = (0.1968\, x_1 + 0.1212\, x_2 + 0.1812\, x_3 + 0.2165\, x_4 + 0.1543\, x_5)$$

$$\beta = (0.1189\, x_1 + 0.3330\, x_2 + 0.1452\, x_3 + 0.0879\, x_4 + 0.1000\, x_5)10^{-3}$$

$$\gamma = (0.3076\, x_1 + 0.0379\, x_2 + 0.4020\, x_3 + 0.5125\, x_4 + 0.2650\, x_5)10^{+4}$$

Thus the energy required for preheating a given sample of limestone

(E_p) from room temperature (T_r) to the dissociation temperature T_d could be computed from the equation

$$(E_p)_{T_d} = \int_{T_r}^{T_d} (\alpha + \beta T - \gamma/T^2)dT \qquad (3.3)$$

or

$$(E_p)_{T_d} = \alpha(T_d - T_r) + 0.5\,\beta(T_d^2 - T_r^2) - \gamma(1/T_r - 1/T_d),\ \text{Kcal/Kg} \qquad (3.4)$$

The preheating energy requirements per Kg of limestone for various compositions were computed from equation (3.4).

3.4.1.2 Endothermic Heat of Dissociation

The energy required for the dissociation of a given sample of limestone is the summation of the heats of dissociation of calcium carbonate and magnesium carbonate constitutents of the stone. The heats of dissociation at reference temperature of $25^{o}C$ are reported in the literature (Boynton, 1967; Zindeveld and Vandenberg, 1971).

For the dissociation of calcium carbonate and magnesium carbonate, the variations in the heats of dissociations at different dissociating temperatures could be accounted for from the equation:

$$(E_d)_{T_d} = (E_d)_{T_r} + \int_{T_r}^{T_d} \Delta C_p \, dT \qquad (3.5)$$

For the reaction : $Ca\ CO_3 \rightarrow CaO + CO_2$

$$\Delta C_p = (C_p)_{CaO} + (C_p)_{CO_2} - (C_p)_{CaCO_3}$$

and for the dissociation of $MgCO_3$

$$MgCO_3 \longrightarrow MGO + CO_2$$

$$\Delta C_p = (C_p)_{MgO} + (C_p)_{CO_2} - (C_p)_{MgCO_3}$$

Using the data on specific heats and maintaining consistency of units, the equations for heats of dissociation for the two carbonates were evolved as:

$$(E_{d_{CaCO_3}})_{T_d} = (E_{d_{CaCO_3}})_{T_r} + \left[6.6(T_d - T_r) - 0.02155\,(T_d^2 - T_r^2) + 41{,}000\,(1/T_r - 1/T_d)\right] 10^{-3},$$

Kcal/Kg (3.6)

and

$$(E_{d_{MgCO_3}})_{T_d} = (E_{d_{MgCO_3}})_{T_r} + 131.0\,(T_d - T_r) - 0.143\,(T_d^2 - T_r^2) - 4{,}430{,}000\,(1/T_r - 1/T_d)\;10^{-3}, \quad \text{Kcal/Kg} \qquad (3.7)$$

Thus for a generalized sample of limestone, the heat of dissociation is given by the equation:

$$(E_{d_{gls}})_{T_d} = (E_{d_{CaCO_3}})_{T_d}\,x_1 + (E_{d_{MgCO_3}})_{T_d}\,x_2, \quad \text{Kcal/Kg} \qquad (3.8)$$

The energy requirements for preheating and dissociation of various types of limestones were computed using a digital computer (SN-23). Computer programme for the same is given in Appendix-A and the results are given in Table-3.13 where X1, X2, X3, X4, X5 are the weight fractions of calcium carbonate, magnesium carbonate, silica, alumina and iron oxide, respectively in a generalized sample of limestone; HPHLS is the energy required for preheating and HDLSS is the heat of dissociation in Kcal/Kg of limestone. The values computed for calcitic and dolomitic limestones agree fairly well with those reported by various investigators (Boynton, 1967; Knibbs and Gee, 1959; Eigen, 1958).

TABLE-3.13

ENERGY REQUIREMENTS IN LIME BURNING

X1	X2	X3	X4	X5	T(K)	HPHLS	HDL
1.000	0.000	0.000	0.000	0.000	1173.0	241.02	403
0.950	0.050	0.000	0.000	0.000	1173.0	244.96	396
0.900	0.100	0.000	0.000	0.000	1173.0	248.89	389
0.850	0.150	0.000	0.000	0.000	1173.0	252.83	382
0.800	0.200	0.000	0.000	0.000	1173.0	256.77	375
0.600	0.400	0.000	0.000	0.000	1173.0	272.51	346
0.500	0.500	0.000	0.000	0.000	1173.0	280.39	332
0.400	0.600	0.000	0.000	0.000	1173.0	288.26	318
0.200	0.800	0.000	0.000	0.000	1173.0	304.01	290
0.000	1.000	0.000	0.000	0.000	1173.0	319.76	262
0.950	0.000	0.050	0.000	0.000	1173.0	241.07	382
0.900	0.000	0.100	0.000	0.000	1173.0	241.11	362
0.900	0.000	0.150	0.000	0.000	1173.0	253.21	362
0.800	0.000	0.200	0.000	0.000	1173.0	241.20	322
0.950	0.000	0.000	0.050	0.000	1173.0	240.63	382
0.900	0.000	0.000	0.100	0.000	1173.0	240.24	362
0.850	0.000	0.000	0.150	0.000	1173.0	239.84	342
0.950	0.000	0.000	0.000	0.050	1173.0	238.61	382
0.900	0.000	0.000	0.000	0.100	1173.0	236.19	362
0.850	0.000	0.000	0.000	0.150	1173.0	233.78	342
1.000	0.000	0.000	0.000	0.000	1223.0	257.87	400
1.000	0.000	0.000	0.000	0.000	1273.0	275.04	398
1.000	0.000	0.000	0.000	0.000	1323.0	292.50	396
1.000	0.000	0.000	0.000	0.000	1373.0	310.27	393
1.000	0.000	0.000	0.000	0.000	1423.0	328.34	390
1.000	0.000	0.000	0.000	0.000	1473.0	346.72	386
0.540	0.460	0.000	0.000	0.000	998.0	207.83	356

3.4.2 Feed Mix Ratio

The input to the lime kiln at the top is a mixed feed of limestone and solid fuel in a given ratio (x_r) by weight. The same is proposed to be determined from the following equation based on the definition of thermal efficiency for a given type of lime kiln:

$$X_r = H_f \eta_l \left[E_d (1-x_u)\right]^{-1} \qquad (3.9)$$

where H_f is the average heat value of the fuel (Kcal/Kg), η_l is the fractional gross thermal efficiency based on output lime, E_d is the endothermic heat of decomposition (Kcal/Kg limestone), and x_u is the fractional degree of underburning acceptable for a given type of kiln and its mode of operation.

3.4.3 Residence Times

On the basis of existing knowledge as summarized in Chapter-2 of this thesis, the available data based on single particle investigations vis-a-vis the semi-empirical approach as attempted in the past were partially modified to compute the design of the coal fired lime shaft kilns by substitution of averaged values of system properties pertinent to this kind of kilns in the indigenous context. The predominant effect

of heat transfer coefficient due to radiation were accounted for in the burning zone by defining effective heat transfer coefficient due to convection and radiation.

For the continuously operated mixed-feed kilns the time required (in hours) under average conditions for the preheating of limestone (θ_p), its burning (θ_b), and the cooling of the product lime lumps (θ_c) are given by the following equations:

$$\theta_p = 686 \, (d_{p_s}{}^3/P_s)^{1/2} \tag{3.10}$$

$$\theta_b = 6350 \, d_{p_s} \left[0.052 \, d_{p_s} + (20.25 + 180 \, d_{p_s} + 6.75 \sqrt{P_s/d_{p_s}})^{-1} \right] \tag{3.11}$$

$$\theta_c = 488 \, (d_{p_s}{}^3/P_s)^{1/2} \tag{3.12}$$

where d_{p_s} is the average size of the stone (m) and P_s is the superficial lime output rate based on average inner cross-sectional area of the kiln. The values of residence times for continuous operation were computed. The results are reported in Tables-3.14 through 3.16.

TABLE-3.14

Computed Values of Preheating Times for Limestones

d_{p_s} (m)	PREHEATING TIME (Hrs)			
	P_s =1.0	P_s =15	P_s =2.0	P_s =25
0.010	0.69	0.56	0.49	0.31
0.025	2.67	2.18	1.89	1.20
0.050	7.68	6.28	5.45	3.45
0.075	14.10	11.53	10.00	6.28
0.100	21.60	17.68	15.30	9.65
0.125	30.40	24.90	21.50	13.66
0.150	39.00	31.90	27.60	17.50

TABLE-3.15

Computed Values of Burning Times for Limestones

d_{p_s} (m)	BURNING TIME (Hrs)			
	P_s=1.0	P_s=1.5	P_s=2.0	P_s=2.5
0.100	0.74	0.64	0.57	0.53
0.025	2.57	2.29	2.10	1.94
0.050	6.12	5.58	5.20	4.92
0.075	9.55	9.22	8.65	7.98
0.100	13.98	13.22	12.65	12.08
0.125	17.90	17.12	16.48	15.93
0.150	22.20	21.30	20.65	20.16

TABLE-3.16

Computed Values of Cooling Time For Quick Lime (Lumps)

d_{p_s} (m)	COOLING TIME (Hrs)			
	P_s=1.0	P_s=1.5	P_s=2.0	P_s=2.5
0.010	0.49	0.40	0.35	0.31
0.025	1.90	1.55	1.35	1.20
0.050	5.47	4.47	3.89	3.47
0.075	10.04	8.22	7.12	6.37
0.100	15.37	12.60	10.90	9.37
0.125	21.60	17.70	15.30	13.75
0.150	27.70	22.70	19.65	17.60

3.4.4 Zonal Heights

Heights of the preheating, burning and cooling zones, in meters, based on residence times and system properties could be computed. The correlations evolved are :

$$H_p = 74.3\ (1 + X_r)\ P_s\ \theta_p/(X_p\ X_s\ X_r\ \rho_{mf}) \qquad (3.13)$$

$$H_b = 74.3\ (1 + X_r')\ P_s\ \theta_b/(X_p\ X_s\ X_r'\ \rho_{mf}') \qquad (3.14)$$

$$H_c = \left[41.7 + 74.3\ (X_r/X_s\ X_r) + 74.3\ (1 - X_s)/X_s\right] P_s\ \theta_c/(X_p\ \rho_{pl}) \qquad (3.15)$$

where x_s is the fractional dissociation of limestone to quick lime ($x_s = 1 - x_u$), x_f is the fractional ash content of fuel, x_p is the fractional purity of limestone in terms of $Ca\ CO_3$, x_r is the limestone to fuel ratio by weight in the feed input, ρ_{mf} is the bulk density of the mixed-feed (Kg/m^3), ρ_{pl} is the bulk density of the product lime (Kg/m^3).

There is an apparent loss of volatile content of coal in the preheating zone of the coal fired kilns (Macedo, 1958). Thus a modified value of stone to fuel ratio by weight (x_r') is employed while computing the height of the burning zone to which the feed enters from the preheating zone

Thus $X_r' = X_r/(1 - X_{fv})$ (3.16)

where x_{fv} is the fractional volatile matter in the sample of coal.

For a closely graded feed of limestone and fuel particles, the bulk density of the mixture is given by the equation :

$$\rho_{mf} = \rho_s \rho_f (1 + X_r) / (\rho_s + X_r \rho_f) \quad (3.17)$$

where ρ_s and ρ_f are the average bulk densities of limestone and fuel, respectively. Similarly, the modified value of the bulk density of the feed entering the burning zone, ρ_{mf} can be computed based on the modified value of x_r'.

Computer Programme for State-of-the-Art Process Engineering design computation is given in Appendix-B and the results for average conditions for a coal-fired lime shaft kiln of 10 tpd capacity are reported in Table-3.18.

3.4.5 Semi-Continuous Operation

The low capacity mixed-feed kilns in the building and small scale chemical industries are generally operated manually in one or

two shifts per day subject to the limitations of fuel, availability of labour and market demand fluctuations. The intermittent charging of raw materials and discharging of product tends to enhance the retention time which in turn leads to lowering down lthe productivity of the kiln.

In view of the operational practices being followed in a typical kiln, the retention time $\theta_{r/z}$ (in hours) for the same could be correlated by the expression :

$$\theta_{r/z} = 24\ \theta_{t/c}\ (1 + A_{l/c})\ (N_d\ \theta_d\ N_s)^{-1} \qquad (3.18)$$

where $\theta_{t/c}$ is the retention time for the continuous operation of the moving bed calciner (hrs.), $A_{l/c}$ is the fractional time lag allowance for manual operation over mechanized operation usually about 0.16 as reported by Azbe (1941), N_d is the number of discharges per shift, N_s is the number of working shifts per day, and θ_d is the average time of each discharge (hrs).

The retention times for several running kilns were determined from the field operation studies and the same were compared with those computed from equation (3.18). The results are presented in Table-3.17.

3.4.6 Wall Thickness of Masonry Shaft

The minimum wall thickness of the masonry kiln for design purpose should be based on the worst conditions prevailing in the burning zone of the kiln. Let R_i and R_o represent the average inner radius and outer radius of the shaft kiln so that the wall thickness, W_t, is:

$$W_t = R_o - R_i$$

Let T_i, T_o and T be the temperature in ^oC for the maximum inner wall surface, minimum desired outerwall surface and surroundings, respectively.

Under steady state conditions, the expression for heat conducted through the wall, Q_{wc} (Chapman, 1960) is given by the equation:

$$Q_{wc} = 2\pi L k_w (T_i - T_o) / \ln (R_o/R_i) \qquad (3.19)$$

and the heat loss from the external surface of the wall to the ambient air, Q_{wa} is given by the expression :

$$Q_{wa} = h_c \, 2\pi R_o \, L \, (T_2 - T_\infty) \qquad (3.20)$$

TABLE-3.17

Comparison of Retention Times for Field Operating Kilns

Kiln No.	Identification of Kiln (Plant, site)	Retention Time Estimated from Field Data (hrs)	Retention Time Computed from Equation (3.18)	Deviation %
1.	KVIC, DDN	53.9	62.6	+16.1
2	KVIC, DDN	64.1	78.0	+21.7
3	CBRI, RKE	32.0	36.0	+12.5
4	PSLW, MRT	81.3	76.4	- 6.0
5	M&C, DDN	100.2	89.5	-10.7
6	VP , DDN	110.7	89.5	-19.2
7	HML, NRNL	111.1	84.0	-24.2
8	GHLI, RPR	83.0	77.4	- 6.7
9	TLI, MZFNR	68.2	75.0	+10.0
10	HC, PNTSB	63.9	72.1	+12.6
11	RC, KLMB	84.0	79.5	- 5.4
12	PC, MDDN	71.0	75.2	+ 5.9

TABLE-I.18

PROCESS ENGINEERING DESIGN OF COAL-FIRED LIME SHAFT KILNS

AVERAGE INPUT DATA

	2.2500	10.0000	0.1000
0.2500	0.2250	1.0000	0.0000
1500.0000		300.0000	800.0000
400.0000	6000.0000	0.4000	0.4500
2.0000	2.0000	0.1600	4.0000

RESULTS OF COMPUTATIONS

NOMINAL DESIGN CAPACITY OF LIME KILN =10.00 TPD

LIMESTONE-TO-FUEL RATIO BY WEIGHT IN FEED INPUT AT TOP OF LIME KILN =

AVERAGE INNER DIAMETER OF THE LIME SHAFT KILN = 2.379 M

RETENTION TIMES (IN HOURS) FOR CONTINUOUS OPERATION :

PREHEATING	BURNING	COOLING	OVERALL
32.13	23.384	22.862	

HEIGHTS OF THE VARIOUS ZONES (IN METERS) FOR CONTINUOUS OPERATION

PREHEATING ZONE	BURNING ZONE	COOLING ZONE	EFFECTIV
4.701	3.237	2.880	

Now under study state conditions

$$Q_{wc} = Q_{wa}$$

Thus

$$k_w(T_i - T_o) / \ln (R_o/R_i) = h_c R_o (T_2 - T_\infty) \qquad (3.21)$$

In the above equations L is the height of the kiln, k_w is the effective thermal conductivity of the wall insulation, h_c is the heat transfer coefficient due to natural convection from the outer wall to air.

The parameters were estimated using the data from Chapman (1960), Bird, et.al (1960), and Perry and Chilton (1968) for maximum inner wall temperature of 1200^{o}C, the outer wall temperature of 40^{o}C and the ambient temperature of 25^{o}C. Keeping in view the thermal and functional requirements of lime kilns a masonry wall thickness of about 0.90 - 1.00 m was considered appropriate as assessed from a trial and error solution of equation (3.21).

3.5 INFERENCES

(i) Field survey indicated wide variations in superficial lime output rates, product qualities and thermal performances of the low capacity

mixed-feed lime shaft kilns. Investigations in the field and laboratory revealed poor thermal performance of these kilns.

(ii) The existing knowledge and available data on process engineering design were partially modified and working correlations were evolved for computation of dimensional specifications of the coal fired lime shaft kilns.

(iii) The state-of-the-art on process engineering correlations, however, left much to be desired as, although, the equations could be used for computing the preliminary design specifications fairly well for average conditions of operation, yet the effect of the influencing design and operational parameters on the performance of the kiln could not be properly assessed.

(iv) On account of the close proximity of constituents in mixed firing the individual temperature profiles for limestone, fuel and the bulk gas phases along the height of the kiln could neither be experimentally determined nor theoretically predicted.

(v) The degrees of calcination of limestone and combustion of coal particles along the height of the burning zone also could not be determined.

(vi) The need was thus established to develop a mechanistic model for the steady state simulation of coal-fired lime shaft kilns with

a view to predicting the effect of various design and operational parameters on their performance and evolve appropriate conditions for optimal design.

CHAPTER-4

MODELLING OF COAL FIRED LIME SHAFT KILN

Chapter-4

MODELLING OF COAL-FIRED LIME SHAFT KILN

4.1 PREAMBLE

Simulation of the mixed-feed lime shaft kiln requires a detailed analysis of the design and operating parameters. The important design parameters are :

(i) Superficial product output rate based on cross-sectional area of kiln $t/(m^2)$ (day)

(ii) Kiln height-to-diameter ratio

(iii) Wall insulation

Operating parameters of significance are :

(i) Limestone properties

a) Size of particles

b) Quality (composition, lattice structure, etc.)

(ii) Fuel properties

a) Size of particles

b) Quality (proximate and ultimate analyses)

(iii) Limestone-to-fuel ratio in feed input

(iv) Excess air

The quality of limestone determines its specific heat, density, calcination temperature and endothermic heat of decomposition. The quality of fuel determines its volatile and fixed carbon fractions, and its heating value.

Performance criteria could be based on :

(i) Superficial lime output rate, $t/(m)^2$ (day), consistent in product lime quality with respect to underburning or overburning.

(ii) Specific energy consumption per unit mass of product lime or thermal efficiency.

4.2 ANALYSIS OF THE PREHEATING ZONE

4.2.1 Definition and Assumptions

Preheating zone is located at the upper portion of the vertical shaft kiln. Mixed charge of limestone and coal particles is fed at the top of the kiln and gets heated to required temperatures as it moves down by exchanging heat from the upward flowing hot gases.

The preheating section is basically a direct contact solid-gas counter-current heat exchanger. This zone is assumed to extend till fuel particle temperature reaches auto-ignition temperature of volatile matter or when the temperature of limestone particles reaches the calcination temperature (about 1173 K) whichever occurs earlier. No changes in composition of limestone particles are effected till the attainment of calcination temperature. However, the demoisturization of coal particles starts in the temperature range of 373-383 K. The volatile matter is assumed to evolve when the fuel temperature lies in the range of about 673-1173 K. Instantaneous combustion of volatile matter in the boundary layer over the surface of the coal particle is assumed when the fuel temperature becomes equal to or greater than the auto-ignition temperature. The auto-ignition of volatile matter is assumed to occur at 948 K. The volatile matter released in the fuel temperature range of 673 to 948 K is assumed to be linear in temperature and it remains unburnt. This results in the partial loss of thermal efficiency. The burning of residual volatileionally combustion of fixed carbon may be essential before limestone attains calcination temperature, and this situation is treated as a part of the burning zone. The release of moisture is assumed to occur during prespecified number of kiln length intervals (number of discrete ΔZ steps) in view of the possible mass transfer limitation during its release through fuel particles.

The basic assumptions made in the analysis of the preheating zone are : (i) Flow patterns of solids and gas are characterized by

plug flow behaviour. Therefore, temperatures of solids and gas vary only along the axis of the kiln and variations in radial direction are ignored, (ii) Thermal conductivities, viscosities and soild volumes are constant in the zone, (iii) Heat loss from the kiln wall is assumed to result only from the exchange of heat between the gas and inside of kiln wall in view of the rapid mixing of gas in radial direction and point contacts of solid particles with kiln wall, (iv) At a given cross-section, the rate of heat transfer within the limestone and fuel particles is very fast as compared to the overall rate of heat transfer from gas to the particles. Consequently, the temperature gradients within the limestone and fuel particles are insignificant. This assumption is corroborated by the investigations of Hills (1968) for limestone particles, and Chung and Yun (1985) for coal particles.

The above assumptions are quite realistic and at the same time simplify the problem to some extent. The bulk movement of gaseous components from one phase to another at appropriate temperatures and their contribution in energy balances is an important feature of the proposed model for the preheating zone. Profiles of temperatures of gas, limestone and fuel particles, and fractional reduction in fuel quantity are obtained along the kiln axis by simultaneous solution of the set of three one dimensional steady state equations.

4.2.2 Differential Energy Balances

Over a differential volume elements, $\pi R_i^2 \Delta Z$ corresponding to width ΔZ in the axial direction at a given location Z (Fig. 4.1) in the zone along the length of the kiln, with Z being taken as zero at the top of the kiln and having an increasing positive value towards the bottom of the kiln, the balances have been written in the finite difference form, where R_i is the internal radius of the kiln. Appropriate modes of heat exchange are considered for interphase heat transfer between limestone and fuel particles, and gas.

4.2.2.1 Heat Balance For Limestones :

Heat is exchanged between the stone particles and the fuel particles by conduction and radiation. Heat is also exchanged between the stone particles and the bulk gas largely by convection and partially by radiation. The net heat received by the limestone particles is utilized in raising the sensible heat content of limestone by increasing its temperature. Thus the heat balance for limestones becomes

$$(h_c+h_r)_{fs} (T_f-T_s) a_f \pi R_i^2 - (h_c+h_r)_{sg} (T_s-T_g) a_s \pi R_i^2 \Delta Z$$

$$= \Delta (\dot{m}_s c_s T_s) \qquad (4.2.2.1.1)$$

where T_g, T_f, T_s are the temperatures of bulk gas, fuel and stone particles, respectively in K; a_f and a_s are the interfacial areas of

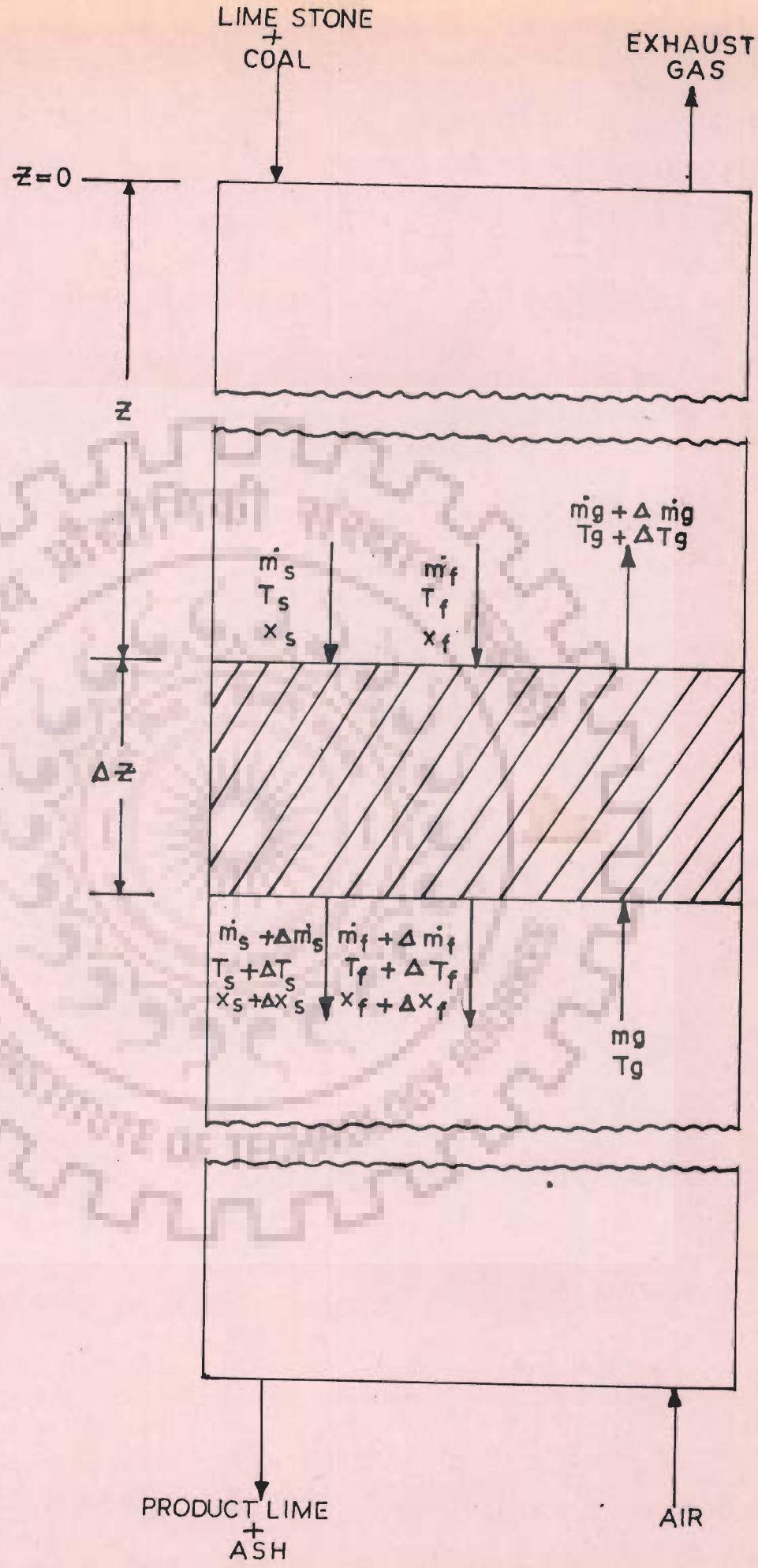


FIG. 4-1– DIFFERENTIAL VOLUME ELEMENT IN A GENERA
SECTION OF LIME SHAFT KILN

fuel and stone particles, m^2/m^3 of bed volume; $\dot{m}_s$ is the mass flow rate of limestone, Kg/hr; C_s is the specific heat of limestone particles, Kcal/(Kg)(K); h_c is the heat transfer coefficient due to conduction between fuel and stone particles in Kcal/(hr)(m^2)(K), and it is heat transfer coefficient due to convection between the gas and stone particles; and h_r is the heat transfer coefficient due to radiation. The subscript fs denotes from fuel to stone, and sg from stone to gas.

The first term on left hand side of the above equation indicates the heat received by the limestone particles from the fuel particles and the second term with negative sign indicates the transfer of heat from limestone particles to gas.

4.2.2.2 Heat Balance For Fuel :

(i) For simple preheating, the fuel particles exchange heat with the bulk gas by convection and radiation. Heat is also exchanged between limestone and fuel particles by conduction and radiation. Thus this balance could be written as:

$$(h_c+h_r)_{gf}\ (T_g-T_f)a_f\pi R_i^2\Delta Z-(h_c+h_r)_{fs}\ (T_f-T_s)a_f\pi R_i^2\Delta Z$$

$$= \Delta\ (\dot{m}_f\ C_f\ T_f) \qquad (4.2.2.2.1)$$

where $\dot{m}_f$ is the mass flow rate of the fuel particles in Kg/hr and C_f is the specific heat of fuel particles. The subscript gf denotes from gas to fuel.

The first term on the left hand side of the above equation indicates the heat received by the fuel particles from the gas and the second term with negative sign shows the heat transfer from fuel particles to stone particles.

(ii) For preheating with demoisturization, the endothermic heat of desorption-cum-vaporization of water has to be accounted for. Thus,

$$(h_c+h_r)_{gf}\,(T_g-T_f)a_f\pi R_1^2\Delta Z - (h_c+h_r)_{fs}\,(T_f-T_s)a_f\pi R_i^2\Delta Z$$

$$- \dot{m}_{f_o}\Delta x_f\,(\lambda_w+C_w\,T_f) = \Delta(\dot{m}_f\,C_f\,T_f) \qquad (4.2.2.2.2)$$

where x_f is the fractional devolatization of fuel based on unit mass of fuel input, λ_w is the endothermic heat of desorption of water in Kcal/Kg, and C_w is the specific heat of water vapour. The third term with negative sign on the left hand side of the above equation indicates the amount of heat required for demoisturization and raising the moisture evolved to fuel temperature.

(iii) For preheating with devolatization without volatile matter combustion, the endothermic heat of devolatilization and for raising the volatile matter evolved to fuel temperature has been similarly accounted in the heat balance as indicated below (Third term on the left hand side):

$$(h_c+h_r)_{gf}\,(T_g-T_f)a_f\,\pi R_i^2\,\Delta Z - (h_c+h_r)_{fs}\,(T_f-T_s)a_f\pi R_i^2\Delta Z$$

$$-\dot{m}_{f_o}\Delta x_f\,(\lambda_{vm}+C_{vm}\,T_f) = \Delta(\dot{m}_f\,C_f\,T_f)$$

(4.2.2.2.3)

where λ_{vm} is the heat of devolatilization in Kcal/hr and C_{vm} is the specific heat of the volatile matter.

4.2.2.3 Gas Phase Heat Balance :

The upward flow of gas (negative Z direction) is counter-current to the downflow (positive Z direction) of limestone and fuel particles. On account of the assumption of good radial mixing for the gas phase and negligible heat exchange between solid phases and wall due to point contacts, the wall heat losses have been accounted for in the heat balance for the gas phase.

(i) For the case of simple preheating, the gas heat balance could be written as :

$$(h_c+h_r)_{gf}\ (T_g-T_f)a_f\ \pi R_i^2\ \Delta Z\ +\ (h_c+h_r)_{gs}\ (T_g-T_s)a_s\ \pi R_i^2 \Delta Z$$

$$+\ \Delta H_l\ =\ \Delta(\dot{m}_g\ C_g\ T_g) \qquad (4.2.2.3.1)$$

where ΔH_l is the heat loss through the kiln wall in Kcal/hr. The left hand side terms indicate the total amount of sensible heat loss and is positive. Thus T_g will increase in positive Z - direction.

(ii) For preheating with demoisturization, the bulk transport of water vapour at a temperature T_f from the fuel to the gas phase takes place. The fourth term with negative sign accounts for this sensible heat receipt by the gas phase in the following heat balance equation :

$$(h_c+h_r)_{gf}\ (T_g-T_f)a_f\ \pi R_i^2 \Delta Z\ +(h_c+h_r)_{gs}\ (T_g-T_s)a_s \pi R_i^2 \Delta Z$$

$$+\ \Delta H_l - \dot{m}_{f_o} \Delta x_f C_{vm} T_f\ =\ \Delta(\dot{m}_g C_g T_g) \qquad (4.2.2.3.3)$$

4.2.2.4 Devolatilization of Coal :

For the case of devolatilization, the fraction of volatile matter evolved from the fuel has been assumed linear to rise in the fuel

temperature for the range of devolatilization temperatures (673 - 1173 K). Thus,

$$\Delta x_f = X_{vm} \Delta T_f/(1173-673) \qquad (4.2.2.4.1)$$

for $673 \leqslant T_f \leqslant 1173$ K

where X_{vm} is the fractional content of volatile matter in coal.

4.3 MODEL FOR COMBUSTION BEHAVIOUR OF A COAL PARTILCE

The proximate analysis of coal provides necessary information for describing its combustion behaviour in a mixed-feed lime shaft kiln. The volatile matter is assumed to evolve when the temperature lies usually in the range of 673-1173 K. The temperature range can be varied, if desired. Instantaneous combustion of volatile matter in the boundary layer over the surface of the coal particle is generally assumed when the fuel temperature becomes equal to or greater than auto-ignition temperature of the volatile matter at conditions prevailing in the kiln at that point. Auto-ignition temperature is assumed as 948 K, but other values can also be assigned if considered necessary. The volatile matter evolved in the fuel temperature range of 673 to 948 K has already been assumed to escape unburnt in the analysis of the preheating zone resulting in partial loss of thermal efficiency.

Instantaneous combustion of volatile matter evolved at fuel temperatures above the auto-ignition temperature of the volatile matter, and oxidation of the fixed carbon content of coal are sufficient to describe the combustion behaviour of the fuel. The release of the volatile matter from the incipient point of its instantaneous combustion is assumed to occur in prespecified discrete ΔZ steps, which can be assigned any desired value, of kilns length intervals in view of the possible mass transfer limitations during its evolution and instantaneous combustion at the surface of the fuel particles resulting in rapid increase in their temperatures. Burning is assumed to be uniform at the exposed surface of coal.

The ignition of the fixed carbon content of the coal particle has been assumed to commence only after the completion of devolatilization. Possibility exists that the ignition of fixed carbon content of fuel may at times occur before the entire volatile matter has been evolved. However, the probability of oxygen reaching the fuel particle surface, so as to cause combustion of the fixed carbon, when the volatile matter is being evolved and getting burnt around the coal particle is extremely small. Therefore, a simplified approach is used whereby ignition of the fixed carbon is assumed to occur after complete burning of the volatile matter evolved beyond the auto-ignition temperature attained by the fuel. This assumption is also corroborated by Lowe, et. al (1977), Conglidis and Geogarkis (1981), and Thring (1962).

The kinetics of shrinking particle size model has been assumed for combustion of the fixed carbon content of coal alongwith the simultaneous removal of ash from the fuel particle. This model is also referred as ash segregation model. The rate of reaction, mass of fixed carbon consumed/(external surface) (time), for combustion of the fixed carbon to carbon dioxide is a first order reaction with respect to the concentration or partial pressure of oxygen in the gas phase. For combustion kinetics, fixed carbon is treated as pure carbon. Two resistances, namely, surface reaction and diffusion of oxygen through the gas film around shrinking coal particle play a dominant roles and these, in turn, determine the effective rate constant for combustion of the fixed carbon. The possibility of formation of carbon monoxide through incomplete combustion of the fixed carbon has been ignored for conditions obtaining in the kiln.

The reaction for combustion of carbon (fixed carbon) to carbon dioxide is described by the equation :

$$C + O_2 \longrightarrow CO_2 \qquad (4.3.1)$$

The rate of combustion of carbon (Levensprel, 1975) is defined as

$$\text{rate} = -(1/s_{ex})\, dm_c/dt,\ Kg/(m^2)\ (hr) \qquad (4.3.2)$$

where s_{ex} is the external surface of the particles, m^2; m_c is the

mass of carbon, Kg; and t is the time, hr. For the case of a spherical particle, the rate expression is written as :

$$\text{rate} = -(1/4\pi r^2)\, d/dt \qquad (4\pi r^3 \rho_{c/3})$$

$$= -\rho_c\, dr/dt \qquad (4.3.3)$$

where ρ_c is the density of carbon (Kg/m^3) and r is the radious of the particle (m) at any given instant. It is a first order reaction with respect to the concentration or partial pressure of oxygen in the gas phase. Using appropriate units, the rate is written in terms of partial pressure of oxygen in the gas phase surrounding the particle as :

$$-\rho_c\, dr/dt = \bar{k}_s\, p_{o_2} \qquad (4.3.4)$$

where $\bar{k}_s$ is the overall rate constant due to combined effect of surface reaction as well as gas film diffusional resistances, $Kg/(m^2)$ (hr) (atm), and p_{o_2} is the partial pressure of oxygen in the gas phase, atm.

The fractional conversion, x_c, of the fixed carbon component of coal is given as :

$$x_c = 1 - (r/r_{p_f})^3 \qquad (4.3.5)$$

where r_{p_f} is the original radius of carbon particle (fuel particle). Differentiating equation (4.3.5)

$$dx_c = -3 r^2 dr / r_{p_f}^3 \qquad (4.3.6)$$

and rearranging

$$dr = -d x_c r_{p_f}^3 / 3 r^2 \qquad (4.3.7)$$

Equation (4.3.5) can be rearranged to give :

$$r^2 = r_{p_f}^2 (1-x_c)^{2/3} \qquad (4.3.8)$$

Substituting for r^2

$$dr = -dx_c r_{p_f}^3 / 3 r_{p_f}^2 (1-x_c)^{2/3}$$

$$= -dx_c r_{p_f} / 3(1-x_c)^{2/3} \qquad (4.3.9)$$

Substituting for dr in equation (4.3.4), we get

$$\rho_c r_{p_f} dx_c / 3(1-x_c)^{2/3} = \bar{k}_s p_{o_2} dt \qquad (4.3.10)$$

For the conditions obtaining in lime shaft kiln, the interval in real time can be expressed as space time interval if solids move in plug flow at an apparent velocity $v_{sf}/\pi R_i^2 (1-\epsilon_b)$, that is

$$dt = dz/\left[v_{sf}/\pi R_i^2(1-\epsilon_b)\right] \qquad (4.3.11)$$

where ϵ_b is the bed porosity and v_{sf} is volumetric flow rate of solids, fuel and limestone-lime particles.

Substitution in equation (7.3.10) gives

$$\rho_c r_{p_f} dx_c v_{sf} / (1-x_c)^{2/3}$$

$$= 3 \bar{k}_s p_{o_2} \pi R_i^2 (1-\epsilon_b) dZ \qquad (4.3.12)$$

In the finite difference form, this equation for fixed carbon combustion is written as :

$$\Delta x_c = 3 \pi R_i^2 \bar{k}_s p_{o_2} (1-\epsilon_b) \Delta Z (1-x_{c_{av}})^{2/3} /$$

$$\rho_c r_{p_f} v_{sf} \qquad (4.3.13)$$

The density of fixed carbon in fuel particles after completion of devolatilization can be related to the initial density of fuel particles as :

$$\rho_c = \rho_f X_{fc}$$

where X_{fc} is the mass fraction of fixed carbon in fuel. Therefore,

$$\Delta x_c = \frac{3\pi R_i^2 \bar{k}_s p_{o_2} \Delta Z (1-\epsilon_b)(1-x_{c_{av}})^{2/3}}{\rho_f X_{fc} r_{p_f} v_{sf}} \qquad (4.3.14)$$

By definition :

$$1/\bar{k}_s = 1/k_s + 1/k_d \qquad (4.3.15)$$

where k_s is the surface rate constant and k_d is the mass transfer coefficient for diffusion of oxygen. Thus,

$$\bar{k}_s = k_s k_d / (k_s + k_d) \qquad (4.3.16)$$

Using appropriate conversion factors, the expression defined by Parker and Hottel (1936) for computation of surface reaction rate constant becomes :

$$k_s = 3.44 \times 10^{11} T_f^{-1/2} \quad e^{-44000/RT_f} \qquad (4.3.17)$$

where R is the gas constant and T_f is the temperature of the fuel particle.

The diffusion rate constant for oxygen through gas film consisting largely of carbon dioxide as the main product of combustion is given by Field (1969) as

$$k_d = 0.2304 \, (T_f/1600)^{0.75} \; / \; d_{p_f} \qquad (4.3.18)$$

where T_f is the fuel film temperature and d_{p_f} is the diameter of the fuel particle.

The equations (4.3.14) through (4.3.18) are used for the computation of fractional degree of combustion of fixed carbon content of fuel. The effective rate constant $\bar{k}_s$ is computed at each axial position based on the conditions prevailing at that point in the kiln.

When the fuel temperature reaches 1573 K (assumed ash fusion temperature) and above, the fusion of ash particle will result in the formation of a porous ash layer around the shrinking core of

fixed carbon interspersed with fine ash particles. Combusion of fixed carbon is then assumed to occur at the interface of the porous ash layer and fixed carbon core. Mass transfer resistance to oxygen diffusion though ash layer is considered insignificant because complete melting of ash with formation of glassy impervious layer is not visualized as this will result in total loss of unburnt fixed carbon in fuel particles. Shrinking of ash layer resulting in the increase of its density is related to the temperature of fuel particle. This is discussed in detail in Chapter-5. The temperature gradient within the fuel particle consisting of ash layer and fixed carbon core is assumed negligible because of rapid heat conduction.

4.4 HEAT CONDUCTION THROUGH LIME LAYER OF A CALCINING LIMESTONE PARTICLE

The shrinking core model (Fig. 2.1) has been assumed for the decomposition of a limestone sphere undergoing calcination with no change in its size. The decomposition starts at the surface of the particle and proceeds inwards towards the centre. At a given instant there is a central core of undecomposed calcium carbonate surrounded by a shell of calcium oxide with reaction carbonate occurring at the interface between the core and the shell. It has further been assumed that the calcination rate controlling mechanism

is the rate of conduction of heat through the lime layer to the limestone-core boundary. The surface of stone exchanges heat with fuel and gases by conduction convection, and radiation mechanisms. The undecomposed limestone core is assumed to remain at the calcination temperature which is considered as constant irrespective of the core size. A part of the heat recieved by the stone surface is used for the heating up of the lime layer. The net amount of heat received at the lime-limestone interface is used for the dissociation of $CaCO_3$. The heat conduction through the porous lime layer can be analysed as a quasi-steady state process because the rate of heat conduction through the outer shell of lime is very fast as compared to the rate of change of temperature at the surface of lime-limestone particles or the rate of reduction of the limestone core radius. This assumption is similar to that used for the analysis of diffusion of gaseous reactant through the layer of soild product to the surface of unreacted core (Levenspiel, 1975). It may be noted that, in general, intraparticle heat conduction is much faster as compared to interparticle mass transfer (Smith, 1970) and therefore quasi-steady state conduction through lime layer is very much justified.

The stone particle conduction equation is solved using the usual quasi-steady state assumption for any specified surface temperature and limestone conversion. The surface temperature and fractional conversion change with axial position which, in turn, affects the sensible heat accumulation in lime layer.

The use of quasi-steady state assumption for heat conduction through product lime layer for computation of instantaneous radial temperature profile in outer lime shell can be obtained by neglecting heat accumulation in the lime layer. Thus, the intraparticle conduction equation for spherical particles can be written in the form :

$$d^2 T/d r^2 + (2/r)\, dT/dr = 0 \qquad (4.4.1)$$

with boundary conditions :

(i) at $r = r_{p_s}$, $T = T_s$

(ii) at $r = r_c$, $T = T_d$

where T is the temperature in the outer lime layer of calcining limestone particle, r is the general radial position in the lime layer, r_c is the radius of the calcium carbonate core, r_{p_s} is the size of the limestone particle, T_s is the temperature at the surface of the limestone-lime particle, and T_d is the temperature of decomposition of limestone.

The solution of the above equation is :

$$T = - C_1/r + C_2 \qquad (4.4.2)$$

where C_1 and C_2 are the constants of integration. The values of the same obtained from the given boundary conditions are :

$$C_1 = r_c\, r_{p_s}\, (T_s - T_d) \;/\; (r_{p_s} - r_c)$$

$$C_2 = T_d + r_{p_s}\, (T_s - T_d) \;/\; (r_{p_s} - r_c) - r_c\, r_{p_s}\, (T_s - T_d) \;/\; r\, (r_{p_s} - r_c)$$

The substitution for C_1 and C_2 in equation (4.4.2) and simplification gives the desired temperature profile in the lime layer ;

$$T = T_d + r_{p_s}\, (T_s - T_d)(1 - r_c/r) \;/\; (r_{p_s} - r_c) \qquad (4.4.3)$$

The instantaneous temperature profile in product lime layer predicted by equation (4.4.3) is valid for lime-limestone particles at any given axial position in the kiln. It may be noted that as the limestone particles move through the burning zone, not only the surface temperature (T_s) changes, but the core radius (r_c) also changes from r_{p_s} to zero. However, for any given values of T_s and r_c, the equation (4.4.3) will remain valid due to the quasi-steady state assumption.

In order to calculate the rate of calcination as lime-limestone

particles move down the burning zone, appropriate consideration to the heating up of the lime layer will have to be given in the heat balance for a calcining limestone particle. The overall sensible heat requirement in heating up of lime layer above calcination temperature may account for nearly 5 to 10 percent of the heat of calcination. Thus,

Heat conducted inward from the external surface of the limestone - lime particle = Heat utilized for calcination of limestone + sensible heat change of the lime layer of the particle.

or

$$k_l \, 4\pi r_{p_s}^2 \, (dT/dr)_{r=r_{p_s}} = - E_s \, \rho_s \, 4\pi r_c^2 \, dr_c/dt + d(S_{hl})/dt \qquad (4.4.4)$$

where k_l is the thermal conductivity of the lime layer, Kcal/(hr)(m)(k); E_s is the endothermic heat of dissociation, Kcal/Kg of limestone; ρ_s is the density of limestone, Kg/m^3; and S_{hl} is the sensible heat content of the lime layer, Kcal. From the generalized nature of temperature profile as indicated by equation (4.4.3), on rearrangement we get

$$dT/dr)_{r=r_{p_s}} = (T_s - T_d)\,(r_c/r_{p_s}) \;/\; r_{p_s}(1-r_c/r_{p_s})$$

Noting that the shrinking unreacted core of radius r_c, can be correlated with the fractional conversion of limestone (x_s) by the expression :

$$(r_c/r_{p_s})^3 = 1 - x_s \qquad (4.4.5)$$

the temperature gradient at lime-limestone particle surface in terms of T_s and x_s can be given as :

$$dT/dr)_{r=r_{p_s}} = (T_s - T_d)(1-x_s)^{1/3} \;/\; r_{p_s}\left[1 - (1-x_s)^{1/3}\right] \qquad (4.4.6)$$

Differentiation of equation (4.4.5) and rearrangement gives

$$r_c^2\, dr_c = r_{p_s}^3\, dx_s \;/\; 3 \qquad (4.4.7)$$

Knowing the temperature profile in lime layer, its sensible heat content, S_{hl}, can be obtained by the expression :

$$S_{hl} = \int_{r_c}^{r_{p_s}} 4\pi r^2 \, dr \, \rho_l \, C_l \left[T_d + r_{p_s} (T_s - T_d) (1 - r_c/r) / (r_{p_s} - r_c) \right] \quad (4.4.8)$$

Integration of the above equation gives :

$$S_{hl} = 4\pi \rho_l C_l \left[T_d (r_{p_s}^3 - r_c^3) / 3 + (T_s - T_d) \left\{ (r_{p_s}^3 - r_c^3) / 3 - \frac{r_c}{2} (r_{p_s}^2 - r_c^2) \right\} / (1 - r_c/r_{p_s}) \right] \quad (4.4.9)$$

which can be simplified to give:

$$S_{hl} = 2\pi r_{p_s}^3 \rho_l C_l / 3 \left\{ 1 - (1-x_s)^{1/3} \right\} \left[2 x_s \left\{ T_s - T_d (1-x_s)^{1/3} \right\} - 3(1-x_s)^{1/3} \left\{ 1 - (1-x_s)^{2/3} \right\} (T_s - T_d) \right] \quad (4.4.10)$$

Substitution of equations (4.4.6), (4.4.7) and (4.4.10) in equation (4.4.4) leads to :

$$k_l \, 4\pi r_{p_s} (T_s - T_d) (1-x_s)^{1/3} / \left\{ 1 - (1-x_s)^{1/3} \right\}$$

$$= E_s \rho_s 4\pi r_{p_s}^3 dx_s / 3\,dt$$

$$+ d/dt \left\{ \frac{\frac{4}{3}\pi r_{p_s}^3 \rho_l C_l}{1-(1-x_s)^{1/3}} \left[x_s \{T_s - T_{al}(1-x_s)^{1/3}\} - \frac{3}{2}(1-x_s)^{1/3} \{ 1-(1-x_s)^{2/3} \} (T_s - T_{al}) \right] \right\}$$

(4.4.11)

which is rearranged to give :

$$\frac{k_l (T_s - T_{al})\, dt}{\{(1-x_s)^{-1/3} - 1\}} = \frac{E_s \rho_s r_{p_s}^2 dx_s}{3} + \frac{\rho_l C_l r_{p_s}^2}{3} d\left\{ \frac{x_s T_s}{\{1-(1-x_s)^{1/3}\}} - \frac{x_s T_{al}(1-x_s)^{1/3}}{\{1-(1-x_s)^{1/3}\}} - 1.5 (T_s - T_{al})(1-x_s)^{1/3} \left[1 + (1-x_s)^{1/3} \right] \right\}$$

(4.4.12)

Now for the conditions obtaining in shaft kiln, dt is related with dZ as per equation (4.3.11). Substitution and simplification in equation (4.4.12), the conduction equation in finite difference form becomes

$$\frac{3 k_l \pi R_c^2 (1-\epsilon_b)(T_s - T_{al}) \Delta Z}{r_{p_s}^2 v_{sf} \{(1-x_{s_{av}})^{-1/3} - 1\}} = E_s \rho_s \Delta x_s + \rho_l C_l \Delta \left\{ \frac{x_s T_s}{1-(1-x_s)^{1/3}} - \frac{x_s T_{al}(1-x_s)^{1/3}}{1-(1-x_s)^{1/3}} - 1.5 (T_s - T_{al})(1-x_s)^{1/3} \left[1 + (1-x_s)^{1/3} \right] \right\}$$

(4.4.13)

4.5 ANALYSIS OF THE BURNING ZONE

4.5.1 Complexities of the Zone and Some Simplifying Assumptions

The analysis and modelling of the burning zone of a mixed-feed lime shaft kiln is extremely complex. A realistic kiln model will have to account for the complicated heat and mass transfer processes alongwith chemical conversion reactions. The main variables to be solved for are : the degree of calcination of limestone, extent of combustion of volatile matter and fixed carbon content of coal, surface temperature of limestone, fuel temperature and bulk gas temperature. Furthermore, it is necessary to account for the release of ash on combustion of the fixed carbon as well as the fusion of ash after the fuel attains ash fusion temperature, variations in particle surface areas, changes in packed bed densities, heating up of the product quick lime layer after properly accounting for its changing temperature profile, modes of heat exchange between solids and gases, changes in heat transfer coefficients, effectiveness factors for estimating active heat exchange surface areas, variations in specific heat with temperature and composition, the changes in surface reaction rate and diffusional transport rate constants for the combustion of the fixed carbon content of the fuel particles, variations in gas emissivities for gas-solid radiant heat exchange, etc.

In view of the highly complicated nature of the burning zone, some simplifying assumptions have to be made to facilitate the solution

of this otherwise intractable problem without sacrificing the reality of the situation at the same time. In the normal operation of a shaft kiln the radial temperature variations of the gas phase and solids may be neglected and may be treated to change only with the axial position (Z) of the kiln.

Based on the generalized assumptions enumerated earlier for the analysis of the preheating zone, and the assumption of quasi-steady state heat conduction for calcining limestone particles, implying that the rate of heat transfer through the product lime layer is fast compared to the rate of shrinkage of the core resulting in the rapid establishment of the temperature profile for any given lime layer surface temperature and unreacted limestone core radius, the following balances are written at a given axial position for a differential element of kiln length:

(i) Heat balance for limestone particles

(ii) Heat balance for fuel particles

(iii) Heat balance for the gas phase

The bulk movement of oxygen at gas temperature from gas phase to burning fuel particle and the gaseous combustion products from fuel at fuel temperature and carbon dioxide produced as a result of calcination of limestone at the product lime layer surface temperature are to be properly accounted for in the heat and mass balances. The above three balances alongwith the appropriate equations

for the calcining behaviour of limestone and the combustion behaviour of the volatile matter and fixed carbon contents of coal particles should suffice to predict the conversion profiles of limestone and fuel particles, and temperature profile of the gas, fuel and surface temperature of lime-limestone particles. The temperature profile for the lime layer was also computed for any lime surface temperature and fractional conversion of limestone. This profile is used to estimate the changes in sensible heat of lime layer which is expected to become important as limestone conversion and surface temperature of lime layer increase.

Although the volatile matter in coal consists of saturated and unsaturated hydrocarbons, tarry vapours, hydrogen, carbon monoxide and other minor constituents (Himus, 1958; and Smith and Stinson, 1952), yet a composition, such as, C_nH_{2n+2} can be assumed for the volatile matter as a reasonable assumption for the simplification of analysis and computation. An average molecular weight of 20 for the decomposed volatile matter has been assumed (Fuchs and Sandhoff, 1942).

The volatile matter is assumed to burn instantaneously and completely resulting in the formation of carbon dioxide and water according to the following chemical reaction :

$$C_nH_{2n+2} + 1/2\ (3n + 1)\ O_2 \longrightarrow nCO_2 + (n+1)H_2O$$

(4.5.1.1)

4.5.2 Differential Material and Energy Balances

The heat conduction equation in lime shell with calcination reaction at lime-limestone interface, the instantaneous combustion of the volatile matter or fixed carbon combustion equations for the fuel have to be used together with material balances and interphase heat balances for obtaining unique solution for each differential kiln volume in the burning zone.

4.5.2.1 Heat Balance for Limestones

No ash is released during the combustion of volatile matter. Ash released during combustion of the fixed carbon at the fuel temperature, when fuel temperature is less than the assumed ash fusion temperature, is assumed to spread over the surface of limestone particles and in the process attains the temperature of the stone surface. The stone particles also receive heat by conduction and radiation from the burning fuel particles. Some of the heat from the fuel is transferred to gas by convection and radiation, if the gas temperature is less than that of the stone.

The net heat received by the lime-limestone particles is utilized mainly for the endothermic calcination process, but some of the heat is also used for the heating up of the quick lime layer formed. The carbon dioxide released at the temperature of calcination

from the reaction interface also gets heated to lime-limestone surface temperature while passing through the lime layer. The transport of carbon dioxide produced from limestone calcination and fuel combustion processes to the gas phase also takes place and needs to be accounted for in the material and energy balances.

Over a differential volume element, $\pi R_i^2 \Delta Z$, of width ΔZ in the axial direction at a given location (Z being taken as positive from top towards lower end of the zone), the heat balance for the limestone particles could be written as :

$$(h_c + h_r)_{fs} (T_f - T_s) a_f \pi R_l^2 \Delta Z - (h_c + h_r)_{sg} (T_s - T_g) a_s \pi$$

$$R_i^2 \Delta Z + m_{f_o} (\Delta x_a) C_a T_f = \dot{m}_{s_o} \Delta x_s E_s + \dot{m}_{s_o} \Delta x_s$$

$$(44/100) C_{CO_2} T_s + \dot{m}_{s_o} \Delta x_s (44/100) C_{CO_2} (T_s - T_d) +$$

$$\Delta (\dot{m}_a C_a T_s) + .56 \dot{m}_{s_o} C_l \Delta \left[x_s T_s / \left\{ 1 - (1-x_s)^{1/3} \right\} - \right.$$

$$x_s T_s (1-x_s)^{1/3} / \left\{ 1 - (1-x_s) \right\} -$$

$$\left. 1.5 (T_s - T_d) (1-x_s)^{1/3} \left\{ 1+(1-x_s)^{1/3} \right\} \right] \qquad (4.5.2.1)$$

where x_s is the conversion based on original mass flow rate of limestone at kiln top, x_a is the fraction of ash released based on

original mass flow rate of fuel at kiln top, $\dot{m}_a$ is the mass flow rate (Kg/hr) of the ash released, $\dot{m}_{s_o}$ is the mass flow rate of limestone and $\dot{m}_{f_o}$ is the mass flow rate of fuel at kiln top (Kg/hr), C_a is the specific heat of ash, Kcal/(Kg)(K); and T_d is the decomposition temperature of limestone (K).

The first and second terms on the left hand side of the above equations are already explained and the third term indicates the sensible heat received by the stone associated with the ash released from the coal during fixed carbon combustion. The first, second, third, fourth and fifth terms on the right hand side of the above equation indicate the calcination heat requirement, sensible heat associated with CO_2 released from stone at T_s, sensible heat required for heating the CO_2 from T_d to T_s while passing through lime layer, sensible heat accumulation in ash spread on stone particles and sensible heat accumulation in lime layer due to changes in its temperature, respectively.

4.5.2.2 Heat Balance for Gas Phase

The bulk of gas phase receives heat from fuel as well as stone particles by convection and radiation alongwith the bulk transport of carbon dioxide from the calcining limestone particles and burning fuel particles at the appropriate temperatures. The transport of water vapour formed during volatile matter burning also needs to be taken into account.

For the case of volatile matter combustion, the gas phase

heat balance can be written as :

$$(h_c + h_r)_{fg} (T_f - T_g) a_f \pi R_i^2 \Delta Z + (h_c + h_r)_{sg} (T_s - T_g) a_s \pi R_i^2 \Delta Z + \dot{m}_{f_o} \Delta x_f (56.5/20) C_{CO_2} T_f + \dot{m}_{f_o} \Delta x_f (41/20) C_w T_f + \dot{m}_{s_o} \Delta x_s (44/100) C_{CO_2} T_s - \dot{m}_{f_o} \Delta x_f (77.5/20) C_{O_2} T_g - \Delta H_l = - \Delta (\dot{m}_g C_g T_g)$$

(4.5.2.2.1)

where C_w is the specific heat of water vapour. The first, second and seventh terms on the left hand side of the above equation are already explained, the third and fourth terms indicate sensible heat of CO_2 and water produced due to volatile matter combustion at T_f , and sixth and seventh terms are the sensible heat of CO_2 at T_s received by gas from calcination of stone and the sensible heat of oxygen supplied by gas at T_g to fuel for volatile matter combustion. It may be noted that one kmol of volatile matter (molecular weight taken is 20) requires 77.5 Kg of O_2 and produces 56.5 Kg of CO_2 and 41 Kg of water during combustion as per the stochiometric equation (4.5.1.1). Right hand side term with negative sign indicates the heat accumulation by the gas in negative z direction, that is, in its direction of flow.

$$(h_c + h_r)_{fg} (T_f - T_g) a_f \pi R_i^2 \Delta Z + (h_c + h_r)_{sg} (T_s - T_g) a_s$$

$$\pi R_i^2 \Delta Z + \dot{m}_{f_o} \Delta x_f (44/12) C_{CO_2} T_f + \dot{m}_{s_o} \Delta x_s (44/100)$$

$$C_{CO_2} T_s - \dot{m}_{f_o} \Delta x_f (32/12) C_{O_2} T_g = - \Delta(\dot{m}_g C_g T_g)$$

(4.5.2.2.2)

The terms in the above equation are self explanatory in view of the fact that one kmol of fixed carbon (molecular weight 12) requires 32 Kg of Oxygen and produces 44 Kg of CO_2 during its combustion.

4.5.2.3 Heat Balance for Fuel

The net heat released from the combustion of volatile matter or fixed carbon content of fuel is supplied to the stone and gas phases. Bulk transport of combustion products at fuel temperature also carry sensible heat alongwith them to the gas phase. Oxygen needed for combustion is received from the gas phase at the temperature of the gas.

For volatile matter combustion, the endothermic heat required for the devolatilization process is also to be accounted for. The differential heat balance for the fuel for the combustion of volatile matter can be written as :

$$\dot{m}_{f_o} \Delta x_f H_{vm} - \dot{m}_{f_o} \Delta x_f \lambda_{vm} + \dot{m}_{f_o} \Delta x_f (77.5/20) C_{O_2} T_g$$

$$= (h_c + h_r)_{fs} (T_f - T_s) a_f \pi R_i^2 \Delta Z + (h_c + h_r)_{fg} (T_f - T_g)$$

$$a_f \pi R_i^2 \Delta Z + \Delta(\dot{m}_f C_f T_f) + \dot{m}_{f_o} \Delta x_f (56.5/20) C_{CO_2}$$

$$T_f + \dot{m}_{f_o} \Delta x_f (41/20) C_w T_f \qquad (4.5.2.3.1)$$

where H_{vm} is the heat of combustion of the volatile matter. The first term and second term with negative sign on the left hand side of the above equation indicate exothermic heat of combustion of gaseous volatile matter and endothermic heat of devolatilization, respectively. The third term on the right hand side of the above equation indicates the sensible heat accumulation of fuel particles. All other terms in the above equations are explained earlier. For the case of fixed carbon combustion, the fuel heat balance becomes

$$\dot{m}_{f_o} \Delta x_f H_{fc} + \dot{m}_{f_o} \Delta x_f (32/12) C_{O_2} T_g = (h_c + h_r)_{fs}$$

$$(T_f - T_s) a_f \pi R_i^2 \Delta Z + (h_c + h_r)_{fg} (T_f - T_g) a_f \pi R_i^2 \Delta Z$$

$$+ \Delta(\dot{m}_f C_f T_f) + \dot{m}_{f_o} \Delta x_f (44/12) C_{CO_2} T_f + \dot{m}_{f_o} \Delta x_a C_a T_f$$

(4.5.2.3.2)

where H_{fc} is the heat of combustion of the fixed carbon (Kcal/Kg). The first term in the above equation indicates the exothermic heat of combustion of the fixed carbon.

4.5.2.4 Material Balance for Limestones

The mass flow rate of limestones decreases along the axis of the kiln in the positive Z - direction on account of the release of carbon dioxide. Thus,

$$\Delta \dot{m}_s = - \dot{m}_{s_o} (44/100) \Delta x_s \qquad (4.5.2.4.1)$$

4.5.2.5 Material Balance for Fuel

The mass flow rate of fuel decreases along the positive Z - direction during the volatile matter release from the fuel. Thus,

$$\Delta \dot{m}_f = - \dot{m}_{f_o} \Delta x_f \qquad (4.5.2.5.1)$$

for $x_f \leq x_{fm} + x_{fv}$

It may be noted that the above equation is also applicable to the preheating zone where demoisturization and devolatization without combustion of volatile matter take place.

For fixed carbon combustion with ash release, the mass flow rate of fuel changes as :

$$\Delta \dot{m}_f = - \dot{m}_{f_o} (\Delta x_f + \Delta x_a) \qquad (4.5.2.5.2)$$

$$\text{for } x_{fm} + x_{fv} \leq x_f \leq x_{ff}$$

No ash is released during fixed combustion with ash fusion. Thus the material balance for this case becomes :

$$\Delta \dot{m}_f = - \dot{m}_{f_o} \Delta x_f \qquad (4.5.2.5.3)$$

$$\text{for } x_{ff} \leq x_f \leq x_{f_{max}}$$

where $x_{f_{max}} = x_{fm} + x_{fv} + x_{fc}$

4.5.2.6 Material Balance for Gas Phase

The changes in mass flow rates of limestone particles and fuel particles account for the change in mass flow rate of gas. Thus,

$$\Delta \dot{m}_g = - \dot{m}_{s_o} \Delta x_s (44/100) - \dot{m}_{f_o} \Delta x_f \qquad (4.5.2.6.1)$$

The first and second terms with negative signs indicate the increase in the mass of gas due to bulk transfer of CO_2 from the calcining limestone particles and the combustion of fuel. It may be noted that the above equation without the first term on the right hand side is also applicable to the preheating zone where only demoisturization or devolatilization without combustion of volatile matter takes place.

4.5.2.7 Material Balance for Ash Release

Ash is assumed to be distributed uniformly alongwith the fixed carbon in the entire volume of the fuel particles. Thus, ash release has a linear relationship with the fixed carbon content of the fuel before fuel attains the ash fusion temperature, that is, $x_{fm} + x_{fv} \leq x_f \leq x_{ff}$ as per the equation :

$$x_a = m\, x_f + C \qquad (4.5.2.7.1)$$

where m and C are the constants to be determined from the limiting conditions :

$$\text{for } x_f = x_{fm} + x_{fv}\,, \quad x_a = 0$$

$$\text{for } x_f = x_{fm} + x_{fv} + x_{fc}\,, \quad x_a = x_{fa} \qquad (4.5.2.7.2)$$

Solving the above equations, we get

$$x_a = x_{fa} (x_f - x_{fm} - x_{fv}/x_{fc}) \quad (4.5.2.7.3)$$

Differentiating the above equation and writing in the finite differcence form, the following relationship is obtained :

$$\Delta x_a = x_{fa} \Delta x_f / x_{fc} \quad (4.5.2.7.4)$$

which is valid for $(x_{fm} + x_{fv}) \leq x_f \leq (x_{fm} + x_{fv} + x_{fc})$.

If ash fusion occurs then the applicability of equation (4.5.2.7.4) will be restricted only upto x_{ff}. The mass flow rate of ash released at any given time in the burning zone is given as :

$$m_a = \dot{m}_{f_o} x_a \quad (4.5.2.7.4)$$

and therefore,

$$m_a = \dot{m}_{f_o} \Delta x_a \quad (4.5.2.7.5)$$

4.5.2.8 Relationship between x_f and x_c

The fractional conversion of fixed carbon in fuel x_c used in equation 4.3.14 is related linearly to the fractional conversion of fuel x_f by an equation similar to equation (4.5.2.7.1) but the limiting conditions are :

for $x_f = x_{fm} + x_{fv}$, $x_c = 0$

and for $x_f = x_{fm} + x_{fv} + x_{fc}$, $x_c = 1$ (4.5.2.7.6)

Solution of linear equation with limiting conditions,

we get

$$x_c = (1/x_{fc}) (x_f - x_{fm} - x_{fv}) \quad (4.5.2.7.7)$$

and therefore,

$$\Delta x_c = \Delta x_f / x_{fc} \quad (4.5.2.7.8)$$

4.5.3 Computation of the Average Temperature of Solid Mass at the end of Burning Zone

The solid mass at the end of the burning zone consists of quick lime particles with or without limestone core, fuel ash and cinders/ash clinkers. The fuel ash has already been assumed to be spread over the surface of the limestone-lime particles. The size and amount of the cinders/ash clinkers at the end of the burning zone is also quite small. Thus the entire lot of solid mass could be assumed to possess uniform average temperature once the combustion of fuel or calcination of limestone is complete.

The average temperature could be computed on the basis of the weighted mean of the different constituents of the solid particles as :

$$T_{solid} = \left\{ \dot{m}_{s_o} x_{s_{av}} (56/100) C_l T_{ll_{av}} + \dot{m}_{s_o} (1-x_{s_{av}}) C_s T_d \right.$$

$$\left. + \dot{m}_{f_o} x_{a_{av}} C_a T_{s_{av}} + \dot{m}_{f_o} (1-x_{f_{av}} - x_{a_{av}}) C_f T_{f_{av}} \right\} /$$

$$\left[\dot{m}_{s_o} x_{s_{av}} (56/100) C_l + \dot{m}_{s_o} (1-x_{s_{av}}) C_s + \right.$$

$$\left. \dot{m}_{f_o} x_{a_{av}} C_{fa} + \dot{m}_{f_o} (1 - x_{f_{av}} - x_{a_{av}}) C_f \right] \qquad (4.5.3.1)$$

where $x_{s_{av}}$ is the fractional conversion of limestone at the end

of the burning zone and $T_{ll_{av}}$ is the average temperature of the lime particles. The $T_{ll_{av}}$ is computed from the sensible heat balance using the lime layer temperature profile at the completion of calcination ($x_{sav} = 1.0$) or at the end of burning zone ($x_f = x_{fm} + x_{fv} + x_{fc}$) whichever occurs earlier as per the following equation :

$$T_{ll_{av}} = T_{s_{av}} / \{1 - (1-x_s)^{1/3}\} - T_d(1-x_{s_{av}}) / \{1-(1-x_{s_{av}})\} - 1.5\,(T_{s_{av}} - T_d)\,(1-x_{s_{av}})^{1/3} \{1+(1-x_{s_{av}})^{1/3}\} / x_{s_{av}} \quad (4.5.3.2)$$

The average temperature of the solid mass computed from equation (4.5.3.1) is used in the analysis of the cooling zone in which the heat exchange takes place from the solid mass to the gas phase.

4.6 ANALYSIS OF THE COOLING ZONE

The cooling zone is located at the lower most part of the kiln. In this zone, the down flowing hot quick lime and coal ash particles exchange heat with the upflowing air. Air is introduced at the bottom of the kiln to supply enough oxygen for the combustion of fuel. Theoretical air requirement is calculated assuming complete

combustion of the volatile matter and fixed carbon in the fuel. The cooling zone is assumed to commence after the attainment of the uniform temperature of lime layer alongwith the unburnt limestone core, if any. The basic assumptions made for the formulation of a mathematical model for this zone are similar to those made for the modelling of the preheating zone. Since no combustion of coal takes place in this zone, all solid materials, including quick lime or lime-limestone particles, ash and clinkers/cinders, are assumed to be at the same temperature, therefore, the analysis of this zone becomes simpler than that of the preheating zone.

The temperature profiles of solids and gas along the axis of the kiln for this zone are obtained by simultaneous solution of the one dimensional steady state heat balance equations for solids and gas. The solids entering the cooling zone from the burning section for the mixed feed kiln comprise of partially or fully calcined particles of stones, fuel ash and cinders/clinkers. This solid mass is assumed to have uniform average temperature as discussed earlier in section (4.5.3).

The heat is assumed to be transferred from the solids to air largely by the mechanism of convection. Thus the model equation for the sensible heat loss of solids due to heat transfer to upflowing air in this zone is (with Z being taken positive towards bottom

of the kiln) :

$$\dot{m}_{s_{av}} \; C_{s_{av}} \; (-\Delta T_s) = (h_c)_{sg} \; (T_s - T_g) \; a_s \; \pi \; R_i^2 \; \Delta Z \qquad (4.6.1)$$

Similarly the net sensible heat gain by the gas in negative z direction, that is, direction of gas flow, is equal to heat received from solids minus heat loss to the wall :

$$-\Delta(\dot{m}_g \; C_g \; T_g) = (h_c)_{sg} \; (T_s - T_g) \; a_s \; \pi \; R_i^2 \; \Delta Z - \Delta H_l \qquad (4.6.2)$$

where $\dot{m}_{s_{av}}$ is the average mass flow rate of the solid mass (Kg/hr) in the cooling zone.

CHAPTER-5

DEVELOPMENT OF SIMULATION PROGRAMME

Chapter-5

DEVELOPMENT OF SIMULATION PROGRAMME

The development of simulation programme invariably requires the estimation of system parameters and properties as a first step. This was also considered necessary for the solution of model equations for mixed-feed lime shaft kiln as discussed in the previous chapter. This chapter presents the correlations used for system parameters and properties estimation, correlation used to estimate heat losses through kiln wall, and the salient features of computer programmes for the three zones of the lime kiln alongwith the information flow diagrams.

5.1 SYSTEM PARAMETERS AND PROPERTIES ESTIMATION

5.1.1 Specific Heats of Components

The correlations for specific heats as functions of temperature for various components were largely taken from Perry and Chilton (1968), but other sources, such as Murray (1947), and Knibbs and Gee (1959) were also used. If more than one correlation were available, the same were checked for different temperatures. The correlations for specific heats in Kcal/(Kg)(K) used finally in the simulation programme with the temperature range over which they are reported to be accurate are given below:

(i) $C_{CaCO_3} = 0.1968 + 0.1189 \times 10^{-3} T - 0.3076 \times 10^{4}/T^{2}$

(Temperature range 273-1033 K) (5.1.1.1)

(ii) $C_{CaO} = 0.1786 + 0.0864 \times 10^{-3} T - 0.1928 \times 10^{4}/T^{2}$

(Temperature range 273-1173 K) (5.1.1.2)

(iii) $C_{O_2} = 0.2584 + 0.8063 \times 10^{-5} T - 5865.6/T^{2}$

(Temperature range 300-5000 K) (5.1.1.3)

(iv) $C_{CO_2} = 0.1441 + 0.2305 \times 10^{-3} T - 0.0776 \times 10^{-6}/T^{2}$

(Temperature range 273-1200 K) (5.1.1.4)

(v) $C_{air} = 0.2372 + 0.2900 \times 10^{-4} T - 1360/T^{2}$

(Temperature range not specified) (5.1.1.5)

(vi) $C_{w} = 0.4567 + 0.8333 \times 10^{-5} T + 0.7444 \times 10^{-7} T^{2}$

(Temperature range 300 - 2500 K) (5.1.1.6)

(vii) $C_{CH_4} = 0.2138 + 0.6194 \times 10^{-3} T - 0.08 \times 10^{-6} T^{2}$

(Temperature range 283-1033 K) (5.1.1.7)

(viii) $C_{coke} = - 0.1640 + 0.1136 \times 10^{-2} T - 0.49 \times 10^{-6} T^{2}$

(Temperature range 294 - 1573 K) (5.1.1.8)

Methane has been assumed to be a close approximation for estimating the specific heat of volatile matter. The specific heat for coke was estimated from a knowledge of its three mean values given for three different temperature ranges as given by Hougen et.al (1956).

5.1.2 Heat Transfer Coefficients

The correlation proposed by Zuideveld and Vandenberg (1971 for computation of gas-solid heat transfer coefficient in Kcal/(hr)-$(m^2)(K)$ was used in the present work. The equation given below is applicable for the range $30 < Re < 3{,}000$:

$$Nu = 1.9\ Re^{0.50}\ Pr^{0.33} \qquad (5.1.2.1)$$

where $Nu = (h_c)_{gs}\ d_p / k_g$

$$Re = d_p\ G\ /\ \mu_g$$

$$Pr = C_g\ \mu_g\ /\ k_g$$

The heat transfer coefficient due to radiation from fuel to stone particles was computed from the well known equation :

$$(h_r)_{fs} = \epsilon\ \sigma_r\ (T_f^4 - T_s^4)\ /\ (T_f - T_s) \qquad (5.1.2.2)$$

where

$$\sigma_r = 4.96 \times 10^{-8}\ \text{Kcal} / (m^2)\ (hr)\ (K^4)$$

Heat transfer coefficient due to radiation between the combustion gases and solid particles was estimated from the equation used by Zuideveld and Vandenberg (1971). The equation is :

$$(h_r)_{sg} = 4.5 + 1.33\ d_p \in_b \qquad (5.1.2.3)$$

where d_p is the average size of particle and $\in_b$ is the bed porosity.

The heat transfer coefficient due to conduction between the fuel and solid particles has been calculated based on an estimated value of effective thermal conductivity of the fuel and solid particles and centre to centre distance between the contacting particles :

$$(h_c)_{fs} = 2\ k_e / (d_{p_s} + d_{p_f}) \qquad (5.1.2.4)$$

where $1/k_e = 1/k_s + 1/k_f \qquad (5.1.2.5)$

is used to compute the effective thermal conductivity for fuel-stone particle heat transfer and is based on the concept of resistances in series on account of the close proximity of the fuel and stone contacting particles.

For computation of wall to fluid heat transfer coefficients for packed beds, the following correlations proposed by Leva et. al (1948) and Smith (1970) were used:

For cooling of hot gases in fixed beds:

$$h_{wg} = 3.50\ (k_g/D_t)\ e^{-4.6\ d_p/D_t}\ (d_p\ G/\mu)^{0.7} \qquad (5.1.2.6)$$

(valid for d_p/D_t = 0.08 - 0.27 and $d_p G/\mu$ = 250-3,000) (5.1.2.6)

For the heating of cool gases in packed beds :

$$h_{wg} = 0.813 (k_g/D_t) e^{-6 d_p/D_t} (d_p G/\mu)^{0.9}$$

(valid for $d_p/D_t < 0.35$) (5.1.2.7)

The free convection equation proposed by Chapman (1960) used for the estimation of heat transfer coefficient from external wall surface of kiln to still air in appropriately revised units is:

$$h_c = 1.22 (\Delta T/L)^{1/4}, \text{ Kcal/(hr)(m}^2\text{)(K)} \quad (5.1.2.8)$$

where $\Delta T = T_{w_o} - T_\infty$, K

L = Height of surface, m

Heat transfer coefficients have been computed at each bed position from the function subprograms as a part of the main executive computer programme.

5.1.3 Heat of Combustion of Volatile Matter

Various correlations have been proposed by investigators for estimation of the calorific value of coal from a knowledge of its

proximate analysis (Lowry, 1945; Majumdar, 1954; and Brame and King, 1955). The heating values of coals of different volatile matter were calculated on dry ash free basis using Gumz's formula (Lowry, 1945) which was found to predict fairly accurate value of heating value for the entire range of coal compositions:

$$H_f = 8,150 + 6,543\ V - 17,308\ V^2,\ \text{Kcal/Kg} \qquad (5.1.3.1)$$

where V is the fractional volatile matter content of dry ash-free coal.

The heating value of volatile matter was then computed by subtracting the heating value of fixed carbon from the computed calorific value of the dry ash free coal (Lowe et. al, 1977 and Majumdar, 1954). The heating value of fixed carbon was taken as 8,200 Kcal/Kg of fixed carbon (Breme and King, 1955). The heating value of volatile matter (Kcal/Kg volatile matter) computed by the above mentioned procedure showed variations in these values with fractional volatile matter content of coal. This conclusion was found to be valid for the Indian coals also (Brame and King, 1955).

5.1.4 Interfacial Areas of Solid Particles

For a packed bed of solids the particle surface area per unit bed volume is given by the following equation (Perry and Chilton, 1968) :

$$a = 6(1- \epsilon_b) / \phi\, d_p \qquad (5.1.4.1)$$

where a is the specific surface or area of particle surface per unit bed volume; ϵ_b is the bed porosity; ϕ is the sphericity of particle, and d_p is the average particle diameter.

Equation (5.1.4.1) may be written as

$$a = a_o(1- \epsilon_b) \qquad (5.1.4.2)$$

where a_o is the particle surface per unit volume of solids and is equal to $6/\phi\, d_p$.

For grannular solids of mixed sizes, as applicable in the case of limestone and fuel particles the average particles diameter may be computed from the equation :

$$1/d_p = \sum x/d_{p,x} \qquad (5.1.4.3)$$

where x is the weight fraction of particle diameter, $d_{p,x}$

The surface area a_o of particles in mixed-feed lime kiln computed by equations given above will give total surface area of limestone and fuel particles present in packed bed. Therefore, a_o can be expressed as the sum of limestone and fuel surface areas:

$$a_o = a_{s_o} + a_{f_o} \qquad (5.1.4.4)$$

In mixed-feed lime kilns the fuel particle size is kept, in general, nearly one-half of that of limestone particles. Thus, some fuel particles can quite easily be incorporated within the interstitial space created by the limestone particles matrix. Let α be the fraction of fuel particles that occupies independent volume in the mixed bed of limestone and coal particles and, therefore, $(1-\alpha)$ is the fraction which is held up within the limestone particles matrix. The α can have a value between zero and unity and it can be correlated as:

$$\alpha = (n_f/n_s - \beta) / (n_f/n_s)$$

$$= 1 - \beta(n_s / n_f) \qquad (5.1.4.5)$$

where n_f and n_s are the number of fuel and stone particles, respectively, and β is a constant that takes into account the number of fuel particles held within the limestone particles matrtix.

The ratio n_f/n_s can be quite easily calculated from the following relationship:

$$n_f/n_s = \left[V_{f_o} / (\pi/6)\ d_{p_f}{}^3\right] / \left[V_{s_o} / (\pi/6)\ d_{p_s}{}^3\right]$$

$$= V_{f_o}\ d_{p_s}{}^3 \ / \ V_{s_o}\ d_{p_f}{}^3 \qquad (5.1.4.6)$$

The subscript 'o' indicates conditions at the top of the kiln, that is, at the inlet of kiln. It is quite clear that

$$V_{f_o} / V_{s_o} = \dot{m}_{f_o} \rho_{s_o} / \dot{m}_{s_o} \rho_{f_o}$$

$$= \rho_{s_o} / X_r \rho_{f_o}$$

Thus

$$n_f/n_s = (1/X_r)(\rho_{s_o} / \rho_{f_o}) (d_{p_s} / d_{p_f})^3 \qquad (5.1.4.7)$$

Substituting for (n_f/n_s) in equation (5.1.4.7), α becomes:

$$\alpha = 1 - \beta X_r (\rho_{f_o} / \rho_{s_o}) (d_{p_f} / d_{p_s})^3 \qquad (5.1.4.8)$$

If we assume that limestone particles form a cubic matrix and one fuel particle is at the body centre of this cube, then each limestone particle of a unit cell will hold one fuel particle. Therefore, β will become equal to unity and this value of β has been used in the computation. But the value of β other than unity can also be used, if considered desirable.

Using the definition of α as discussed above, the effective surface areas per unit volume of the bed can be expressed as:

$$a_{s_o} = 6\ V_s/\phi_s\ d_p(V_s+\alpha V_f) \qquad (5.1.4.9)$$

$$a_{f_o} = 6\ V_f/\phi_f\ d_p\ (V_s + \alpha V_f) \qquad (5.1.4.10)$$

where V_s and V_f are the individual volumes of limestone and fuel particles.

Thus the surface area of limestone and fuel particles per unit volume of kiln bed can be given as:

$$a_s = 6\ (1-\epsilon_b)\ /\ \phi_s\ d_p\ (1+\alpha V_f/V_s) \qquad (5.1.4.11)$$

$$a_f = 6\ (1-\epsilon_b)\ (V_f/V_s)\ /\ \phi_f d_p\ (1+\alpha V_f/V_s) \qquad (5.1.4.12)$$

Computations of specific surface areas for limestone and fuel particles are carried out using the above equations in the main executive computer programme for the kiln zone in which the reduction in volume of fuel particles due to burning of fixed carbon does not occur. The variations on account of changing particle size of fuel due to fixed carbon combustion and density changes after ash fusion are also taken into account in the programme for the burning zone. The phenomenological reasoning behind the development of modified equations for surface area computations during fixed carbon burning of fuel without and with ash fusion is discussed below.

For the case of fixed carbon combustion, size of the fuel particles keeps on decreasing. The fuel particles held up within the unit cells of limestone particles on size reduction will not affect the total bed volume, but may result only in increase in the bed porosity. But the volume of fuel particles present outside the unit cell of limestone particles will be reduced on size reduction. This, in effect, will lead to an increase in the surface area of limestone per unit bed volume since the ratio of limestone particles to total bed volume will increase. In the present case, the limestone particles volume is not assumed to change in the kiln, the decrease in the independent volume of fuel particles relative to limestone volume can be expressed for $x_f \geq (x_{fm}+x_{fv})$ as :

Independent volume of fuel particles / Volume of limestone particles $= \propto V_f (1-x_{fa}-x_f)/V_s(1-x_{fa}-x_{fm}-x_{fv})$

(5.1.4.13)

and increasing limestone surface area per unit bed volume a_s' in this zone, assuming constant bed porosity, will become :

$$a_s' = a_s(1+ \propto V_f/V_s) \; / \{$$

$$1 + \propto V_f(1-x_{fa} - x_f) \; / \; V_s \; (1-x_{fa}-x_{fm}-x_{fv}) \} \qquad (5.1.4.14)$$

The numerical value of the terms in bracket for $x_f \geq (x_{fm}+x_{fv})$ is greater than unity and increases with increase in x_f after the evolution of moisture and volatile matter. The value of limestone surface area per unit bed volume before the commencement of fixed carbon combustion, a_s, has already been defined earlier by equation (5.1.4.11).

The fuel surface area will, however, decrease due to combustion of fixed carbon and consequent reduction in particle size. Since the surface area is proportional to square of diameter and volume is proportional to cube of diameter of fuel particles, the reduction in surface area due to fixed carbon burning for $x_f \geq (x_{fm}+x_{fv})$ can be expressed as:

Change in surface area per unit volume change

$$= (V_f/V_s)\left[(1 - x_{fa} - x_f) \;/\; (1-x_{fa}-x_{fm}-x_{fv})\right]^{2/3} \qquad (5.1.4.15)$$

and changing fuel surface area per unit bed volume a'_f in this zone, assuming constant bed porosity, will become:

$$a'_f = a_f \left(\frac{1-x_{fa}-x_f}{1-x_{fa}-x_{fm}-x_{fv}}\right)^{2/3} \left\{\frac{1+\alpha\, V_f/V_s}{1+\alpha\,\frac{V_f}{V_s}\left(\frac{1-x_{fa}-x_f}{1-x_{fa}-x_{fm}-x_{fv}}\right)}\right\} \qquad (5.1.4.16)$$

The value of fuel surface area per unit bed volume before the commencement of fixed carbon combustion, a_f, has already been defined earlier by equation (5.1.4.12).

In the derivation of the above equations it is assumed that ash formed on burning of fixed carbon is not retained by the fuel particle and is held inside the interstitial space of limestone particle matrix without requiring independent bed volume. The presence of ash in interstitial space will reduce the porosity of bed. The assumption of constant bed porosity is, therefore, reasonable because decrease in porosity due to presence of ash is compensated by the reduction in the volume of fuel particles held up within the interstitial space of limestone particles.

At the point of ash fusion corresponding to an assumed temperature (T_{ff}) of 1573 K, the conditions are :

$$x_f = x_{ff}$$

$$\ell_f = \ell_{ff}$$

If the temperature of fuel particles exceed T_{ff}, ash formed due to

combustion of fixed carbon will not be released and it forms a porous layer around the unburnt core.

During ash fusion (for $x_{ff} \leq x_f \leq 1-x_{fa}$) the ash layer around unburnt core of the fuel particles will tend to fuse more and more with increase in fuel temperature. The increase in ash layer density due to progressive fusion is related to fuel temperature according to the relation:

$$\rho_f = \rho_{ff} (T_f/T_{ff})^a \qquad (5.1.4.17)$$

where a is a constant to account for the extent of density variation of ash with fuel temperature. The constituents of fuel during ash fusion are: core having unburnt fixed carbon with associated ash and outer shell of fused ash.

The independent volume of fuel particles relative to limestone volume, assumed constant, for $x_f \geq x_{ff}$ can be expressed as:

Independent volume of fuel particles / Volume of limestone particles =

$$\propto \frac{V_f}{V_s}\left[\left(\frac{1-x_{fa}-x_f}{1-x_{fa}-x_{fv}-x_{fc}}\right) + \frac{(x_f - x_{ff})x_{fc}(T_{ff}/T_a)^a}{(1-x_{fa}-x_{fv}-x_{fc})}\right.$$

$$\left.\left(\rho_f/\rho_{ash}\right)\right] \qquad (5.1.4.18)$$

The first term within parenthesis inside large bracket of the above equation indicates the normal reduction in fuel core on account of fixed carbon combustion and the second term inside large bracket takes into account the additional volume of fused ash sticking on to the outer surface of the burning fuel particle after properly accounting for the density variation of the outer shell of fused ash. Therefore, increase in limestone surface area per unit bed volume after commencement of ash fusion, a_s'' , assuming constant bed porosity, will become:

$$a_s'' = a_s \left\{ \frac{1 + \alpha \frac{V_f}{V_s}}{1 + \alpha \frac{V_f}{V_s} \left[\left(\frac{1 - x_{fa} - x_f}{1 - x_{fa} - x_{fm} - x_{fv}} \right) + \frac{(x_f - x_{ff}) x_{fa}}{(1 - x_{fm} - x_{fv} - x_{fa})} \left(\frac{T_{ff}}{T_f} \right)^a \frac{\rho_f}{\rho_{ff}} \right]} \right\}$$

(5.1.4.19)

The reduction in surface area of fuel particles on account of reduction in volume due to fixed carbon burning and ash fusion for $x_f > x_{ff}$ has now to be accounted for. Since the surface area is proportioned to square of diameter and volume is proportional to cube of diameter, the reduction in surface area of fuel unit volume change is given by:

$$= \frac{V_f}{V_s} \left\{ \frac{1 - x_{fa} - x_{ff}}{(1 - x_{fa} - x_{fm} - x_{fv})} \right\}^{2/3} \left[\left(\frac{1 - x_{fa} - x_f}{1 - x_{fa} - x_{ff}} \right) + \frac{(x_f - x_{ff}) x_{fa}}{1 - x_{fa} - x_{ff}} \left(\frac{T_{ff}}{T_f} \right)^a \frac{\rho_f}{\rho_{ash}} \right]^{2/3}$$

(5.1.4.20)

and change in fuel surface area per unit bed volume with commencement of ash fusion, a_f'', assuming constant bed porosity, will become:

$$a_f'' = a_f \left\{ \frac{\left(1+\alpha \frac{V_f}{V_s}\right)\left(\frac{1-x_{fa}-x_{ff}}{1-x_{fa}-x_{fm}-x_{fv}}\right)^{2/3}\left[\left(\frac{1-x_{fa}-x_f}{1-x_{fa}-x_{ff}}\right)+\frac{(x_f-x_{ff})x_{fa}}{1-x_{fa}-x_{ff}}\left(\frac{T_{ff}}{T_f}\right)^a \frac{\rho_f}{\rho_{ash}}\right]^{1/3}}{1+\alpha \frac{V_f}{V_s}\left[\left(\frac{1-x_{fa}-x_f}{1-x_{fa}-x_{fm}-x_{fv}}\right)+\frac{(x_f-x_{ff})x_{fa}}{(1-x_{fm}-x_{fv}-x_{fa})}\left(\frac{T_{ff}}{T_f}\right)^a\left(\rho_f/\rho_{ash}\right)\right]} \right\}$$

(5.1.4.21)

5.2 HEAT LOSS THROUGH KILN WALL

The kiln wall consists of ordinary bricks masonry lined inside with firebricks.

Let R_i = inner radius of kiln, m

W_{fb} = fire bricks lining thickness, m

The kiln radius upto the level of fire bricks is:

R_{fb} = $R_i + W_{fb}$, m

R_o = outer radius of kiln, m

= $R_{fb} + W_{rb}$

T_{gi} = bulk gas temperature, K

T_{wi} = average inner wall temperature, K

T_{wo} = outer wall temperature, K

T_{fb} = temperature at the interface of firebricks and clay bricks, K

Over a differential element of width ΔZ in the axial direction of kiln, heat is assumed to be transferred from the bulk gas to the inner wall of kiln by convective and radiative exchanges:

$$Q_{gw} = 2\pi R_i \Delta Z (h_c + h_r)_{gw} (T_{gi} - T_{wi}) \quad (5.2.1)$$

Heat conducted through firebricks insulation is given by the equation (Chapman, 1960):

$$Q_{fb} = \frac{2\pi \Delta Z \, k_{fb} (T_{wi} - T_{fb})}{\ln (R_{fb}/R_i)} \quad (5.2.2)$$

Similarly, heat conducted through burnt clay (red) bricks is:

$$Q_{rb} = 2\pi \Delta Z \, k_{rb} (T_{fb} - T_{wo}) / \ln(R_o/R_{fb}) \quad (5.2.3)$$

Heat is lost from the external kiln wall to ambient largely by natural convection:

$$Q_{wa} = (h_c)_{wa} 2\pi R_o \Delta Z (T_{wo} - T_\infty) \quad (5.2.4)$$

where T represents the ambient air temperature.

Under steady state conditions, all heat transfer rates involving transfer steps in series must be equal:

$$Q_{gw} = Q_{fb} = Q_{rb} = Q_{wa} = \Delta H_l \qquad (5.2.5)$$

Defining overall (effective) heat transfer coefficient, $(U_i)_{eff}$, on the basis of inner wall area of kiln, the heat exchange from the bulk gas phas to the ambient air may be represented as :

$$\Delta H_l = (U_i)_{eff} \; 2\pi R_i \; \Delta Z \; (T_{gi}-T_\infty) \qquad (5.2.6)$$

The combination of equation (5.2.1) through (5.2.6) leads to :

$$(U_i)_{eff} = R_i^{-1} \left\{ 1/R_i \; (h_c)_{gw} + \ln(R_{fb}/R_i)/k_{fb} + \ln(R_o/R_{fb}) \; / \; k_{rb} + 1 \; / \; r_o(h_c+h_r)_{wa} \right\}^{-1} \qquad (5.2.7)$$

The main executive programmes first estimate the overall heat transfer coefficient using equation (5.2.7) through function subprograms for the individual heat transfer coefficients and then compute wall heat losses from equation (5.2.6) for all the three zones of the lime kiln.

5.3 SALIENT FEATURES OF COMPUTER PROGRAMMES

The sets of differential equations derived for the analysis of the preheating and burning zones are highly non-linear in nature, particularly those used to predict the behaviour of the burning zone. These equations were solved by using appropriate numerical techniques.

The system equations of the preheating, burning and cooling zones are written in the forward finite difference form and they are solved over the differential element along the axis of the kiln for the (i + 1)th grid point knowing the set of values of the ith grid point. The solutions are converged within the prespecified tolerance limits. This methodology of computations is continued starting with the input parameters for a given zone until final conditions defining the end of that zone are attained. In this manner dependent variables of temperature and fractional conversion are computed for these zones. The problem of convergence is quite troublesome for the burning zone in view of many complexities and highly non-linear behaviour. Enormous difficulties were encountered in the estimation of system parameters for obtaining a unique and realistic solution. Many strategies of ordering of system equations were tried to achieve rapid convergence within the acceptable limits of accuracy. The choice of appropriate equations for estimating heat and mass transport and reaction rate coefficients was limited in view of the lack of published information appropriate to this system.

The computer programmes were written in FORTRAN IV. Salient features for the same are discussed as follows:

5.3.1 The Preheating Zone

Fig. 5.1 represents the information flow diagram for the analysis of the preheating zone. Programme for the same is given in the Appendix-C. It analyses the cases of simple preheating, preheating with desorption of water from coal particles, and preheating with devolatilization without combustion of the volatile matter. For a given set of input conditions at top of the lime kiln and relevant data, the cross-sectional area and inner diameter of the kiln are computed for a nominal lime production rate prespecified as 10 tonnes per day and the chosen value of the design variable - superficial lime output rate based on cross-sectional area of kiln (tonnes) / (sqm) (day). The flow rates of limestone and coal particles at top of kiln and required air flow rates (induced at the bottom of the kiln) are computed. Provision has been made for computation of the heating value of coal and heat of combustion of volatile matter (though not required for the analysis of the preheating zone).

The specific heats of various components as functions of temperature and the interfacial packing surfaces for limestone (ASPZ) and coal particles (AFPZ) are computed. The energy and material

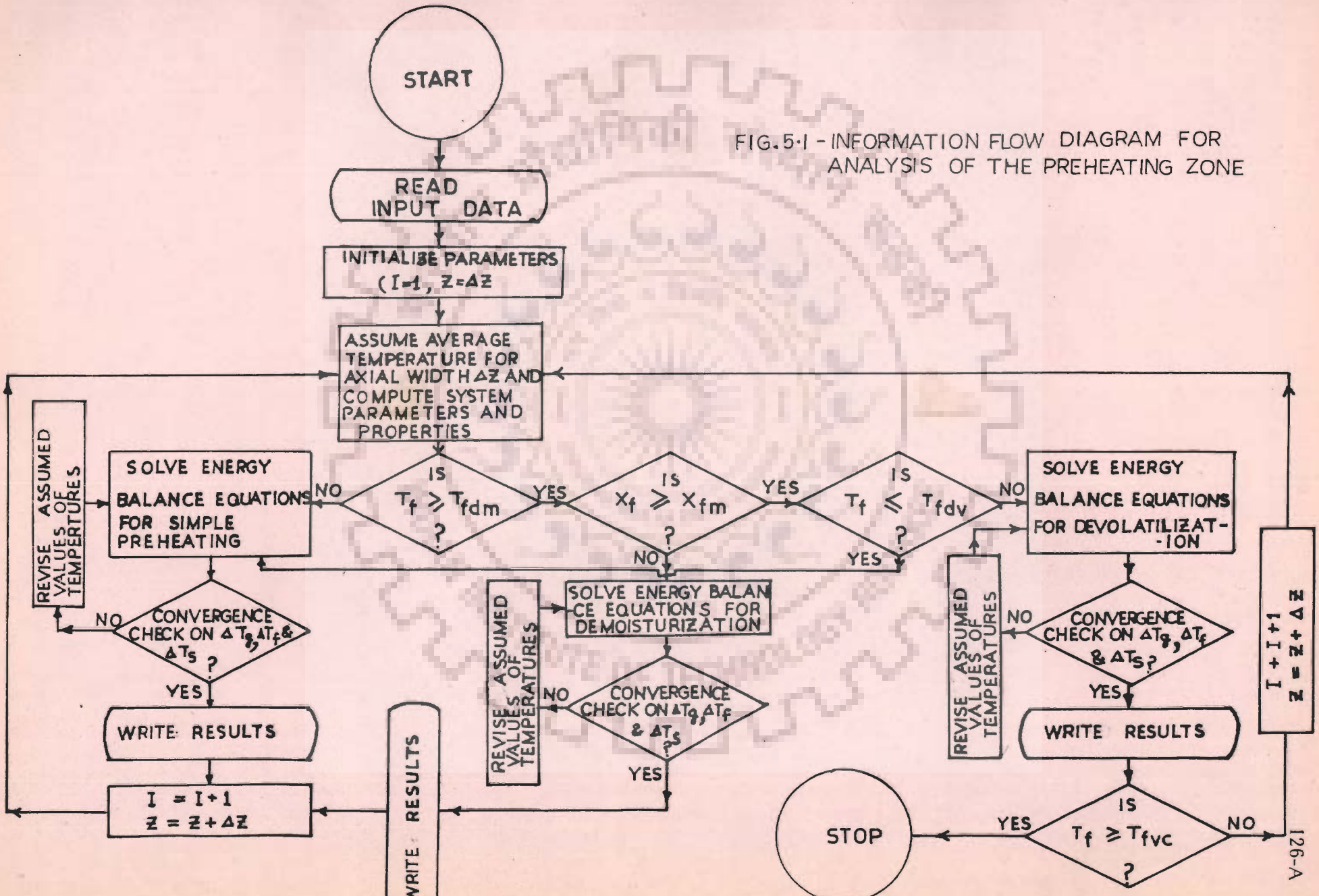


FIG.5·1 - INFORMATION FLOW DIAGRAM FOR ANALYSIS OF THE PREHEATING ZONE

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balances are then computed for conditions prevailing in a differential zone of the preheating section. Function subprograms are given at the end of the main executive programme for computation of the heat transfer coefficients from fuel to stone (HFS), fuel to bulk gas (HFG), stone to bulk gas (HSG), bulk gas to kiln wall (HGW), and external wall surface to ambient air (HWA) at any axial position (Z) measured from top of the kiln.

The system equations are linearized, put in difference form and for assumed average temperatures of limestone (TSAVG), fuel (TFAVG) and bulk gas phase (TGAVG), the new values of the same are computed for stone, fuel and gas from the respective heat balances. The fractional degrees of demoisturization and devolatilization are computed by making use of the assumptions already discussed in Chapter-4.

The new computed values are compared with the old values (assumed or previously computed) and if the desired tolerance levels on the three temperatures are not achieved, the computations are repeated by using the new computed values of temperatures as revised initial values for the next iteration. This iterative procedure is continued till convergence for a differential width ΔZ is obtained.

The computation then moves to the next axial location and the procedure is continued till the end of the preheating zone. The end of the preheating zone is defined when the fuel achieves the

prespecified autoignition temperature at which instantaneous combustion of the volatile matter is assumed to occur. In this region gas temperatures are always higher than those of limestone and fuel particles and heat transfer takes place from gas to solids. The three temperatures, therefore, increase as we move from kiln inlet to the end of the preheating zone.

5.2.3 The Burning Zone

The analysis of this zone was observed to be highly complex due to combustion reactions of volatile matter and fixed carbon and calcination of limestone, and also due to changes in surface areas of limestone-lime and fuel particles per unit bed volume as well as due to radial temperature gradients in limestone lime particles.

The auto-ignition of volatile matter at the surface of fuel particles raises their temperature quickly above that of gas and limestone-lime particles. Heat is then transferred from fuel to gas and also to limestone-lime particles. Since the surface temperatures of limestone-lime particles is expected to keep on rising in most of the burning zone to meet the heat conduction requirements for calcination, heat transfer will also occur from these particles to gas. Thus gas temperatures will be expected to fall very rapidly in the burning zone. In the burning zone combustion of fixed carbon is assumed to occur only after all the volatile matter is evolved as

discussed in Chapter-4.

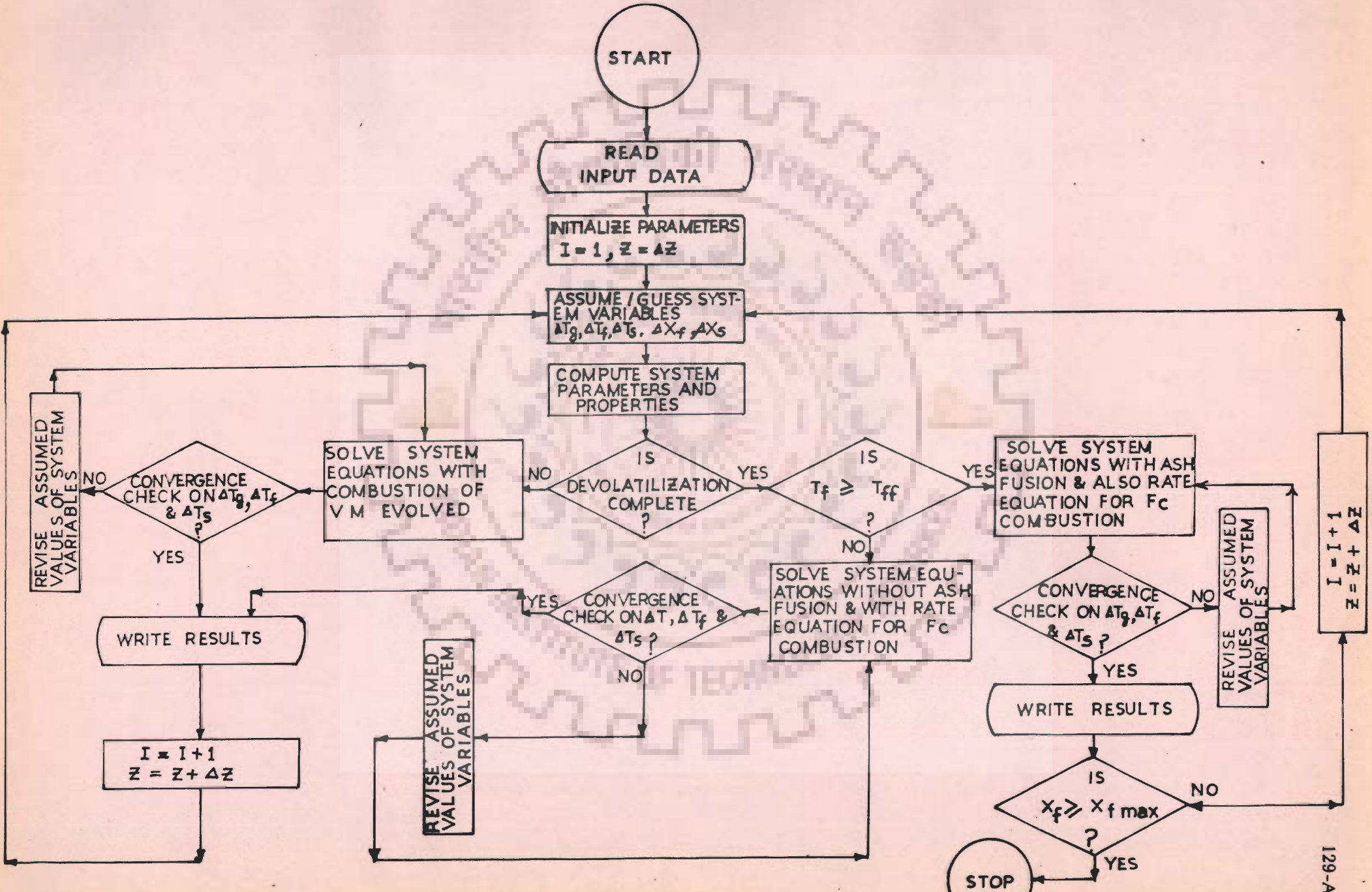
The results of computations indicated the existence of the following subzones of the burning zone :

(i) Buffer Zone : incorporating volatile matter combustion, but only preheating of limestone upto the calcination temperature. No intraparticle temperature gradients are assumed to exist in limestone particles.

(ii) Calcination Zone : incorporating combustion of residual volatile matter, if any, and fixed carbon alongwith calcination of limestone. Limestone core is at dissociation temperature and temperature gradients exist in the outer shell of lime.

(iii) Finising Zone : incorporating combustion of the remaining part of the fixed carbon content of coal, if any, after complete calcination. No intraparticle temperature gradients are assumed to exist in lime particles.

An information flow diagram for analysis of the burning zone is given in Fig. 5.2 and the computer programme for the same is given in Appendix-D. The values of the system variables and properties alongwith the relevant output data obtained from the computed results


START
READ INPUT DATA
INITIALIZE PARAMETERS I = 1, Z = ΔZ
ASSUME / GUESS SYSTEM VARIABLES ΔTg, ΔTf, ΔTs, ΔXf, ΔXs
COMPUTE SYSTEM PARAMETERS AND PROPERTIES
IS DEVOLATILIZATION COMPLETE ?
NO
YES
SOLVE SYSTEM EQUATIONS WITH COMBUSTION OF V M EVOLVED
CONVERGENCE CHECK ON ΔTg, ΔTf & ΔTs ?
NO
REVISE ASSUMED VALUES OF SYSTEM VARIABLES
YES
WRITE RESULTS
I = I+1
Z = Z+ ΔZ
IS Tf ≥ Tff ?
YES
NO
SOLVE SYSTEM EQUATIONS WITHOUT ASH FUSION & WITH RATE EQUATION FOR Fc COMBUSTION
CONVERGENCE CHECK ON ΔT, ΔTf & ΔTs ?
YES
NO
REVISE ASSUMED VALUES OF SYSTEM VARIABLES
SOLVE SYSTEM EQUATIONS WITH ASH FUSION & ALSO RATE EQUATION FOR Fc COMBUSTION
CONVERGENCE CHECK ON ΔTg, ΔTf & ΔTs ?
NO
YES
REVISE ASSUMED VALUES OF SYSTEM VARIABLES
WRITE RESULTS
I = I + 1
Z = Z + ΔZ
IS Xf ≥ Xf max ?
NO
YES
STOP

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of the preheating zone are fed as input data to the main executive programme for burning zone. The heat of combustion of the volatile matter is computed from the knowledge of the proximate analysis of coal using equation (5.1.3.1).

The heat transfer coefficients, the effectiveness factors for heat exchange among the phases, variations in interfacial areas, specific heats of components at different temperatures, the material balances to compute flow rates, compositions, etc. are then estimated by the computations in this zone.

The model equations for dissociation of limestone, combustion of coal particles, and heat balances for the stone, fuel and gas phases are utilized in the programme to compute the temperature changes of limestone-lime particles, fuel particles and gas alongwith degree of calcination of limestone and combustion of coal over a differential volume element of width ΔZ at a location (Z) along the axis of the kiln from a knowledge of the initial guessed values of the five system dependent variables, that is, T_s, T_f, T_g, x_s amd x_f . Initial guess value for each of the dependent parameter is obtained from second order polynomial utilizing the converged values for three previous Z steps as soon as they become available to reduce computation time by achieving faster convergence.

Attempts have been made to solve the highly non-linear system

equations within the stipulated ranges of tolerance levels. During the computations it was observed that one hundred iterations were, in general, sufficient for achieving convergence. For a prespecified ΔZ value, in some cases computed values showed either oscillations or divergence. Therefore, if the desired convergence was not achieved in the maximum specified iterations, the provision was made in the programme to reduce the step size ΔZ by one-tenth of the prespecified ΔZ value and continue the reduction in the ΔZ value till desired convergence was achieved within one hundred iterations. This value of ΔZ was used in subsequent computations for a given set till further reduction in step size was found necessary due to non-attainment of convergence in one hundred iterations.

The burning zone programme solves all the three subzones, that is, upto the point of complete combustion of the fixed carbon in fuel particles. Ash fusion temperature of 1573 K has been assumed, this can be varied if desired, beyond which the fusion and non-removal of ash from fuel particles was assumed not to hinder the fixed carbon combustion process in view of very small size of fuel particles at this stage.

It may be noted that the average lime particle temperature is computed at the begining of the finishing zone by sensible heat balance of lime particle. Similarly, average solid mass, consisting

of limestone-lime particles, free ash and cinders/ash clinkers, temperature is computed at the end of the finishing zone by appropriate sensible heat balance.

Function subprograms are given at the end of the main executive programme for computation of various interphase heat transfer coefficients, fuel to gas, lime-limestone particles to gas, fuel to lime-limestone particles, kiln wall to ambient air, and for overall rate constant for combustion of fixed carbon content of coal due to combined effect of surface combustion reaction rate constant and mass transfer resistance for oxygen transport for combustion of fixed carbon to carbon-dioxide.

5.3.3 The Cooling Zone

An information flow diagram for the analysis of the cooling zone is given in Fig. 5.3. The computer programme for the analysis of the same is given in the Appendix-E. It is basically analogous to that of the simple preheating zone with signs reversed as the heat is transferred from the solid mass consisting of stone particles (quick lime lumps) free ash and cinders/ash clinkers to the bulk of the gas phase. The system properties and relevant output data from the burning zone is taken as input data in this programme and the desired computations are done to obtain the temperature profile for the gas

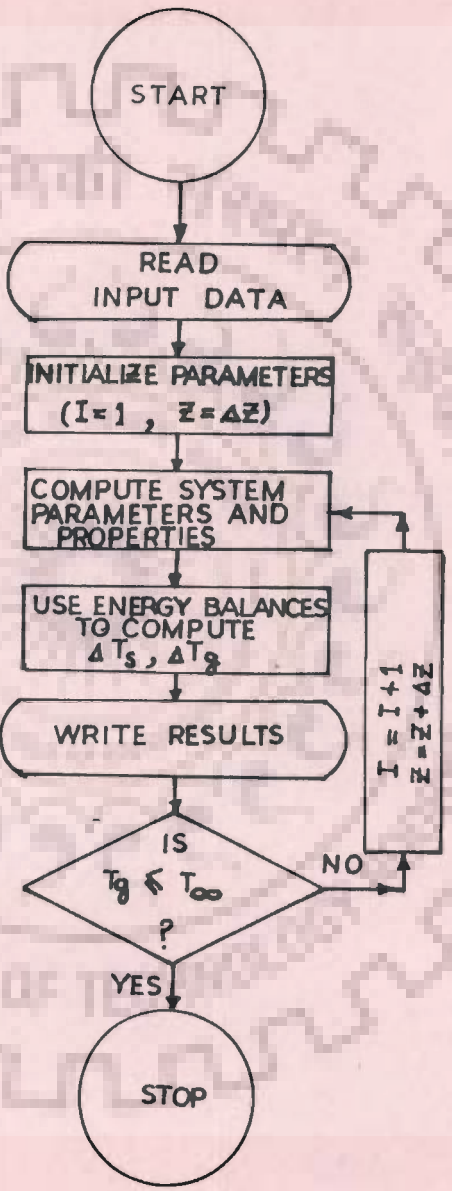


FIG. 5.3 - INFORMATION FLOW DIAGRAM FOR ANALYSIS OF COOLING ZONE

phase and solid particles from the gas and solid energy balances. In these computations it may be noted that the entire solid mass is considered as one phase due to the reasons discusssed in Chapter-4. The computations are terminated at the point where the temperature of gas approaches that of the incoming ambient air from the bottom of the kiln. Function subprograms for computation of heat transfer coefficients are given at the end of the main executive programme.

CHAPTER-6

RESULTS AND DISCUSSION

Chapter-6

RESULTS AND DISCUSSION

6.1 CHOICE OF PARAMETERS FOR SIMULATION STUDIES

The values of important design, operation and system parameters were carefully chosen keeping in view the general industrial practice and published literature. Some design and operating parameters were varied within the ranges commonly encountered for mixed-feed lime shaft kilns. Some system parameters had to be varied in different kiln zones to obtain acceptable results. This section briefly discusses these parameters.

The values of important parameters corresponding to average design and operating conditions and their ranges investigated are given in Table-6.1.

Lime shaft kilns with a nominal lime production rate of 10 tonnes/day are generally considered optimum for natural draft operation and are abundantly used in building lime industry in India. The Central Building Research Institute, Roorkee, and the Khadi and Village Industries Commission, Bombay have also advocated the use of lime shaft kilns with a lime production rate of 10 tonnes/dayfor natural draft operation in the small scale sector.

TABLE-6.1

Important Design & Operating Conditions : Average Values & Ranges Investigated

Sl.No.	Parameter	Symbol	Units	Average Value	Range
	Design				
1.	Nominal lime production rate	P_n	t/day	10	Not varied
2.	Superficial lime output rate	P_s	$t/(m^2)(day)$	2.25	2.0 - 2.5
3.	Inner lining thickness of fire bricks	W_{fb}	m	0.23	Fixed
4.	Wall thickness of burnt clay (red) bricks	W_{rb}	m	0.69	0.46 - 0.92
5.	Kiln exhaust gas temperature	T_{g_o}	K	748	698 - 798
	Operating				
6.	Limestone-to-fuel ratio by weight in feed input	X_r	t/t	5.5	5.0 - 6.0
7.	Particle size of limestone	d_{p_s}	m	0.100	0.088 - 0.112
8.	Particle size of fuel	d_{p_f}	m	0.050	0.044 - 0.056
9.	Fractional content of volatile matter in fuel	X_{fv}	-	0.225	0.150 - 0.300
10.	Excess air fraction	X_{ea}	-	0.125	0.000 - 0.250

The average values (base conditions) and the ranges of parameter values specified for different design and operating parameters are also based on the field studies of Indian building lime industry. In order to have a general purpose simulation programme all design and operating conditions are to be specified as input data.

It is important to note that the kiln exhaust temperature (T_{g_o}) has been given the status of a design variable while the effective kiln height L_e is not included as a design variable in Table-6.1. For any new design situation L_e needs to be computed and it depends greatly on T_{g_o} in addition to other operating and design parameters. However, for an existing kiln, L_e will have to be specified as a design parameter and the value of T_{g_o} will have to be assumed for starting the computations from the top of the kiln for computing L_e. If the computed value of L_e does not agree with the design value, then iteration over T_{g_o} needs to be carried out by treating it as a recycle variable till the convergence on L_e is achieved. If no value of T_{g_o} is able to give convergence on L_e, some other operating parameter may have to be suitably modified for achieving convergence.

The values of the important system parameters used in the simulation are given in Table-6.2. The values of these parameters

TABLE-6.2

Values of Major System Parameters

Sl. No.	Parameter	Symbol	Units	Value	Remarks
1	2	3	4	5	6
1.	Ambient air/ room temperature	T_{∞}	K	300	
2.	Temperature for start of demoisturzation from fuel	T_{dm}	K	373-383	Total moisture release is assumed uniform in 8 intervals of ΔZ of 0.05 m each corresponding to an approximate residence time of 1.4 hours.
3.	Temperature for initiation of devolatilization of fuel	T_{dvm}	K	673	Release of volatile matter in the temperature range of 673 to 1173 K is assumed to be linear with respect to increase in fuel temperature
4.	Auto-ignition temprature of volatile matter	T_{vmc}	K	948	Volatile matter remaining at 948 K is assumed to release uniformly in 10 intervals of ΔZ of 0.05 m each corresponding to an approximate residence time of 1.8 hours
5.	Ash fusion temperature of fuel	T_{ff}	K	1,573	-
6.	Moisture fraction in fuel	X_{fm}	Kg/Kg	0.05	-
7.	Ash content in fuel	X_{fa}	Kg/Kg	0.25	-

1	2	3	4	5	6
8.	Heat of demoisturization	H_{dm}	Kcal/Kg	875	-
9.	Heat of devolatilization	H_{dv}	Kcal/Kg	650	
10.	Heat of combustion of volatile matter	H_{vm}	Kcal/Kg	9,024	Computed from equation (5.1.3.1) for average fuel proximate analysis
11.	Heat of combustion of volatile matter	H_{fc}	Kcal/Kg	8,200	–
12.	Chemical formula for volatile matter	C_nH_{2n+2}	-	n = 1.29	Molecular weight is taken as 20 based on apprximate composition of the volatile matter obtained during coal carbonization
13.	Effectiveness factors for heat exchange from:				The values and their variations are discussed in the text
	(a) Stone-to-gas	η_{sg}	-	0.0125-0.0250	
	(b) Fuel-to-stone	η_{fs}	-	0.150-0.200	
	(c) Fuel-to-gas	η_{fg}	-	0.0150-0.0500	
	(d) Gas-to-kiln wall	η_{gw}	-	0.100 (fixed)	

have been kept the same for all the sets of design and operating conditions. However, the nature of the simulation programme remains of general purpose only, since all these system parameters are to be basically read as input data.

A brief justification is given below for some of the system parameter values given in Table-6.2. In standard procedure for proximate analysis of fuel (Brame and King, 1955), finely ground powdered coal sample is kept at 373 to 383 K for about one hour to determine moisture content. In the present study as the size of coal particles is substantial and varies from 44 to 56 mm, time requirement for complete demoisturization will be much greater and, therefore, the passage of fuel through 0.4 m kiln length corresponding to a mean residence time of about 1.4 hours has been assumed.

The volatile matter is usually released in the temperature range of 400 to 900^{o}C (Fuchs and Sandhoff; Himus, 1958, and Lowry, 1945) and it is assumed to be evolved linearly with temperature in this range. However, this linear behaviour of volatile matter evolution with the temperature continues till the fuel achieves autoignition temperature for the volatile matter. The standard procedure for volatile matter determination requires keeping the finely ground powdered fuel in a muffle furnace at 1173 $\pm$ 15 K for seven minutes. For fuel particles size range used in this investigation, time requirement for the evolution of the residual volatile matter after

the commencement of its combustion will be much greater, and, therefore, a mean residence time of about 1.8 hours is provided.

The auto-ignition temperatures in air for the important constituents in the volatile matter evolved from coal are generally in the range of 537 to 750^{O}C (Brame and King, 1955; Himus, 1958; Lees, 1980; and Shaw 1974). Presence of inerts enhances the ignition temperature and it can also suppress the combustion. For the purpose of estimation of system properties, methane (molecular weight 16) may be taken as a close approximation of the volatile matter (assumed molecular weight 20). Reported values for the ignition temperature of methane are from 556 to 700^{O}C in the oxygen environment and from 650-750^{O}C in the ambient air (Brame and King, 1955). The oxygen content in the kiln gas at a position where combustion of the volatile matter is likely to occur will be much lower due to the combustion of the fixed carbon and a part of the volatile matter in the burning zone. Furthermore, the carbon dioxide content will be much higher due to the calcination of limestone, combustion of fixed carbon and a part of the volatile matter. This will also reduce the partial pressure of oxygen in the kiln gas and will increase the spontaneous ignition temperature for the volatile matter. Accordingly, the assumed value of 948 K (675^{O}C) for the spontaneous auto-ignition temperature is quite reasonable. However, this value can also be varied, if considered desirable.

The ash fusion temperature is reported usually in the range of 1493 to 1613 K for different types of ashes produced as a result of combustion of coal (Brame and King, 1955; Himus, 1958; and Lowry, 1945). Basically ash fusion temperature depends upon the ash composition. Ash fusion temperature T_{ff} is assumed as 1573 K in the present work. The same can be varied, if considered desirable, depending upon the actual nature of ash.

The endothermic heat of demoisturization from the fuel particles has been estimated as the sum of the normal values of latent heat and heat of desorption of water vapour. The volatile matter is evolved due to thermal decomposition of coal and requires the endothermic heat for the breakage of relevant bonds. Since no published information could be found regarding the endothermic heat of devolatilization, the same was estimated from a knowledge of the heats of thermal decomposition for heavy petroleum residues (Nelson, 1958). The values used are given in Table-6.2 and some other values can be substituted if more precise information about them is available.

Heat of combustion of fixed carbon (H_{fc}) is chosen as 8200 Kcal/Kg as per the Gautal's formula for estimation of heating value of fuel from the knowledge of its proximate analysis (Brame and King, 1955).

The inclusion of effectiveness factors for interphase heat or mass transfer accounts for the fact that the entire solid surface is not active for the interphase exchanges in packed beds (Perry and Chilton, 1968; Smith, 1970). For a mixed feed lime shaft kiln, pronounced decrease in heat exchange rates can be expected due to dead spaces for flow at the places of contact between particles of mixed sizes. Since exact estimates were not available, different values for effectiveness factors were tried so as to achieve realistic temperature and conversion profiles and to obtain proper calcination at a reasonable superficial lime output rate with a kiln of proper height. The following values of effectiveness factors for various interphase heat exchanges are used in different zones for all sets of design and operating conditions:

	Pre-heating zone	Burning zone from to	Cooling zone
Stone to gas, η_{sg}	0.0250	0.0250 - 0.0125	0.0125
Fuel to gas, η_{fg}	0.050	0.050 - 0.015	-
Fuel to stone, η_{fs}	0.200	0.200 - 0.150	-
Gas to kiln wall, η_{gw}	0.100	0.100	0.100

The values of effectiveness factors are not allowed to change in the preheating and cooling zones because no changes occur in packed

bed conditions for these zones. However, the values of effectiveness factors are assumed to decrease linearly with increase in fixed carbon combustion as particles of lime-limestone and fuel move down in the burning zone because the packed bed characteristics change significantly due to the release of ash and reduction in fuel particles size. For obvious reasons the values of effectiveness factors at the beginning and end of the burning zone are identical to those used in preheating zone and cooling zone, respectively.

The ash released on account of burning of the fixed carbon spreads on the stone particles. Reduction in the fuel volume may lead to some increase in the bed porosity. But ash may also cause plugging of the bed at some places which will result in gas channeling and poor gas solid contact. The tendency towards plugging will increase with increase in ash quantity and, therefore, η_{sg} is allowed to decrease from 0.0250 to 0.0125 as fixed carbon burns progressively till it is completely consumed.

The ash released on account of fixed carbon burning of coal particles is assumed to attain stone temperature instantaneously due to the high contact area. The shrinking fuel particles are likely to be trapped in ash layer over lime-limestone particles more and more as ash quantity grows and fuel particles size reduces. The existence

of product ash layer after ash fusion over burning fuel particles will also hinder the heat exchange rate from fuel to gas. Thus η_{fg} is allowed to decrease more sharply than η_{sg}, i.e. from 0.050 to 0.015 as fixed carbon burns progressively till it is completely consumed.

The possibility of the existence of powdered ash layer in between lime-limestone and fuel particles with increase in ash quantity is quite high and this will hinder the heat exchange rate from fuel to limestone particles. Further, product ash layer after ash fusion on burning fuel particles will create additional reduction in fuel to stone heat exchange. Therefore, η_{fs} is allowed to decrease from 0.20 to 0.15 as fixed carbon burns progressively till it is consumed completely.

Table-6.3 lists the important parameters related to kiln design, operation and energy efficiencies. In addition to these some other computed parameters, such as, particle surface areas, interphase heat transfer coefficients and rates and cumulative wall heat loss are also given in the Tables of results F.1 to F.9, Appendix-F. These were not important as far as the overall design and performance of the kiln is concerned but they give a deeper insight into actual phenomenological behaviour inside the kiln as lime-limestone and fuel particles and gas pass through different axial positions of the kiln.

TABLE-6.3

Computed Parameters of Significance

Sl.	Parameter	Symbol	Units
1.	Effective kiln height	L_e	m
	1.1 Height of preheating zone	H_{pz}	m
	1.2 Height of burning zone	H_{bz}	m
	1.3 Height of cooling zone	H_{cz}	m
2.	Limestone-lime surface temperature	T_s	K
3.	Fuel temperature	T_f	K
4.	Gas temperature	T_g	K
5.	Fractional limestone calcination	x_s	Kg/Kg
6.	Fractional fuel conversion	x_f	%
7.	Input heat accounted	IHA	%
8.	Thermal efficiency	η_ℓ	%
9.	Sensible heat loss in kiln exhaust gas	SHLKEG	%
10.	Sensible heat loss in product lime and fuel residues	SHLPL	%
11.	Combustion heat loss in unburnt volatile matter	CHLUVM	%
12.	Heat loss through kiln wall	HLKW	%

First six computed parameters listed in Table-6.3 are already explained earlier. Input heat accounted (IHA) is the ratio of all output heat terms to all input heat terms, both sensible and latent. IHA gives an idea of the overall heat balance achieved for the kiln as a whole. From energy efficiency point of view, the thermal efficiency appears to be the most important and widely used term and is defined (Boynton, 1967) as:

$$\text{Thermal efficiency} = \frac{\text{Theoretical heat required for calcination}}{\text{total heat of combustion of fuel supplied}} \qquad (6.1.1)$$

Some investigators might prefer to include the sensible heat required to preheat limestone to calcination temperature in the numerator of right hand side of the above defining equation. But this is not very proper because a significant fraction of the total sensible heat of product lime and carbon dioxide is recovered in the cooling and preheating zones, respectively. The remaining terms in Table-6.3 specify the various specific heat loss terms and give an idea of the individual contributions to the overall heat loss.

It may be noted again that the effective kiln height (L_e) is treated as an output-design parameter and its value is computed by the simulation system. However, if the computed value of the effective kiln height becomes very large, natural draft operation may not be feasible. The field survey indicates that the kiln heights vary from 5 to 12 m for lime production rates of 5 to 15 tonnes per day (Table-3.1). However, one kiln was observed to have an effective height of 14.5 m with nominal lime production of 20 tonnes per day with a provision for forced draft. This kiln was observed by the author to give lime production rate of only about 14 tonnes per day with natural draft. Thus, it may be quite realistic to impose a maximum limit of 14 m for the effective kiln height for which natural draft operation may be considered feasible. Furthermore, for small capacity low investment kilns with lime production rates of approximately 10 tonnes per day, the maximum limit of 14 m for L_e may also be justified from operational convenience also.

6.2 SIMULATION RESULTS FOR THE BASE CONDITIONS

6.2.1 General

The computer programmes written in Fortran IV were run on the digital computer SN-73 manufacured by ESSEN (Indian Version

of PDP-11/73 of DEC, USA) and installed at the Central Building Research Institute, Roorkee. Unique solutions were obtained for all the cases. Execution time for each set of conditions for the three zones varied, in general, from 50 to 100, 150 to 300 and 30-50 seconds for preheating, burning and cooling zones, respectively.

Results obtained in respect of temperature and conversion profiles alongwith interfacial areas of solid particles, interphase heat transfer coefficients, interphase heat exchange rates and cumulative wall heat losses for the base conditions corresponding to average values of design and operating parameters are reported in Tables F.1 (A-1) through F.1 (A-3) for the preheating-cum-devolatilization zone (without volatile matter combustion), the burning zone (incorporating the combustion of volatile matter and fixed carbon contents of fuel), and the cooling zone, respectively. Results for burning zone also include the ratio of sensible heat accumulation in lime layer to the total heat (sensible heat plus heat of calcination) received by limestone-lime particles in the axial width ΔZ, lime layer sensible heat above the dissociation temperature T_d, and partial pressures of oxygen and carbon dioxide.

The relevant profiles for the three zones of the lime kiln are given in Figs. 6.1 through 6.3. The curves were plotted using HP 7475 A Colour Graphics Plotter manufactured by Hewlett-Packard

of USA and installed at the Central Building Research Institute, Roorkee.

6.2.2 Temperature Profiles and Fuel Behaviour in the preheating zone

Fig. 6.1 shows the temperature profiles of gas, fuel and limestone particles as well as the fractional weight loss (x_f) of fuel in the preheating zone of the lime kiln. The fuel temperature initially rises at a sharp rate upto a temperature of 373 K, incipient demoisturization temperature, for the case of simple preheating. As no moisture is evolved, the fuel weight loss remains zero as indicated by a straight line on the abscissa of the graph. Thereafter, the process of demoisturization starts and the rate of rise of fuel temperature along the axial direction during its downward movement in the kiln falls for next eight intervals of ΔZ of 0.05 m during which the total moisture (weight percent of fuel) was assumed to release at a uniform rate. Thus x_f shows a linear change in its value 0 to 0.05. Since the fuel attained a temperature of 379.3 K at the completion of demoisturization, and devolatilization is not assumed to commence until T_f becomes 673 K, its temperature again shows a sharper rise and x_f value remains constant at 0.05. As the difference between gas temperature (T_g) and fuel temperature (T_f)

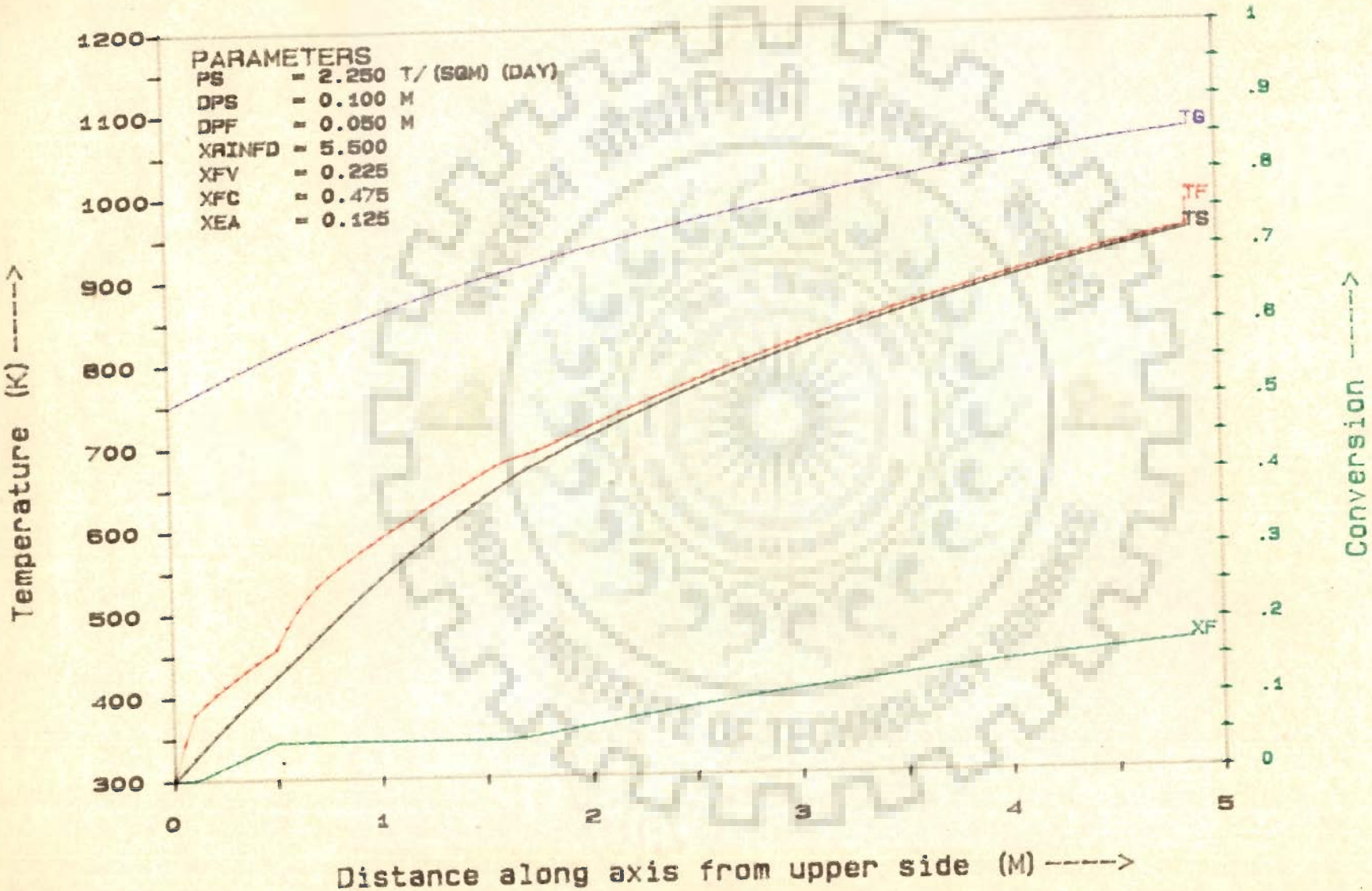


FIG.6.1 – TEMPERATURE PROFILES & FUEL BEHAVIOUR IN PREHEATING ZONE

becomes smaller, the rate of heat transfer from gas to fuel ($-Q_{fg}$) decreases and the rate of rise of T_f also decreases.

As the fuel attains a temperature of 673 K, the release of volatile matter requires latent heat of devolatilization, and hence the rate of rise in T_f with distance along the axis of the kiln shows a further decline. Since the rate of devolatilization is proportional to the rate of change in T_f, the fuel conversion values show a proportional increase with T_f till the fuel attains auto-ignition temperature for the volatile matter, that is, 948 K or a slightly higher value achieved for the first time by the fuel. Temperature at which auto-ignition occurred was observed to lie always within 948 and 951 K for all the conditions investigated. This also indicates the end of the preheating-cum-devolatilization zone without involving combustion of the volatile matter.

In the preheating zone the limestone temperature (T_s) shows a gradual increase as it moves downward along the axis of the kiln without attaining the calcination temperature (T_d) of 1173 K. Thus variation in limestone temperature is uniform and only the rate of increase of T_s shows a decrease with increase in T_s because of declining rate of heat transfer from gas to limestone ($-Q_{sg}$) as a result of decrease in (T_g-T_s). In this zone the gas temperature (T_g) also shows a similar behaviour as that of T_s except that its rate

of rise is much smaller in comparison to that of T_s because total thermal inertia of the gas ($\dot{m}_g C_g$) is much higher than that of the stone ($\dot{m}_s C_s$). This will also indicate that the kiln exhaust gases can never be cooled by heat exchange to the limestone and fuel to the ambient temperature even for an infinitely long preheating zone, since temperature pinch-in between hot and cold stream will have to occur at the end of the preheating zone. Under these conditions of infinite preheating zone length, the following conditions will have to be satisfied for the kiln to be functional, that is, to have limestone calcination in the burning zone:

$$T_g = T_s = T_f = 948 \text{ K (Auto-ignition temperature)}$$

At this condition, the kiln exhaust gas temperature T_{g_o} will be close to 620 K.

6.2.3 Temperature and Conversion Profiles in the Burnzing Zone

Table F.1 (A-2) and Fig. 6.2 depicts the temperature and conversion profiles obtained for the base conditions in the burning zone.

6.2.3.1 Fuel Temperature

Initially, the temperature rise of the fuel is very sharp on account of the volatile matter evolved since the fuel attains the assumed auto-ignition temperature for the volatile matter (948 K)

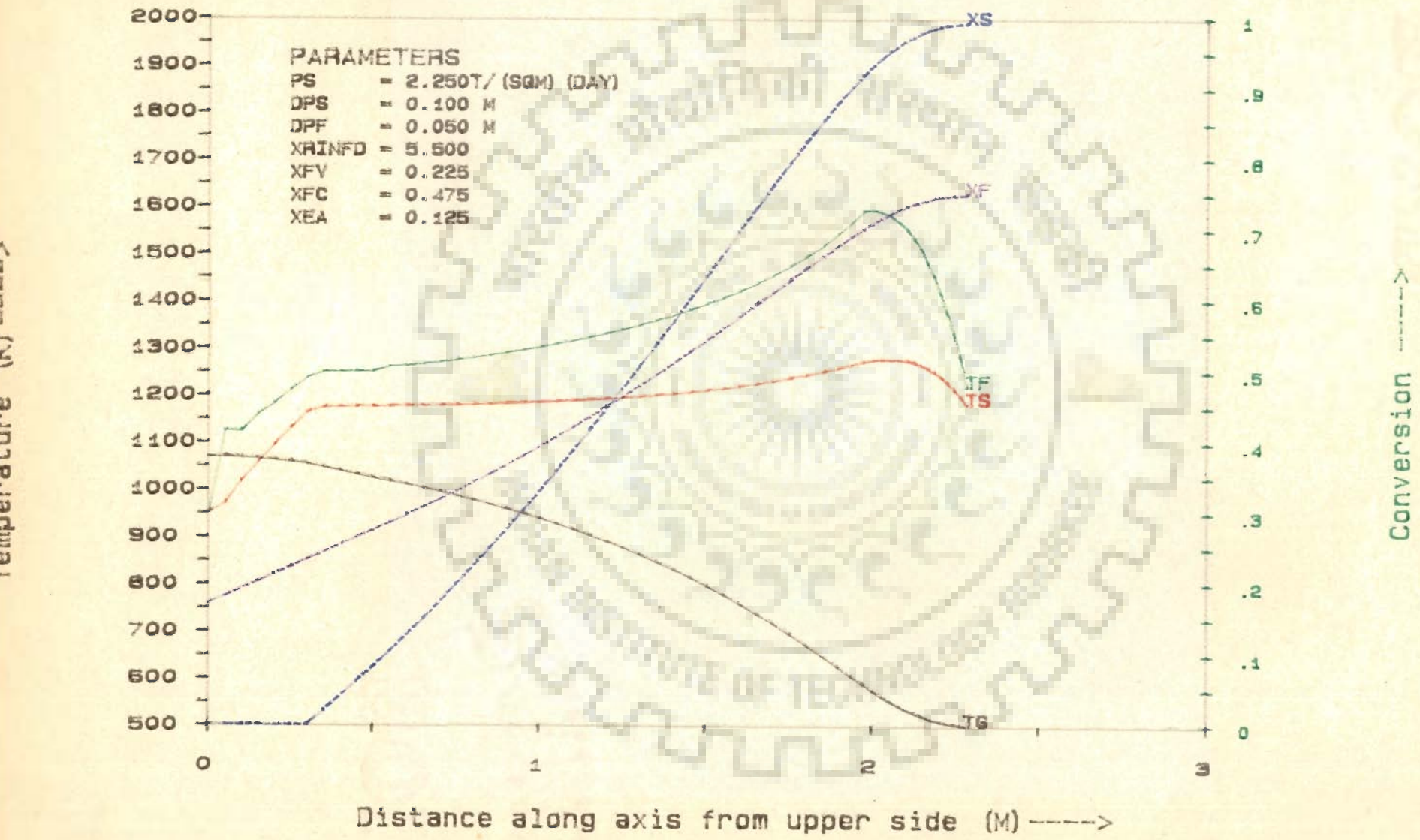


FIG.6.2 - TEMPERATURE & CONVERSION PROFILES IN BURNING ZONE

or higher. T_f shows a decline in the next ΔZ interval and then increases with increase in Z. In the actual situation, this discontinuity in the fuel temperature should not occur. At the inlet of the burning zone, it may be noted that T_g was greater than T_f, while T_f and T_s were very close to each other. (T_g = 1069.7 K, T_f = 949.7 K and T_s = 947.4 K). In one ΔZ interval T_f rose by 176.2 K and becomes very much higher than T_s and also higher than T_g (T_f = 1125.9 K, T_s = 970.1 K and T_g = 1069.5 K). The interphase heat transfer rates Q_{fs}, Q_{fg} and Q_{sg} are computed at the average converged temperatures at the two grid points for the ΔZ interval. The heat transfer rate from fuel to stone (Q_{fs}) has very high radiant heat transfer contribution which depends on the difference of fourth power of the respective temperatures ($T_f^4 - T_s^4$). In view of the foregoing reasons, the Q_{fs} value for the first ΔZ interval is only 135 Kcal/hr and this shoots to an extremely high value of 12426 Kcal/hr for the next ΔZ interval (Table 6.1, A-21). The corresponding values for heat transfer rates from fuel to gas (Q_{fg}) in the first and second ΔZ intervals are - 408 and + 191 Kcal/hr, respectively. Thus the total heat transferred from fuel in the second ΔZ interval is 12617 Kcal/hr. The heat generated in fuel by the combustion of volatile matter in second Z interval is only 12611 Kcal/hr ($\dot{m}_{f_o} \Delta x_f H_{vm}$) and is slightly lesser than that transferred from the fuel. It is, therefore, clear that the fuel temperature will show a fall at the end of second interval (T_f = 1122.4 K) because the heat generated in fuel is lower than the heat

transferred from fuel to stone and gas. This discontinuity in T_f behaviour for the first two ΔZ intervals could be avoided by reducing the value of ΔZ interval to a lower value, say 0.01 m, for an initial kiln length of 0.10 to 0.15 m at the beginning of the burning zone. This will avoid such a large change in Q_{fs} and, therefore, in T_f. T_f will then show a more smooth behaviour at the beginning of the burning zone.

At the completion of the volatile matter evolution vis-a-vis its instantaneous combustion, the fuel attains a temperature of 1250.5 K which is sufficiently high to have an appreciable rate of combustion of the fixed carbon, as oxygen will now be able to reach the surface of the fuel particles. It may be noted that the size of the fuel particles (d_{p_f}) and, therefore, its surface area (a_f) do not change till the completion of combustion of the volatile matter. But once the fixed carbon begins to burn, ash segregation from the fuel particles takes place leading to shrinkage of the fuel size and consequent reduction in its surface area. Reduction in a_f will also affect the rate of heat generation by combustion of the fixed carbon and also the rate of heat transfer from the fuel particles to gas and the limestone particles. The changes in fuel particles temperature T_f in burning zone depend upon the net rate of heat accumulation by the fuel particles, that is, the rate of generation of heat by combustion of the fixed carbon minus the heat transfer rates Q_{fs} and Q_{fg}.

It is clear from the tabulated results in Table F.1 (A-2) and Fig. 6.2 that T_f rises upto a maximum value of 1594.3 K as the fuel particles move downward in the burning zone. When T_f approaches the ash fusion temperature (T_{ff}) of 1573 K or higher for the first time, the fusion of ash checks its segregation from the fuel particles and further combustion of the fixed carbon will approach the shrinking core model, eventhough the particle size will change to some extent due to the assumption of density variations with T_f. The ash layer is assumed to be porous and quite thin so that the diffusion of oxygen to the surface of the fixed carbon core is assumed to take place without substantial hindrance. Further, the temperature gradients across the thin ash layer are neglected so that the entire fuel particle consisting of the ash layer and the fixed carbon core is assumed to be at a uniform temperature. With the commencement of ash fusion, reduction in external surface area of fuel particles (a_f) is very small, but the reduction in surface area of the core on account of combustion of the fixed carbon is effected rather rapidly with increasing x_f. Thus, soon after initiation of the process of ash fusion, that is, for x_f greater than x_{ff}, Q_{fs} and Q_{fg} exceed the rate of heat generation due to the fixed carbon combustion and hence the fuel temperature (T_f) starts falling. It may be noted from the Table F.1 (A-2) that $T_{f_{max}}$ occurs at an axial distance Z of 2.0 m from the commencement of the burning zone and T_f is 1218.9 K at the end of the burning zone with the burning zone height (H_{bz}) of 2.28 m.

6.2.3.2 Surface Temperature of Limestone-Lime Particles

Table F.1 (A-2) and Fig. 6.2 also show the variations in the stone surface temperature T_s with axial position from the start of the burning zone, Z. At the start of the burning zone T_s is 947.4 K and it rises rapidly to its decomposition temperature (T_d) of 1173 K. The slow rise in T_s in the first ΔZ interval of the burning zone may be attributed partly to the error due to the choice of Z = 0.05 m as per the explanation given earlier and partly to the fact that T_f is extremely close to T_s (T_f = 949.7 K and T_s = 947.4 K) and, therefore, Q_{fs} will be very small at the start of the burning zone. After the limestone particles traverse a distance of 0.35 m in the burning zone, T_s reaches the calcination temperature (T_s = 1173.2 K) and further increase in T_s is greatly reduced since most of the net heat received by heat exchange ($Q_{fs} - Q_{sg}$) is consumed in the calcination of the limestone particles. This is obvious from the extremely low values of RSHLHD in Table F.1 (A-2). RSHLHD is the ratio of the sensible heat accumulation in the lime layer to the net heat (sensible plus calcination) received by the lime-limestone particles. It may also be noted that only upto an axial distance of 0.15 m in the burning zone, T_g is greater than T_s. After that T_s becomes much larger than T_g and the heat transfer rate from the stones to gas (Q_{sg}) tends to increase for most of the burning

zone in the downward direction. With increase in T_f, T_s also increases to meet the heat conduction requirements through the growing thickness of the lime layer. T_s attains a maximum value of 1277.0 K at Z = 2.025 m soon after the maximum value of T_f at Z = 2.000 m. The ratio RSHLHD also increases to a maximum value of 0.1166 at Z = 2.180 m. It may also be noted that the net heat received by the limestone-lime particles by heat exchange $(Q_{fs} - Q_{sg})$ also increases with increase in downward axial distance Z, attains a maximum value at Z = 1.600 m and then starts decreasing with further increase in Z. $(Q_{fs} - Q_{sg})$ is found to be always positive (upto Z = 2.260 m). For the last Z interval at the end of the burning zone x_f, x_s, T_f, T_s and T_g were obtained by second order polynomial equations using sets of the previous three converged values for each of the variables to ensure complete combustion of the fuel $(x_f = x_{f_{max}} = 1 - x_{fa})$ at the end of the burning zone since it was found to be virtually impossible to obtain their values by solving the model equations due to various constraints.

6.2.3.3 Bulk Gas Temperature

Table F.1 (A-2) and Fig. 6.2 show the variation in gas temperatures (T_g) with axial position (Z) from the start of the burning zone. At the end of the preheating zone T_g was higher than T_f as

well as T_s. But after the very first ΔZ interval of 0.05 m, T_f becomes appreciably higher than T_g and after four ΔZ intervals of 0.05 m each, T_s also becomes higher than T_g. Thus the net heat received by the gas from the heat exchange (Q_{fg} + Q_{sg}) becomes positive at Z = 0.150 m and remains positive thereafter with a maximum value at Z = 1.500 m. In addition, the gas also receives heat by convective transport of the hot combustion gaseous products at T_g and the product of calcination, carbon dioxide gas, at T_s. Convective transport to gas is always positive. Since the gas flows from the bottom to the top of the kiln, that is, in the negative Z direction, T_g falls in the positive Z direction and the rate of fall of T_g will increase with increase in the rate of total heat (Q_{fg} + Q_{sg} + Convective transport) received by the gas. Thus, T_g drops from the beginning to the end of the burning zone with steepest fall at Z = 1.850 m. T_g drops from 1069.7 K at the beginning to 500.6 K at the end of the burning zone.

6.2.3.4 Fuel Conversion

Table F.1 (A-2) and Fig. 6.2 also show the variation in fractional fuel conversion (x_f) with axial position (Z) from the start of the burning zone. During the volatile matter combustion x_f is linearly increasing with increase in Z as a sequel to the assumption that the residual volatile matter at the auto-ignition temperature

is released uniformly in ten intervals of Z of 0.05 m each due to the mass transport limitations as pointed out earlier in Table-6.2. After the completion of the volatile matter combustion at Z = 0.5 m, the fixed carbon combustion rate will depend upon the overall rate constant per unit area of the fixed carbon core surface due to the combined effect of surface reaction and mass transfer resistances ($\bar{k}_s$), area of the fixed carbon core surface which is releated to the two third power of the fixed carbon remaining unburnt and T_g. Increase in $\bar{k}_s$ is rapid with increase in T_f initially, but at very high values of T_f, $\bar{k}_s$ tends to approach an assymptotic value. Thus x_f increases rapidly with Z upto the ash fusion temperature and then its further increase is relatively slow. However, it may be noted that x_f rises monotonically with Z till the entire fixed carbon is burnt, that is, $x_f = 1 - x_{fa} = 0.75$.

6.2.3.5 Limestone Conversion

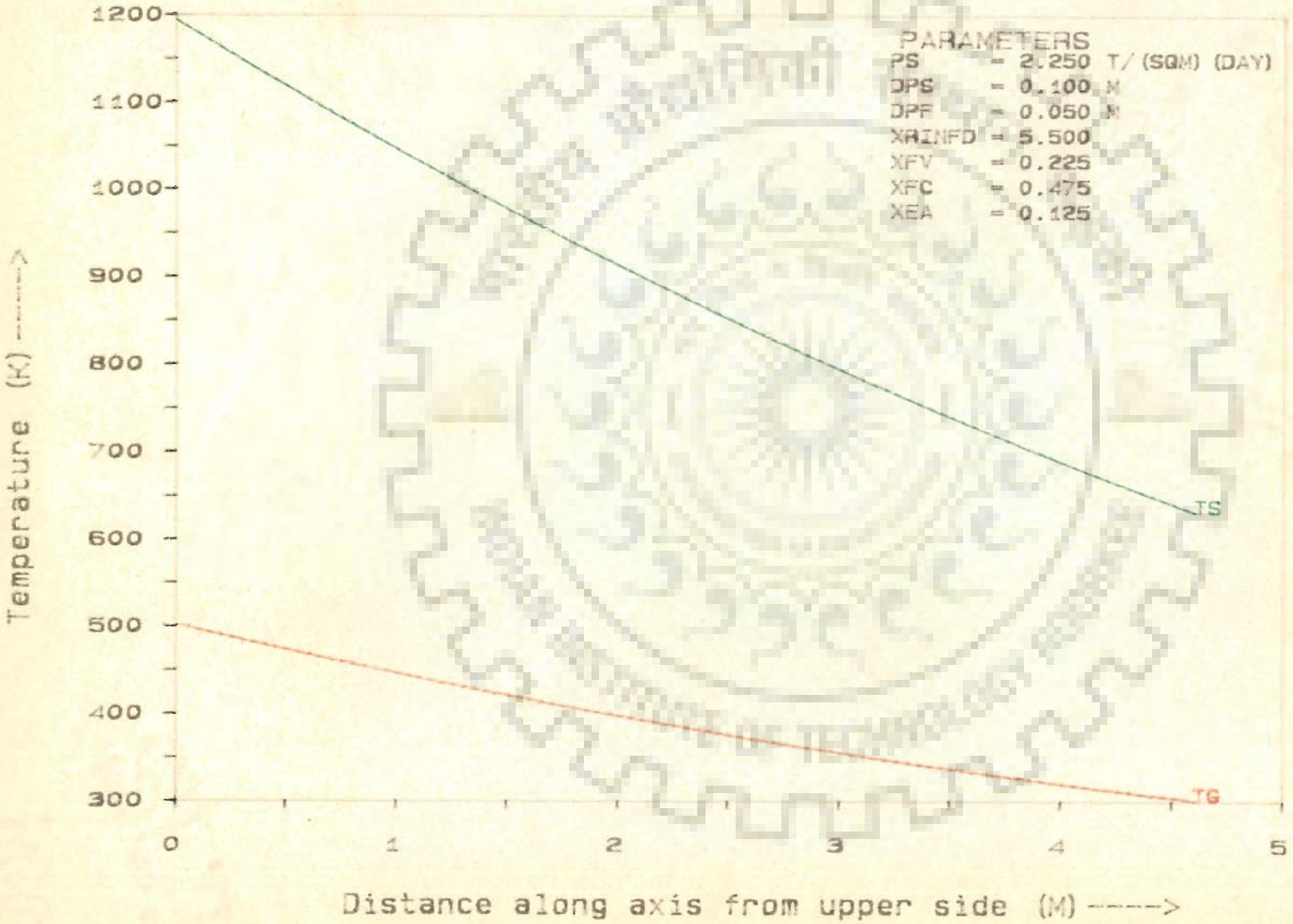
Table F.1 (A-2) and Fig. 6.2 indicate the variation in fractional limestone conversion (x_s) with axial distance (Z). No limestone calcination occurs ($x_s = 0$) till T_s is less than the calcination temperature (T_d) of 1173 K upto Z = 0.35 m. Thence, the rate of x_s increase is closely related to the rate of net heat received by the limestone - lime particles ($Q_{fs} - Q_{sg}$). Thus, the rate of x_s increase is maximum at Z = 1.6 m, corresponding

to the maximum (Q_{fs} - Q_{sg}) value, and then it slows down till the end of the burning zone. It is observed that 99.3 percent calcination of limestone occurs till the end of the burning zone in this case.

6.2.4 Temperature Profiles in the Cooling Zone

Table F.1 (A-3) and Fig. 6.3 depict the solids and gas temperature profiles in the cooling zone for the base conditions. The weighted mass temperature of all solids at the end of the burning zone was calculated using the equation (4.5.3.1). The calcination of unconverted limestone remaining at the end of the burning zone, if any is considered insignificant in the cooling zone in view of the extremely rapid drop in solid mass temperature below the calcination temperature of 1173 K, even though T_s at the end of the burning zone may be somewhat higher than 1173 K. The weighted solid mass temperature and the gas temperature at the beginning of the cooling zone are 1194.7 and 500.6 K, respectively. The corresponding temperatures at the end of the cooling zone are 632.2 and 299.6 K. It may be noted that the cooling zone is assumed to end when the gas temperature for the first time becomes equal to or less than the ambient temperature T_∞ (300 K).

Fig. 6.3 indicates that the rate of drop of T_s is faster as compared to T_g because of the thermal inertia of the solids is lesser



6.3 - TEMPERATURE PROFILES IN COOLING ZONE

than that of the gas as already explained in section 6.2.2. It is quite clear from the Fig. 6.3 that the complete recovery of sensible heat from the solids will not be possible even with an infinitely large cooling zone. For the assumed pinch-in of temperatures T_g and T_s at the end of the cooling zone with $T_g = T_\infty = 300$ K for an infinite cooling zone will occur only if the weighted mass temperature of all the solids at the beginning of the cooling zone is equal to 862 K. Thus, the lime-limestone particles temperature (T_s) at the end of the burning zone will be lower than 862 K. Such a low T_s value at the end of the burning zone is undesirable for proper calcination in the burning zone. Such a situation will mean unrealistically high limestone to fuel ratio (X_r) and correspondingly extremely low fractional degree of calcination, x_s. It, therefore, appears that for the most optimal operation, the following conditions must occur at the end of the burning zone :

$$T_s = 1173 \text{ K} \quad \text{and} \quad x_s = 1.00.$$

Under these conditions the product lime temperature at the end of the cooling zone is expected to be close to 625 K for this case of average design and operating parameter values.

6.2.5 Important Design and Performance Results from Simulation

In sections 6.2.2 to 6.2.4 the temperature and conversion profiles have been discussed in detail to provide phenomenological

understanding of the changes in limestone, fuel and gas in the preheating, burning and cooling zones of the kiln. Table 6.4 gives the important design and performance results obtained from simulation. For the base conditions (Set No. 1) and for the variations in the parameter values. The tabulated results give effective kiln height (L_e), fractional degree of calcination (x_s), product lime exit temperature, product quality and thermal efficiency. These results are of greatest interest to a designer or an operator of a lime shaft kiln. Table 6.5 gives the details of heights for the three zones, namely, the preheating, burning, and cooling, and the values of maximum limestone-lime surface temperature ($T_{s_{max}}$) and fuel temperature ($T_{f_{max}}$) alongwith their positions from the top of the kiln. $T_{s_{max}}$ and x_s are used to characterize product quality in the following manner :

Product Quality	Defining Conditions
Wellburnt	$x_s \geq 0.95$ and $T_{s_{max}} < 1573K$
Underburnt	$x_s < 0.95$ and $T_{s_{max}} < 1573K$
Overburnt	x_s is not specified and $1573K \leq T_{s_{max}} < 1773K$
Deadburnt	x_s is not specified and $T_{s_{max}} \geq 1773K$

$T_{s_{max}}$ specifications for burning quality are based only on extremely limited published information, but the values used appear to be reasonable and are in general agreement with the lime manufacturing practices (Boynton, 1967).

For the base conditions excellent design and performance results are predicted by the simulation. Table-6.6 gives details of the energy balance and important heat losses as input heat accounted (IHA) defined in section 6.1, fraction of the volatile matter in fuel escaping unburnt (FVMU), sensible heat loss in kiln exhaust gas (SHLKEG), combustion heat loss in unburnt volatile matter (CHLUVM), sensible heat loss in product lime (SHLPL) and heat loss through kiln wall (HLKW). Thermal efficiency (η_t) and energy loss terms FVMU, SHLKEG, CHLUVM, SHLPL and HLKW are based on heat of combustion of the total volatile matter and the fixed carbon. The value of IHA indicates the exent to which total input heat terms (sensible plus heats of combustion) are accounted for in the output heat terms for the kiln. In view of the complexities involved in computations, IHA values in the range of 93.18 to 100.1 percent are considered excellent. The thermal efficiency is 36.9 percent and the major sources of heat losses are : SHLKEG = 28.9 percent, CHLUVM = 18.5 percent and SHLPL = 4.4 percent. The possibility of improving thermal efficiency by reducing heat losses is discussed in subsequent sections in which the results for variations in parameters are discussed. But

TABLE-6.4

Design and Performance Results Obtained from the Simulation System

Set No.	Parameter Varied	Value of Parameter	Effectie Kiln Ht. (m)	Fractional Degree of Calcination	Exit Lime Temperature (K)	Product(Lime) Quality	Thermal Efficiency (Percent)
1	2	3	4	5	6	7	8
1(A)	Nil	The Base Conditions	11.7	0.9929	632.2	Wellburnt	36.87
2(A)	Particle size of limestone	0.088	9.6	0.9874	683.2	Wellburnt	36.66
2(B)	-do- (d_{p_s})	0.112	13.5	0.9916	607.4	Wellburnt	36.82
3(A)	Particle size of fuel(d_{p_f})	0.044	11.2	0.9884	627.3	Wellburnt	36.70
3(B)	-do-	0.056	11.9	0.9894	662.5	Wellburnt	36.73
4(A)	Superficial lime output rate (P_s)	2.00	10.9	0.9956	633.6	Wellburnt	36.96
4(B)	-do-	2.50	12.4	1.0000	624.0	Wellburnt	37.13
5(A)	Limestone to fuel ratio (X_r)	5.0	8.9	1.0000	1234.2	Overburnt	33.75
5(B)	-do-	6.0	14.7	0.9370	503.6	Underburnt	37.95

Table Contd. .../

1	2	3	4	5	6	7	8
6(A)	Volatile matter content(X_{fv})	0.150	8.4	1.0000	1374.2	Overburnt	35.89
6(B)	-do-	0.300	19.4	0.8741	418.8	Underburnt	35.33
7(A)	Excess Air Fraction (X_{ea})	0.00	10.30	1.0000	791.1	Wellburnt	37.13
7(B)	-do-	0.25	13.9	0.9847	491.8	Wellburnt	36.56
8(A)	Wall thickness of brick masonry (W_{rb})	0.46	11.7	0.9937	634.3	Wellburnt	36.89
8(B)	-do-	0.92	11.5	0.9921	646.6	Wellburnt	36.84
9(A)	Exhaust gas temperature	698.0	10.4	0.9680	907.9	Wellburnt	35.94
9(B)	-do- (T_{g_o})	798.0	13.6	1.0000	533.8	Wellburnt	37.13

Note: The base conditions are; d_{p_s} = 0.100 m; d_{p_f} = 0.050 m; P_s = 2.25 t/(m^2) (day); X_r = 5.5 t/t; X_{fv} = 0.225; X_{ea} = 0.125, W_{rb} = 0.69 m and T_{g_o} = 748 K .

The values of the parameters varied are in the same units as those used for the base conditions.

TABLE-6.5

DETAILS of Kiln Zonal Heights and Maximum Temperature Locations

Set No.	Heights of the zones (m)			Maximum Temperatures (K) and Their Axial Location (m) from top of Kiln			
	Preheating	Burning	Cooling	Stone Surface $T_{s_{max}}$	Z for $T_{s_{max}}$	Fuel $T_{f_{max}}$	Z for $T_{f_{max}}$
1(A)	4.85	2.28	4.60	1277.0	6.88	1594.3	6.85
2(A)	4.10	2.29	3.25	1251.5	6.15	1576.7	6.13
2(B)	5.50	2.28	5.75	1294.1	7.53	1581.8	7.50
3(A)	4.75	1.88	4.55	1290.8	6.42	1608.6	6.34
3(B)	4.85	2.73	4.35	1258.7	7.35	1586.1	7.32
4(A)	4.50	2.06	4.30	1341.7	6.38	1579.7	6.67
4(B)	5.15	2.49	4.75	1270.4	7.34	1581.7	7.31
5(A)	5.00	2.27	1.60	1608.6	7.23	1710.1	7.15
5(B)	4.75	2.27	7.70	1240.8	6.75	1580.5	6.72
6(A)	4.65	2.77	1.00	1607.1	7.39	1676.7	7.37
6(B)	5.05	1.89	12.45	1231.6	6.69	1576.7	6.69
7(A)	4.60	2.40	3.25	1286.9	6.82	1585.9	6.71
7(B)	5.10	2.19	6.65	1267.7	7.03	1581.4	7.00
8(A)	4.80	2.28	4.60	1277.7	6.83	1594.9	6.80
8(B)	4.85	2.28	4.40	1276.0	6.88	1593.4	6.85
9(A)	6.35	2.29	1.75	1256.5	8.35	1574.8	8.32
9(B)	3.95	2.27	7.40	1399.0	6.20	1593.3	5.92

TABLE-6.6

Details of Energy Balances and Significant Heat Losses

Set No.	IHA (Percent)	FVMU (Fraction)	SHLKEG (Percent)	CHLUVM (Percent)	SHLPL (Percent)	HLKW (Percent)
1(A)	93.98	0.5409	28.91	18.53	4.35	1.59
2(A)	94.25	0.5373	28.91	18.41	5.18	1.36
2(B)	93.98	0.5474	28.91	18.76	3.98	1.79
3(A)	93.81	0.5448	28.91	18.67	4.29	1.50
3(B)	94.41	0.5419	28.91	18.57	4.84	1.65
4(A)	93.78	0.5350	28.91	18.33	4.36	1.50
4(B)	94.60	0.5537	28.91	18.97	4.20	1.66
5(A)	100.07	0.5472	28.39	15.71	13.99	1.42
5(B)	94.52	0.5503	29.44	18.86	2.82	1.71
6(A)	99.29	0.5462	26.99	14.44	17.54	1.51
6(B)	96.31	0.5549	32.56	22.05	1.64	1.95
7(A)	94.60	0.5430	26.68	18.61	6.89	1.53
7(B)	94.25	0.5498	31.15	18.84	2.33	1.66
8(A)	93.99	0.5371	28.91	18.40	4.38	1.71
8(B)	94.00	0.5393	28.91	18.48	4.58	1.47
9(A)	94.44	0.5463	25.39	18.53	9.23	1.76
9(B)	96.76	0.5477	32.54	18.77	2.87	1.55

the tabulated values of the thermal efficiency for all the sets of conditions show that by adjusting the effective kiln height (L_e), the thermal efficiency in the range of 36.9 $\pm$ 1.5 percent is possible. L_e value of 11.7 m obtained from the base conditions is quite reasonable and the natural draft may very well meet the combustion air flow requirements.

6.3 EFFECT OF VARIATIONS IN THE DESIGN AND OPERATIONAL PARAMETERS

The average conditions for the design and operation of a lime shaft kiln are given in Table-6.1. For studying the effect of variations in the design and operational parameters, it was considered desirable to vary only one parameter at a time in the specified range given in Table 6.1 keeping all the other parameters corresponding to the average values. Furthermore, the values of the important system parameters were not changed and the same were maintained as given in Table-6.2. The two additional values of the varying parameters, namely, at the minimum and the maximum of the ranges, were used for obtaining simulation results. These two computed results alongwith the same obtained for the base conditions form a set for each parameter variation. Each of the eight parameters, which were permitted to vary, is treated as an independently varying parameter

in order to study the effect of the same. The results of this sensitivity analysis can be very useful in the evolution of optimal conditions for design and operation of such types of the low capacity mixed-feed kilns. The detailed computed results are given in the Appendix-F, tables F.2 to F.9 with A-1 to A-3 and B-1 to B-3 being subclassifications for the minimum and maximum values of parameters varied in the analysis of the three zones of the kiln. The computed values of the important design and performance results of simulation are also given in tables 6.4 to 6.6.

The general trends for changes in temperatures and conversions in the preheating, burning and cooling zones were similar to those obtained for the base conditions. Thus, further discussion on the same is not considered essential. The effect of the variations in the design and operating variables can be discussed properly with the help of the tabulated results as given in tables 6.4 to 6.6.

6.3.1 Particle Size of Limestone (d_{p_s})

The effective height of the kiln (L_e) shows a considerable change with variation in particle size of limestone as per set numbers 1 and 2 in Tables-6.4 through 6.6. For d_{p_s} increase by 1.27 times, the increase in L_e is 1.40 times. Therefore, assuming power law variation L_e appears to be proportional to $(d_{p_s})^{1.4}$. The state-of-the-art correlations for the preheating, burning and cooling

times appear to depend upon 0.5, 1.0 to 2.0 and 0.5 power of d_{p_s}, respectively, as per equations 3.10 through 3.12 discussed earlier in Chapter-3. The effect of variations in d_{p_s} on fractional degree of calcination is less than 0.6 percent and on thermal efficiency is less than 0.2 percent. The quality of the product lime as well as the thermal efficiency are, therefore, insignificantly affected by changes in d_{p_s} in the selected range of investigation.

The slight reduction in the fractional conversion of limestone (x_s) for smaller size of the particle may be attributable to the uniformity of the effectiveness factors (η_{sg}) used for the different d_{p_s} values. In a practical situation, it is well known that the η_{sg} values may decrease for smaller sizes of limestones. This, in turn, will reduce the heat exchange rate from limestones to gas, and thereby will increase the rate of net heat received by the limestone particles in the burning zone ($Q_{fs} - Q_{sg}$); and, therefore, x_s.

6.3.2 Particle Size of Fuel (d_{p_f})

Set numbers 1 and 3 in Tables-6.4 to 6.6 do not indicate any significant variations in the effective kiln height, fractional degree of calcination and thermal efficiency on account of the changes in the particle size of the fuel. For d_{p_f} increase by 1.27 times, the increase in L_e is only 1.07 times, the change in x_s is only 0.5 percent

and the thermal efficiency changes by only 0.2 percent. The product lime remains well burnt in all the three cases. However, the results show that the d_{p_s}/d_{p_f} ratio of approximately 2 appears to be the most satisfactory. This conclusion is in conformity with the thumb rule prescribed earlier in the Indian Standards on the design of the mixed-feed lime shaft kilns (I.S. 1849, 1967 and I.S. 1861, 1961).

6.3.3 Superficial Lime Output Rate (P_s)

The results obtained for variation in superficial lime output rate are given in the set numbers 1 and 4, and in Tables-6.4 through 6.6. It is seen that the effective height of the kiln (L_e) increases by about 15 percent when P_s is increased from 2.0 to 2.5 tonnes/(m^2) (day). The change in x_s is nearly 0.7 percent and the same in thermal efficiency is about 0.3 percent. Product lime is well burnt in all the three cases. The power law assumption indicates that L_e is proportional to $(P_s)^{0.6}$. This agrees very well with variations in height as a function of $(P_s)^{0.5}$, as suggested by the state-of-the-art correlations (equations 3.10 through 3.15). The construction cost of the kiln is expected to be proportional to the kiln wall area ($\pi D_i L_e$) where D_i is the internal diameter of the kiln. For a specified nominal lime production rate, D_i is proportional to $(P_s)^{-0.5}$. Thus, the cost of the kiln is approximately proportional to $(P_s)^{0.1}$, that is, a very small dependence on P_s. However, larger diameter and smaller height kilns may not be preferable, eventhough the initial

cost may be slightly less, because of the possibility of non-uniformity of feeding vis-a-vis product withdrawal and also significant non-uniformity in the gas flow over the entire inner cross-section of the kiln for a lower P_s value. Slightly higher x_s and thermal efficiency values and lower value of $T_{s_{max}}$ may tilt the balance in favour of higher P_s value of 2.5 tonnes/(m^2)(day). This value of P_s is in conformity with the recommendations of the Indian Standards Institution (ISI, 1961 and 1967). With increase in P_s the gas velocity increases which tends to improve the gas-solid heat transfer coefficients resulting in improved heat exchange rates. The thermal performance of a coal fired kiln can, therefore, be enhanced slightly by increasing P_s, say to about 3.0 t/(m^2)(day), and correspondingly the effective kiln height upto a maximum limit of 14 m for the natural draft.

6.3.4 Limestone-to-Fuel-Ratio in Feed Input (X_r)

Set numbers of 1 and 5 in Tables-6.4 to 6.6 describe the effect of changes in limestone-to-fuel-ratio (by weight) in the feed input at the top of the shaft kiln. The X_r value has a pronounced effect on the height of the kiln. Increase in X_r from 5.0 to 6.0 increases L_e from 8.9 to 14.7 m and thermal efficiency by 4.2 percent, decreases product lime exit temperature from 1234.2 to 503.6 K and changes the product lime characteristics from the overburnt to the

underburnt conditions. In view of the lower thermal efficiency and the overburnt quality of lime X_r below 5.5 is undesirable. X_r value of 6.0 is also unacceptable because L_e exceeds the limiting value of 14.0 m imposed for the low capacity natural draft kiln and also due to the underburnt quality of the product lime. However, X_r value of about 5.8 may give well burnt product lime, satisfy the restriction on L_e and may improve thermal efficiency by nearly 0.5 percent. From the Table-6.6, it is clear that at a higher value of X_r reduction in the sensible heat loss in the product lime is so significant that it not only compensates for the increases in other sources of heat losses, but also improves the overall thermal efficiency. The lower product lime exit temperature will also facilitate its handling.

6.3.5 Volatile Matter Content in Fuel (X_{fv})

The effect of the volatile matter in fuel X_{fv} can be assessed from the set numbers 1 and 6 in Tables-6.4 through 6.6. The effective height of kiln increases with increase in X_{fv}. The use of a fuel with X_{fv} of 0.15 also results in the overburnt lime product with L_e as low as 8.5 m. The overburning can be avoided by increasing P_s and/or limestone-to-fuel ratio X_r which, in turn, will require additional kiln height and may also improve the thermal efficiency. It is, thus, obvious that a fuel with a low volatile matter content, say coke, can be effectively used at high P_s and X_r to produce well burnt lime at good thermal efficiency. Probably this explains the choice of the

coke fired lime shaft kilns for the large scale manufacture of lime for use in the chemical and allied industries. The tabulated values for the set number 6 (B) corresponding to X_{fv} of 0.30 are correct only if air is available at the bottom of the kiln not at ambient temperature of 300 K, but at a temperature considerably higher than 313 K. An approximate energy balance shows that the cooling zone height becomes infinite when $T_s = T_g = 312.5$ K. Thus, for natural draft operation a fuel with X_{fv} values higher than 0.25 may not be very successful unless someone is willing to operate at low limestone-to-fuel-ratio of about 5.0. Another problem with a high X_{fv} fuel is the underburnt nature of the product lime. This can also be solved to a large extent by using X_r close to 5.0.

6.3.6 Excess Air (X_{ea})

Data obtained for variations in excess air used for combustion are given as set numbers 1 and 7 and Tables-6.4 to 6.6. Tabulated results indicate that increasing the amount of excess air has unsuitable effect since the kiln height L_e is increased, fractional degree of calcination is reduced and the thermal efficiency is also reduced. Thus use of excess air must be as low as possible so long as it does not affect the inherent combustion characteristics of fuel.

Table-6.6 indicates that for all the cases studied, fraction of the volatile matter in the fuel that remains unburnt varies from 53.7 to 55.5% with a mean value of 54.5%. It is, therefore, clear

that even for 0 percent excess here (calculated on the basis of complete combustion of fixed carbon and total volatile matter) case substantial quantity of excess oxygen remains in the exhaust gas at the top of the kiln. Because of the intrinsic characteristics of the shaft kilns, nearly 54.5 percent of the volatile matter is bound to remain unburnt. Even for zero percent theoretical air case, calculations show that actually it amounts to using 28.4 percent excess air, if the same is computed on the basis of that required for the combustion of the fixed carbon and the fraction of volatile matter actually being burnt. Thus, the supply of air can be significantly reduced to lower than what is computed even for the so called zero percent excess air case.

6.3.7 Wall Thickness of Masonry Shaft (W_{rb})

For the range of wall thicknesses investigated in this study, set numbers 1 and 8 in Tables-6.4 to 6.6 indicate totally insignificant changes in the kiln height (L_e), fractional degree of calcination (x_s) and thermal efficiency. This is also clear from Table-6.6, since increase in burnt clay birck thickness from 0.46 to 0.92 m has hardly reduced the wall heat loss from 1.7 to 1.5 percent, a totally insignificant change. Wall heat loss values in masonry kilns, in general, have lower heat losses by conduction through wall than those reported for steel shell coke fired kilns. Boynton (1967) reports kiln wall heat loss for steel shell coke fired kilns in the range of 2 to 3 percent and therefore, kiln wall losses for the masonary kilns in the range

of 1.4 to 1.8 percent appear to be quite reasonable.

6.3.8 Exhaust Gas Temperature (T_{g_o})

The effect of exhaust gas temperature (T_{g_o}) when used as an input parameter is given in set numbers 1 and 9 in Tables-6.4 to 6.6. Increase in T_{g_o} from 698 to 798 K increases the effective kiln length (L_e) by 1.31 times, fractional degree of calcination by 3.2 percent and thermal efficiency by 2.2 percent. The product lime is well burnt in all the three cases. Table-6.5 indicates that use of T_{g_o} of 798 K requires smaller preheating zone, but considerably longer cooling zone. While T_{g_o} of 690 K requires larger preheating zone, but considerably smaller cooling zone. Consequently preheating of air by cooling of the product lime for T_{g_o} of 798 K is considerably larger as compared to that for T_{g_o} of 698 K.

Table 6.6 indicates that for T_{g_o} of 798 K, eventhough sensible heat loss in kiln exhaust gas (SHLKEG) is increased by 7.1 percent, but this is well compensated by decrease in sensible heat loss in product lime (SHLPL) by 6.3 percent as compared to that for T_{g_o} of 698 K. In section 6.2.2 it has been indicated that use of T_{g_o} close to 620 K may require an infinite length of the cooling zone, because in that case the condition at the end of the preheating zone would be : $T_g = T_s = T_f = 948$ K (auto-ignition temperature for the volatile matter). Due to higher thermal efficiency and x_s,

use of T_{g_o} close to 798 K for designing a coal-fired lime shaft kiln appears to be quite appropriate.

6.4 CONDITIONS FOR OPTIMAL DESIGN AND OPERATION

In view of the discussions in the foregoing sections, it is expected that some thought be given to identify the optimal conditions for the mixed-feed lime shaft kilns having natural draft operation, eventhough the aim of the present investigation was largely to develop a uniquely stable and efficient simulation system for these kilns, a stupendous task in itself, and not to carry out rigorous optimization studies for such kilns. The parametric sensitivity analysis provides a sound basis for predicting the effect of individual variation in an input design or operating parameter on the output design and/or performance parameters. A realistic objective function for optimization may be to minimize specific energy consumption subject to two constraints, namely, wellburnt lime product and a maximum of 14 m kiln height for the natural draft operation. Occasionally, we may like to maximise productivity of an existing kiln by sacrificing, to a limited extent either specific energy consumption or lime product quality. From a kiln owner's point of view, the net profit may be the sole criterion for an optimal kiln. Thus, for rigorous optimization studies, it becomes necessary to clearly define the objective function and constraints on the system.

Since optimization was not the aim of this investigation,

no effort has been made in that direction. However, on the basis of discussions given earlier, the following design and operating conditions may be the most appropriate from the thermal efficiency point of view for a nominal lime production rate (P_n) of 10 tpd:

(i) Particle size of limestone (d_{p_s}) = 0.100 m

(ii) Ratio of particle size of fuel to size of limestone (d_{p_f}/d_{p_s}) = 0.5

(iii) Superficial lime output rate (P_s) = 3.0 t/(m^2) (day)

(iv) Limestone to fuel ratio (X_r) = 5.8

(v) Fractional content of volatile matter in fuel (X_{fv}) = as low as possible, but not exceeding 0.25

(vi) Excess air based on total combustion of fixed carbon and total volatile matter (X_{ea}) = - 10 percent

(vii) Wall thickness of masonry shaft (W_{rb}) excluding lining thickness of fire bricks = 0.46 m

(viii) Exhaust gas temperature (T_{g_o}) = 813 K

These conditions will meet the requirements of well burnt lime quality

and maximum effective kiln height restriction to 14 m and at the same time may give thermal efficiency better than 38.5 percent. Use of higher T_{g_o} is recommended for two other reasons. Firstly, it will result in a desirable product lime temperature of nearly 498 K which will facilitate its quick handling. Secondly effort can also be made to use these higher temperature kiln exhaust gases with or without combustion of the unburnt volatile matter for some other heating application.

For the above conditions, effective kiln height (L_e)to its internal diameter (D_i) ratio is nearly 6.5. This ratio is expected to vary widely for kilns with different nominal lime production rates. However, from the construction point of view, it may be desirable to have a suitable ratio of L_e/D_i . It is suggested that the design value of L_e/D_i may be kept close to 6.5 by suitably adjusting the superficial lime output rates in the range of 2.5 to 3.0 and d_{p_s} between 0.075 to 0.125 m for P_n in the range of 5 to 20 tpd subject to the maximum L_e value of 14 m.

CHAPTER-7
CONCLUSIONS AND RECOMMENDATIONS

Chapter-7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 Field surveys indicate wide variations in the design and operating practices of the mixed-feed lime shaft kilns resulting in many cases one or more of the following :

(i) Low thermal efficiencies

(ii) Poor lime quality

(iii) Low lime productivity

7.1.2 Thumb rules and/or the state-of-the-art correlations provide a reasonable but crude base for the design or operation of these kilns. However, they do not lead to the optimal design or operation of such kilns.

7.1.3 No attempt has been made so far to scientifically simulate the mixed-feed lime shaft kilns. The only reported effort relates to gas fired kilns with many unrealistic simplifying assumptions. Thus, the major contribution of the present investigation is the development

of a simulation system for the mixed-feed lime shaft kilns using realistic and, in general, rigorous description of the phenomenological behaviour. This simulation system is uniquely stable and efficient for widely varying design and operating conditions.

7.1.4 With the help of this simulation system, parametric sensitivity analysis for all the major design and operating parameters has been carried out; and the important findings are summarized in Tables-6.4 to 6.6.

7.1.5 The sensitivity analysis led to the identification of the following optimal design and/or operating conditions:

(i) Particle size of limestone (d_{p_s}) =0.100 m

(ii) Ratio of particle size of fuel to size of limestone (d_{p_f}/d_{p_s}) = 0.5

(iii) Superficial lime output rate (P_s) = 3.0 t/(m^2) (day)

(iv) Limestone to fuel ratio (X_r) =5.8

(v) Fractional content of volatile matter in fuel (X_{fv}) = as low as possible, but not exceeding 0.25

(vi) Excess air based on total combustion of fixed carbon and total volatile matter (X_{ea})

= - 10 percent

(vii) Wall thickness of masonry shaft (W_{rb}) excluding fire bricks = 0.46 m

(viii) Exhaust gas temperature (T_{g_o}) = 813 K

subject to the constraint of well burnt lime product, the maximum kiln height of 14 m for the natural draft operation and the best possible thermal efficiency.

7.1.6 It appears that the thermal efficiencies better than 40 percent are improbable to achieve in these kilns. However, the same in the range of 38 to 39 percent can be easily achieved by optimizing the design and operation of the mixed-feed lime shaft kiln for each specific application.

7.2 RECOMMENDATIONS

7.2.1 Effort should be made to experimentally measure the temperature profiles of the gas, lime-limestone particles and the fuel particles as a function of axial position in a mixed-feed lime shaft kiln.

7.2.2 Possibility of the mass transfer limitations for diffusion of the product carbon dioxide through the quick lime layer, and its effect on the validity of the heat conduction controlled lime-limestone calcination model needs to be investigated for the large sized limestone particles.

7.2.3 It is necessary to find a method to effectively use the large amount of the sensible heat and the heat of combustion of the unburnt volatile matter in the exhaust gas of the lime shaft kiln. This combined heat loss through the kiln exhaust gas varied from 41.4 to 54.6 percent with a mean value of 47.4 percent of the total heat of combustion of coal.

7.2.4 The simulation system developed in the present investigation must be subjected to a more rigorous optimization of design and operation of the lime shaft kilns. It may be extended on the suggested lines for optimization of the existing kiln of prespecified height and diameter for achieving optimal operation in terms of the lime quality, productivity and the thermal efficiency.

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C                        (APPENDIX-A)
C ***************************************************************
C                ENERGY REQUIREMENTS IN LIME BURNING
C ***************************************************************
      OPEN(UNIT=1,NAME='ELB.DAT',TYPE='OLD')
      READ(1,*)NW,N
      OPEN(UNIT=NW,NAME='ELBRES.OUT',TYPE='NEW')
      WRITE(NW,5)
      WRITE(NW,10)
    5 FORMAT(22X,'ENERGY REQUIREMENTS IN LIME BURNING'/)
   10 FORMAT(/'       X1        X2        X3        X4        X5
     1      T(K)     HPHLS     HDLSS'/)
   15 FORMAT(5F10.3,F10.1,2F10.2)
      DO20J=1,N
      READ(1,*)X1,X2,X3,X4,X5,T
      CAO=0.560*X1*XA
      OMG=0.476*X2*XA
      TQL=CAO+OMG
C     PREHEATING ENERGY PER KG OF LIMESTONE SAMPLE (HPHLS)
      ALPHA=0.1968*X1+0.1216*X2+0.1312*X3+0.2165*X4+0.1543*X5
      BETA=(0.1189*X1+0.333*X2+0.1452*X3+0.0879*X4+.1*X5)/10.**3
      GAMMA=(0.3076*X1+0.0379*X2+0.4020*X3+0.5126*X4+0.2650*X5)*10.**4
      HPHLS=ALPHA*(T-298.)+(BETA/2.)*(T**2-293.**2)-GAMMA*(1./298.-1./T)
C     HPHQL=HPHLS/TQL
C     HEAT OF DISSOCIATION PER KG OF LIMESTONE (HDLSS)
      HDCAL=425.+(6.6*(T-298.)-.02155*(T**2-298.**2))/10.**3+41.*(1./
     1 298.-1./T)
      HDMAG=343.+(131.*(T-298.)-.143*(T**2-298.**2))/10.**3-4430.*(1./
     1 298.-1./T)
      HDLSS=HDCAL*X1+HDMAG*X2
C     HDQL=HDLSS*XA/TQL
      TYPE 15,X1,X2,X3,X4,X5,T,HPHLS,HDLSS
      WRITE(NW,15)X1,X2,X3,X4,X5,T,HPHLS,HDLSS
   20 CONTINUE
      CLOSE(UNIT=1)
      CLOSE(UNIT=NW)
      STOP
      END
```

```
C                    (APPENDIX-B)
CCCCC ***************************************************************
      STATE-OF-THE-ART PROCESS ENGINEERING COMPUTATIONS FOR THE
            DESIGN OF COAL-FIRED LIME SHAFT KILNS
C     ***************************************************************
      OPEN(UNIT=1,FILE='LKD.DAT',TYPE='OLD')
      READ(1,*) NW
      OPEN(UNIT=NW,FILE='LKDRES.OUT',TYPE='NEW')
      READ(1,*) PS,TPD,DPS
      READ(1,*) XFA,XFV,XP,XS
      READ(1,*) RHOBSO,RHOBFO,RHOBL
      READ(1,*) ES,HF,ETAL,FAS
      READ(1,*) ANS,AND,ALC,THETAD
      WRITE(NW,20)
      WRITE(NW,25)
      WRITE(NW,05) NW
      WRITE(NW,10) PS,TPD,DPS
      WRITE(NW,15) XFA,XFV,XP,XU
      WRITE(NW,10) RHOBSO,RHOBFO,RHOBL
      WRITE(NW,15) ES,HF,ETAL,FAS
      WRITE(NW,15) ANS,AND,ALC,THETAD
      WRITE(NW,30)
    5 FORMAT(38X,I4)
   10 FORMAT(24X,3F12.4)
   15 FORMAT(16X,4F12.4)
   20 FORMAT(11X,'PROCESS ENGINEERING DESIGN OF COAL-FIRED
     1 LIME SHAFT KILNS'/)
   25 FORMAT(//31X,'AVERAGE INPUT DATA'/)
   30 FORMAT(//28X,23HRESULTS OF COMPUTATIONS/)
   35 FORMAT(/2X,69HLIMESTONE-TO-FUEL RATIO BY WEIGHT IN FEED
     1 INPUT AT TOP OF LIME KILN =,F6.3)
   40 FORMAT(/14X,'RETENTION TIMES (IN HOURS) FOR CONTINUOUS
     1 OPERATION :'/)
   45 FORMAT(10X,'PREHEATING',13X,'BURNING',13X,'COOLING
     1',4X,'OVERALL FOR KILN'/)
   50 FORMAT(4F20.3)
   55 FORMAT(/7X,'HEIGHTS OF THE VARIOUS ZONES (IN METERS) FOR
     1 CONTINUOUS OPERATION :'/)
   65 FORMAT(/12X,47HAVERAGE INNER DIAMETER OF THE LIME SHAFT KILN =,
     1F6.3,' M')
   70 FORMAT(5X,'PREHEATING ZONE',8X,'BURNING ZONE',8X,'COOLING
     1 ZONE',4X,'EFFECTIVE HEIGHT'/)
   75 FORMAT(/16X,38HNOMINAL DESIGN CAPACITY OF LIME KILN =,
     1F5.2,' TPD')
      AREA=TPD/PS
      RI=SQRT(AREA/3.14)
      DI=2.*RI
      XU=1.-XS
      XR=HF*ETAL/(ES*(1.-XU))
      THETAP=(686.*DPS**1.5)/(FAS*SQRT(PS))
      THETAB=6350.*DPS*(0.052*DPS+1./((20.25+180.*DPS+6.75*SQRT(
     1PS/DPS))*FAS))
      THETAC=(488.*DPS**1.5)/(FAS*SQRT(PS))
      THETAT=THETAP+THETAB+THETAC
      RHOBM=RHOBSO*RHOBFO*(1.+XR)/(RHOBSO+XR*RHOBFO)
      XRDASH=XR/(1.-XFV)
      RHOBMD=RHOBSO*RHOBFO*(1.+XRDASH)/(RHOBSO+XRDASH*RHOBFO)
      HPZ=74.3*(1.+XR)*PS*THETAP/(XP*XS*XR*RHOBM)
      HBZ=74.3*(1.+XRDASH)*PS*THETAB/(XP*XS*XRDASH*RHOBMD)
      HCZ=(41.7+74.3*XFA/(XS*XR)+74.3*(1.-XS)/XS)*PS*THETAC/
     1(XP*RHOBL)
      HOVRAL=HPZ+HBZ+HCZ
      WRITE(NW,75) TPD
      WRITE(NW,35) XR
      WRITE(NW,65) DI
      WRITE(NW,40)
      WRITE(NW,45)
      WRITE(NW,50) THETAP,THETAB,THETAC,THETAT
      WRITE(NW,55)
      WRITE(NW,70)
      WRITE(NW,50) HPZ,HBZ,HCZ,HOVRAL
      CLOSE(UNIT=1)
      CLOSE(UNIT=NW)
      STOP
      END
```

```
C                    (APPENDIX-C)
C ***************************************************************
C                    SIMULATION OF LIME SHAFT KILN :
C     PROGRAMME FOR PREHEATING AND DEVOLATILIZATION ZONES FOR ANALYSIS
C                    STARTING FROM TOP OF THE KILN
C ***************************************************************
      DIMENSION TG(400),TF(400),TS(400)
      DIMENSION TGGG(400),TFFF(400),TSSS(400)
      DIMENSION MG(400),MF(400),XR(400),XF(400)
      DIMENSION TITLE(80),STITLE(80),DATAIN(80),RESTAB(80)
      REAL KG,MUG,MG,MF,MSF
      OPEN(UNIT=1,FILE='PDV.DAT',TYPE='OLD')
      READ(1,15) TITLE
      READ(1,15) STITLE
      READ(1,15) DATAIN
      READ(1,15) RESTAB
      READ(1,*) NP,NW,NPRINT
      OPEN(UNIT=NW,FILE='PDVRES.OUT',TYPE='NEW')
      OPEN(UNIT=NP,FILE='PDVPLT.OUT',TYPE='NEW')
C ***************************************************************
C     THE FORTRAN VARIABLES USED IN THE FOLLOWING INPUT STATEMENTS
C     ARE DEFINED SUBSEQUENT TO EACH STATEMENT GENERALLY IN ORDER
C     OF THEIR APPEARANCE
C ***************************************************************
      READ(1,*) TG(1),TF(1),TS(1)
C                (BULK GAS TEMPERATURE,FUEL TEMPERAITURE AND STONE
C                SURFACE TEMPERATURE)
      READ(1,*) PS,XRINFD,TPD
C                (SUPERFICIAL PRODUCT OUTPUT RATE BASED ON EMPTY KILN
C                CROSS-SECTION,LIMESTONE-TO-FUEL-RATIO IN FEED MIX,
C                NOMINAL PRODUCTION RATE OF LIME SHAFT KILN)
      READ(1,*) DPS,DPF,PHIS,PHIF,EBED,DZ
C                (PARTICLE SIZE OF LIMESTONE,PARTICLE SIZE OF FUEL,
C                SPHERICITY OF STONE PARTICLE,SPHERICITY OF FUEL
C                PARTICLE,BED POROSITY,AXIAL WIDTH OF DIFFERENTIAL
C                ELEMENT)
      READ(1,*) XFM,XFV,XFC,XFA,XEA
C                (FRACTIONAL MOISTURE CONTENT,VOLATILE MATTER,FIXED
C                CARBON,ASH CONTENT AND FRACTIONAL EXESS AIR)
      READ(1,*) RHOFO,RHOSO,CFO,HLTWTR,HLTDVM
C                (DENSITY OF FUEL,STONE PARTICLES,SPECIFIC HEAT OF
C                FUEL,HEAT OF DESORPTION-CUM-DEMOISTURIZATION FROM
C                FUEL,LATENT HEAT OF DEVOLATILIZATION)
      READ(1,*) ETASG,ETAFG,ETAFS,ETAFSC,ETAGW
C                (EFFECTIVENESS FACTORS FOR HEAT EXCHANGE FROM STONE
C                TO GAS,FUEL TO GAS,FUEL TO STONE,ETC.)
      READ(1,*) ALPHA,GAMMA,UNTDMZ,UNTDVZ
C                (CONSTANTS TO ACCOUNT FOR GAS EMISSIVITIES,DEMOISTUR-
C                IZATION AND DEVOLATILIZATION PROCESSES)
      READ(1,*) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,TAMB,TWOPDV
C                (THERMAL CONDUCTIVITY OF FIRE BRICKS,RED BURNT CLAY
C                BRICKS,THICKNESS OF FIRE BRICKS INSULATION,BURNT
C                CLAY BRICKS,EMISSIVITY OF RED BRICKS SURFACE,AMBIENT
C                TEMPERATURE AND EXTERNAL WALL TEMPERATURE)
      READ(1,*) KG,MUG,TKS,RGAS,SIGMAR,EMSVTY,VIEWFO
C                GAS THERMAL CONDUCTIVITY,VISCOSITY,THERMAL CONDUCTI-
C                VITY OF STONE,GAS CONSTANT,RADIATION CONSTANT,EMISS-
C                IVITY OF COAL,VIEW FACTOR)
      READ(1,*) TPHZ,TPHDVZ,TPHCVM,TOLER1,TOLER2
C                (TEMPERATURES FOR ONSET OF DEVOLATILIZATION PROCESS,
C                COMBUSTION OF VOLATILE MATTER,COMPLETION OF VM EVOLU-
C                TION AND TOLERANCES)
      READ(1,*) IMAX,ITMAX,IRANDM,MINLMT,MAXLMT
C                (CONSTANTS,MAXIMUM/MINIMUM VALUES)
      WRITE(NW,85) TITLE
      WRITE(NW,85) STITLE
      WRITE(NW,90) DATAIN
      WRITE(NW,25) NP,NW,NPRINT
      WRITE(NW,30) TG(1),TF(1),TS(1)
      WRITE(NW,30) PS,XRINFD,TPD
      WRITE(NW,50) DPS,DPF,PHIS,PHIF,EBED,DZ
      WRITE(NW,45) XFM,XFV,XFC,XFA,XEA
      WRITE(NW,45) RHOFO,RHOSO,CFO,HLTWTR,HLTDVM
      WRITE(NW,45) ETASG,ETAFG,ETAFS,ETAFSC,ETAGW
      WRITE(NW,10) ALPHA,GAMMA,UNTDMZ,UNTDVZ
      WRITE(NW,40) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,TAMB,TWOPDV
      WRITE(NW,35) KG,MUG,TKS,RGAS,SIGMAR,EMSVTY,VIEWFO
      WRITE(NW,45) TPHZ,TPHDVZ,TPHCVM,TOLER1,TOLER2
      WRITE(NW,55) IMAX,ITMAX,IRANDM,MINLMT,MAXLMT
```

```
   10    FORMAT(16X,4F12.4)
   15    FORMAT(80A1)
   20    FORMAT(//30X,19HRESULTS OF ANALYSIS/)
   25    FORMAT(25X,3I10)
   30    FORMAT(22X,3F12.4)
   35    FORMAT(2X,4F10.4,E12.4,2F12.4)
   40    FORMAT(1X,7F11.4)
   45    FORMAT(10X,5F12.4)
   50    FORMAT(4X,6F12.4)
   55    FORMAT(10X,5I12)
   60    FORMAT(3X,I4,10F12.4)
   65    FORMAT(/5X,28HVM COMBUSTION STARTS AT XF =,F7.4,27H AND
        1 AT HEIGHT (FROM TOP) =,F6.3,' M')
   70    FORMAT(/10X,52HHEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION
        1 ZONE =,F6.3,' M')
   75    FORMAT(1X,I4,F8.3,F9.5,3F8.2,6F8.2,4F9.1)
   80    FORMAT(2F16.4,3F16.2)
   85    FORMAT(80A1)
   90    FORMAT(//80A1/)
   95    FORMAT(F16.3,F16.4,3F16.2)
  105    FORMAT(/2X,41HENTHALPIES OF GAS,STONE AND FUEL AT TOP =,
        1F8.1,',',F8.1,' &',F8.1,' KCAL/HR')
  110    FORMAT(/1X,44HENTHALPIES OF GAS,STONE AND FUEL AT BOTTOM
        1 =,F8.1,',',F8.1,' &',F8.1,' KCAL/HR')
  115    FORMAT(F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,','
        1,F5.3)
  120    FORMAT(F6.4,',',F6.4,',',F7.2,',',F7.2,',',F7.2)
  125    FORMAT(1X,I4)
  130    FORMAT(//4X,'I',4X,'Z(M)',7X,'XF',3X,'TG(I)',3X,'TF(I)',3X,'TS(
        1I)',3X,'TW(K)',5X,'HFS',5X,'HFG',5X,'HSG',4X,'ASPZ',4X,'AFPZ'
        2,6X,'QFS',6X,'QFG',6X,'QSG',3X,'DELHTL'/)
  135    FORMAT(/9X,46HHEAT LOSS THROUGH WALL OF PREHEATING SECTION =,
        1F8.1,' KCAL/HR')
  140    FORMAT(/15X,33HTOTAL HEAT FOR DEMOISTURIZATION =,F9.1,' KCAL/
        1HR')
         AREA=TPD/PS
         RI=SQRT(AREA/3.14)
         DI=2.*RI
         WS=PS*AREA*1000.*100./(24.*56.)
         WF=WS/XRINFD
C   ******************************************************************
C        THEORETICAL AIR REQUIREMENT AND HEAT OF COMBUSTION OF VM
C   ******************************************************************
         THO2VM=(77.77/20.)*XFV
         THO2FC=(32./12.)*XFC
         TOTLO2=THO2VM+THO2FC
         TOTLN2=TOTLO2/0.305
         THAIR=TOTLO2+TOTLN2
         WA=WF*THAIR*(1.+XEA)
         VMFDAF=XFV/(XFV+XFC)
         FCFDAF=XFC/(XFV+XFC)
         HFNDAF=8150.+6543.*VMFDAF-17308.*(VMFDAF**2)
         CVFNET=HFNDAF*(XFV+XFC)
         HFVM=(HFNDAF-8200.*FCFDAF)/VMFDAF
C   ******************************************************************
         WRITE(NW,50) DI,WS,WF,WA,CVFNET,HFVM
         WRITE(NP,115) PS,DPS,DPF,XRINFD,XFV,XFC,XEA
         WRITE(NW,20)
C        WRITE(NW,90) RESTAB
         WRITE(NW,130)
         XFMIN=0.0
         XFMAX=XFM+XFV
         RPF=DPF/2.0
         RPS=DPS/2.0
         TKFMIN=0.15
         TKFMAX=1.25
         CFCMAX=0.40
         CFAMAX=0.75*CFCMAX
         CFMAX=(CFCMAX*XFC+CFAMAX*XFA)/(XFC+XFA)
         AREA=3.14*RI**2
         RHOS=RHOSO
         VIEWF=VIEWFO
         XSTONE=WS/(WS+WF)
         XFUEL=WF/(WS+WF)
         DPSAVG=1./(XSTONE/DPS+XFUEL/DPF)
         VFSRAT=RHOSO/(RHOFO*XRINFD)
         ALFA=1.-((DPF/DPS)**3)/VFSRAT
         ASPZ=6.*(1.-EBED)/(PHIS*DPSAVG*(1.+ALFA*VFSRAT))
         AFPZ=6.*(1.-EBED)*VFSRAT/(PHIF*DPSAVG*(1.+ALFA*VFSRAT))
         RFB=RI+FBTHIK
```

```
      RO=RFB+RBTHIK
      DO=2.*RO
      CSTKLN=(ALOG(RFB/RI)/FBCDTY)+(ALOG(RO/RFB)/RBCDTY)
      BETA=XFM+XFV*(TPHDVZ-TPHZ)/(TPHCVM-TPHZ)
      I=1
      XF(1)=0.0
      WG(1)=WA+WF*(1.-XFA)+WS*0.44
      MF(1)=WF*(1.0-XF(1))
      XR(1)=WS/MF(1)
      MSF=WS+MF(1)
      WGN2T=WA*0.768
      WGO2T=WA*.232-WF*((XFC*32./12.)-(XFMAX-BETA)*(77.77/20.))
      WGCO2T=WS*0.44+WF*XFC*(44./12.)+WF*(XFMAX-BETA)*(56.58/20.)
      WGH2OT=WF*(XFM+(XFMAX-BETA)*(41.15/20.))
      WGVMT=WF*(BETA-XFM)
      WGTTLT=WGN2T+WGO2T+WGCO2T+WGH2OT+WGVMT
      TWO=TWOPDV
    2 TGAVG=TG(I)
      TFAVG=TF(I)
      TSAVG=TS(I)
      TSOLD=TSAVG
      TFOLD=TFAVG
      TGOLD=TGAVG
      XFAVG=XF(I)
      WGAVG=MG(I)
      WFAVG=MF(I)
      WSAVG=WS
      WAVGTL=WGAVG+WFAVG+WSAVG
      XWG=WGAVG/WAVGTL
      XWF=WFAVG/WAVGTL
      XWS=WSAVG/WAVGTL
      TBORRG=TGAVG*XWG+TFAVG*XWF+TSAVG*XWS
C     ***************************************************************
C     SPECIFIC HEATS OF VARIOUS CONSTITUENTS
C     ***************************************************************
      CPO2=0.2584+(0.3063*TGAVG*10.**-5)-5865.6/(TGAVG**2)
      CPCO2=0.1441+(.2305*TGAVG*10.**-3)-(.0776*10.**-6)/(TGAVG**2)
      CPCO2F=0.1441+(.2305*TFAVG*10.**-3)-(.0776*10.**-6)/(TFAVG**2)
      CPAIR=0.2372+(0.2900*TGAVG*10.**-4)-1360./(TGAVG**2)
      CPWTRG=.4567+(.8333*TGAVG*10.**-5)+(.7444*TGAVG*TGAVG*10.**-7)
      CPWTRF=.4567+(.8333*TFAVG*10.**-5)+(.7444*TFAVG*TFAVG*10.**-7)
      CPVMG=0.2138+(.6194*TGAVG*10.**-3)+(.0800*TGAVG*TGAVG*10.**-6)
      CPVMF=0.2138+(.6194*TFAVG*10.**-3)+(.0800*TFAVG*TFAVG*10.**-6)
      CS=0.1968+(0.1189*TSAVG*10.**-3)-(0.3076*10.**4)/(TSAVG**2)
      CF=CFO+(XFAVG/XFMAX)*(CFMAX-CFO)
C     ***************************************************************
      DPAVG=(DPS*WSAVG+DPF*WFAVG)/(WSAVG+WFAVG)
      XRAVG=WSAVG/WFAVG
      TGI=TGAVG
      TKF=((TKFMAX-TKFMIN)*XFAVG+(TKFMIN*XFMAX-TKFMAX*XFMIN))/
     1(XFMAX-XFMIN)
      EFFKS=TKS*TKF/(TKS+TKF)
      WGN2Z=WGN2T
      IF(XFAVG.LE.BETA) WGO2Z=WGO2T
      IF(XFAVG.GT.BETA) WGO2Z=WGO2T+WF*(XFAVG-BETA)*(77.77/20.)
      IF(XFAVG.LE.BETA) WGCO2Z=WGCO2T
      IF(XFAVG.GT.BETA) WGCO2Z=WGCO2T-WF*(XFAVG-BETA)*(56.58/20.)
      IF(XFAVG.EQ.XFMIN) WGH2OZ=WGH2OT
      IF(XFAVG.GT.XFMIN.AND.XFAVG.LE.XFM) WGH2OZ=WGH2OT-
     1WF*(XFAVG-XFMIN)
      IF(XFAVG.GE.XFM.AND.XFAVG.LE.BETA)WGH2OZ=WGH2OT-WF*(XFM-XFMIN)
      IF(XFAVG.GT.BETA) WGH2OZ=WGH2OT-WF*(XFM-XFMIN)-WF*
     1(XFAVG-BETA)*(41.15/20.)
      IF(XFAVG.LE.BETA) WGVMZ=WGVMT
      IF(XFAVG.GT.BETA) WGVMZ=0.0
      WGAIRZ=WGN2Z+WGO2Z
      WGTTLZ=WGAIRZ+WGCO2Z+WGH2OZ+WGVMZ
      XGAIRZ=WGAIRZ/WGTTLZ
      XGCO2Z=WGCO2Z/WGTTLZ
      XGH2OZ=WGH2OZ/WGTTLZ
      XGVMZ=WGVMZ/WGTTLZ
      CG=CPAIR*XGAIRZ+CPCO2*XGCO2Z+CPWTRG*XGH2OZ+CPVMG*XGVMZ
      IF(I.GT.1) GO TO 23
      CGTOP=CG
   23 RHOF=RHOFC*(1.-XFAVG)
      ASSPZ=ETASG
      ASFPZ=ETAFG
      ASFRPZ=ETAFS
      G=WGAVG/AREA
      CORFAC=1.-(ALPHA*(XFAVG-XFMIN)/(BETA-XFMIN))
```

```
      IF(TF(I).LT.TPHDVZ) GO TO 16
      IF(BETACV.GT.C.) GO TO 13
      BETACV=XF(I)
      HEIGHT=(FLOAT(I)-1.)*DZ
   13 CONTINUE
      ASSPZ=ETASG
      ASFPZ=ETAFG
      ASFRPZ=ETAFSC
      KG=0.044C
      MUG=0.1296
      CORFAC=(1.-ALPHA)-((GAMMA-ALPHA)*(XFAVG-BETACV)/(1.-XFA-BETACV))
C*****************************************************************
C     HEAT TRANSFER COEFFICIENTS
C*****************************************************************
   16 HCHRFS=HFS(EFFKS,DPS,DPF,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
      HCHRSG=HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
      HCHRFG=HFG(EBED,DPF,KG,MUG,CG,G,CORFAC)
C*****************************************************************
      IF(I.EQ.1) GO TO 36
      QFS=HCHRFS*(TFAVG-TSAVG)*AFPZ*ASFRPZ*AREA*DZ
      QFG=HCHRFG*(TFAVG-TGAVG)*AFPZ*ASFPZ*AREA*DZ
      QSG=HCHRSG*(TSAVG-TGAVG)*ASPZ*ASSPZ*AREA*DZ
      GO TO 37
   36 ENGASI=MG(I)*CG*(TG(I)-273.0)
      ENSTNI=WS*CS*(TS(I)-273.0)
      ENFULI=MF(I)*CF*(TF(I)-273.0)
   37 Z=(FLOAT(I)-1.)*DZ
      Y=(I/NPRINT)-FLOAT(I)/FLOAT(NPRINT)
      IF(Y.NE.C) GO TO 3
C     WRITE(NW,55)Z,XF(I),TG(I),TF(I),TS(I)
      TYPE 95,Z,XF(I),TG(I),TF(I),TS(I)
      WRITE(NP,120)Z,XF(I),TG(I),TF(I),TS(I)
      WRITE(NW,75)I,Z,XF(I),TG(I),TF(I),TS(I),TWO,
     1HCHRFS,HCHRFG,HCHRSG,ASPZ,AFPZ,QFS,QFG,QSG,DELHTL
    3 IF((TS(I).LT.TS(I-1)).OR.(XF(I).LT.XF(I-1))) GO TO 21
      IF(TF(I).GE.TPHCVM.AND.HVM.EQ.C.) GO TO 21
      IF(XF(I).GE.XFMAX.AND.HVM.GT.C.) GO TO 21
      IF(XF(I).GE.XFMAX.AND.TF(I).GE.TPHCVM) GO TO 21
      IF(TS(I).GE.TPHCVM) GO TO 21
      IF(TF(I).GE.TPHDVZ) GO TO 21
      I=I+1
      IF(I.GT.IMAX) GO TO 21
      ITER=1
      IF(TF(I-1).GT.TPHZ.AND.TF(I-1).LT.TPHDVZ) GO TO 33
      TGGG(ITER)=TG(I-1)
      TFFF(ITER)=TF(I-1)
      TSSS(ITER)=TS(I-1)
      GO TO 34
   33 IF(XF(I-4).LE.XFMIN) GO TO 28
      XFASNM=(2.*XF(I-1)-3.*XF(I-2)+XF(I-3))*(XF(I-1)-XF(I-2))
      XFASDN=2.*XF(I-2)-3.*XF(I-3)+XF(I-4)
      IF(XFASDN.EQ.C.) GO TO 28
      XF(I)=XF(I-1)+XFASNM/XFASDN
      GO TO 29
   28 XF(I)=3.*XF(I-1)-3.*XF(I-2)+XF(I-3)
   29 TG(I)=3.*TG(I-1)-3.*TG(I-2)+TG(I-3)
      TF(I)=3.*TF(I-1)-3.*TF(I-2)+TF(I-3)
      TS(I)=3.*TS(I-1)-3.*TS(I-2)+TS(I-3)
      DELTG=TG(I)-TG(I-1)
      DELTF=TF(I)-TF(I-1)
      DELTS=TS(I)-TS(I-1)
      DLTGIP=DELTG
      DLTFIP=DELTF
      DLTSIP=DELTS
      TGIP=TG(I)
      TFIP=TF(I)
      TSIP=TS(I)
      TGGG(ITER)=TGIP
      TFFF(ITER)=TFIP
      TSSS(ITER)=TSIP
C*****************************************************************
C     ESTIMATION OF WALL HEAT LOSSES
C*****************************************************************
   34 DELTWO=TWOPDV-TAMB
      AHWA=HWA(DZ,REEMSY,SIGMAR,TWOPDV,TAMB,DELTWO)
      AHGW=HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
      IF(AHWA.EQ.C.) GO TO 9
      UIEFFI=RI*(1./(RI*AHGW)+CSTKLN+1./(RO*AHWA))
      UIEFF=1./UIEFFI
      DELHL=UIEFF*2.*3.14*RI*DZ*(TGI-TAMB)
```

```
      DELHTL=DELHTL+DELHL
      TWI=TGI-DELHL/(3.14*DI*DZ*AHGW)
      TWO=TAMB+DELHL/(3.14*DO*DZ*AHWA)
      TWOPDV=TWO
C     ****************************************************************
    9 IF(TF(I-1)-373.0) 1,1,4
    1 XF(I)=XF(I-1)
      DELXF=0.0
      XFAVG=XF(I)
      HVM=0.0
      GO TO 7
    4 IF(TF(I-1)-TPHZ) 5,5,6
C     ****************************************************************
C     DEGREE OF DEMOISTURIZATION OF FUEL
C     ****************************************************************
    5 DELXF=(0.99999*XFM-XFMIN)/UNTDMZ
      XF(I)=XF(I-1)+DELXF
      IF(XF(I).GE.(0.99999*XFM)) XF(I)=0.99999*XFM
      DELXF=XF(I)-XF(I-1)
      XFAVG=(XF(I-1)+XF(I))/2.0
      HVM=0.0
      GO TO 7
    6 IF(XF(I-1).EQ.BETACV) GO TO 11
      IF(XF(I-1).EQ.XFMAX) GO TO 21
      IF(BETACV.GT.0.) GO TO 11
      IF(TF(I-1)-TPHDVZ) 8,8,11
C     ****************************************************************
C     DEGREE OF DEVOLATILIZATION WITHOUT COMBUSTION OF VM
C     ****************************************************************
    8 DELXF=(XFV/(TPHCVM-TPHZ))*DELTF
      XF(I)=XF(I-1)+DELXF
      IF(XF(I).GE.(0.999*XFMAX)) XF(I)=XFMAX
      XFAVG=(XF(I-1)+XF(I))/2.0
      HVM=0.0
      GO TO 7
C     ****************************************************************
C     PROVISION FOR COMPUTATION OF DEGREE OF DEVOLATILIZATION WITH
C     COMBUSTION OF VM
C     ****************************************************************
   11 DELXF=(XFMAX-BETACV)/UNTDVZ
      IF(XFV.EQ.0.) DELXF=0.0
      XF(I)=XF(I-1)+DELXF
      IF(XF(I).GE.(0.999*XFMAX)) XF(I)=XFMAX
      XFAVG=(XF(I-1)+XF(I))/2.0
      HVM=HFVM
      IF(XFV.EQ.0.) HVM=0.0
    7 DELMF=-WF*DELXF
      MF(I)=MF(I-1)+DELMF
      DELMG=-WF*DELXF
      MG(I)=MG(I-1)+DELMG
      WFAVG=(MF(I-1)+MF(I))/2.0
      MSF=WS+WFAVG
      WGAVG=(MG(I-1)+MG(I))/2.0
      XR(I)=WS/MF(I)
C     ****************************************************************
C     HEAT BALANCE FOR LIMESTONES
C     ****************************************************************
      ALSB1=HCHRFS*(TFAVG-TSAVG)*AFPZ*ASFRPZ*AREA*DZ
      ALSB2=HCHRSG*(TSAVG-TGAVG)*ASPZ*ASSPZ*AREA*DZ
      ALSBT=ALSB1-ALSB2
      DELTS=ALSBT/(WS*CS)
      IF(TF(I-1).GT.TPHZ.AND.TF(I-1).LT.TPHDVZ) DELTS=
     1(DELTS+DLTSIP)/2.0
      TS(I)=TS(I-1)+DELTS
      TSAVG=(TS(I-1)+TS(I))/2.0
C     ****************************************************************
C     GAS PHASE HEAT BALANCE
C     ****************************************************************
      ALGB1=HCHRFG*(TFAVG-TGAVG)*AFPZ*ASFPZ*AREA*DZ
      ALGB2=HCHRSG*(TSAVG-TGAVG)*ASPZ*ASSPZ*AREA*DZ
      IF(TF(I-1).LT.373.0) ALGB3=0.0
      IF(TF(I-1).GT.373.0.AND.XF(I-1).LT.XFM) ALGB3=
     1WF*DELXF*CPWTRF*(TFAVG-273.0)
      IF(XF(I-1).GE.(.99999*XFM).AND.TF(I-1).LT.TPHZ) ALGB3=0.0
      IF(TF(I-1).GT.TPHZ.AND.HVM.EQ.0.) ALGB3=
     1WF*DELXF*CPVMF*(TFAVG-273.0)
      IF(HVM.EQ.0.) GO TO 24
      ALGB3=0.0
      ALGB4=-WF*DELXF*(77.77/20.)*CPO2*(TGAVG-273.0)
      ALGB5=WF*DELXF*(56.58/20.)*CPCO2F*(TFAVG-273.0)
```

```
      ALGB6=WF*DELXF*(41.15/20.)*CPWTRF*(TFAVG-273.0)
   24 ALGBT=ALGB1+ALGB2+ALGB3+ALGB4+ALGB5+ALGB6
      ALGBT=ALGBT-DELHL
      ALGBN=ALGBT+CG*(TGAVG-273.0)*DELMG
      DELTG=-ALGBN/(CG*WGAVG)
      IF(TF(I-1).GT.TPHZ.AND.TF(I-1).LT.TPHDVZ) DELTG=
     1(DELTG+DLTGIP)/2.0
      TG(I)=TG(I-1)+DELTG
      TGAVG=(TG(I-1)+TG(I))/2.0
C     ******************************************************************
   27 IF(TF(I-1).LT.373.0)ALFBT=0.0
      IF(TF(I-1).GT.373.0.AND.XF(I-1).LT.XFM)ALFBT=-WF*DELXF*HLTWTR
      IF(XF(I-1).GE.(.99999*XFM).AND.TF(I-1).LE.TPHZ) ALFBT=0.0
      IF(TF(I-1).GT.TPHZ.AND.TF(I-1).LT.TPHDVZ)ALFBT=-WF*DELXF*HLTDVM
      IF(TF(I-1).GT.TPHDVZ.AND.HVM.GT.0.)ALFBT=WF*HVM*DELXF+
     1WF*DELXF*(77.77/20.)*CPC2*(TGAVG-273.0)-WF*DELXF*HLTDVM
C     ******************************************************************
C
C     HEAT BALANCE FOR FUEL
C     ******************************************************************
      ARFB1=HCHRFS*(TFAVG-TSAVG)*AFPZ*ASFRPZ*AREA*DZ
      ARFB2=HCHRFG*(TFAVG-TGAVG)*AFPZ*ASFPZ*AREA*DZ
      ARFB3=-WF*CF*(TFAVG-273.0)*DELXF
      IF(TF(I-1).LT.373.0) ARFB4=0.0
      IF(TF(I-1).GT.373.0.AND.XF(I-1).LT.XFM) ARFB4=
     1WF*DELXF*CPWTRF*(TFAVG-273.)
      IF(XF(I-1).LE.XFM.AND.TF(I-1).LT.TPHZ) ARFB4=0.0
      IF(TF(I-1).GT.TPHZ.AND.HVM.EQ.0.) ARFB4=
     1WF*DELXF*CPVMF*(TFAVG-273.)
      IF(HVM.EQ.0.) GO TO 12
      ARFB4=0.0
      ARFB5=WF*DELXF*(56.58/20.)*CPCO2F*(TFAVG-273.)
      ARFB6=WF*DELXF*(41.15/20.)*CPWTRF*(TFAVG-273.)
   12 ARFBT=ARFB1+ARFB2+ARFB3+ARFB4+ARFB5+ARFB6
      ALFBN=ALFBT-ARFBT
      DELTF=ALFBN/(WF*CF*(1.0-XFAVG))
      IF(TF(I-1).LT.TPHZ.OR.TF(I-1).GT.TPHDVZ) GO TO 26
      IF(DELTF.GT.0.0.AND.DELXF.GT.0.) GO TO 26
      DELXF=0.999*DELXF
      XF(I)=XF(I-1)+DELXF
      XFAVG=(XF(I)+XF(I-1))/2.0
      DELTF=DELXF/(XFV/(TPHCVM-TPHZ))
      TF(I)=TF(I-1)+DELTF
      TFAVG=(TF(I-1)+TF(I))/2.0
      GO TO 27
C     ******************************************************************
   26 IF(TF(I-1).GT.TPHZ.AND.TF(I-1).LT.TPHDVZ) DELTF=
     1(DELTF+DLTFIP)/2.0
      TF(I)=TF(I-1)+DELTF
      TFAVG=(TF(I-1)+TF(I))/2.0
      THRCFL=WF*HVM*DELXF
      HCHLS=WS*CS*(TS(I)-TS(I-1))
      HCHEFL=WF*CF*((TF(I)-273.)*(1.-XF(I))-
     1(TF(I-1)-273.)*(1.-XF(I-1)))
      HCHGAS=-CG*(MG(I)*(TG(I)-273.)-MG(I-1)*(TG(I-1)-273.))
      THCSFG=HCHLS+HCHEFL+HCHGAS
      IF(I.LE.IRANDM) GO TO 17
      IF(ITER.GT.MINLMT.AND.ITER.LT.MAXLMT) GO TO 17
      WRITE(NW,60)ITER,DELXF,DELTG,DELTF,DELTS,DELMF,DELMG,UIEFF,
     1G,CG,CORFAC
C     ******************************************************************
C
C     CONVERGENCE CRITERIA ON AVERAGED VALUES OF TEMPERATURES
C     ******************************************************************
   17 IF(TGAVG.EQ.TG(I-1)) GO TO 14
      TGG=ABS((TGAVG-TGOLD)/(TGAVG-TG(I-1)))
   14 IF(TSAVG.EQ.TS(I-1)) GO TO 19
      TSS=ABS((TSAVG-TSOLD)/(TSAVG-TS(I-1)))
   19 IF(TFAVG.EQ.TF(I-1)) GO TO 22
      TFF=ABS((TFAVG-TFOLD)/(TFAVG-TF(I-1)))
   22 IF(TSS.GT.TOLER1)GO TO 18
      IF(TGG.GT.TOLER1)GO TO 18
C     ******************************************************************
      IF(TFF.GT.TOLER2)GO TO 18
      IF(TS(I).GE.(0.999*TPHCVM)) TS(I)=TPHCVM
      ENGASO=MG(I)*CG*(TG(I)-273.0)
      ENSTNO=WS*CS*(TS(I)-273.0)
      ENFULO=MF(I)*CF*(TF(I)-273.0)
      GO TO 2
   18 TFOLD=TFAVG
      TSOLD=TSAVG
      TGOLD=TGAVG
```

```
      ITER=ITER+1
      IF(ITER.GT.ITMAX) GO TO 21
      TGGG(ITER)=TG(I)
      TFFF(ITER)=TF(I)
      TSSS(ITER)=TS(I)
      DELTG=((TGGG(ITER)+TGGG(ITER-1))/2.0)-TG(I-1)
      DELTF=((TFFF(ITER)+TFFF(ITER-1))/2.0)-TF(I-1)
      DELTS=((TSSS(ITER)+TSSS(ITER-1))/2.0)-TS(I-1)
      TG(I)=TG(I-1)+DELTG
      TF(I)=TF(I-1)+DELTF
      TS(I)=TS(I-1)+DELTS
      TGAVG=(TG(I)+TG(I-1))/2.0
      TFAVG=(TF(I)+TF(I-1))/2.0
      TSAVG=(TS(I)+TS(I-1))/2.0
      HCHRFS=HFS(EFFKS,DPS,DPF,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
      HCHRSG=HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
      HCHRFG=HFG(EBED,DPF,KG,MUG,CG,G,CORFAC)
      TGOLD=TGAVG
      TFOLD=TFAVG
      TSOLD=TSAVG
      IF(TF(I).GT.373.0.AND.XF(I).LT.XFM) GO TO 7
      IF(HVM.EQ.0.) GO TO 9
      GO TO 7
   21 IF(I.GT.IMAX) I=I-1
      THDMZN=WF*XFM*HLTWTR
      WRITE(NW,65) BETACV,HEIGHT
      WRITE(NW,70) Z
      WRITE(NW,105) ENGASI,ENSTNI,ENFULI
      WRITE(NW,110) ENGASO,ENSTNO,ENFULO
      WRITE(NW,135) DELHTL
      WRITE(NW,140) THDMZN
      WRITE(NP,125) I
      CLOSE(UNIT=1)
      CLOSE(UNIT=NP)
      CLOSE(UNIT=NW)
      STOP
      END

C     ****************************************************************
C           END OF MAIN PROGRAM
C     ****************************************************************

C     ****************************************************************
C           FUNCTION SUBPROGRAMS ARE LISTED AS FOLLOWS
C     ****************************************************************

      FUNCTION HFS(EFFKS,DPS,DPF,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
      HCFS=2.0*EFFKS/(DPS+DPF)
      HRFS=EMSVTY*SIGMAR*VIEWF*(TFAVG**2+TSAVG**2)*(TFAVG+TSAVG)
      HFS=HCFS+HRFS
      RETURN
      END

C     ****************************************************************

      FUNCTION HFG(EBED,DPF,KG,MUG,CG,G,CORFAC)
      REAL KG,MUG
      RE=DPF*G/MUG
      PR=CG*MUG/KG
      HCFG=(1.9*KG/DPF)*(RE**0.5)*(PR**0.33)
      HRFG=4.5+1.33*DPF*EBED
      HRFG=HRFG*CORFAC
      HFG=HCFG+HRFG
      RETURN
      END

C     ****************************************************************

      FUNCTION HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
      REAL KG,MUG
      RE=DPS*G/MUG
      PR=CG*MUG/KG
      HCSG=(1.9*KG/DPS)*(RE**0.5)*(PR**0.33)
      HRSG=4.5+1.33*DPS*EBED
      HRSG=HRSG*CORFAC
      HSG=HCSG+HRSG
      RETURN
      END

C     ****************************************************************
```

```
      FUNCTION HWA(DZ,RBEMSY,SIGMAR,TWOPDV,TAMB,DELTWO)
      HCWA=1.22*(DELTWC/DZ)**(1./4.)
      HRWA=RBEMSY*SIGMAR*(TWOPDV**2+TAMB**2)*(TWOPDV+TAMB)*0.0
      HWA=HCWA+HRWA
      RETURN
      END

C     ***************************************************************************

      FUNCTION HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
      REAL KG,MUG
      DPDTR=DPAVG/DI
      RE=DPAVG*G/MUG
      HCGW1=3.50*(KG/DI)*EXP(-4.6*DPDTR)*RE**0.7
      HCGW2=0.813*(KG/DI)*EXP(-6.0*DPDTR)*RE**0.9
      HCGW=(HCGW1+HCGW2)/2.0
      HRGW=4.5+1.33*DPAVG*EBED
      HRGW=HRGW*CORFAC
      HGW=(HCGW+HRGW)*ETAGW
      RETURN
      END

C     ***************************************************************************
C           END OF FUNCTION SUBPROGRAMS
C     ***************************************************************************
```

```
C                    (APPENDIX-D)
C     ****************************************************************
C              SIMULATION OF LIME SHAFT KILN :
C      PROGRAM FOR THE ANALYSIS OF THE BURNING ZONE FROM UPPER SIDE
C     ****************************************************************
      DIMENSION TG(200),TF(200),TS(200)
      DIMENSION MF(200),MS(200),MG(200)
      DIMENSION TGDEL(125),TFDEL(125),TSDEL(125)
      DIMENSION POG(200),DF(200),Z(200),DATAIN(80)
      DIMENSION XA(200),XC(200),XF(200),XS(200),XR(200)
      DIMENSION XADEL(125),XCDEL(125),XFDEL(125),XSDEL(125)
      REAL KS,KD,KG,MUG,MG,MF,MS,MSF,N2MZ
      OPEN(UNIT=1,FILE='BNG.DAT',TYPE='OLD')
      READ(1,195) DATAIN
      READ(1,*) NP,NW,NPRINT
      OPEN(UNIT=NW,FILE='BNGRES.OUT',TYPE='NEW')
      OPEN(UNIT=NP,FILE='BNGPLT.OUT',TYPE='NEW')
C     ****************************************************************
C     FORTRAN VARIABLES USED IN THE INPUT STATEMENTS ARE DEFINED
C     AFTER EACH STATEMENT GENERALLY IN ORDER OF THEIR APPEARANCE
C     ****************************************************************
      READ(1,*) XF(1),XS(1),TG(1),TF(1),TS(1)
C              (DEGREES OF COMBUSTION OF FUEL,CALCINATION OF LIMEST-
C              ONE,TEMPERATURES OF BULK GAS,FUEL AND STONE SURFACE)
      READ(1,*) PS,XRINFD,TPD
C              (SUPERFICIAL PRODUCT OUTPUT RATE BASED ON EMPTY KILN
C              CROSS-SECTION,LIMESTONE-TO-FUEL-RATIO IN FEED MIX,
C              NOMINAL PRODUCTION RATE OF LIME SHAFT KILN)
      READ(1,*) DPS,DPF,PHIS,PHIF,EBED,DELZ
C              (PARTICLE SIZES OF LIMESTONE,FUEL,SPHERICITIES OF
C              STONE,FUEL PARTICLES,BED POROSITY,AXIAL WIDTH OF
C              DIFFERENTIAL ELEMENT)
      READ(1,*) XFM,XFV,XFC,XFA,XEA
C              (FRACTIONAL VALUES OF MOISTURE CONTENT,VOLATILE
C              MATTER,FIXED CARBON,ASH IN FUEL,EXCESS AIR)
      READ(1,*) ETASG,ETAFG,ETAFS,ETASGF,ETAFGF,ETAFSF,ETAGW
C              (EFFECTIVENESS FACTORS FOR HEAT EXCHANGE BETWEEN
C              STONE,FUEL AND GASEOUS PHASES)
      READ(1,*) ES,HFFC,ASHFAC,UNTDVZ,HLTDVM
C              (ENDOTHERMIC HEAT OF DECOMPOSITION OF LIMESTONE,HEATS
C              OF COMBUSTION OF VOLATILE MATTER,FIXED CARBON,FACTOR
C              FOR FUSION OF ASH,CONSTANT FOR DEVOLATILIZATION WITH
C              COMBUSTION,LATENT HEAT FOR DEVOLATILIZATION PROCESS)
      READ(1,*) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,TAMB,TWOBNG
C              (THERMAL CONDUCTIVITIES OF FIRE BRICKS,RED BURNT CLAY
C              BRICKS,THICKNESSES OF FIRE BRICKS INSULATION,RED CLAY
C              BRICKS,EMISSIVITY OF RED BRICKS,AMBIENT TEMPERATURE
C              AND EXTERNAL WALL TEMPERATURE)
      READ(1,*) KG,MUG,TKL,RGAS,SIGMAR,EMSVTY,VIEWFO
C              (GAS THERMAL CONDUCTIVITY,VISCOSITY,THERMAL CONDUCTI-
C              VITY OF LIME LAYER,UNIVERSAL GAS CONSTANT,RADIATION
C              CONSTANT,EMISSIVITY OF COAL,VIEW FACTOR)
      READ(1,*) RHOSO,RHOFO,RHOASH,FACTOR,ALPHA,BETACV,GAMMA
C              (DENSITIES OF LIMESTONE,FUEL,ASH,CONSTANT TO ACCOUNT
C              FOR DIFFUSIONAL RESISTANCE FOR TRANSFER OF OXYGEN FROM
C              BULK GAS PHASE TO CARBON SURFACE,OTHER CONSTANTS TO
C              ACCOUNT FOR VARIATIONS IN GAS EMISSIVITY,TEMPERATURE
C              OF INCIPIENT COMBUSTION OF VOLATILE MATTER,ETC)
      READ(1,*) TPHZ,TPHDVZ,TPHCVM,TD,TFASHF
C              (TEMPERATURES FOR ONSET OF DEVOLATILIZATION,COMBUST-
C              IONOF VOLATILE MATTER,COMPLETION OF VM EVOLUTION,DI-
C              SSOCIATION OF LIMESTONE,FUSION OF FUEL ASH)
      READ(1,*) TOLER1,TOLER2,TOLER3,TOLER4,TOLER5
C              (TOLERANCE LEVELS FOR DIFFERENT VARIABLES)
      READ(1,*) IMAX,ITERMX,IRANDM,MINLMT,MAXLMT
C              (CONSTANTS,MAXIMUM/MINIMUM VALUES)
      WRITE(NW,60)
      WRITE(NW,65)
      WRITE(NW,70) DATAIN
      WRITE(NW,25) NP,NW,NPRINT
      WRITE(NW,85) XF(1),XS(1),TG(1),TF(1),TS(1)
      WRITE(NW,30) PS,XRINFD,TPD
      WRITE(NW,35) DPS,DPF,PHIS,PHIF,EBED,DELZ
      WRITE(NW,45) XFM,XFV,XFC,XFA,XEA
      WRITE(NW,40) ETASG,ETAFG,ETAFS,ETASGF,ETAFGF,ETAFSF,ETAGW
      WRITE(NW,45) ES,HFFC,ASHFAC,UNTDVZ,HLTDVM
      WRITE(NW,40) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,TAMB,TWOBNG
      WRITE(NW,80) KG,MUG,TKL,RGAS,SIGMAR,EMSVTY,VIEWFO
      WRITE(NW,40) RHOSO,RHOFO,RHOASH,FACTOR,ALPHA,BETACV,GAMMA
```

```
      FCFDAF=XFC/(XFV+XFC)
      HFNDAF=8150.+6543.*VMFDAF-17308.*(VMFDAF**2)
      CVFNET=HFNDAF*(XFV+XFC)
      HFVM=(HFNDAF-8200.*FCFDAF)/VMFDAF
C     ************************************************************
      WRITE(NW,45) DI,WS,WF,WA,HFVM
      WRITE(NP,180) PS,DPS,DPF,XRINFD,XFV,XFC,XEA
      WRITE(NW,155)
      WRITE(NW,100)
      XSMIN=0.0
      XSMAX=1.0
      XCMIN=0.0
      XCMAX=1.0
      XFMIN=XF(1)
      XFMAX=(1.-XFA)
      XAMIN=0.0
      XAMAX=XFA
      XFVMIN=0.999*(XFM+XFV)
      XFVMAX=1.001*(XFM+XFV)
      RPF=DPF/2.0
      RPS=DPS/2.0
      TKFMIN=0.15
      TKFMAX=1.25
      CFO=0.25
      CFCMAX=0.40
      CFAMAX=0.75*CFCMAX
      CFMAX=(CFCMAX*XFC+CFAMAX*XFA)/(XFC+XFA)
      VIEWF=VIEWFO
      ALPHA1=(ETAFSF/ETAFS-1.)/(1.-XFM-XFV-XFA)
      BETA1=(ETAFGF/ETAFG-1.)/(1.-XFM-XFV-XFA)
      GAMMA1=(ETASGF/ETASG-1.)/(1.-XFM-XFV-XFA)
      XRAVG=WS/(WF*(1.-XFMIN))
      RHOL=RHOSC*0.56
      RHOS=RHOSC*(1.0-XS(1)*.44)
      RHOF=RHOFC*(1.-XFMIN)
      VR=XRAVG*RHOF/RHOS
      XSTONE=WS/(WS+WF)
      XFUEL=WF/(WS+WF)
      DPSAVG=1./(XSTONE/DPS+XFUEL/DPF)
      VFSRAT=RHOSO/(RHOFO*XRINFD)
      ALFA=1.-((DPF/DPS)**3)/VFSRAT
      ASBZO=6.*(1.-EBED)/(PHIS*DPSAVG*(1.+ALFA*VFSRAT))
      AFBZO=6.*(1.-EBED)*VFSRAT/(PHIF*DPSAVG*(1.+ALFA*VFSRAT))
      RFB=RI+FBTHIK
      RO=RFB+RBTHIK
      DO=2.*RO
      CSTKLN=(ALOG(RFB/RI)/FBCDTY)+(ALOG(RO/RFB)/RECDTY)
      BETA=XFM+XFV*(TPHDVZ-TPHZ)/(TPHCVM-TPHZ)
      I=1
      Z(I)=0.0
      DZ=DELZ
      DF(I)=DPF
      TWO=TWOBNG
      XC(1)=XCMIN
      MG(1)=WA+WF*(XFMAX-XFMIN)+WS*(XSMAX-XS(1))*0.44
      WO2Z1=WA*.232-WF*(XFMAX-XFM-XFV)*(32./12.)
      IF(XF(1).LE.(XFM+XFV)) WO2Z1=WO2Z1-WF*(XFM+XFV-XF(1))*
     1(77.77/20.0)
      WCO2Z1=WS*(XSMAX-XS(1))*.44+WF*(XFMAX-XFM-XFV)*44./12.
      IF(XF(1).LE.(XFM+XFV)) WCO2Z1=WCO2Z1+WF*(XFM+XFV-XF(1))*
     1(56.58/20.)
      IF(XF(1).LE.(XFM+XFV)) WH2OZ1=WF*(XFM+XFV-XF(1))*(41.15/20.)
      IF(XF(1).GT.(XFM+XFV)) WH2OZ1=0.0
    2 TGAVG=TG(I)
      TFAVG=TF(I)
      TSAVG=TS(I)
      IF(XF(I).GE.XFVMIN.AND.XF(I).LE.XFVMAX) XF(I)=(XFM+XFV)
      IF(XF(I).GT.(XFM+XFV)) GO TO 51
      DF(I)=DPF
      XC(I)=XCMIN
      XA(I)=XAMIN
      GO TO 52
   51 IF(XFASHF.LE.0.) GO TO 48
      XA(I)=XA(I-1)
      GO TO 52
   48 DF(I)=DPF*(((XFMAX-XF(I))/(XFMAX-XFM-XFV))**(1./3.))
      XA(I)=XAMAX*((XF(I)-XFM-XFV)/(XFMAX-XFM-XFV))+XAMIN
   52 G=MG(I)/AREA
      MS(I)=WS*(1.0-XS(I)*.44)
      MF(I)=WF*(1.0-XF(I)-XA(I))
```

```
      IF(MF(I).EQ.0.) GO TO 49
      XR(I)=MS(I)/MF(I)
   49 WN2Z=WA*0.768
      N2MZ=WN2Z/28.0
      IF(XF(I).LT.(XFM+XFV)) WO2Z=WO2Z1+WF*(XF(I)-XF(1))*(77.77/20.)
      IF(XF(I).GE.(XFM+XFV).AND.XF(1).LT.(XFM+XFV)) WO2Z=WO2Z1+
     1WF*(XFM+XFV-XF(1))*(77.77/20.)+WF*(XF(I)-XFM-XFV)*(32./12.)
      IF(XF(1).GE.(XFM+XFV)) WO2Z=WO2Z1+WF*(XF(I)-XFM-XFV)*(32./12.)
      O2MZ=WO2Z/32.0
      IF(XF(I).LT.(XFM+XFV)) WCO2Z=WCO2Z1-WF*(XF(I)-XF(1))*
     1(56.58/20.0)-WS*(XS(I)-XS(1))*.44
      IF(XF(I).GE.(XFM+XFV).AND.XF(1).LT.(XFM+XFV)) WCO2Z=WCO2Z1-
     1WF*(XFM+XFV-XF(1))*(56.58/20.)-WF*(XF(I)-XFM-XFV)*(44./12.)-
     2WS*(XS(I)-XS(1))*.44
      IF(XF(1).GE.(XFM+XFV)) WCO2Z=WCO2Z1-WF*(XF(I)-XFM-XFV)*
     1(44./12.)-WS*(XS(I)-XS(1))*.44
      CO2MZ=WCO2Z/44.0
      IF(XF(I).LT.(XFM+XFV)) WH2OZ=WH2OZ1-WF*(XF(I)-XF(1))*
     1(41.15/20.)
      IF(XF(I).GE.(XFM+XFV)) WH2OZ=0.0
      H2OMZ=WH2OZ/18.0
      TMGZ=O2MZ+CO2MZ+N2MZ+H2OMZ
      PCG(I)=O2MZ/TMGZ
      PCO2G=CO2MZ/TMGZ
C     ******************************************************************
C     SPECIFIC HEATS OF VARIOUS CONSTITUENTS
C     ******************************************************************
      CPO2=0.2584+(0.8063*TGAVG*10.**-5)-5865.6/(TGAVG**2)
      CPCO2=0.1441+(0.2305*TGAVG*10.**-3)-(.0776*10.**-6)/(TGAVG**2)
      CPCO2F=0.1441+(.2305*TFAVG*10.**-3)-(.0776*10.**-6)/(TFAVG**2)
      CPCO2S=0.1441+(.2305*TSAVG*10.**-3)-(.0776*10.**-6)/(TSAVG**2)
      CPAIR=0.2372+(0.2900*TGAVG*10.**-4)-1360./(TGAVG**2)
      CS=0.1968+(0.1189*TSAVG*10.**-3)-(0.3076*10.**4)/(TSAVG**2)
      CPWTRG=.4567+(.8333*TGAVG*10.**-5)+(.7444*TGAVG*TGAVG*10.**-7)
      CPWTRF=.4567+(.8333*TFAVG*10.**-5)+(.7444*TFAVG*TFAVG*10.**-7)
      IF(TF(I).GE.1573.0) GO TO 57
      IF(XF(I).GT.(XFM+XFV)) GO TO 81
      CF=CFO+(XF(I)/(XFM+XFV))*(CFMAX-CFO)
      GO TO 57
   81 IF(XFASHF.GT.0.) GO TO 57
      CFCOKE=-0.1640+(.1136*TFAVG*10.**-2)-(.49*TFAVG*TFAVG*10.**-6)
      CFASH=0.75*CFCOKE
      CF=(CFCOKE*XFC+CFASH*XFA)/(XFC+XFA)
C     ******************************************************************
   57 XRAVG=XR(I)
      DFAVG=DF(I)
      IF(XFASHF.GT.C.) DFAVG=(DF(I)+DFBZAF)/2.0
      PCGAVG=PCG(I)
      XCAVG=XC(I)
      XFAVG=XF(I)
      XSAVG=XS(I)
      XAAVG=XA(I)
      WGAVG=WG(I)
      WFAVG=WF(I)
      WSAVG=WS(I)
      WAAVG=WF*XAAVG
      IF(XSAVG.LE.0.) GO TO 62
C     ******************************************************************
C     AVERAGE TEMPERATURE OF CALCINED LIME LAYER
C     ******************************************************************
      SHBKLI=(1.-XSAVG)**(1./3.)
      IF(SHBKLI.EQ.1.) GO TO 62
      SHBKL1=XSAVG*TSAVG/(1.-SHBKLI)
      SHBKL2=XSAVG*TD*SHBKLI/(1.-SHBKLI)
      SHBKL3=1.5*(TSAVG-TD)*SHBKLI*(1.+SHBKLI)
      SHBBLI=SHBKL1-SHBKL2-SHBKL3
      TLLAVG=SHBBLI/XSAVG
C     ******************************************************************
      CL=0.1786+(0.0864*TLLAVG*10.**-3)-(0.1928*10.**4)/(TLLAVG**2)
      CPCO2L=.1441+(.2305*TLLAVG*10.**-3)-(.0776*10.**-6)/(TLLAVG**2)
   62 DFAVG=(DFS*WSAVG+DFAVG*WFAVG)/(WSAVG+WFAVG)
      IF(HUDLSC.EQ.C.) GO TO 41
      RSHLHD=DELSHS/(HUDLSC+DELSHS)
   41 IF(XS(I-1).GE.XSMAX) GO TO 124
      DELSHT=DELSHT+DELSHS
  124 IF(XS(I-1).EQ.XSMAX.AND.XS(I-1).EQ.XSMAX) RSHLHD=1.0
      WGAIRZ=WN2Z+WO2Z
      WGCO2Z=WCO2Z
      WGH2OZ=WH2OZ
      CG=(WGAIRZ*CPAIR+WGCO2Z*CPCO2+WGH2OZ*CPWTRG)/
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      1(WGAIRZ+WGCO2Z+WGH2OZ)
      TGI=TGAVG
      CORFAC=(1.-ALPHA)-((GAMMA-ALPHA)*(XFAVG-BETA)/
      1(1.-XFA-BETA))
      MSF=WSAVG+WFAVG+WAAVG
      ASNMR=ASBZO*(1.+ALFA*VFSRAT)
      ASDNR=(1.+ALFA*VFSRAT*(1.-XFA-XFAVG)/(1.-XFM-XFV-XFA))
      AFNMR1=AFBZO*(1.+ALFA*VFSRAT)
      IF(XFASHF.GT.C.) GO TO 106
      AFNMR2=((1.-XFA-XFAVG)/(1.-XFM-XFV-XFA))**(2./3.)
      AFNMR=AFNMR1*AFNMR2
      AFDNR=ASDNR
      ASBZ=ASNMR/ASDNR
      AFBZ=AFNMR/AFDNR
  106 RHOS=RHOSO*(1.-XSAVG*0.44)
      IF(XFASHF.GT.C.) RHOF=RHOFAF*((TFAVG/TFASHF)**ASHFAC)
      IF(XF(I).GT.(XFM+XFV)) GO TO 71
      RHOF=RHOFC*(1.-XFAVG)
      ASBZ=ASBZC
      AFBZ=AFBZC
      TKF=((TKFMAX-TKFMIN)*XFAVG/(XFM+XFV))+TKFMIN
   71 VSFAVG=(WSAVG/RHOS)+(WFAVG/RHOF)+(WAAVG/RHOASH)
      IF(TS(I).LE.TD) TKS=0.85
      IF(TS(I).GT.TD) TKS=TKL
      EFFKS=TKS*TKF/(TKS+TKF)
      IF(XFAVG.GE.(C.999*XFMAX).OR.I.GE.IRANDM) GO TO 61
C     ***************************************************************
C     OVERALL DIFFUSIONAL RESISTANCE AND HEAT TRANSFER COEFFICIENTS
C     ***************************************************************
      BARKS=DASHKS(RGAS,TFAVG,TGAVG,DFAVG,FACTOR)
      HCHRFS=HFS(EFFKS,DPS,DFAVG,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
      HCHRFG=HFG(EBED,DFAVG,KG,MUG,CG,G,CORFAC)
   61 HCHRSG=HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
C     ***************************************************************
      IF(XFAVG.GT.(XFM+XFV)) GO TO 76
      ASSBZ=ETASG
      ASFBZ=ETAFG
      ASFRBZ=ETAFS
      GO TO 72
   76 ASSBZ=ETASG*(1.+GAMMA1*(XFAVG-XFM-XFV))
      ASFBZ=ETAFG*(1.+BETA1*(XFAVG-XFM-XFV))
      ASFRBZ=ETAFS*(1.+ALPHA1*(XFAVG-XFM-XFV))
   72 VR=XRAVG*RHOF/RHOS
      A=(1.+VR)*DPS/(6.*(1.-EBED)*VR)
      FAF=A*AFBZ*ASFRBZ
      FAS=A*ASBZ*ASSBZ
      IF(TF(I).LT.TFASHF.AND.XFASHF.LE.C.) GO TO 54
      IF(XFASHF.GT.C.) GO TO 59
      XFASHF=XF(I)
      DFBZAF=DF(I)
      AFBZAF=AFBZ
      RHOFAF=RHOF
      CFFCAF=CFCOKE
      CFASHF=CFASH
      HEIGHT=Z(I)
   59 ASNMR=ASNMR
      ASDNR1=ASDNR
      IF(TF(I).LT.TF(I-1)) GO TO 107
      RHOFAC=(TFASHF/TFAVG)**ASHFAC
  107 ASDNR2=(ALFA*VFSRAT*RHOFC*XFA*(XFAVG-XFASHF)/(RHOASH*
      1(1.-XFM-XFV-XFA)))*RHOFAC
      ASDNR=ASDNR1+ASDNR2
      ASBZ=ASNMR/ASDNR
      AFNMR1=AFNMR1
      AFNMR2=((1.-XFA-XFASHF)/(1.-XFM-XFV-XFA))**(2./3.)
      IF(TF(I).LT.TF(I-1)) GO TO 108
      RHOFAC=(TFASHF/TFAVG)**ASHFAC
  108 AFNMR3=((1.-XFA-XFAVG)/(1.-XFA-XFASHF)+RHOFC*XFA*(XFAVG-XFASHF
      1)/((1.-XFA-XFASHF)*RHOASH)*RHOFAC)**(2./3.)
      AFNMR=AFNMR1*AFNMR2*AFNMR3
      AFDNR=ASDNR
      AFBZ=AFNMR/AFDNR
      CFNUM=(CFASHF*XFA*(XFMAX-XFASHF)/XFC)+CFFCAF*(XFMAX-XFAVG)
      CFDNR=(XFA*(XFMAX-XFASHF)/XFC)+(XFMAX-XFAVG)
      CF=CFNUM/CFDNR
   54 QFS=HCHRFS*(TFAVG-TSAVG)*AFBZ*ASFRBZ*AREA*DZ
      QFG=HCHRFG*(TFAVG-TGAVG)*AFBZ*ASFBZ*AREA*DZ
      QSG=HCHRSG*(TSAVG-TGAVG)*ASBZ*ASSBZ*AREA*DZ
      IF(I.NE.1) GO TO 101
      ENGASI=MG(I)*CG*(TG(I)-273.0)
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      ENSTNI=MS(I)*CS*(TS(I)-273.0)
      ENFULI=MF(I)*CF*(TF(I)-273.0)
      IF(I.NE.IRANDM) GO TO 101
      WRITE(NW,205)
  101 Y=(I/NPRINT)-FLOAT(I)/FLOAT(NPRINT)
      IF(Y.NE.0) GO TO 7
      TYPE 55,Z(I), XF(I),XS(I),POG(I),TG(I),TF(I),TS(I),TLLAVG
      WRITE(NW,145)I,Z(I),XF(I),XS(I),TG(I),TF(I),TS(I),TWO,
     1RSHLHD,DELSHT,HCHRFS,HCHRFG,HCHRSG,ASBZ,AFBZ,QFS,QFG,QSG,
     2DELHTL,PCG(I),PCO2G
      WRITE(NP,135)Z(I),XF(I),XS(I),TG(I),TF(I),TS(I)
    7 IF(XF(I).GE.XFMAX.AND.TS(I).LE.(TD+10.)) GO TO 21
      IF(XS(I).LT.XS(I-1).OR.XF(I).LT.XF(I-1)) GO TO 21
      IF(XCAVG.GE.XCMAX.OR.XFAVG.GE.XFMAX) GO TO 21
    3 I=I+1
      IF(I.GT.IMAX) GO TO 21
      Z(I)=Z(I-1)+DZ
      IF(XF(I-1).LT.(XFM+XFV)) HF=HFVM
      IF(XF(I-1).GE.(XFM+XFV).AND.XF(I-1).LT.XFMAX) HF=HFFC
C     ***************************************************************
C     ESTIMATION OF WALL HEAT LOSSES
C     ***************************************************************
      DELTWO=TWOBNG-TAMB
      AHWA=HWA(DZ,REEMSY,SIGMAR,TWOBNG,TAMB,DELTWO)
      AHGW=HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
      IF(AHWA.EQ.0.) GO TO 33
      UIEFFI=RI*(1./(RI*AHGW)+CSTKLN+1./(RO*AHWA))
      UIEFF=1./UIEFFI
      DELHL=UIEFF*3.14*DI*DZ*(TGI-TAMB)
      DELHTL=DELHTL+DELHL
      TWI=TGI-DELHL/(3.14*DI*DZ*AHGW)
      TWO=TAMB+DELHL/(3.14*DO*DZ*AHWA)
      TWOBNG=TWO
C     ***************************************************************
      K=0
   33 IF(TS(I-1)-TD) 1,4,4
    4 IF(XS(I-1).EQ.XSMAX) GO TO 6
      X1=(3.*AREA*RHOBM*DZ)
      X2=-HCHRSG*(TSAVG-TGAVG)*FAS+HCHRFS*(TFAVG-TSAVG)*FAF
      X3=(ES*RHOSO*MSF*RPS)
      DELXSP=X1*X2/X3
      XS(I)=XS(I-1)+DELXSP
      XSAVG=(XS(I-1)+XS(I))/2.0
    1 ITER=1
    9 IF(XSAVG.GT.XSMIN) GO TO 5
      IF(XS(I-1).EQ.XSMIN.AND.TS(I-1).GE.TD) GO TO 5
      XS(I)=XS(I-1)
      DELXS=0.0
      XSAVG=XS(I)
      GO TO 6
    5 IF(ITER.EQ.1.AND.XF(I-1).GE.(XFM+XFV)) GO TO 31
   10 IF(XS(I-1).GE.(0.999*XSMAX)) GO TO 6
      IF(XSIP.LT.XSMAX) GO TO 67
      DELXS=XSMAX-XS(I-1)
      GO TO 22
C     ***************************************************************
C     STONE HEAT BALANCE DURING CALCINATION OF LIMESTONE
C     ***************************************************************
   67 J=0
      IF(ITER.EQ.1) GO TO 104
      DXSOLD=XSDEL(ITER-1)
      GO TO 113
  104 DXSOLD=DELXS
  113 ALHSB1=HCHRFS*(TFAVG-TSAVG)*AFBZ*ASFRBZ*AREA*DZ
      ALHSB2=HCHRSG*(TSAVG-TGAVG)*ASBZ*ASSBZ*AREA*DZ
      ALHSB3=WF*DELXA*CFASH*(TFAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ALHSB3=0.0
      ALHSBT=ALHSB1-ALHSB2+ALHSB3
      ARHSB1=WF*XAAVG*CFASH*DELTS
      IF(XF(I-1).LT.(XFM+XFV)) ARHSB1=0.0
      ARHSB2=WF*DELXA*CFASH*(TSAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ARHSB2=0.0
      DELSHS=WS*0.56*CL*DELSH
      ARHSB3=DELSHS
      ARHSBT=ARHSB1+ARHSB2+ARHSB3
      ALHSBN=ALHSBT-ARHSBT
      DELXS=ALHSBN/(WS*(ES+(CPCO2L*(TSAVG-TD)+CPCO2S*
     1(TSAVG-273.))*44./100.))
      DXSNEW=DELXS
      IF(DXSNEW.EQ.0.) GO TO 19
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      IF(ABS((DXSNEW-DXSOLD)/DXSNEW).LE.TOLER4) GO TO 114
   19 J=J+1
      IF(J.GE.ITERMX) GO TO 114
      DXSOLD=(DXSOLD+DXSNEW)/2.0
      GO TO 113
  114 IF(XS(I-3).LE.XSMIN.OR.DLXSIP.LE.0.) GO TO 22
      DXSLWR=(1.-TOLER1)*DLXSIP
      DXSUPR=(1.+TOLER1)*DLXSIP
      IF(DELXS.LT.DXSLWR.OR.DELXS.GT.DXSUPR)DELXS=(DELXS+DLXSIP)/2.0
   22 IF(DELXS.LT.0.) DELXS=0.0
      IF(I.GE.IRANDM) DELXS=DLXSIP
      IF(ITER.EQ.1) GO TO 86
      DELXS=(DELXS+XSDEL(ITER-1))/2.0
   86 XSDEL(ITER)=DELXS
    6 IF(XS(I-1).GT.(0.999*XSMAX)) DELXS=0.0
      XS(I)=XS(I-1)+DELXS
      XSAVG=(XS(I-1)+XS(I))/2.0
C     ******************************************************************
      IF(XC(I-1).GT.(0.999*XCMAX)) GO TO 63
      IF(XCIP.LT.XCMAX) GO TO 66
      DELXC=XCMAX-XC(I-1)
      GO TO 29
   66 IF(XF(I-1).GE.(XFM+XFV)) GO TO 73
C     ******************************************************************
C     FRACTIONAL DEVOLATILIZATION OF FUEL FOR VM COMBUSTION
C     ******************************************************************
      DELXF=(XFM+XFV-BETACV)/UNTDVZ
      XF(I)=XF(I-1)+DELXF
      XFAVG=(XF(I-1)+XF(I))/2.0
      XFDEL(ITER)=DELXF
      GO TO 8
C     ******************************************************************
C     DEGREE OF COMBUSTION OF FIXED CARBON CONTENT OF FUEL
C     ******************************************************************
   73 DXCBKT=(1.-XCAVG)**(2./3.)
      DXCNUM=3.*AREA*(1.-EBED)*BARKS*POGAVG*DXCBKT*DZ
      DXCDNR=RHOFO*(XFMAX-XFM-XFV)*RPF*VSFAVG
      IF(DXCDNR.EQ.0.) GO TO 126
      DELXC=DXCNUM/DXCDNR
  126 IF(XC(I-3).LE.XCMIN.OR.DLXCIP.LE.0.) GO TO 29
      DXCLWR=(1.-TOLER1)*DLXCIP
      DXCUPR=(1.+TOLER1)*DLXCIP
      IF(DELXC.LT.DXCLWR.OR.DELXC.GT.DXCUPR)DELXC=(DELXC+DLXCIP)/2.0
   29 IF(DELXC.LT.0.) DELXC=0.0
      IF((2.*XC(I-1)-XC(I-2)).GT.XCMAX) DELXC=XCMAX-XC(I-1)
      IF(I.GE.IRANDM) DELXC=DLXCIP
      IF(ITER.EQ.1) GO TO 87
      DELXC=(DELXC+XCDEL(ITER-1))/2.0
   87 XCDEL(ITER)=DELXC
   63 IF(XC(I-1).GT.(.999*XCMAX).OR.XF(I-1).GT.(.999*XFMAX))DELXC=0.0
      XC(I)=XC(I-1)+DELXC
      XCAVG=(XC(I)+XC(I-1))/2.0
      XF(I)=(XFMAX-XFM-XFV)*XC(I)+(XFM+XFV)
      DELXF=XF(I)-XF(I-1)
      XFDEL(ITER)=DELXF
      XFAVG=(XF(I-1)+XF(I))/2.0
C     ******************************************************************
      IF(XSIP.LT.XSMAX.OR.XFIP.LT.XFMAX) GO TO 8
      DELXF=XFMAX-XF(I-1)
      DELXS=XSMAX-XS(I-1)
      DELTG=DLTGIP
      DELTF=DLTFIP
      DELTS=DLTSIP
      XF(I)=XF(I-1)+DELXF
      XS(I)=XS(I-1)+DELXS
      TG(I)=TG(I-1)+DELTG
      TF(I)=TF(I-1)+DELTF
      TS(I)=TS(I-1)+DELTS
      GO TO 53
   31 ZIP=Z(I-1)+DZ
C     ******************************************************************
C     PREDICTIONS ON VALUES OF PARAMETERS
C     ******************************************************************
      AXS=((XS(I-1)-XS(I-2))/(Z(I-1)-Z(I-2))-(XS(I-2)-XS(I-3))/
     1(Z(I-2)-Z(I-3)))/(Z(I-1)-Z(I-3))
      AXC=((XC(I-1)-XC(I-2))/(Z(I-1)-Z(I-2))-(XC(I-2)-XC(I-3))/
     1(Z(I-2)-Z(I-3)))/(Z(I-1)-Z(I-3))
      ATG=((TG(I-1)-TG(I-2))/(Z(I-1)-Z(I-2))-(TG(I-2)-TG(I-3))/
     1(Z(I-2)-Z(I-3)))/(Z(I-1)-Z(I-3))
      ATF=((TF(I-1)-TF(I-2))/(Z(I-1)-Z(I-2))-(TF(I-2)-TF(I-3))/
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     1(Z(I-2)-Z(I-3)))/(Z(I-1)-Z(I-3))
     ATS=((TS(I-1)-TS(I-2))/(Z(I-1)-Z(I-2))-(TS(I-2)-TS(I-3))/
     1(Z(I-2)-Z(I-3)))/(Z(I-1)-Z(I-3))
     BXS=(XS(I-1)-XS(I-2))/(Z(I-1)-Z(I-2))-AXS*(Z(I-1)+Z(I-2))
     BXC=(XC(I-1)-XC(I-2))/(Z(I-1)-Z(I-2))-AXC*(Z(I-1)+Z(I-2))
     BTG=(TG(I-1)-TG(I-2))/(Z(I-1)-Z(I-2))-ATG*(Z(I-1)+Z(I-2))
     BTF=(TF(I-1)-TF(I-2))/(Z(I-1)-Z(I-2))-ATF*(Z(I-1)+Z(I-2))
     BTS=(TS(I-1)-TS(I-2))/(Z(I-1)-Z(I-2))-ATS*(Z(I-1)+Z(I-2))
     CXS=XS(I-3)-AXS*Z(I-3)*Z(I-3)-BXS*Z(I-3)
     CXC=XC(I-3)-AXC*Z(I-3)*Z(I-3)-BXC*Z(I-3)
     CTG=TG(I-3)-ATG*Z(I-3)*Z(I-3)-BTG*Z(I-3)
     CTF=TF(I-3)-ATF*Z(I-3)*Z(I-3)-BTF*Z(I-3)
     CTS=TS(I-3)-ATS*Z(I-3)*Z(I-3)-BTS*Z(I-3)
     IF(XS(I-3).LE.XSMIN) GO TO 12
     XS(I)=AXS*ZIP*ZIP+BXS*ZIP+CXS
     GO TO 13
  12 XS(I)=XS(I-1)+DELXS
  13 IF(XS(I).GE.XSMAX) XS(I)=XSMAX
     IF(XC(I-3).LE.XCMIN) GO TO 77
     XC(I)=AXC*ZIP*ZIP+BXC*ZIP+CXC
     XF(I)=(XFMAX-XFM-XFV)*XC(I)+(XFM+XFV)
     GO TO 79
  77 XC(I)=XC(I-1)+DELXC
     XF(I)=XF(I-1)+DELXF
  79 IF(XC(I).GE.XCMAX) XC(I)=XCMAX
     IF(XF(I).GE.XFMAX) XF(I)=XFMAX
     TG(I)=ATG*ZIP*ZIP+BTG*ZIP+CTG
     TF(I)=ATF*ZIP*ZIP+BTF*ZIP+CTF
     TS(I)=ATS*ZIP*ZIP+BTS*ZIP+CTS
     IF(XS(I).LT.XS(I-1)) XS(I)=XS(I-1)
     IF(XC(I).LT.XC(I-1)) XC(I)=XC(I-1)
     IF(XF(I).LT.XF(I-1)) XF(I)=XF(I-1)
     DELXS=XS(I)-XS(I-1)
     DELXC=XC(I)-XC(I-1)
     DELXF=XF(I)-XF(I-1)
     DELTF=TF(I)-TF(I-1)
     DELTS=TS(I)-TS(I-1)
     DELTG=TG(I)-TG(I-1)
 102 DLXSIP=DELXS
     DLXCIP=DELXC
     DLXFIP=DELXF
     DLTFIP=DELTF
     DLTSIP=DELTS
     DLTGIP=DELTG
     XSDEL(ITER)=DELXS
     XCDEL(ITER)=DELXC
     XFDEL(ITER)=DELXF
     TFDEL(ITER)=DELTF
     TSDEL(ITER)=DELTS
     TGDEL(ITER)=DELTG
     XSAVG=(XS(I-1)+XS(I))/2.0
     XCAVG=(XC(I-1)+XC(I))/2.0
     XFAVG=(XF(I-1)+XF(I))/2.0
     TFAVG=(TF(I)+TF(I-1))/2.0
     TSAVG=(TS(I)+TS(I-1))/2.0
     TGAVG=(TG(I)+TG(I-1))/2.0
     XSIP=XS(I)
     XCIP=XC(I)
     XFIP=XF(I)
     TGIP=TG(I)
     TFIP=TF(I)
     TSIP=TS(I)
     IF(XFAVG.GE.(0.999*XFMAX).OR.I.GE.IRANDM) GO TO 83
     BARKS=DASHKS(RGAS,TFAVG,TGAVG,DFAVG,FACTOR)
     HCHRFS=HFS(EFFKS,DPS,DFAVG,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
     HCHRFG=HFG(EBED,DFAVG,KG,MUG,CG,G,CORFAC)
  83 HCHRSG=HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
  78 CONTINUE
C    IF(I.LT.IRANDM) GO TO 11
C    WRITE(NW,150)ITER,DLXFIP,DLXSIP,DLTGIP,DLTFIP,DLTSIP,DLXCIP,
C    1G,CORFAC,DFAVG,BARKS,HCHRFS,DZ
  11 ITER=ITER+1
     GO TO 9
   8 IF(XF(I-1).GE.(XFM+XFV)) GO TO 68
     XA(I)=XA(I-1)
     XC(I)=XC(I-1)
     GO TO 69
  68 XA(I)=XAMAX*((XF(I)-XFM-XFV)/(XFMAX-XFM-XFV))+XAMIN
  69 IF(XFASHF.GT.0.) XA(I)=XA(I-1)
     DELXA=XA(I)-XA(I-1)
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```
      XAAVG=(XA(I-1)+XA(I))/2.0
      WAAVG=WF*XAAVG
      DELMF=-WF*(DELXF+DELXA)
      MF(I)=MF(I-1)+DELMF
      WFAVG=(MF(I-1)+MF(I))/2.0
      DELMS=-WS*DELXS*0.44
      MS(I)=MS(I-1)+DELMS
      WSAVG=(MS(I)+MS(I-1))/2.0
      MSF=WSAVG+WFAVG+WAAVG
      DELMG=-WS*DELXS*0.44-WF*DELXF
      MG(I)=MG(I-1)+DELMG
      WGAVG=(MG(I-1)+MG(I))/2.0
      IF(XS(I)-XSMIN) 14,14,15
C     ******************************************************************
C     STONE HEAT BALANCE DURING NON-CALCINATION OF LIMESTONE
C     ******************************************************************
   14 ALHSB1=HCHRFS*(TFAVG-TSAVG)*AFBZ*ASFRBZ*AREA*DZ
      ALHSB2=HCHRSG*(TSAVG-TGAVG)*ASBZ*ASSBZ*AREA*DZ
      ALHSB3=WF*DELXA*CFASH*(TFAVG-273.)
      IF(XF(I-1).LT.(XFM+XFV)) ALHSB3=0.0
      ALHSBT=ALHSB1-ALHSB2+ALHSB3
      ARHSBT=WF*DELXA*CFASH*(TSAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ARHSBT=0.0
      ALHSBN=ALHSBT-ARHSBT
      DELTS=ALHSBN/(WS*CS+WF*XAAVG*CFASH)
      IF(XF(I-1).GE.(XFM+XFV)) GO TO 74
      DELTS=ALHSBN/(WS*CS)
      GO TO 58
   74 IF(XS(I).EQ.XSMAX.AND.XS(I-1).LT.XSMAX) DELTS=(ALHSBN-WS*(XS(I
     1)-XS(I-1)))/(WS*XSAVG*.56*CL+WF*XAAVG*CFASH)
      IF(XSAVG.GE.(0.999*XSMAX)) DELTS=ALHSBN/
     1(WS*XSAVG*0.56*CL+WF*XAAVG*CFASH)
      IF(XSAVG.GE.(0.999*XSMAX)) GO TO 58
      IF(XF(I-1).LT.(XFM+XFV).OR.DLTSIP.LE.0.) GO TO 58
      DTSLWR=(1.-TOLER2)*DLTSIP
      DTSUPR=(1.+TOLER2)*DLTSIP
      IF(DELTS.LT.DTSLWR.OR.DELTS.GT.DTSUPR)DELTS=(DELTS+DLTSIP)/2.0
      IF(ITER.EQ.1) GO TO 88
   58 DELTS=(DELTS+TSDEL(ITER-1))/2.0
   88 TSDEL(ITER)=DELTS
      IF(XS(I).EQ.XSMAX.AND.XS(I-1).LT.XSMAX) TS(I-1)=TLLAVG
      TS(I)=TS(I-1)+DELTS
      TSAVG=(TS(I-1)+TS(I))/2.0
C     ******************************************************************
      GO TO 16
   15 IF(XS(I).EQ.XSMAX.AND.XS(I-1).LT.XSMAX) GO TO 14
      IF(XSAVG.GE.(0.999*XSMAX)) GO TO 14
      IF(XS(I-1).LE.XSMIN.AND.TS(I-1).LT.TD) GO TO 28
      IF(XS(I-1).GE.(0.999*XSMAX)) GO TO 28
C     ******************************************************************
C     HEAT CONDUCTION THROUGH LIME LAYER
C     ******************************************************************
      IF(XS(I-1).EQ.1.) GO TO 121
      SHBKTP=(1.-XS(I-1))**(1./3.)
  121 IF(SHBKTP.EQ.1.) GO TO 28
      SHBKP1=XS(I-1)*(TSAVG-1173.)/(1.-SHBKTP)
      SHBKP2=XS(I-1)*(TD-1173.)*SHBKTP/(1.-SHBKTP)
      SHBKP3=1.5*(TSAVG-TD)*SHBKTP*(1.+SHBKTP)
      SHBBTP=SHBKP1-SHBKP2-SHBKP3
   28 CONTINUE
      HCLDNR=3.*TKL*AREA*(1.-EBED)*DZ
      HCLNUM=ES*RHOSO*VSFAVG*RPS*RPS
      IF(XSAVG.EQ.1.) GO TO 123
      ARHBKT=1./((1.-XSAVG)**(1./3.))
  123 ARHBBT=(ARHBKT-1.)*DELXS
      IF(HCLDNR.EQ.0.) GO TO 127
      ARHSP1=ARHBBT*HCLNUM/HCLDNR
  127 IF(XS(I) .GE. 1.) GO TO 122
      SHBKTI=(1.-XS(I))**(1./3.)
  122 IF(SHBKTI.EQ.1.) GO TO 27
      SHBKT1=XS(I)*(TSAVG-1173.)/(1.-SHBKTI)
      SHBKT2=XS(I)*(TD-1173.)*SHBKTI/(1.-SHBKTI)
      SHBKT3=1.5*(TSAVG-TD)*SHBKTI*(1.+SHBKTI)
      SHBBTI=SHBKT1-SHBKT2-SHBKT3
      DELSH=SHBBTI-SHBBTP
      IF(HCLDNR.EQ.0.) GO TO 27
      DELSHP=RHOCL*CL*RPS*RPS*DELSH*(ARHBKT-1.)*VSFAVG/HCLDNR
   27 ARHSP2=DELSHP
      ARHSPT=ARHSP1+ARHSP2
      TSINEW=TD+ARHSPT
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```
      DELTS=TSINEW-TS(I-1)
      IF(XF(I-1).LT.(XFM+XFV).OR.DLTSIP.LE.0.) GO TO 36
      DTSLWR=(1.-TOLER2)*DLTSIP
      DTSUPR=(1.+TOLER2)*DLTSIP
      IF(DELTS.LT.DTSLWR.OR.DELTS.GT.DTSUPR)DELTS=(DELTS+DLTSIP)/2.0
   36 IF(I.GE.IRANDM) DELTS=DLTSIP
      IF(ITER.EQ.1) GO TO 89
      DELTS=(DELTS+TSDEL(ITER-1))/2.0
   89 TSDEL(ITER)=DELTS
      TS(I)=TS(I-1)+DELTS
      TSAVG=(TS(I-1)+TS(I))/2.0
C     ****************************************************************
C     HEAT BALANCE FOR GAS PHASE
C     ****************************************************************
   16 ALHGB1=HCHRFG*(TFAVG-TGAVG)*AFBZ*ASFBZ*AREA*DZ
      ALHGB2=HCHRSG*(TSAVG-TGAVG)*ASBZ*ASSBZ*AREA*DZ
      ALHGB3=WF*DELXF*(44./12.)*CPCO2F*(TFAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ALHGB3=WF*DELXF*(56.58/20.0)*
     1CPCO2F*(TFAVG-273.0)
      ALHGB4=WS*DELXS*(44./100.)*CPCO2S*(TSAVG-273.0)
      ALHGB5=-WF*DELXF*(32./12.)*CPO2*(TGAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ALHGB5=-WF*DELXF*(77.77/20.0)*
     1CPO2*(TGAVG-273.0)
      ALHGB6=WF*DELXF*(41.15/20.0)*CPWTRF*(TFAVG-273.0)
      IF(XF(I-1).GE.(XFM+XFV)) ALHGB6=0.0
      ALHGBT=ALHGB1+ALHGB2+ALHGB3+ALHGB4+ALHGB5+ALHGB6
      ALHGBT=ALHGBT-DELHL
      ALHGBN=ALHGBT+CG*(TGAVG-273.0)*DELMG
      DELTG=-ALHGBN/(CG*WGAVG)
      IF(XF(I-1).LT.(XFM+XFV).OR.DLTGIP.GE.0.) GO TO 34
      DTGLWR=(1.-TOLER2)*DLTGIP
      DTGUPR=(1.+TOLER2)*DLTGIP
      IF(DELTG.LT.DTGLWR.OR.DELTG.GT.DTGUPR)DELTG=(DELTG+DLTGIP)/2.0
   34 IF(I.GE.IRANDM) DELTG=DLTGIP
      IF(ITER.EQ.1) GO TO 91
      DELTG=(DELTG+TGDEL(ITER-1))/2.0
   91 TGDEL(ITER)=DELTG
      TG(I)=TG(I-1)+DELTG
      TGAVG=(TG(I-1)+TG(I))/2.0
C     ****************************************************************
C     HEAT BALANCE FOR FUEL
C     ****************************************************************
      ALHFB1=WF*HF*DELXF
      ALHFB2=WF*DELXF*(32./12.)*CPO2*(TGAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ALHFB2=WF*DELXF*(77.77/20.0)*
     1CPO2*(TGAVG-273.0)
      ALHFB3=-WF*DELXF*HLTOVM
      IF(XF(I-1).GE.(XFM+XFV)) ALHFB3=0.0
      ALHFBT=ALHFB1+ALHFB2+ALHFB3
      ARHFB1=HCHRFS*(TFAVG-TSAVG)*AFBZ*ASFREZ*AREA*DZ
      ARHFB2=HCHRFG*(TFAVG-TGAVG)*AFBZ*ASFBZ*AREA*DZ
      ARHFB3=-WF*CF*(TFAVG-273.0)*(DELXF+DELXA)
      ARHFB4=WF*DELXF*(44./12.)*CPCO2F*(TFAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ARHFB4=WF*DELXF*(56.58/20.0)*
     1CPCO2F*(TFAVG-273.0)
      ARHFB5=WF*DELXF*(41.15/20.0)*CPWTRF*(TFAVG-273.0)
      IF(XF(I-1).GE.(XFM+XFV)) ARHFB5=0.0
      ARHFB6=WF*DELXA*CFASH*(TFAVG-273.0)
      IF(XF(I-1).LT.(XFM+XFV)) ARHFB6=0.0
      ARHFBT=ARHFB1+ARHFB2+ARHFB3+ARHFB4+ARHFB5+ARHFB6
      ALHFBN=ALHFBT-ARHFBT
      DELTF=ALHFBN/(WF*CF*(1.0-XFAVG-XAAVG))
      IF(XF(I-1).LT.(XFM+XFV)) DELTF=ALHFBN/(WF*CF*(1.-XFAVG))
      IF(XF(I-1).LT.(XFM+XFV).OR.DLTFIP.LE.0.) GO TO 37
      DTFLWR=(1.-TOLER2)*DLTFIP
      DTFUPR=(1.+TOLER2)*DLTFIP
      IF(DELTF.LT.DTFLWR.OR.DELTF.GT.DTFUPR)DELTF=(DELTF+DLTFIP)/2.0
   37 IF(I.GE.IRANDM) DELTF=DLTFIP
      IF(ITER.EQ.1) GO TO 92
      DELTF=(DELTF+TFDEL(ITER-1))/2.0
   92 TFDEL(ITER)=DELTF
      TF(I)=TF(I-1)+DELTF
      TFAVG=(TF(I-1)+TF(I))/2.0
      HUDLSC=WS*ES*DELXS
C     ****************************************************************
      IF(I.LT.IRANDM) GO TO 23
      IF(ITER.GT.MINLMT.AND.ITER.LT.(1+ITERMX/2)) GO TO 23
      IF(ITER.GT.(MINLMT+ITERMX/2).AND.ITER.LT.MAXLMT) GO TO 23
C     WRITE(NW,150)ITER,XFDEL(ITER),XSDEL(ITER),TGDEL(ITER),TFDEL(
C     1ITER),TSDEL(ITER),XCDEL(ITER),G,CORFAC,DFAVG,BARKS,HCHRFS,DZ
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C     ****************************************************************
C     CONVERGENCE  CRITERIA
C     ****************************************************************
   23 IF(ITER.EQ.1) GO TO 43
      IF(TFDEL(ITER).EQ.0.) GO TO 38
      TFFDEL=ABS((TFDEL(ITER)-TFDEL(ITER-1))/TFDEL(ITER))
   38 IF(TFDEL(ITER).EQ.0.) TFFDEL=0.0
      IF(TSDEL(ITER).EQ.0.) GO TO 17
      TSSDEL=ABS((TSDEL(ITER)-TSDEL(ITER-1))/TSDEL(ITER))
   17 IF(TSDEL(ITER).EQ.0.) TSSDEL=0.0
      IF(XSDEL(ITER).EQ.0.) GO TO 39
      XSSDEL=ABS((XSDEL(ITER)-XSDEL(ITER-1))/XSDEL(ITER))
   39 IF(XSDEL(ITER).EQ.0.) XSSDEL=0.0
      IF(TGDEL(ITER).EQ.0.) GO TO 42
      TGGDEL=ABS((TGDEL(ITER)-TGDEL(ITER-1))/TGDEL(ITER))
   42 IF(TGDEL(ITER).EQ.0.) TGGDEL=0.0
      IF(XS(I).GT.XSMIN) GO TO 26
      IF(TSSDEL.GT.TOLER5) GO TO 20
      GO TO 18
   26 IF(XSSDEL.GT.TOLER4) GO TO 20
   18 IF(TGGDEL.GT.TOLER5) GO TO 20
      IF(TFFDEL.GT.TOLER5) GO TO 20
C     ****************************************************************
      IF(XS(I).EQ.XSMIN.AND.TS(I).GE.TD) GO TO 67
      IF(I.LT.IRANDM) GO TO 53
C     WRITE(NW,125)ITER,DELXF,DELXS,DELTG,DELTF,DELTS
   53 IF(XF(I-1).LT.(XFM+XFV)) GO TO 93
      DLXCIC=DELXC
      DLXFIC=DELXF
      DLXSIC=DELXS
      DLTGIC=DELTG
      DLTFIC=DELTF
      DLTSIC=DELTS
      IF(DLXCIC.EQ.0.0.OR.DLXFIC.EQ.0.) GO TO 96
      IF(ABS((DLXCIC-DLXCIP)/DLXCIC).GT.TOLER3) GO TO 94
      IF(ABS((DLXFIC-DLXFIP)/DLXFIC).GT.TOLER3) GO TO 94
   96 IF(DLXSIC.EQ.0.) GO TO 97
      IF(ABS((DLXSIC-DLXSIP)/DLXSIC).GT.TOLER3) GO TO 94
   97 IF(DLTGIC.EQ.0.) GO TO 98
      IF(ABS((DLTGIC-DLTGIP)/DLTGIC).GT.TOLER3) GO TO 94
   98 IF(DLTFIC.EQ.0.) GO TO 99
      IF(ABS((DLTFIC-DLTFIP)/DLTFIC).GT.TOLER3) GO TO 94
   99 IF(DLTSIC.EQ.0.) GO TO 93
      IF(ABS((DLTSIC-DLTSIP)/DLTSIC).GT.TOLER3) GO TO 94
   93 Z(I)=Z(I-1)+DZ
      IF(DELXS.GT.0.0.AND.TS(I).LT.TD) TS(I)=TD
      DELZ=DZ
      IF(XSAVG.GE.(.999*XSMAX)) TLLAVG=TSAVG
      IF(XFAVG.GE.(.999*XFMAX)) CF=CFASH
      TSOLID=(WS*XSAVG*0.56*CL*TLLAVG+WS*(1.-XSAVG)*CS*TD+
     1WF*XAAVG*CFASH*TSAVG+WF*(1.-XFAVG-XAAVG)*CF*TFAVG)/
     2(WS*XSAVG*0.56*CL+WS*(1.-XSAVG)*CS+WF*XAAVG*CFASH+
     3WF*(1.-XFAVG-XAAVG)*CF)
      ENGASO=MG(I)*CG*(TG(I)-273.0)
      ENSTNO=WS*XSAVG*0.56*CL*(TLLAVG-273.)+WS*(1.-XSAVG)*
     1CS*(TD-273.)
      ENFULO=MF(I)*CF*(TF(I)-273.0)
      ENASHO=WAAVG*CFASH*(TS(I)-273.0)
   56 IF(XS(I).GE.(.999*XSMAX)) XS(I)=XSMAX
      IF(XC(I).GE.(.999*XCMAX)) XC(I)=XCMAX
      IF(XF(I).GE.(.999*XFMAX)) XF(I)=XFMAX
      L=0
      GO TO 2
   94 N2MZ=WN2Z/28.0
      IF(XF(I).LT.(XFM+XFV)) WO2Z=WO2Z1+WF*(XF(I)-XF(1))*(77.77/20.)
      IF(XF(I).GE.(XFM+XFV).AND.XF(1).LT.(XFM+XFV)) WO2Z=WO2Z1+
     1WF*(XFM+XFV-XF(1))*(77.77/20.)+WF*(XF(I)-XFM-XFV)*(32./12.)
      IF(XF(1).GE.(XFM+XFV)) WO2Z=WO2Z1+WF*(XF(I)-XFM-XFV)*(32./12.)
     2MZ=WO2Z/32.0
      IF(XF(I).LT.(XFM+XFV)) WCO2Z=WCO2Z1-WF*(XF(I)-XF(1))*
     1(56.58/20.0)-WS*(XS(I)-XS(1))*.44
      IF(XF(I).GE.(XFM+XFV).AND.XF(1).LT.(XFM+XFV)) WCO2Z=WCO2Z1-
     1WF*(XFM+XFV-XF(1))*(56.58/20.)-WF*(XF(I)-XFM-XFV)*(44./12.)-
     2WS*(XS(I)-XS(1))*.44
      IF(XF(1).GE.(XFM+XFV)) WCO2Z=WCO2Z1-WF*(XF(I)-XFM-XFV)*
     1(44./12.)-WS*(XS(I)-XS(1))*.44
      CO2MZ=WCO2Z/44.0
      IF(XF(I).LT.(XFM+XFV)) WH2OZ=WH2OZ1-WF*(XF(I)-XF(1))*
     1(41.15/20.)
      IF(XF(I).GE.(XFM+XFV)) WH2OZ=0.0
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      H2OMZ=WH2CZ/18.0
      TMGZ=O2MZ+CO2MZ+N2MZ+H2OMZ
      POG(I)=O2MZ/TMGZ
      POGAVG=(POG(I)+POG(I-1))/2.0
      IF(XF(I) .EQ. XFMAX) GO  TO 129
      DF(I)=DPF*(((XFMAX-XF(I))/(XFMAX-XFM-XFV))**(1./3.))
129   IF(XFASHF.GT.0.) DF(I)=(DF(I)+DFBZAF)/2.0
      DFAVG=(DF(I)+DF(I-1))/2.0
      G=WGAVG/AREA
      ASNMR=ASBZO*(1.+ALFA*VFSRAT)
      ASDNR=(1.+ALFA*VFSRAT*(1.-XFA-XFAVG)/(1.-XFM-XFV-XFA))
      AFNMR1=AFBZO*(1.+ALFA*VFSRAT)
      IF(XFASHF.GT.0.) GO TO 109
      IF((XFA+XFAVG) .EQ. 1) GO TO  131
      AFNMR2=((1.-XFA-XFAVG)/(1.-XFM-XFV-XFA))**(2./3.)
131   AFNMR=AFNMR1*AFNMR2
      AFDNR=ASDNR
      ASBZ=ASNMR/ASDNR
      AFBZ=AFNMR/AFDNR
109   RHOS=RHOSO*(1.-XSAVG*0.44)
      IF(XFASHF.GT.0.) RHOF=RHOFAF*((TFAVG/TFASHF)**ASHFAC)
      VSFAVG=(WSAVG/RHOS)+(WFAVG/RHOF)+(WAAVG/RHOASH)
      IF(XFASHF.LE.0.) GO TO 103
      ASNMR=ASNMR
      ASDNR1=ASDNR
      IF(TF(I).LT.TF(I-1)) GO TO 111
      RHOFAC=(TFASHF/TFAVG)**ASHFAC
111   ASDNR2=(ALFA*VFSRAT*RHOFO*XFA*(XFAVG-XFASHF)/(RHOASH*
     1(1.-XFM-XFV-XFA)))*RHOFAC
      ASDNR=ASDNR1+ASDNR2
      ASBZ=ASNMR/ASDNR
      AFNMR1=AFNMR1
      AFNMR2=((1.-XFA-XFASHF)/(1.-XFM-XFV-XFA))**(2./3.)
      IF(TF(I).LT.TF(I-1)) GO TO 112
      RHOFAC=(TFASHF/TFAVG)**ASHFAC
112   IF((XFA+XFAVG) .EQ. 1.) GO TO 132
      AFNMR3=((1.-XFA-XFAVG)/(1.-XFA-XFASHF)+RHOFO*XFA*(XFAVG-XFASHF
     1)/((1.-XFA-XFASHF)*RHOASH)*RHOFAC)**(2./3.)
132   AFNMR=AFNMR1*AFNMR2*AFNMR3
      AFDNR=ASDNR
      AFBZ=AFNMR/AFDNR
103   ITER=1
      L=L+1
      IF(L.EQ.5) GO TO 93
      GO TO 102
 20   IF(ITER.EQ.1) GO TO 43
      XCAVG=XC(I-1)+(XCDEL(ITER)+XCDEL(ITER-1))/4.0
      XFAVG=XF(I-1)+(XFDEL(ITER)+XFDEL(ITER-1))/4.0
      XSAVG=XS(I-1)+(XSDEL(ITER)+XSDEL(ITER-1))/4.0
      TFAVG=TF(I-1)+(TFDEL(ITER)+TFDEL(ITER-1))/4.0
      TSAVG=TS(I-1)+(TSDEL(ITER)+TSDEL(ITER-1))/4.0
      TGAVG=TG(I-1)+(TGDEL(ITER)+TGDEL(ITER-1))/4.0
 43   ITER=ITER+1
      IF(ITER.NE.ITERMX) GO TO 82
      IF(XF(I-1).LT.(XFM+XFV)) GO TO 82
      DZ=DZ-0.005
      IF(DZ.LE.0.010) DZ=0.010
      K=K+1
      IF(K.LE.5.OR.DZ.NE.0.010) GO TO 1
      IRANDM=I
      GO TO 1
 82   IF(ITER.GT.ITERMX) GO TO 21
      GO TO 9
 21   IF(I.GT.IMAX.OR.ITER.GT.ITERMX) I=I-1
      ASCZ=ASBZ+AFBZ
      DPAVG=(DPS*WSAVG+DFAVG*(WFAVG+WAAVG))/(WSAVG+WFAVG+WAAVG)
      THCMVM=WF*XFV*HFVM
      THCMFC=WF*XFC*HFFC
      OHVMFC=THCMVM+THCMFC
      HLUFVM=WF*(BETACV-XFM)*HFVM
      THDVZN=WF*XFV*HLTDVM
      ENHCAL=WS*XSAVG*ES
      WRITE(NW,140) XFASHF,HEIGHT
      WRITE(NW,160) Z(I)
      WRITE(NW,115) TSCLID,ASCZ
      WRITE(NW,200) DPAVG,XSAVG
      WRITE(NW,170) ENGASI,ENSTNI,ENFULI
      WRITE(NW,175) ENGASO,ENSTNO,ENFULO,ENASHO
      WRITE(NW,210) DELHTL
      WRITE(NW,215) THCMVM
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      WRITE(NW,220) THCMFC
      WRITE(NW,225) OHVMFC
      WRITE(NW,230) HLUFVM
      WRITE(NW,235) THDVZN
      WRITE(NW,240) ENHCAL
      WRITE(NP,190) I
      CLOSE(UNIT=NP)
      CLOSE(UNIT=NW)
      STOP
      END
C     ******************************************************************
C     END OF MAIN PROGRAM
C     ******************************************************************
C     ******************************************************************
C     FUNCTION SUBPROGRAMS
C     ******************************************************************
      FUNCTION HFS(EFFKS,DPS,DFAVG,EMSVTY,SIGMAR,VIEWF,TFAVG,TSAVG)
      HCFS=2.0*EFFKS/(DPS+DFAVG)
      HRFS=EMSVTY*SIGMAR*VIEWF*(TFAVG**2+TSAVG**2)*(TFAVG+TSAVG)
      HFS=HCFS+HRFS
      RETURN
      END
C     ******************************************************************
      FUNCTION HFG(EBED,DFAVG,KG,MUG,CG,G,CORFAC)
      REAL KG,MUG
      RE=DFAVG*G/MUG
      PR=CG*MUG/KG
      IF(RE .EQ. 0.) GO TO 1
      HCFG=(1.9*KG/DFAVG)*(RE**0.5)*(PR**0.33)
    1 HRFG=4.5+1.33*DFAVG*EBED
      HRFG=HRFG*CORFAC
      HFG=HCFG+HRFG
      RETURN
      END
C     ******************************************************************
      FUNCTION HSG(EBED,DPS,KG,MUG,CG,G,CORFAC)
      REAL KG,MUG
      RE=DPS*G/MUG
      PR=CG*MUG/KG
      HCGS=(1.9*KG/DPS)*(RE**0.5)*(PR**0.33)
      HRGS=4.5+1.33*DPS*EBED
      HRGS=HRGS*CORFAC
      HSG=HCGS+HRGS
      RETURN
      END
C     ******************************************************************
      FUNCTION DASHKS(RGAS,TFAVG,TGAVG,DFAVG,FACTOR)
      REAL KS,KD
      KS=3.44E+11*EXP(-44000./(RGAS*TFAVG))/SQRT(TFAVG)
      KD=(0.2304*FACTOR*(TFAVG/1600.0)**0.75)/DFAVG
      DASHKS=1./(1./KS+1./KD)
      RETURN
      END
C     ******************************************************************
      FUNCTION HWA(DZ,RBEMSY,SIGMAR,TWOBNG,TAMB,DELTWO)
      HCWA=1.22*(DELTWO/DZ)**(1./4.)
      HRWA=RBEMSY*SIGMAR*(TWOBNG**2+TAMB**2)*(TWOBNG+TAMB)*0.0
      HWA=HCWA+HRWA
      RETURN
      END
C     ******************************************************************
      FUNCTION HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
      REAL KG,MUG
      DPDTR=DPAVG/DI
      RE=DPAVG*G/MUG
      HCGW1=3.50*(KG/DI)*EXP(-4.60*DPDTR)*RE**0.7
      HCGW2=0.813*(KG/DI)*EXP(-6.0*DPDTR)*RE**0.9
      HCGW=(HCGW1+HCGW2)/2.0
      HRGW=4.5+1.33*DPAVG*EBED
      HRGW=HRGW*CORFAC
      HGW=(HCGW+HRGW)*ETAGW
      RETURN
      END
C     ******************************************************************
C     END OF FUNCTION SUBPROGRAMS
C     ******************************************************************
```

```
      WRITE(NW,45) TPHZ,TPHDVZ,TPHCVM,TD,TFASHF
      WRITE(NW,85) TOLER1,TOLER2,TOLER3,TOLER4,TOLER5
      WRITE(NW,50) IMAX,ITERMX,IRANDM,MINLMT,MAXLMT
   25 FORMAT(25X,3I10)
   30 FORMAT(22X,3F12.4)
   35 FORMAT(4X,6F12.4)
   40 FORMAT(1X,7F11.4)
   45 FORMAT(10X,5F12.4)
   50 FORMAT(15X,5I10)
   55 FORMAT(1X,F7.4,2F10.6,F12.4,4F10.3)
   60 FORMAT(25X,'SIMULATION OF LIME SHAFT KILN')
   65 FORMAT(26X,'ANALYSIS OF THE BURNING ZONE')
   70 FORMAT(//80A1/)
   75 FORMAT(8F10.4)
   80 FORMAT(1X,4F11.4,E12.4,2F11.4)
   85 FORMAT(10X,5F12.5)
   90 FORMAT(16X,4F12.4)
   95 FORMAT(I5,8F8.1,F10.4)
  100 FORMAT(/3X,'I',2X,'Z(M)',6X,'XF',6X,'XS',2X,'TG(K)',2X,
     1'TF(K)',2X,'TS(K)',1X,'TW(K)',1X,'RSHLHD',1X,'DELSHT',3X,
     2'HFS',2X,'HFG',2X,'HSG',1X,'ASBZ',1X,'AFBZ',4X,'QFS',3X,
     3'QFG',2X,'QSG',1X,'DELHTL',2X,'PO2G',1X,'PCO2G'/)
  105 FORMAT(I5,6F10.1,F15.4)
  110 FORMAT(5F12.4,2F10.6)
  115 FORMAT(/2X,67HTEMPERATURE OF SOLIDS FROM BURNING ZONE AS INPUT
     1 FOR COOLING ZONE =,F7.1,' K'/3X,41HAND SPECIFIC SURFACE
     2 OF SOLID PARTICLES =,F5.2,' SQM PER CUM OF KILN VOLUME')
  120 FORMAT(I5,5F12.1,F15.9)
  125 FORMAT(5X,I5,2F15.9,3F12.4)
  130 FORMAT(I8,6F12.4)
  135 FORMAT(I8,5F10.4,2F11.6)
  140 FORMAT(/1X,25HASH FUSION STARTS AT XF =,F7.4,39H AT
     1 HEIGHT (FROM TOP OF BURNING ZONE) =,F6.3,' M')
  145 FORMAT(1X,I3,F6.3,2F8.5,3F7.1,F6.1,F7.4,F7.0,F6.1,4F5.1,F7.0,
     13F6.0,2F6.3)
  150 FORMAT(I8,2F9.6,3F9.3,7F11.4)
  155 FORMAT(//30X,19HRESULTS OF ANALYSIS/)
  160 FORMAT(/22X,28HHEIGHT OF THE BURNING ZONE =,F6.3,' M')
  165 FORMAT(F10.4,2F14.4,3F14.2)
  170 FORMAT(/2X,41HENTHALPIES OF GAS,STONE AND FUEL AT TOP =,
     1F8.1,',',F8.1,' &',F8.1,' KCAL/HR')
  175 FORMAT(/15X,48HENTHALPIES OF GAS,STONE,FUEL AND ASH AT BOTTOM
     1 =/18X,F8.1,',',F8.1,',',F7.1,' &',F8.1,' KCAL/HR')
  180 FORMAT(F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,','
     1,F5.3)
  185 FORMAT(F6.4,',',F6.4,',',F6.4,',',F7.2,',',F7.2,',',F7.2)
  190 FORMAT(1X,I4)
  195 FORMAT(8CA1)
  200 FORMAT(/1X,33HAVERAGE SIZE OF SOLID PARTICLES =,F6.3,' M',28H
     1 AND DEGREE OF CALCINATION =,F7.4)
  205 FORMAT(/)
  210 FORMAT(/10X,43HHEAT LOSS THROUGH WALL OF BURNING SECTION =,
     1F9.1,' KCAL/HR')
  215 FORMAT(/8X,45HTOTAL HEAT OF COMBUSTION OF VOLATILE MATTER =,
     1F10.1,' KCAL/HR')
  220 FORMAT(/10X,42HTOTAL HEAT OF COMBUSTION OF FIXED CARBON =,
     1F10.1,' KCAL/HR')
  225 FORMAT(/6X,50HOVERALL HEAT OF VOLATILE MATTER AND FIXED CARBON
     1 =,F10.1,' KCAL/HR')
  230 FORMAT(/6X,50HHEAT LOSS IN UNBURNT FRACTION OF VOLATILE MATTER
     1 =,F10.1,' KCAL/HR')
  235 FORMAT(/11X,40HTOTAL LATENT HEAT FOR DEVOLATILIZATION =,
     1F10.1,' KCAL/HR')
  240 FORMAT(/4X,53HTOTAL ENDOTHERMIC HEAT FOR CALCINATION OF LIME
     1STONE =,F10.1,' KCAL/HR')
      AREA=TPD/FS
      RI=SQRT(AREA/3.14)
      DI=2.*RI
      WS=PS*AREA*1000.*100./(24.*56.)
      WF=WS/XRINFD
C     ************************************************************
C     THEORETICAL AIR REQUIREMENT AND HEAT OF COMBUSTION OF VM
C     ************************************************************
      THO2VM=(77.77/20.)*XFV
      THO2FC=(32./12.)*XFC
      TOTLO2=THO2VM+THO2FC
      TOTLN2=TOTLO2/0.305
      THAIR=TOTLO2+TOTLN2
      WA=WF*THAIR*(1.+XEA)
      VMFDAF=XFV/(XFV+XFC)
```

```
C ***************************************************************
C              SIMULATION OF LIME SHAFT KILN :
C PROGRAMME FOR THE ANALYSIS OF COOLING ZONE STARTING FROM UPPER SIDE
C ***************************************************************
      DIMENSION TS(400),TF(400),TG(400),DATAIN(80)
      REAL KG,MUG
      OPEN(UNIT=1,FILE='CLG.DAT',TYPE='OLD')
      READ(1,95) DATAIN
      READ(1,*) NP,NW,NPRINT,IMAX
      OPEN(UNIT=NW,FILE='CLGRES.OUT',TYPE='NEW')
      OPEN(UNIT=NP,FILE='CLGPLT.OUT',TYPE='NEW')
C     ***************************************************************
C     THE FORTRAN VARIABLES USED IN THE FOLLOWING ARE DEFINED AFTER
C     EACH STATEMENT GENERALLY IN ORDER OF THEIR APPEARANCE
C     ***************************************************************
      READ(1,*) TG(1),TF(1),TS(1)
C     (TEMPERATURES OF BULK GAS,FUEL AND STONE SURFACE)
      READ(1,*) PS,XRINFD,TPD,DPS,DPF,DZ
C     (SUPERFICIAL PRODUCT OUTPUT RATE BASED ON EMPTY KILN CROSS-
C     SECTION,STONE-TO-FUEL-RATIO IN KILN FEED INPUT,NOMINAL
C     PRODUCTION RATE OF LIME SHAFT KILN,PARTICLE SIZE OF LIMESTONE,
C     COAL IN KILN FEED,AXIAL WIDTH OF DIFFERENTIAL ELEMENT)
      READ(1,*) DPAVG,XSAVG,ASCZ,EBED,GAMMA,ETASG,ETAGW
C     (AVERAGE SIZE OF SOLIDS,DEGREE OF CALCINATION OF LIMESTONE,
C     INTERFACIAL PACKING SURFACE OF SOLIDS,BED POROSITY,
C     CONSTANT FOR EMISSIVITY,EFFECTIVENESS FACTOR FOR HEAT EXCHANGE)
      READ(1,*) XFM,XFV,XFC,XFA,XEA
C     (FRACTIONAL VALUES OF MOISTURE CONTENT,VOLATILE MATTER,FIXED
C     CARBON,ASH CONTENT OF FUEL AND EXCESS AIR)
      READ(1,*) KG,MUG,TAMB,TWOCLG
C     THERMAL CONDUCTIVITY OF GAS,VISCOSITY OF GAS,AMBIENT TEMPERATU-
C     RE,EXTERNAL WALL TEMPERATURE)
      READ(1,*) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,SIGMAR
C     (THERMAL CONDUCTIVITIES OF FIRE BRICKS,RED BURNT CLAY BRICKS,
C     THICKNESSES OF FIRE BRICKS INSULATION,RED BRICKS,EMISSIVITY OF
C     RED BRICKS SURFACE,RADIATION CONSTANT)
      WRITE(NW,25)
      WRITE(NW,30)
      WRITE(NW,35) DATAIN
      WRITE(NW,05) NP,NW,NPRINT,IMAX
      WRITE(NW,10) TG(1),TF(1),TS(1)
      WRITE(NW,50) PS,XRINFD,TPD,DPS,DPF,DZ
      WRITE(NW,45) DPAVG,XSAVG,ASCZ,EBED,GAMMA,ETASG,ETAGW
      WRITE(NW,15) XFM,XFV,XFC,XFA,XEA
      WRITE(NW,60) KG,MUG,TAMB,TWOCLG
      WRITE(NW,20) FBCDTY,RBCDTY,FBTHIK,RBTHIK,RBEMSY,SIGMAR
    5 FORMAT(20X,4I10)
   10 FORMAT(22X,3F12.4)
   15 FORMAT(10X,5F12.4)
   20 FORMAT(4X,5F12.4,E12.4)
   25 FORMAT(25X,'SIMULATION OF LIME SHAFT KILN')
   30 FORMAT(26X,'ANALYSIS OF THE COOLING ZONE')
   35 FORMAT(//80A1/)
   40 FORMAT(//30X,19HRESULTS OF ANALYSIS/)
   45 FORMAT(1X,7F11.4)
   50 FORMAT(4X,6F12.4)
   55 FORMAT(/24X,27HHEIGHT OF THE COOLING ZONE=,F5.3,'M')
   60 FORMAT(16X,4F12.4)
   65 FORMAT(1X,I4,F11.3,3F10.2,2F7.1,2F9.1)
   70 FORMAT(/1X,62HENTHALPIES OF PRODUCT LIME AND ASH/CINDERS AT
```

```
     1 BOTTOM OF KILN =,F8.1,' KCAL/HR')
  75 FORMAT(16X,F16.4,2F16.2)
  80 FORMAT(F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,',',F5.3,',',
     1,F5.3)
  85 FORMAT(F6.4,',',F7.2,',',F7.2)
  90 FORMAT(1X,I4)
  95 FORMAT(80A1)
 100 FORMAT(/4X,'I',7X,'Z(M)',5X,'TG(K)',5X,'TS(K)',5X,'TW(K)',4X,
     1'HSG',3X,'ASCZ',6X,'QSG',3X,'DELHTL'/)
 105 FORMAT(/11X,42HENTHALPY OF AIR INTO LIME KILN AT BOTTOM =,
     1F8.1,' KCAL/HR')
 110 FORMAT(/10X,43HHEAT LOSS THROUGH WALL OF COOLING SECTION =,
     1F9.1,' KCAL/HR')
     AREA=TPD/PS
     RI=SQRT(AREA/3.14)
     DI=2.*RI
     WS=PS*AREA*1000.*100./(24.*56.)
     WF=WS/XRINFD
C    ****************************************************************
C    THEORETICAL AIR REQUIREMENT
C    ****************************************************************
     THO2VM=(77.77/20.)*XFV
     THO2FC=(32./12.)*XFC
     TOTLO2=THO2VM+THO2FC
     TOTLN2=TOTLO2/0.305
     THAIR=TOTLO2+TOTLN2
     WA=WF*THAIR*(1.+XEA)
C    ****************************************************************
     WRITE(NW,15) AREA,DI,WS,WF,WA
     WRITE(NW,40)
     WRITE(NP,80) PS,DPS,DPF,XRINFD,XFV,XFC,XEA
     WRITE(NW,100)
     RFB=RI+FBTHIK
     RO=RFB+RBTHIK
     DO=2.*RO
     CSTKLN=(ALOG(RFB/RI)/FBCDTY)+(ALOG(RO/RFB)/RBCDTY)
     CORFAC=1.-GAMMA
     ASSCLZ=ETASG
     WSCLZ=WS*XSAVG*0.56+WS*(1.-XSAVG)+WF*XFA
     WGCLZ=WA
     DV=AREA*DZ
     DAS=ASCZ*ASSCLZ*DV
     G=WGCLZ/AREA
     WGAVG=WA
     WSAVG=WSCLZ
     WAVGTL=WGAVG+WSAVG
     XWG=WGAVG/WAVGTL
     XWS=WSAVG/WAVGTL
     TWO=TWOCLG
     I=1
   1 TGAVG=TG(I)
     TSAVG=TS(I)
     TFAVG=TSAVG
     TBOPRG=TGAVG*XWG+TSAVG*XWS
C    ****************************************************************
C    SPECIFIC HEATS OF DIFFERENT CONSTITUENTS
C    ****************************************************************
     CS=0.1968+(0.1189*TSAVG*10.**-3)-(0.3076*10.**4)/(TSAVG**2)
     CL=0.1786+(0.0864*TSAVG*10.**-3)-(0.1928*10.**4)/(TSAVG**2)
     CFASH=(-0.1640+(0.1136*TFAVG*10.**-2)-(0.49*TFAVG*TFAVG*10.**
```

```
     1-6))*0.75
     CSAVG=(WS*XSAVG*0.56*CL+WS*(1.-XSAVG)*CS+WF*XFA*CFASH)/WSCLZ
     CG=0.2372+(0.2900*TGAVG*10.**-4)-(1360./TGAVG**2)
C    ****************************************************************
     AHSG=HSG(EBED,DPAVG,KG,MUG,CG,G,CORFAC)
     TGI=TGAVG
   2 Z=(FLOAT(I)-1.)*DZ
     QSG=AHSG*(TS(I)-TG(I))
     X=(I/NPRINT)-FLOAT(I)/FLOAT(NPRINT)
     IF(X.NE.0) GO TO 7
     TYPE 60,Z,TG(I),TF(I),TS(I)
     WRITE(NP,85)Z,TG(I),TS(I)
     WRITE(NW,65)I,Z,TG(I),TS(I),TWO,AHSG,ASCZ,QSG,DELHTL
     IF(TG(I).LE.TAMB) GO TO 21
   7 I=I+1
     IF(I.GT.IMAX) GO TO 21
C    ****************************************************************
C    ESTIMATION OF WALL HEAT LOSSES
C    ****************************************************************
     DELTWO=TWOCLG-TAMB
     AHWA=HWA(DZ,RBEMSY,SIGMAR,TWOCLG,TAMB,DELTWO)
     AHGW=HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
     IF(AHWA.EQ.0.) GO TO 3
     UIEFFI=RI*(1./(RI*AHGW)+CSTKLN+1./(RO*AHWA))
     UIEFF=1./UIEFFI
     DELHL=UIEFF*2.*3.14*DZ*RI*(TGI-TAMB)
     DELHTL=DELHTL+DELHL
     TWI=TGI-DELHL/(3.14*DI*DZ*AHGW)
     TWO=TAMB+DELHL/(3.14*DO*DZ*AHWA)
     TWOCLG=TWO
C    ****************************************************************
   3 TS(I)=TS(I-1)-AHSG*(TS(I-1)-TG(I-1))*DAS/(WSCLZ*CSAVG)
     TF(I)=TS(I)
     DELHS=WSCLZ*CSAVG*(TS(I)-TS(I-1))
     TG(I)=TG(I-1)+(DELHS-DELHL)/(WGCLZ*CG)
     DELTG=TG(I)-TG(I-1)
     DELTF=TF(I)-TF(I-1)
     DELTS=TS(I)-TS(I-1)
     GO TO 1
  21 IF(I.GT.IMAX) I=I-1
     HCLZ=Z
     SHLPLM=WSCLZ*CSAVG*(TS(I)-273.0)
     ENAIRI=WA*CG*(TG(I)-273.0)
     WRITE(NW,55)HCLZ
     WRITE(NW,70)SHLPLM
     WRITE(NW,105)ENAIRI
     WRITE(NW,110)DELHTL
     WRITE(NP,90)I
     CLOSE(UNIT=1)
     CLOSE(UNIT=NP)
     CLOSE(UNIT=NW)
     STOP
     END

C    ****************************************************************
C    END OF MAIN PROGRAM
C    ****************************************************************
```

```
C     ****************************************************************
C     FUNCTION SUBPROGRAMS
C     ****************************************************************

      FUNCTION HSG(EBED,DPAVG,KG,MUG,CG,G,CORFAC)
      REAL KG,MUG
      RE=DPAVG*G/MUG
      PR=CG*MUG/KG
      HCSG=(1.9*KG/DPAVG)*(RE**0.5)*(PR**0.33)
      HRSG=4.5+1.33*DPAVG*EBED
      HRSG=HRSG*CORFAC
      HSG=HCSG+HRSG
      RETURN
      END

C     ****************************************************************

      FUNCTION HWA(DZ,RBEMSY,SIGMAR,TWOCLG,TAMB,DELTWO)
      HCWA=1.22*(DELTWO/DZ)**(1./4.)
      HRWA=RBEMSY*SIGMAR*(TWOCLG**2+TAMB**2)*(TWOCLG+TAMB)*0.0
      HWA=HCWA+HRWA
      RETURN
      END

C     ****************************************************************

      FUNCTION HGW(EBED,DPAVG,DI,KG,MUG,G,CORFAC,ETAGW)
      REAL KG,MUG
      DPDTR=DPAVG/DI
      RE=DPAVG*G/MUG
      HCGW1=3.50*(KG/DI)*EXP(-4.6*DPDTR)*RE**0.7
      HCGW2=0.813*(KG/DI)*EXP(-6.0*DPDTR)*RE**0.9
      HCGW=(HCGW1+HCGW2)/2.0
      HRGW=HRGW*CORFAC
      HGW=(HCGW+HRGW)*ETAGW
      RETURN
      END

C     ****************************************************************
C     END OF FUNCTION SUBPROGRAMS
C     ****************************************************************
```

(APPENDIX-F)

NOMENCLATURE AND TABLES OF SIMULATION RESULTS

AFBZ Interfacial area of fuel particles in burning zone, m^2/m^3 of bed volume

AFPZ Interfacial area of fuel particles in preheating zone, m^2/m^3 of bed volume

ASBZ Interfacial area of lime-limestone particles in burning zone, m^2/m^3 of bed volume

ASCZ Interfacial area of solid mass in cooling zone, m^2/m^3 of bed volume

ASPZ Interfacial area of limestone particles in preheating zone

DELHTL Cumulative wall heat loss upto a given axial location Z (ith grid point) in a zone, Kcal/hr

DELSHT Sensible heat accumulation in lime layer upto a given axial location (ith grid point) in burning zone, Kcal/hr

DPF Particle size of fuel, m

DPS Particle size of limestone, m

HFZ Heat transfer coefficient from fuel particles to gas, Kcal/(hr) (m^2) (K)

HFS Heat transfer coefficient from fuel to stone particles, Kcal/(hr) $(m^2)(K)$

HSG Heat transfer coefficient from stone particles to gas phase, Kcal/(hr) (m^2) (K)

I Grid point in a zone (I = 1 at Z = 0)

PCO2G Partial pressure of carbon dioxide, atm

PO2G Partial pressure of oxygen, atm

PS Superficial product lime output rate, $t/(m^2)$ (day)

QFG Heat exchange rate from fuel to gas, Kcal/hr

QFS Heat exchange rate from fuel to stone particles, Kcal/hr

QSG Heat exchange rate from stone particles to gas, Kcal/hr

RSHLHD Ratio of sensible heat change of the lime layer to total heat received by limestone-lime particles in burning zone (interval Δ Z)

TF Temperature of fuel particles, K

TG Temperature of bulk gas phase, K

TS Temperature of solid particles/mass, surface temperature of limestone-lime particles, K

TW External wall temperature of kiln surface, K

XEA Excess air fraction

XF Fractional fuel conversion based on original mass

XFC Mass fraction of fixed carbon content in fuel

XFV Mass fraction of volatile matter content in fuel

XRINFD Limestone to fuel ratio (W/W) in feed input to lime kiln

XS Fractional conversion of limestone based on original mass

Z Axial position along a zone from its upper section to the lower side, m

TABLE F .1 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 1 (A)

(AVERAGE CONDITIONS)

				2		3		1				
				748.0000		300.0000		300.0000				
				2.2500		5.5000		10.0000				
	C.1000		C.0500		C.8000		C.8000		C.4500		C.0500	
		C.0500		C.2250		C.4750		C.2500		C.1250		
		1400.0000		2400.0000		C.2500		875.0000		650.0000		
		C.0250		C.0500		C.2000		C.1500		C.1000		
			C.0850		C.9000		8.0000		10.0000			
	1.0100	C.6000		C.2300		C.6900		C.9000		300.0000	318.0000	
	C.0467		C.1336		C.9000	1.9870		C.496CE-07		1.0000		C.0000
			673.0000		948.0000		1173.0000		C.0250		C.0250	
				200		100		195		5		198
		2.3794		744.0477		135.2814		1394.5542		5925.4355		9024.1592

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.000000	748.00	300.00	300.00	318.00	4.93	25.07	19.08	40.11	12.50	0.0	0.0	0.0	0.0
2	0.050	0.000000	754.67	342.86	313.14	318.92	5.92	25.08	19.09	40.11	12.50	97.8	-1434.8	-1878.5	0.0
3	0.100	0.000000	761.06	379.28	326.48	318.97	6.97	25.10	19.10	40.11	12.50	204.6	-1331.0	-1850.0	134.2
4	0.150	0.000628	767.41	391.03	339.77	319.23	7.79	25.09	19.10	40.11	12.50	221.8	-1311.9	-1819.7	202.2
5	0.200	0.001255	773.66	401.88	352.73	319.41	8.60	25.09	19.09	40.11	12.50	354.7	-1295.7	-1790.3	272.2
6	0.250	0.001883	779.80	411.90	365.37	319.60	9.41	25.08	19.08	40.11	12.50	243.3	-1281.8	-1762.0	342.1
7	0.300	0.002500	785.86	421.40	377.69	319.79	10.22	25.08	19.07	40.11	12.50	248.3	-1269.2	-1734.9	413.7
8	0.350	0.003125	791.83	430.49	389.71	319.97	11.04	25.07	19.06	40.11	12.50	250.1	-1256.9	-1708.1	485.7
9	0.400	0.003750	797.73	439.26	401.43	320.15	11.86	25.06	19.05	40.11	12.50	249.4	-1247.9	-1682.6	558.5
10	0.450	0.004375	803.54	447.85	412.85	320.32	12.69	25.06	19.05	40.11	12.50	246.7	-1237.9	-1658.0	632.1
11	0.500	0.005000	809.28	456.28	424.00	320.49	13.52	25.05	19.04	40.11	12.50	242.5	-1228.5	-1634.3	706.6
12	0.550	0.005000	814.78	461.71	435.27	320.66	14.86	25.06	19.05	40.11	12.50	383.5	-1159.3	-1610.6	781.1
13	0.600	0.005000	820.18	501.83	447.02	320.84	16.11	25.08	19.09	40.11	12.50	490.8	-1108.6	-1584.1	855.7
14	0.650	0.005000	825.50	518.02	459.02	321.01	17.29	25.09	19.06	40.11	12.50	566.8	-1070.6	-1555.9	934.4
15	0.700	0.005000	830.37	531.44	471.11	321.19	18.41	25.10	19.07	40.11	12.50	617.0	-1044.2	-1526.7	1011.7
16	0.750	0.005000	835.32	542.90	483.17	321.34	19.49	25.11	19.08	40.11	12.50	646.8	-1020.7	-1497.2	1089.9
17	0.800	0.005000	840.16	553.12	495.08	321.50	20.55	25.12	19.09	40.11	12.50	662.6	-1001.7	-1467.8	1169.1
18	0.850	0.005000	844.92	562.53	506.80	321.66	21.60	25.14	19.10	40.11	12.50	669.0	-985.9	-1438.5	1249.4
19	0.900	0.005000	849.59	571.41	518.28	321.81	22.66	25.15	19.10	40.11	12.50	669.0	-971.6	-1410.4	1329.7
20	0.950	0.005000	854.17	579.96	529.51	321.96	23.72	25.16	19.11	40.11	12.50	665.0	-958.6	-1382.7	1411.0
21	1.000	0.005000	858.67	588.27	540.46	322.11	24.80	25.17	19.12	40.11	12.50	658.5	-945.3	-1355.6	1492.2
22	1.050	0.005000	863.09	596.42	551.19	322.25	25.89	25.18	19.13	40.11	12.50	650.5	-932.6	-1329.2	1574.4
23	1.100	0.005000	867.43	604.45	561.65	322.39	26.99	25.19	19.14	40.11	12.50	641.7	-920.1	-1303.8	1657.5
24	1.150	0.005000	871.69	612.38	571.86	322.53	28.10	25.20	19.14	40.11	12.50	632.7	-907.7	-1278.9	1741.5
25	1.200	0.005000	875.89	620.22	581.84	322.67	29.23	25.21	19.15	40.11	12.50	623.4	-895.3	-1254.7	1826.5
26	1.250	0.005000	880.01	627.98	591.58	322.80	30.37	25.22	19.16	40.11	12.50	614.1	-882.9	-1231.2	1912.4
27	1.300	0.005000	884.06	635.62	601.09	322.93	31.53	25.23	19.16	40.11	12.50	604.9	-870.6	-1208.3	1999.3
28	1.350	0.005000	888.04	643.19	610.39	323.06	32.69	25.24	19.17	40.11	12.50	595.7	-858.4	-1186.2	2087.2
29	1.400	0.005000	891.95	650.67	619.49	323.19	33.87	25.25	19.18	40.11	12.50	586.7	-846.2	-1164.7	2176.0
30	1.450	0.005000	895.80	658.05	628.38	323.31	35.06	25.26	19.18	40.11	12.50	577.9	-834.1	-1143.8	2265.7
31	1.500	0.005000	899.58	665.34	637.08	323.43	36.25	25.27	19.19	40.11	12.50	569.1	-822.1	-1123.5	2356.4
32	1.550	0.005000	903.30	672.53	645.59	323.55	37.45	25.27	19.20	40.11	12.50	560.5	-810.2	-1103.8	2448.0
33	1.600	0.005000	906.96	679.58	653.91	323.67	38.66	25.28	19.20	40.11	12.50	551.9	-798.5	-1084.7	2540.5
34	1.650	0.005196	910.53	683.95	661.98	323.78	39.70	25.29	19.20	40.11	12.50	543.4	-795.5	-1066.3	2633.9
35	1.700	0.005349	914.05	687.44	669.84	323.89	40.65	25.29	19.20	40.11	12.50	540.2	-796.0	-1048.5	2728.2
36	1.750	0.005547	917.52	691.72	677.73	323.99	41.60	25.29	19.20	40.11	12.50	536.9	-793.3	-1030.1	2823.4
37	1.800	0.005781	920.95	696.98	685.46	324.10	42.72	25.29	19.20	40.11	12.50	532.5	-786.9	-1016.2	2919.5
38	1.850	0.006038	924.34	702.09	693.05	324.19	43.82	25.29	19.20	40.11	12.50	527.1	-778.7	-1003.2	3016.5
39	1.900	0.006298	927.69	708.35	700.53	324.29	44.93	25.29	19.20	40.11	12.50	520.1	-770.6	-990.6	3114.4
40	1.950	0.006542	930.99	713.79	707.89	324.39	46.03	25.29	19.20	40.11	12.50	492.2	-763.1	-978.0	3213.2
41	2.000	0.006788	934.25	719.20	715.14	324.48	47.14	25.29	19.20	40.11	12.50	478.9	-755.6	-965.5	3312.9
42	2.050	0.007036	937.48	724.65	722.28	324.57	48.29	25.29	19.20	40.11	12.50	468.7	-747.7	-953.1	3413.5
43	2.100	0.007287	940.66	730.12	729.31	324.66	49.58	25.29	19.19	40.11	12.50	461.8	-739.7	-941.2	3515.0
44	2.150	0.007537	943.79	735.55	736.24	324.75	50.50	25.29	19.19	40.11	12.50	456.6	-731.6	-929.7	3617.4
45	2.200	0.007783	946.89	740.91	732.10	324.84	51.63	25.29	19.19	40.11	12.50	252.7	-723.7	-918.5	3620.9

46	2.250	0.0[illegible]026	949.95	746.25	717.71	324.91	52.75	25.29	19.19	40.11	12.50	248.8	-[illegible]	-9[illegible]	[illegible]
47	2.300	0.0[illegible]207	956.85	751.45	743.24	325.01	53.68	25.29	19.19	40.11	12.50	244.9	-[illegible]	-8[illegible]	[illegible]
48	2.350	0.0[illegible]504	956.92	756.75	748.70	325.10	54.98	25.29	19.19	40.11	12.50	240.9	-[illegible]	-8[illegible]	[illegible]
49	2.400	0.0[illegible]735	956.98	761.78	754.07	325.18	56.11	25.29	19.18	40.11	12.50	240.3	-[illegible]	-8[illegible]	[illegible]
50	2.450	0.0[illegible]960	961.61	766.94	759.38	325.26	57.24	25.29	19.18	40.11	12.50	239.1	-[illegible]	-8[illegible]	[illegible]
51	2.500	0.0[illegible]105	964.71	771.98	764.61	325.34	58.37	25.29	19.18	40.11	12.50	238.5	-[illegible]	-8[illegible]	[illegible]
52	2.550	0.0[illegible]411	967.56	776.94	769.78	325.42	59.49	25.29	19.18	40.11	12.50	237.7	-[illegible]	-8[illegible]	[illegible]
53	2.600	0.0[illegible]647	970.37	781.82	774.88	325.50	60.61	25.29	19.18	40.11	12.50	236.9	-[illegible]	-8[illegible]	[illegible]
54	2.650	0.0[illegible]842	973.15	786.64	779.91	325.58	61.72	25.29	19.17	40.11	12.50	236.1	-[illegible]	-8[illegible]	[illegible]
55	2.700	0.1[illegible]054	975.90	791.40	784.87	325.66	62.84	25.29	19.17	40.11	12.50	235.3	-[illegible]	-8[illegible]	[illegible]
56	2.750	0.1[illegible]269	978.61	796.11	789.76	325.74	63.95	25.29	19.17	40.11	12.50	234.5	-[illegible]	-8[illegible]	[illegible]
57	2.800	0.1[illegible]470	981.30	800.74	794.58	325.81	65.06	25.29	19.17	40.11	12.50	233.7	-[illegible]	-8[illegible]	[illegible]
58	2.850	0.1[illegible]675	983.95	805.34	799.33	325.88	66.17	25.29	19.17	40.11	12.50	232.9	-[illegible]	-8[illegible]	[illegible]
59	2.900	0.1[illegible]874	986.57	809.84	804.01	325.95	67.28	25.29	19.17	40.11	12.50	232.1	-[illegible]	-8[illegible]	[illegible]
60	2.950	0.1[illegible]074	989.16	814.31	808.62	326.02	68.38	25.29	19.17	40.11	12.50	231.3	-[illegible]	-8[illegible]	[illegible]
61	3.000	0.1[illegible]270	991.72	818.72	813.16	326.10	69.49	25.29	19.17	40.11	12.50	230.5	-[illegible]	-8[illegible]	[illegible]
62	3.050	0.1[illegible]464	994.25	823.07	817.64	326.17	70.57	25.29	19.17	40.11	12.50	229.7	-[illegible]	-8[illegible]	[illegible]
63	3.100	0.1[illegible]656	996.76	827.37	822.05	326.24	71.65	25.29	19.16	40.11	12.50	228.9	-[illegible]	-8[illegible]	[illegible]
64	3.150	0.1[illegible]845	999.25	831.62	826.40	326.31	72.75	25.29	19.16	40.11	12.50	228.1	-[illegible]	-8[illegible]	[illegible]
65	3.200	0.1[illegible]032	1001.71	835.81	830.68	326.37	73.84	25.29	19.16	40.11	12.50	227.3	-[illegible]	-8[illegible]	[illegible]
66	3.250	0.1[illegible]217	1004.16	839.96	834.90	326.44	74.92	25.29	19.16	40.11	12.50	226.5	-[illegible]	-8[illegible]	[illegible]
67	3.300	0.1[illegible]400	1006.58	844.05	839.05	326.50	76.00	25.29	19.16	40.11	12.50	225.7	-[illegible]	-8[illegible]	[illegible]
68	3.350	0.1[illegible]582	1008.97	848.08	843.15	326.57	77.08	25.29	19.16	40.11	12.50	224.9	-[illegible]	-8[illegible]	[illegible]
69	3.400	0.1[illegible]763	1011.34	852.07	847.19	326.63	78.15	25.29	19.16	40.11	12.50	224.1	-[illegible]	-8[illegible]	[illegible]
70	3.450	0.1[illegible]943	1013.68	856.01	851.17	326.70	79.22	25.29	19.16	40.11	12.50	223.3	-[illegible]	-8[illegible]	[illegible]
71	3.500	0.1[illegible]122	1016.00	859.91	855.11	326.76	80.29	25.29	19.15	40.11	12.50	222.5	-[illegible]	-8[illegible]	[illegible]
72	3.550	0.1[illegible]301	1018.30	863.78	859.00	326.82	81.36	25.29	19.15	40.11	12.50	221.7	-[illegible]	-8[illegible]	[illegible]
73	3.600	0.1[illegible]479	1020.57	867.61	862.85	326.88	82.43	25.29	19.15	40.11	12.50	220.9	-[illegible]	-8[illegible]	[illegible]
74	3.650	0.1[illegible]657	1022.82	871.34	867.42	326.94	83.49	25.29	19.15	40.11	12.50	220.1	-[illegible]	-8[illegible]	[illegible]
75	3.700	0.1[illegible]834	1025.06	875.06	871.25	327.00	84.55	25.29	19.15	40.11	12.50	219.3	-[illegible]	-8[illegible]	[illegible]
76	3.750	0.1[illegible]010	1027.28	878.71	875.00	327.06	85.62	25.29	19.15	40.11	12.50	218.5	-[illegible]	-8[illegible]	[illegible]
77	3.800	0.1[illegible]186	1029.48	882.36	878.71	327.12	86.68	25.29	19.15	40.11	12.50	217.7	-[illegible]	-8[illegible]	[illegible]
78	3.850	0.1[illegible]361	1031.66	885.94	882.39	327.18	87.74	25.29	19.15	40.11	12.50	216.9	-[illegible]	-8[illegible]	[illegible]
79	3.900	0.1[illegible]536	1033.83	889.49	886.01	327.24	88.80	25.29	19.15	40.11	12.50	216.1	-[illegible]	-8[illegible]	[illegible]
80	3.950	0.1[illegible]710	1035.98	892.99	889.60	327.29	89.86	25.29	19.14	40.11	12.50	215.3	-[illegible]	-8[illegible]	[illegible]
81	4.000	0.1[illegible]884	1038.12	896.45	893.14	327.35	90.92	25.29	19.14	40.11	12.50	214.5	-[illegible]	-8[illegible]	[illegible]
82	4.050	0.1[illegible]057	1040.24	899.88	896.64	327.41	91.98	25.29	19.14	40.11	12.50	213.7	-[illegible]	-8[illegible]	[illegible]
83	4.100	0.1[illegible]229	1042.35	903.29	900.09	327.46	93.04	25.29	19.14	40.11	12.50	212.9	-[illegible]	-8[illegible]	[illegible]
84	4.150	0.1[illegible]401	1044.44	906.67	903.51	327.51	94.09	25.29	19.14	40.11	12.50	212.1	-[illegible]	-8[illegible]	[illegible]
85	4.200	0.1[illegible]573	1046.52	909.99	906.89	327.56	95.14	25.29	19.14	40.11	12.50	211.3	-[illegible]	-8[illegible]	[illegible]
86	4.250	0.1[illegible]744	1048.58	913.18	910.22	327.62	96.19	25.29	19.14	40.11	12.50	210.5	-[illegible]	-8[illegible]	[illegible]
87	4.300	0.1[illegible]914	1050.63	916.28	913.52	327.67	97.24	25.29	19.14	40.11	12.50	209.7	-[illegible]	-8[illegible]	[illegible]
88	4.350	0.1[illegible]084	1052.67	919.28	916.78	327.72	98.29	25.29	19.14	40.11	12.50	208.9	-[illegible]	-8[illegible]	[illegible]
89	4.400	0.1[illegible]254	1054.70	922.17	919.01	327.77	99.34	25.29	19.14	40.11	12.50	208.1	-[illegible]	-8[illegible]	[illegible]
90	4.450	0.1[illegible]424	1056.72	924.95	921.19	327.82	100.39	25.29	19.13	40.11	12.50	207.3	-[illegible]	-8[illegible]	[illegible]
91	4.500	0.1[illegible]593	1058.73	927.61	923.34	327.87	101.43	25.29	19.13	40.11	12.50	206.5	-[illegible]	-8[illegible]	[illegible]
92	4.550	0.1[illegible]762	1060.73	930.04	925.45	327.92	102.48	25.29	19.13	40.11	12.50	205.7	-[illegible]	-8[illegible]	[illegible]
93	4.600	0.1[illegible]930	1062.72	932.53	927.53	327.97	103.52	25.29	19.13	40.11	12.50	204.9	-[illegible]	-8[illegible]	[illegible]
94	4.650	0.1[illegible]097	1064.70	934.66	929.58	328.02	104.57	25.29	19.13	40.11	12.50	204.1	-[illegible]	-8[illegible]	[illegible]
95	4.700	0.16772	1066.39	941.01	938.59	328.07	105.53	25.29	19.13	40.11	12.50	203.3	-[illegible]	-8[illegible]	[illegible]
96	4.750	0.1[illegible]06	1068.17	943.94	941.56	328.11	106.49	25.29	19.13	40.11	12.50	202.5	-[illegible]	-8[illegible]	[illegible]
97	4.800	0.17039	1067.95	946.83	944.51	328.16	106.44	25.29	19.13	40.11	12.50	201.7	-[illegible]	-8[illegible]	[illegible]
98	4.850	0.1717C	1069.70	949.69	947.42	328.21	107.38	24.56	12.61	40.11	12.50	200.9	-[illegible]	-8[illegible]	[illegible]

VM COMBUSTION STARTS AT XF = 0.1717 AND AT HEIGHT (FROM TOP) = 4.850 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.850 M

ENTHALPIES OF GAS,STONE AND FUEL AT TOP =245730.2, 3983.5 & 913.1 KCAL/HR

ENTHALPIES OF GAS,STONE AND FUEL AT BOTTOM =452915.6,153376.8 & 24383.5 KCAL/HR

HEAT LOSS THROUGH WALL OF PREHEATING SECTION = 9134.4 KCAL/HR

TOTAL HEAT FOR DEMOISTURIZATION = 5918.6 KCAL/HR

TABLE P.1 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 1 (A)

(AVERAGE CONDITIONS)

			2	3	1				
	0.1717C		0.CCCCC	1C69.69995	949.69000	947.41998			
			2.25CC	5.5000	10.CCCC				
	C.1CCC	C.05CC	C.8CCC	C.8CCC	C.45CC	C.05CC			
	C.C5CC		0.225C	0.475C	0.25CC	0.125C			
0.C25C	C.05CC		0.2000	0.0125	C.0150	0.15CC	0.1000		
	400.CCCC	E200.CCCC		5.0000	10.CCCC	650.CCCC			
1.0160	C.6CCC		0.23CC	0.6900	0.9000	30C.CCCC	328.2100		
0.0440	C.1256		C.8CCC	1.9870	0.45E0E-07	1.0000	C.6CCC		
24C0.0000	140C.CCCC	720.CCCC		1.2500	C.C850	0.1717	0.5000		
	673.CCCC	948.CCCC	1173.CCCC	1173.CCCC	1573.CCCC				
	0.C2500	C.2CCCC	0.C5000	C.CCCC1	0.C1000				
150	1CC	149	2	149					
2.3794	744.C477	135.2814	1394.5542	9024.1592					

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELMTL	PC2G	PC02G
1	C.CCC	0.17170	0.CCCCC	1069.7	949.7	947.4	337.2	C.CCCC	C.	107.2	24.5	18.6	40.1	12.5	135.	-405.	-506.	0.	0.C54	0.242
2	C.C5C	C.1C6C3	C.CCCCC	1069.5	1125.9	970.1	337.2	C.CCCCC	C.	143.9	24.4	18.5	40.1	12.5	12426.	191.	-411.	110.	0.C57	0.244
3	C.1CC	C.1C6C3	C.CCCCC	1C69.7	1122.4	1016.8	337.7	C.CCCCC	C.	151.9	24.3	18.4	40.1	12.5	8916.	185.	-201.	220.	0.C56	0.247
4	C.15C	C.1C6C3	C.CCCCC	1C69.3	1119.7	1055.4	337.7	C.CCCCC	C.	158.1	24.2	18.3	40.1	12.5	9702.	318.	-41.	329.	0.C56	0.249
5	C.2CC	C.1C6C3	C.CCCCC	1C68.6	1118.1	1093.4	337.7	C.CCCCC	C.	165.1	24.1	18.2	40.1	12.5	9164.	408.	120.	437.	0.C56	0.251
6	C.25C	C.1C6C3	C.CCCCC	1C68.1	1117.1	1122.7	337.7	C.CCCCC	C.	171.2	24.0	18.1	40.1	12.5	8777.	511.	288.	546.	0.C56	0.253
7	C.3CC	C.1C6C3	C.CCCCC	1C67.7	1117.	1146.2	337.7	C.CCCCC	C.	177.2	23.9	18.1	40.1	12.5	8777.	609.	455.	655.	0.C56	0.255
8	C.35C	C.1C6C3	C.CCCCC	1C67.4	1116.9	1162.5	337.7	C.CCCCC	C.	183.2	23.9	18.0	40.1	12.5	8777.	691.	621.	755.	0.C56	0.257
9	C.4CC	C.1C6C3	C.CCCCC	1C67.1	1117.	1173.7	337.7	C.CCCCC	C.	189.2	23.8	17.9	40.1	12.5	9294.	771.	786.	855.	0.C56	0.259
10	C.45C	C.1C6C3	C.CCCCC	1C66.8	1117.1	1179.4	337.7	C.CCCCC	C.	195.2	23.8	17.8	40.1	12.5	9275.	844.	952.	955.	0.C56	0.261
11	C.5CC	C.1C6C3	C.CCCCC	1C66.3	1117.4	1184.2	337.7	C.CCCCC	C.	201.2	23.7	17.7	40.1	12.5	9246.	911.	1115.	1053.	0.C56	0.263
12	C.55C	C.1C6C3	C.CCCCC	1C65.8	1117.9	1188.7	337.7	C.CCCCC	C.	207.2	23.6	17.6	40.1	12.5	9219.	973.	1274.	1150.	0.C56	0.265
13	C.6CC	C.1C6C3	C.CCCCC	1C65.4	1118.6	1192.9	337.7	C.CCCCC	C.	213.2	23.5	17.5	40.1	12.5	9194.	1032.	1430.	1246.	0.C56	0.267
14	C.65C	C.1C6C3	C.CCCCC	1C65.1	1119.4	1196.9	337.7	C.CCCCC	C.	219.2	23.4	17.4	40.2	12.4	10444.	1088.	1582.	1342.	0.C56	0.269
15	C.7CC	C.1C6C3	C.CCCCC	1C64.8	1120.3	1200.8	337.7	C.CCCCC	C.	225.2	23.3	17.3	40.4	12.2	10264.	1142.	1730.	1438.	0.C56	0.271
16	C.75C	C.1C6C3	C.CCCCC	1C64.5	1121.3	1204.6	337.7	C.CCCCC	C.	231.2	23.2	17.2	40.5	12.1	10625.	1194.	1874.	1534.	0.C56	0.273
17	C.8CC	C.1C6C3	C.CCCCC	1C64.2	1122.4	1208.3	337.7	C.CCCCC	C.	237.2	23.1	17.0	40.7	11.9	10564.	1244.	2015.	1629.	0.C56	0.275
18	C.85C	C.1C6C3	C.CCCCC	1C63.9	1123.6	1211.9	337.7	C.CCCCC	C.	243.2	23.1	16.9	40.9	11.7	11141.	1292.	2154.	1724.	0.C56	0.277
19	C.9CC	C.1C6C3	C.CCCCC	1C63.6	1124.8	1215.4	337.7	C.CCCCC	C.	249.2	23.0	16.8	41.0	11.5	11411.	1338.	2292.	1818.	0.C56	0.279
20	C.95C	C.1C6C3	C.CCCCC	1C63.3	1126.1	1218.8	337.7	C.CCCCC	C.	255.2	23.0	16.6	41.2	11.4	11669.	1382.	2429.	1912.	0.C56	0.281
21	1.0CC	C.1C6C3	C.CCCCC	1C63.0	1127.4	1222.1	337.7	C.CCCCC	C.	261.2	22.9	16.5	41.4	11.2	11926.	1424.	2566.	2006.	0.C56	0.283
22	1.C5C	C.1C6C3	C.CCCCC	1C62.7	1128.7	1225.3	337.7	C.CCCCC	C.	267.2	22.8	16.4	41.6	11.1	12231.	1465.	2703.	2100.	0.C56	0.285
23	1.1CC	C.1C6C3	C.CCCCC	1C62.4	1130.1	1228.4	337.7	C.CCCCC	C.	273.2	22.8	16.3	41.8	10.9	12531.	1504.	2840.	2194.	0.C56	0.287
24	1.15C	C.1C6C3	C.CCCCC	1C62.1	1131.5	1231.5	337.7	C.CCCCC	C.	279.2	22.7	16.2	42.0	10.8	12825.	1542.	2977.	2288.	0.C56	0.289
25	1.2CC	C.1C6C3	C.CCCCC	1C61.8	1132.9	1234.6	337.7	C.CCCCC	C.	285.2	22.6	16.1	42.2	10.6	13113.	1579.	3114.	2382.	0.C56	0.291
26	1.25C	C.1C6C3	C.CCCCC	1C61.5	1134.3	1237.7	337.7	C.CCCCC	C.	291.2	22.6	16.0	42.4	10.5	13395.	1614.	3251.	2476.	0.C56	0.293
27	1.3CC	C.1C6C3	C.CCCCC	1C61.2	1135.8	1240.8	337.7	C.CCCCC	C.	297.2	22.5	15.9	42.6	10.3	13672.	1648.	3388.	2570.	0.C56	0.295
28	1.35C	C.1C6C3	C.CCCCC	1C60.9	1137.2	1243.9	337.7	C.CCCCC	C.	303.2	22.4	15.8	42.8	10.2	13944.	1681.	3525.	2664.	0.C56	0.297
29	1.4CC	C.1C6C3	C.CCCCC	1C60.6	1138.7	1247.0	337.7	C.CCCCC	C.	309.2	22.4	15.7	43.0	10.0	14212.	1713.	3662.	2758.	0.C56	0.299
30	1.45C	C.1C6C3	C.CCCCC	1C60.3	1140.2	1250.1	337.7	C.CCCCC	C.	315.2	22.3	15.6	43.2	9.9	14476.	1744.	3799.	2852.	0.C56	0.301
31	1.5CC	C.1C6C3	C.CCCCC	1C60.0	1141.7	1253.2	337.7	C.CCCCC	C.	321.2	22.2	15.5	43.4	9.7	14736.	1774.	3936.	2946.	0.C56	0.303
32	1.55C	C.1C6C3	C.CCCCC	1C59.7	1143.2	1256.3	337.7	C.CCCCC	C.	327.2	22.2	15.4	43.6	9.6	14992.	1803.	4073.	3040.	0.C56	0.305
33	1.6CC	C.1C6C3	C.CCCCC	1C59.4	1144.7	1259.4	337.7	C.CCCCC	C.	333.2	22.1	15.3	43.8	9.4	15244.	1831.	4210.	3134.	0.C56	0.307
34	1.65C	C.1C6C3	C.CCCCC	1C59.1	1146.2	1262.5	337.7	C.CCCCC	C.	339.2	22.0	15.2	44.0	9.3	15493.	1858.	4347.	3228.	0.C56	0.309
35	1.7CC	C.1C6C3	C.CCCCC	1C58.8	1147.7	1265.6	337.7	C.CCCCC	C.	345.2	22.0	15.1	44.2	9.1	15738.	1884.	4484.	3322.	0.C56	0.311
36	1.75C	C.1C6C3	C.CCCCC	1C58.5	1149.2	1268.7	337.7	C.CCCCC	C.	351.2	21.9	15.0	44.4	9.0	15980.	1909.	4621.	3416.	0.C56	0.313
37	1.8CC	C.1C6C3	C.CCCCC	1C58.2	1150.7	1271.8	337.7	C.CCCCC	C.	357.2	21.8	14.9	44.6	8.8	16218.	1933.	4758.	3510.	0.C56	0.315
38	1.85C	C.1C6C3	C.CCCCC	1C57.9	1152.2	1274.9	337.7	C.CCCCC	C.	363.2	21.8	14.8	44.8	8.7	16453.	1956.	4895.	3604.	0.C56	0.317
39	1.9CC	C.1C6C3	C.CCCCC	1C57.6	1153.7	1278.	337.7	C.CCCCC	C.	369.2	21.7	14.7	45.0	8.5	16685.	1978.	5032.	3698.	0.C56	0.319
40	1.95C	C.1C6C3	C.CCCCC	1C57.3	1155.2	1281.1	337.7	C.CCCCC	C.	375.2	21.7	14.6	45.2	8.4	16914.	1999.	5169.	3792.	0.C56	0.321
41	2.CCC	C.1C6C3	C.CCCCC	1C57.0	1156.7	1284.2	337.7	C.CCCCC	C.	381.2	21.6	14.5	45.4	8.2	17140.	2019.	5306.	3886.	0.C56	0.323
42	2.C5C	C.1C6C3	C.CCCCC	1C56.7	1158.2	1287.3	337.7	C.CCCCC	C.	387.2	21.6	14.4	45.6	8.1	17363.	2038.	5443.	3980.	0.C56	0.325
43	2.1CC	C.1C6C3	C.CCCCC	1C56.4	1159.7	1290.4	337.7	C.CCCCC	C.	393.2	21.5	14.3	45.8	7.9	17583.	2056.	5580.	4074.	0.C56	0.327
44	2.15C	C.1C6C3	C.CCCCC	1C56.1	1161.2	1293.5	337.7	C.CCCCC	C.	399.2	21.5	14.2	46.0	7.8	17800.	2074.	5717.	4168.	0.C56	0.329
45	2.2CC	C.1C6C3	C.CCCCC	1C55.8	1162.7	1296.6	337.7	C.CCCCC	C.	405.2	21.4	14.1	46.2	7.6	18015.	2091.	5854.	4262.	0.C56	0.331
46	2.25C	C.1C6C3	C.CCCCC	1C55.5	1164.2	1299.7	337.7	C.CCCCC	C.	411.2	21.4	14.0	46.4	7.5	18227.	2107.	5991.	4356.	0.C56	0.333
47	2.3CC	C.1C6C3	C.CCCCC	1C55.2	1165.7	1302.8	337.7	C.CCCCC	C.	417.2	21.3	13.9	46.6	7.3	18436.	2123.	6128.	4450.	0.C56	0.335
48	2.35C	C.1C6C3	C.CCCCC	1C54.9	1167.2	1305.9	337.7	C.CCCCC	C.	423.2	21.3	13.8	46.8	7.2	18643.	2137.	6265.	4544.	0.C56	0.337
49	2.4CC	C.1C6C3	C.CCCCC	1C54.6	1168.7	1309.	337.7	C.CCCCC	C.	429.2	21.2	13.7	47.0	7.0	18847.	2151.	6402.	4638.	0.C56	0.339
50	2.45C	C.1C6C3	C.CCCCC	1C54.3	1170.2	1312.1	337.7	C.CCCCC	C.	435.2	21.2	13.6	47.2	6.9	19048.	2164.	6539.	4732.	0.C56	0.341
51	2.5CC	C.1C6C3	C.CCCCC	1C54.0	1171.7	1315.2	337.7	C.CCCCC	C.	441.2	21.1	13.5	47.4	6.7	19247.	2176.	6676.	4826.	0.C56	0.343
52	2.55C	C.1C6C3	C.CCCCC	1C53.7	1173.2	1318.3	337.7	C.CCCCC	C.	447.2	21.1	13.4	47.6	6.6	19443.	2188.	6813.	4920.	0.C56	0.345
53	2.6CC	C.1C6C3	C.CCCCC	1C53.4	1174.7	1321.4	337.7	C.CCCCC	C.	453.2	21.0	13.3	47.8	6.4	19636.	2199.	6950.	5014.	0.C56	0.347
54	2.65C	C.1C6C3	C.CCCCC	1C53.1	1176.2	1324.5	337.7	C.CCCCC	C.	459.2	21.0	13.2	48.0	6.3	19827.	2209.	7087.	5108.	0.C56	0.349
55	2.7CC	C.1C6C3	C.CCCCC	1C52.8	1177.7	1327.6	337.7	C.CCCCC	C.	465.2	20.9	13.1	48.2	6.1	20015.	2219.	7224.	5202.	0.C56	0.351
56	2.75C	C.1C6C3	C.CCCCC	1C52.5	1179.2	1330.7	337.7	C.CCCCC	C.	471.2	20.9	13.0	48.4	6.0	20200.	2228.	7361.	5296.	0.C56	0.353
57	2.8CC	C.1C6C3	C.CCCCC	1C52.2	1180.7	1333.8	337.7	C.CCCCC	C.	477.2	20.8	12.9	48.6	5.8	20383.	2236.	7498.	5390.	0.C56	0.355
58	2.85C	C.1C6C3	C.CCCCC	1C51.9	1182.2	1336.9	337.7	C.CCCCC	C.	483.2	20.8	12.8	48.8	5.7	20563.	2244.	7635.	5484.	0.C56	0.357
59	2.9CC	C.1C6C3	C.CCCCC	1C51.6	1183.7	1340.	337.7	C.CCCCC	C.	489.2	20.7	12.7	49.0	5.5	20741.	2251.	7772.	5578.	0.C56	0.359
60	2.95C	C.1C6C3	C.CCCCC	1C51.3	1185.2	1343.1	337.7	C.CCCCC	C.	495.2	20.7	12.6	49.2	5.4	20916.	2257.	7909.	5672.	0.C56	0.361
61	3.CCC	C.1C6C3	C.CCCCC	1C51.0	1186.7	1346.2	337.7	C.CCCCC	C.	501.2	20.6	12.5	49.4	5.2	21089.	2263.	8046.	5766.	0.C56	0.363

46	2.100	0.73315	0.97015	534.6	1552.2	1273.0	305.8	0.0967	4360.	349.8	25.9	12.3	47.0	2.4	3903.	116.	616.	3038.	0.204	0.008
47	2.120	0.73655	0.97525	528.4	1533.6	1269.4	305.6	0.1035	4535.	338.7	26.0	12.3	47.1	2.3	2764.	85.	495.	3047.	0.205	0.007
48	2.140	0.73955	0.97906	522.5	1512.2	1264.5	305.2	0.1094	4695.	329.2	26.1	12.2	47.1	2.2	2419.	80.	467.	3054.	0.206	0.006
49	2.160	0.74215	0.98333	517.9	1486.6	1258.2	305.1	0.1140	4837.	317.0	26.3	12.2	47.1	2.1	2067.	75.	463.	3060.	0.207	0.004
50	2.180	0.74430	0.98636	513.7	1454.8	1250.1	305.0	0.1160	4957.	304.3	26.4	12.2	47.1	2.1	1727.	71.	477.	3067.	0.207	0.003
51	2.200	0.74605	0.98881	510.0	1418.7	1240.0	304.9	0.1155	5052.	289.0	26.6	12.2	47.1	2.0	1395.	66.	471.	3073.	0.208	0.003
52	2.220	0.74742	0.99068	507.0	1378.3	1227.7	304.9	0.1092	5119.	272.4	26.8	12.2	47.2	2.0	1063.	62.	463.	3079.	0.208	0.002
53	2.240	0.74844	0.99195	504.4	1333.4	1213.6	304.8	0.0951	5159.	254.6	27.0	12.2	47.2	1.9	792.	59.	454.	3085.	0.208	0.002
54	2.260	0.74914	0.99271	502.3	1283.6	1197.7	304.7	0.0715	5177.	235.8	27.3	12.2	47.2	1.9	521.	55.	445.	3092.	0.209	0.001
55	2.280	0.75000	0.99294	500.6	1218.9	1180.4	304.7	0.0376	5180.	235.8	27.3	12.2	47.2	1.9	230.	50.	434.	3097.	0.209	0.001

ASH FUSION STARTS AT XF = 0.7011 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.970 M

HEIGHT OF THE BURNING ZONE = 2.280 M

TEMPERATURE OF SOLIDS FROM BURNING ZONE AS INPUT FOR COOLING ZONE = 1194.7 K
AND SPECIFIC SURFACE OF SOLID PARTICLES =49.09 SQM PER CUM OF KILN VOLUME

AVERAGE SIZE OF SOLID PARTICLES = 0.094 M AND DEGREE OF CALCINATION = 0.9929

ENTHALPIES OF GAS,STONE AND FUEL AT TOP =448826.3,153561.? & 24425.3 KCAL/HR

ENTHALPIES OF GAS,STONE,FUEL AND ASH AT BOTTOM =
78341.6,108604.4, 1038.1 & 3517.8 KCAL/HR

HEAT LOSS THROUGH WALL OF BURNING SECTION = 3097.5 KCAL/HR

TOTAL HEAT OF COMBUSTION OF VOLATILE MATTER = 274680.2 KCAL/HR

TOTAL HEAT OF COMBUSTION OF FIXED CARBON = 526921.1 KCAL/HR

OVERALL HEAT OF VOLATILE MATTER AND FIXED CARBON = 801601.3 KCAL/HR

HEAT LOSS IN UNBURNT FRACTION OF VOLATILE MATTER = 148571.5 KCAL/HR

TOTAL LATENT HEAT FOR DEVOLATILIZATION = 19784.9 KCAL/HR

TOTAL ENDOTHERMIC HEAT FOR CALCINATION OF LIMESTONE = 295517.8 KCAL/HR

TABLE P.1 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 1 (A)

(AVERAGE CONDITIONS)

```
                                  2           3           1         250
                              500.6000    1194.7000   1194.7000
          2.2500      5.5000      10.0000          0.1000      0.0500      0.0500
0.0940        0.9929     49.0900      0.4500          0.9000      0.0125      0.1000
                0.0500      0.2250      0.4750      0.2500      0.1250
                      0.0312      0.0882     300.0000    304.7000
               1.0100      0.6000      0.2300      0.6900      0.9000   0.4960E-07
                     4.4444      2.3794    744.0477    135.2814   1394.5542
```

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	500.60	1194.70	304.70	10.7	49.1	7419.4	0.0
2	0.050	497.62	1186.94	304.66	10.7	49.1	7366.9	11.7
3	0.100	494.66	1179.21	304.60	10.7	49.1	7314.5	23.3
4	0.150	491.72	1171.53	304.55	10.7	49.1	7262.4	34.7
5	0.200	488.80	1163.88	304.49	10.7	49.1	7210.5	45.9
6	0.250	485.90	1156.27	304.43	10.7	49.1	7158.8	56.9
7	0.300	483.01	1148.70	304.38	10.7	49.1	7107.3	67.8
8	0.350	480.15	1141.16	304.33	10.7	49.1	7056.1	78.5
9	0.400	477.31	1133.67	304.27	10.7	49.1	7005.0	89.0
10	0.450	474.48	1126.21	304.22	10.7	49.1	6954.2	99.3
11	0.500	471.67	1118.79	304.16	10.7	49.1	6903.6	109.5
12	0.550	468.89	1111.40	304.11	10.7	49.1	6853.2	119.6
13	0.600	466.12	1104.06	304.05	10.7	49.1	6803.0	129.4
14	0.650	463.37	1096.75	304.00	10.7	49.1	6753.0	139.1
15	0.700	460.64	1089.47	303.95	10.7	49.1	6703.3	148.7
16	0.750	457.93	1082.24	303.89	10.7	49.1	6653.7	158.0
17	0.800	455.23	1075.04	303.84	10.7	49.1	6604.4	167.3
18	0.850	452.56	1067.88	303.79	10.7	49.1	6555.3	176.3
19	0.900	449.90	1060.76	303.74	10.7	49.1	6506.4	185.2
20	0.950	447.26	1053.67	303.68	10.6	49.1	6457.7	194.0
21	1.000	444.64	1046.62	303.63	10.6	49.1	6409.3	202.6
22	1.050	442.04	1039.61	303.58	10.6	49.1	6361.0	211.0
23	1.100	439.46	1032.64	303.53	10.6	49.1	6313.0	219.3
24	1.150	436.89	1025.70	303.47	10.6	49.1	6265.1	227.5
25	1.200	434.34	1018.80	303.42	10.6	49.1	6217.5	235.4
26	1.250	431.82	1011.93	303.37	10.6	49.1	6170.1	243.3
27	1.300	429.30	1005.10	303.32	10.6	49.1	6123.0	251.0
28	1.350	426.81	998.31	303.27	10.6	49.1	6076.0	258.5
29	1.400	424.33	991.55	303.22	10.6	49.1	6029.2	265.9
30	1.450	421.88	984.84	303.17	10.6	49.1	5982.7	273.2
31	1.500	419.44	978.15	303.12	10.6	49.1	5936.4	280.3
32	1.550	417.01	971.51	303.07	10.6	49.1	5890.3	287.2
33	1.600	414.61	964.90	303.02	10.6	49.1	5844.4	294.1
34	1.650	412.22	958.32	302.97	10.6	49.1	5798.7	300.7
35	1.700	409.85	951.78	302.92	10.6	49.1	5753.2	307.3
36	1.750	407.50	945.28	302.87	10.6	49.1	5707.9	313.7
37	1.800	405.16	938.81	302.82	10.6	49.1	5662.9	319.9
38	1.850	402.84	932.38	302.77	10.6	49.1	5618.1	326.1
39	1.900	400.54	925.99	302.72	10.6	49.1	5573.5	332.1
40	1.950	398.25	919.63	302.67	10.6	49.1	5529.1	337.9
41	2.000	395.99	913.31	302.62	10.6	49.1	5484.9	343.6
42	2.050	393.73	907.02	302.57	10.6	49.1	5440.9	349.2
43	2.100	391.50	900.77	302.52	10.6	49.1	5397.2	354.7
44	2.150	389.28	894.55	302.47	10.6	49.1	5353.6	360.0
45	2.200	387.08	888.37	302.43	10.6	49.1	5310.3	365.2

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HEIGHT OF THE COOLING ZONE=4.6COM

ENTHALPIES OF PRODUCT LIME AND ASH/CINDERS AT BOTTOM OF KILN = 37704.5 KCAL/HR

ENTHALFY OF AIR INTO LIME KILN AT ECTTOM = 8543.3 KCAL/HR

HEAT LOSS THFOUGH WALL OF COOLING SECTION = 480.5 KCAL/HR

TABLE F.2 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 2(A)

(DFS=0.038 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELHTL
1	0.000	0.000	746.00	500.00	300.00	316.00	5.05	25.07	20.01	46.40	14.46	0.0	0.0	0.0	0.0
3	0.100	0.000	763.39	389.66	380.00	318.00	7.50	25.10	20.05	46.40	14.46	77.3	-15.7	-22.7	132.4
5	0.200	0.000	777.99	417.44	368.65	319.31	9.50	25.10	20.05	46.40	14.46	77.3	-14.7	-21.7	269.4
7	0.300	0.000	792.03	445.63	358.77	319.74	11.51	25.09	20.04	46.40	14.46	77.3	-13.7	-20.7	410.4
9	0.400	0.000	805.57	461.55	421.95	320.15	13.54	25.09	20.02	46.40	14.46	77.3	-12.7	-19.7	554.3
11	0.500	0.000	818.66	461.33	442.46	320.54	15.58	25.08	20.01	46.40	14.46	77.3	-11.7	-18.7	700.2
13	0.600	0.000	831.33	527.25	471.35	320.93	17.63	25.08	20.00	46.40	14.46	77.3	-10.7	-17.7	848.0
15	0.700	0.000	843.62	556.16	500.25	321.31	19.69	25.08	20.00	46.40	14.46	77.3	-9.7	-16.7	997.8
17	0.800	0.000	855.40	570.54	529.15	321.68	21.76	25.08	20.00	46.40	14.46	77.3	-8.7	-15.7	1149.5
19	0.900	0.000	866.83	570.56	558.05	322.04	23.84	25.08	20.00	46.40	14.46	77.3	-7.7	-14.7	1303.2
22	1.000	0.000	877.90	571.36	586.95	322.40	25.93	25.08	20.00	46.40	14.46	77.3	-6.7	-13.7	1458.8
23	1.100	0.000	888.63	622.80	615.85	322.75	28.03	25.08	20.00	46.40	14.46	77.3	-5.7	-12.7	1616.3
25	1.200	0.000	899.00	624.66	644.75	323.09	30.14	25.08	20.00	46.40	14.46	77.3	-4.7	-11.7	1775.8
27	1.300	0.000	909.03	671.16	644.77	323.43	32.26	25.08	20.00	46.40	14.46	77.3	-3.7	-10.7	1937.2
29	1.400	0.000	918.74	684.93	644.15	323.76	34.39	25.08	20.00	46.40	14.46	77.3	-2.7	-9.7	2100.5
31	1.500	0.000	928.13	694.41	643.53	324.08	36.53	25.08	20.00	46.40	14.46	77.3	-1.7	-8.7	2265.8
33	1.600	0.000	937.21	707.71	642.91	324.40	38.68	25.08	20.00	46.40	14.46	77.3	-0.7	-7.7	2433.0
35	1.700	0.000	945.98	721.00	642.29	324.71	40.84	25.08	20.00	46.40	14.46	77.3	0.3	-6.7	2602.2
37	1.800	0.000	954.44	734.28	641.67	325.02	43.01	25.08	20.00	46.40	14.46	77.3	1.3	-5.7	2773.3
39	1.900	0.017	962.61	746.56	641.05	325.32	45.19	25.08	20.00	46.40	14.46	77.3	2.3	-4.7	2946.4
41	2.000	0.056	970.50	758.84	640.43	325.62	47.38	25.08	20.00	46.40	14.46	77.3	3.3	-3.7	3121.4
43	2.100	0.096	978.11	771.12	639.81	325.91	49.58	25.08	20.00	46.40	14.46	77.3	4.3	-2.7	3298.4
45	2.200	0.136	985.46	783.40	639.19	326.20	51.79	25.08	20.00	46.40	14.46	77.3	5.3	-1.7	3477.3
47	2.300	0.177	992.55	795.68	638.57	326.48	54.01	25.08	20.00	46.40	14.46	77.3	6.3	-0.7	3658.2
49	2.400	0.218	999.38	807.96	637.95	326.76	56.24	25.08	20.00	46.40	14.46	77.3	7.3	0.3	3841.1
51	2.500	0.259	1005.97	820.24	637.33	327.03	58.48	25.08	20.00	46.40	14.46	77.3	8.3	1.3	4025.9
53	2.600	0.300	1012.32	832.52	636.71	327.30	60.73	25.08	20.00	46.40	14.46	77.3	9.3	2.3	4212.7
55	2.700	0.342	1018.43	844.80	636.09	327.57	62.99	25.08	20.00	46.40	14.46	77.3	10.3	3.3	4401.4
57	2.800	0.384	1024.31	857.08	635.47	327.83	65.26	25.08	20.00	46.40	14.46	77.3	11.3	4.3	4592.1
59	2.900	0.426	1029.97	869.36	634.85	328.09	67.54	25.08	20.00	46.40	14.46	77.3	12.3	5.3	4784.7
61	3.000	0.469	1035.41	881.64	634.23	328.35	69.83	25.08	20.00	46.40	14.46	77.3	13.3	6.3	4979.3
63	3.100	0.512	1040.64	893.92	633.61	328.60	72.13	25.08	20.00	46.40	14.46	77.3	14.3	7.3	5175.8
65	3.200	0.555	1045.66	906.20	632.99	328.85	74.44	25.08	20.00	46.40	14.46	77.3	15.3	8.3	5374.3
67	3.300	0.599	1050.48	918.48	632.37	329.10	76.76	25.08	20.00	46.40	14.46	77.3	16.3	9.3	5574.7
69	3.400	0.643	1055.10	930.76	631.75	329.34	79.09	25.08	20.00	46.40	14.46	77.3	17.3	10.3	5777.1
71	3.500	0.687	1059.53	943.04	631.13	329.58	81.43	25.08	20.00	46.40	14.46	77.3	18.3	11.3	5981.4
73	3.600	0.732	1063.77	955.32	630.51	329.81	83.78	25.08	20.00	46.40	14.46	77.3	19.3	12.3	6187.7
75	3.700	0.777	1067.83	967.60	629.89	330.04	86.14	25.08	20.00	46.40	14.46	77.3	20.3	13.3	6395.9
77	3.800	0.822	1071.72	979.88	629.27	330.27	88.51	25.08	20.00	46.40	14.46	77.3	21.3	14.3	6606.1
79	3.900	0.868	1075.43	992.16	628.65	330.49	90.89	25.08	20.00	46.40	14.46	77.3	22.3	15.3	6818.2
81	4.000	0.914	1078.98	1004.44	628.03	330.71	93.28	25.08	20.00	46.40	14.46	77.3	23.3	16.3	7032.3
83	4.100	0.960	1082.37	1016.72	627.41	330.93	95.68	25.08	20.00	46.40	14.46	77.3	24.3	17.3	7248.3
85	4.200	1.007	1085.61	1029.00	626.79	331.14	98.09	25.08	20.00	46.40	14.46	77.3	25.3	18.3	7466.3
87	4.300	1.054	1088.70	1041.28	626.17	331.35	100.51	25.08	20.00	46.40	14.46	77.3	26.3	19.3	7686.2
89	4.400	1.102	1091.65	1053.56	625.55	331.56	102.94	25.08	20.00	46.40	14.46	77.3	27.3	20.3	7908.1
91	4.500	1.150	1094.47	1065.84	624.93	331.76	105.38	25.08	20.00	46.40	14.46	77.3	28.3	21.3	8131.9
93	4.600	1.198	1097.16	1078.12	624.31	331.96	107.83	25.08	20.00	46.40	14.46	77.3	29.3	22.3	8357.7
95	4.700	1.247	1099.73	1090.40	623.69	332.16	110.29	25.08	20.00	46.40	14.46	77.3	30.3	23.3	8585.4
97	4.800	1.296	1102.19	1102.68	623.07	332.35	112.76	25.08	20.00	46.40	14.46	77.3	31.3	24.3	8815.1
99	4.900	1.346	1104.54	1114.96	622.45	332.54	115.24	25.08	20.00	46.40	14.46	77.3	32.3	25.3	9046.7
101	5.000	1.396	1106.79	1127.24	621.83	332.73	117.73	25.08	20.00	46.40	14.46	77.3	33.3	26.3	9280.3

VM COMBUSTION STARTS AT XF = 0.1709 AND AT HEIGHT (FROM TOP) = 4.100 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.100 M

TABLE P.2 (A2).

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 2 (A)

(DPS=0.086 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	GFS	GFG	GSG	DELMTL	PG26	PCG26
1	0.000	0.17085	0.00000	1056.2	946.	946.0	307.0	0.0000	0.	107.4	24.5	19.5	46.4	14.5	152.	-442.	-902.	0.	0.0000	0.0000
2	0.100	0.19115	0.00000	1060.3	1115.	1015.6	307.1	0.0000	0.	150.0	24.1	19.3	46.4	14.5	255.	-224.	216.	0.	0.0000	0.0000
3	0.200	0.21253	0.00000	1062.9	1174.	1069.7	307.1	0.0000	0.	181.0	24.1	19.2	46.4	14.5	911.	171.	1158.	0.	0.0000	0.0000
4	0.300	0.23533	0.00000	1063.7	1163.	1116.7	307.0	0.0000	0.	212.0	23.9	19.0	46.4	14.5	942.	447.	1559.	0.	0.0000	0.0000
5	0.400	0.25966	0.00000	1063.9	1141.	1153.6	306.9	0.0000	0.	240.6	23.6	18.7	46.4	14.5	972.	722.	1960.	0.	0.0000	0.0000
6	0.500	0.28571	0.00000	1063.9	1119.	1174.6	306.9	0.0000	0.	268.8	23.2	18.5	46.4	14.5	1002.	997.	2360.	0.	0.0000	0.0000
7	0.600	0.31366	0.00000	1063.9	1099.	1192.4	306.9	0.0000	0.	296.6	22.8	18.2	46.4	14.5	1032.	1272.	2760.	0.	0.0000	0.0000
8	0.700	0.34377	0.00000	1063.9	1080.	1207.7	306.9	0.0000	0.	319.5	22.5	18.0	46.4	14.5	1062.	1547.	3160.	0.	0.0000	0.0000
9	0.800	0.37622	0.00000	1063.9	1063.	1221.9	306.9	0.0000	0.	342.1	22.1	17.8	46.4	14.5	1092.	1822.	3560.	0.	0.0000	0.0000
10	0.900	0.41145	0.00000	1063.9	1048.	1235.1	306.9	0.0000	0.	364.4	21.8	17.6	46.4	14.5	1122.	2097.	3960.	0.	0.0000	0.0000
11	1.000	0.45000	0.00000	1063.9	1035.	1247.7	306.9	0.0000	0.	386.0	21.5	17.4	46.4	14.5	1152.	2372.	4360.	0.	0.0000	0.0000
12	1.100	0.49140	0.00000	1063.9	1023.	1259.8	306.9	0.0000	0.	406.6	21.2	17.2	46.4	14.5	1182.	2647.	4760.	0.	0.0000	0.0000
13	1.200	0.53577	0.00000	1063.9	1012.	1271.9	306.9	0.0000	0.	426.3	20.9	17.0	46.4	14.5	1212.	2922.	5160.	0.	0.0000	0.0000
14	1.300	0.58371	0.00000	1063.9	1002.	1283.8	306.9	0.0000	0.	445.1	20.6	16.8	46.4	14.5	1242.	3197.	5560.	0.	0.0000	0.0000
15	1.400	0.63555	0.00000	1063.9	992.	1295.6	306.9	0.0000	0.	463.0	20.3	16.6	46.4	14.5	1272.	3472.	5960.	0.	0.0000	0.0000
16	1.500	0.69144	0.00000	1063.9	983.	1307.3	306.9	0.0000	0.	480.1	20.0	16.4	46.4	14.5	1302.	3747.	6360.	0.	0.0000	0.0000
17	1.600	0.75161	0.00000	1063.9	974.	1318.9	306.9	0.0000	0.	496.4	19.7	16.2	46.4	14.5	1332.	4022.	6760.	0.	0.0000	0.0000
18	1.700	0.81660	0.00000	1063.9	965.	1330.4	306.9	0.0000	0.	511.9	19.4	16.0	46.4	14.5	1362.	4297.	7160.	0.	0.0000	0.0000
19	1.800	0.88691	0.00000	1063.9	957.	1341.8	306.9	0.0000	0.	526.7	19.1	15.8	46.4	14.5	1392.	4572.	7560.	0.	0.0000	0.0000
20	1.900	0.96313	0.00000	1063.9	949.	1353.1	306.9	0.0000	0.	540.8	18.8	15.6	46.4	14.5	1422.	4847.	7960.	0.	0.0000	0.0000
21	2.000	1.04600	0.00000	1063.9	941.	1364.3	306.9	0.0000	0.	554.2	18.5	15.4	46.4	14.5	1452.	5122.	8360.	0.	0.0000	0.0000
22	2.100	1.13670	0.00000	1063.9	933.	1375.4	306.9	0.0000	0.	567.0	18.2	15.2	46.4	14.5	1482.	5397.	8760.	0.	0.0000	0.0000
23	2.200	1.23500	0.00000	1063.9	926.	1386.4	306.9	0.0000	0.	579.2	17.9	15.0	46.4	14.5	1512.	5672.	9160.	0.	0.0000	0.0000
24	2.300	1.34200	0.00000	1063.9	919.	1397.3	306.9	0.0000	0.	590.8	17.6	14.8	46.4	14.5	1542.	5947.	9560.	0.	0.0000	0.0000
25	2.400	1.45900	0.00000	1063.9	912.	1408.2	306.9	0.0000	0.	601.8	17.3	14.6	46.4	14.5	1572.	6222.	9960.	0.	0.0000	0.0000
26	2.500	1.58700	0.00000	1063.9	906.	1419.0	306.9	0.0000	0.	612.2	17.0	14.4	46.4	14.5	1602.	6497.	10360.	0.	0.0000	0.0000
27	2.600	1.72700	0.00000	1063.9	900.	1429.7	306.9	0.0000	0.	622.0	16.7	14.2	46.4	14.5	1632.	6772.	10760.	0.	0.0000	0.0000
28	2.700	1.88000	0.00000	1063.9	894.	1440.4	306.9	0.0000	0.	631.3	16.4	14.0	46.4	14.5	1662.	7047.	11160.	0.	0.0000	0.0000
29	2.800	2.04700	0.00000	1063.9	889.	1451.0	306.9	0.0000	0.	640.0	16.1	13.8	46.4	14.5	1692.	7322.	11560.	0.	0.0000	0.0000
30	2.900	2.22800	0.00000	1063.9	884.	1461.5	306.9	0.0000	0.	648.1	15.8	13.6	46.4	14.5	1722.	7597.	11960.	0.	0.0000	0.0000
31	3.000	2.42400	0.00000	1063.9	879.	1472.0	306.9	0.0000	0.	655.6	15.5	13.4	46.4	14.5	1752.	7872.	12360.	0.	0.0000	0.0000
32	3.100	2.63500	0.00000	1063.9	875.	1482.4	306.9	0.0000	0.	662.5	15.2	13.2	46.4	14.5	1782.	8147.	12760.	0.	0.0000	0.0000
33	3.200	2.86100	0.00000	1063.9	871.	1492.8	306.9	0.0000	0.	668.8	14.9	13.0	46.4	14.5	1812.	8422.	13160.	0.	0.0000	0.0000
34	3.300	3.10300	0.00000	1063.9	867.	1503.1	306.9	0.0000	0.	674.5	14.6	12.8	46.4	14.5	1842.	8697.	13560.	0.	0.0000	0.0000
35	3.400	3.36200	0.00000	1063.9	863.	1513.3	306.9	0.0000	0.	679.6	14.3	12.6	46.4	14.5	1872.	8972.	13960.	0.	0.0000	0.0000
36	3.500	3.63900	0.00000	1063.9	860.	1523.5	306.9	0.0000	0.	684.0	14.0	12.4	46.4	14.5	1902.	9247.	14360.	0.	0.0000	0.0000
37	3.600	3.93400	0.00000	1063.9	857.	1533.6	306.9	0.0000	0.	687.8	13.7	12.2	46.4	14.5	1932.	9522.	14760.	0.	0.0000	0.0000
38	3.700	4.25000	0.00000	1063.9	854.	1543.7	306.9	0.0000	0.	691.0	13.4	12.0	46.4	14.5	1962.	9797.	15160.	0.	0.0000	0.0000
39	3.800	4.58000	0.00000	1063.9	851.	1553.7	306.9	0.0000	0.	693.6	13.1	11.8	46.4	14.5	1992.	10072.	15560.	0.	0.0000	0.0000
40	3.900	4.93000	0.00000	1063.9	849.	1563.7	306.9	0.0000	0.	695.6	12.8	11.6	46.4	14.5	2022.	10347.	15960.	0.	0.0000	0.0000
41	4.000	5.28000	0.00000	1063.9	846.	1573.7	306.9	0.0000	0.	697.0	12.5	11.4	46.4	14.5	2052.	10622.	16360.	0.	0.0000	0.0000
42	4.100	5.63000	0.00000	1063.9	844.	1583.6	306.9	0.0000	0.	697.8	12.2	11.2	46.4	14.5	2082.	10897.	16760.	0.	0.0000	0.0000
43	4.200	5.97000	0.00000	1063.9	842.	1593.6	306.9	0.0000	0.	698.0	11.9	11.0	46.4	14.5	2112.	11172.	17160.	0.	0.0000	0.0000
44	4.300	6.30000	0.00000	1063.9	840.	1603.5	306.9	0.0000	0.	697.6	11.6	10.8	46.4	14.5	2142.	11447.	17560.	0.	0.0000	0.0000
45	4.400	6.62000	0.00000	1063.9	838.	1613.4	306.9	0.0000	0.	696.6	11.3	10.6	46.4	14.5	2172.	11722.	17960.	0.	0.0000	0.0000
46	4.500	6.93000	0.00000	1063.9	836.	1623.3	306.9	0.0000	0.	695.0	11.0	10.4	46.4	14.5	2202.	11997.	18360.	0.	0.0000	0.0000
47	4.600	7.23000	0.00000	1063.9	834.	1633.2	306.9	0.0000	0.	692.8	10.7	10.2	46.4	14.5	2232.	12272.	18760.	0.	0.0000	0.0000
48	4.700	7.52000	0.00000	1063.9	832.	1643.1	306.9	0.0000	0.	690.0	10.4	10.0	46.4	14.5	2262.	12547.	19160.	0.	0.0000	0.0000
49	4.800	7.80000	0.00000	1063.9	830.	1653.0	306.9	0.0000	0.	686.6	10.1	9.8	46.4	14.5	2292.	12822.	19560.	0.	0.0000	0.0000
50	4.900	8.07000	0.00000	1063.9	828.	1662.9	306.9	0.0000	0.	682.6	9.8	9.6	46.4	14.5	2322.	13097.	19960.	0.	0.0000	0.0000
51	5.000	8.33000	0.00000	1063.9	826.	1672.8	306.9	0.0000	0.	678.0	9.5	9.4	46.4	14.5	2352.	13372.	20360.	0.	0.0000	0.0000
52	5.100	8.58000	0.00000	1063.9	824.	1682.7	306.9	0.0000	0.	672.8	9.2	9.2	46.4	14.5	2382.	13647.	20760.	0.	0.0000	0.0000
53	5.200	8.82000	0.00000	1063.9	822.	1692.6	306.9	0.0000	0.	667.0	8.9	9.0	46.4	14.5	2412.	13922.	21160.	0.	0.0000	0.0000
54	5.300	9.05000	0.00000	1063.9	820.	1702.5	306.9	0.0000	0.	660.6	8.6	8.8	46.4	14.5	2442.	14197.	21560.	0.	0.0000	0.0000
55	5.400	9.27000	0.00000	1063.9	818.	1712.4	306.9	0.0000	0.	653.6	8.3	8.6	46.4	14.5	2472.	14472.	21960.	0.	0.0000	0.0000
56	5.500	9.48000	0.00000	1063.9	816.	1722.3	306.9	0.0000	0.	646.0	8.0	8.4	46.4	14.5	2502.	14747.	22360.	0.	0.0000	0.0000
57	5.600	9.68000	0.00000	1063.9	814.	1732.2	306.9	0.0000	0.	637.8	7.7	8.2	46.4	14.5	2532.	15022.	22760.	0.	0.0000	0.0000
58	5.700	9.87000	0.00000	1063.9	812.	1742.1	306.9	0.0000	0.	629.0	7.4	8.0	46.4	14.5	2562.	15297.	23160.	0.	0.0000	0.0000
59	5.800	10.05000	0.00000	1063.9	810.	1752.0	306.9	0.0000	0.	619.6	7.1	7.8	46.4	14.5	2592.	15572.	23560.	0.	0.0000	0.0000
60	5.900	10.23000	0.00000	1063.9	808.	1761.9	306.9	0.0000	0.	609.6	6.8	7.6	46.4	14.5	2622.	15847.	23960.	0.	0.0000	0.0000
61	6.000	10.39000	0.00000	1063.9	806.	1771.8	306.9	0.0000	0.	599.0	6.5	7.4	46.4	14.5	2652.	16122.	24360.	0.	0.0000	0.0000
62	6.100	10.54000	0.00000	1063.9	804.	1781.7	306.9	0.0000	0.	587.8	6.2	7.2	46.4	14.5	2682.	16397.	24760.	0.	0.0000	0.0000
63	6.200	10.68000	0.00000	1063.9	802.	1791.6	306.9	0.0000	0.	576.0	5.9	7.0	46.4	14.5	2712.	16672.	25160.	0.	0.0000	0.0000
64	6.300	10.81000	0.00000	1063.9	800.	1801.5	306.9	0.0000	0.	563.6	5.6	6.8	46.4	14.5	2742.	16947.	25560.	0.	0.0000	0.0000
65	6.400	10.93000	0.00000	1063.9	798.	1811.4	306.9	0.0000	0.	550.6	5.3	6.6	46.4	14.5	2772.	17222.	25960.	0.	0.0000	0.0000
66	6.500	11.04000	0.00000	1063.9	796.	1821.3	306.9	0.0000	0.	537.0	5.0	6.4	46.4	14.5	2802.	17497.	26360.	0.	0.0000	0.0000
67	6.600	11.14000	0.00000	1063.9	794.	1831.2	306.9	0.0000	0.	522.8	4.7	6.2	46.4	14.5	2832.	17772.	26760.	0.	0.0000	0.0000
68	6.700	11.23000	0.00000	1063.9	792.	1841.1	306.9	0.0000	0.	508.0	4.4	6.0	46.4	14.5	2862.	18047.	27160.	0.	0.0000	0.0000
69	6.800	11.31000	0.00000	1063.9	790.	1851.0	306.9	0.0000	0.	492.6	4.1	5.8	46.4	14.5	2892.	18322.	27560.	0.	0.0000	0.0000
70	6.900	11.38000	0.00000	1063.9	788.	1860.9	306.9	0.0000	0.	476.6	3.8	5.6	46.4	14.5	2922.	18597.	27960.	0.	0.0000	0.0000
71	7.000	11.44000	0.00000	1063.9	786.	1870.8	306.9	0.0000	0.	460.0	3.5	5.4	46.4	14.5	2952.	18872.	28360.	0.	0.0000	0.0000
72	7.100	11.49000	0.00000	1063.9	784.	1880.7	306.9	0.0000	0.	442.8	3.2	5.2	46.4	14.5	2982.	19147.	28760.	0.	0.0000	0.0000
73	7.200	11.53000	0.00000	1063.9	782.	1890.6	306.9	0.0000	0.	425.0	2.9	5.0	46.4	14.5	3012.	19422.	29160.	0.	0.0000	0.0000
74	7.300	11.56000	0.00000	1063.9	780.	1900.5	306.9	0.0000	0.	406.6	2.6	4.8	46.4	14.5	3042.	19697.	29560.	0.	0.0000	0.0000
75	7.400	11.58000	0.00000	1063.9	778.	1910.4	306.9	0.0000	0.	387.6	2.3	4.6	46.4	14.5	3072.	19972.	29960.	0.	0.0000	0.0000
76	7.500	11.59000	0.00000	1063.9	776.	1920.3	306.9	0.0000	0.	368.0	2.0	4.4	46.4	14.5	3102.	20247.	30360.	0.	0.0000	0.0000
77	7.600	11.59000	0.00000	1063.9	774.	1930.2	306.9	0.0000	0.	347.8	1.7	4.2	46.4	14.5	3132.	20522.	30760.	0.	0.0000	0.0000
78	7.700	11.58000	0.00000	1063.9	772.	1940.1	306.9	0.0000	0.	327.0	1.4	4.0	46.4	14.5	3162.	20797.	31160.	0.	0.0000	0.0000
79	7.800	11.56000	0.00000	1063.9	770.	1950.0	306.9	0.0000	0.	305.6	1.1	3.8	46.4	14.5	3192.	21072.	31560.	0.	0.0000	0.0000
80	7.900	11.53000	0.00000	1063.9	768.	1959.9	306.9	0.0000	0.	283.6	0.8	3.6	46.4	14.5	3222.	21347.	31960.	0.	0.0000	0.0000
81	8.000	11.49000	0.00000	1063.9	766.	1969.8	306.9	0.0000	0.	261.0	0.5	3.4	46.4	14.5	3252.	21622.	32360.	0.	0.0000	0.0000
82	8.100	11.44000	0.00000	1063.9	764.	1979.7	306.9	0.0000	0.	237.8	0.2	3.2	46.4	14.5	3282.	21897.	32760.	0.	0.0000	0.0000
83	8.200	11.38000	0.00000	1063.9	762.	1989.6	306.9	0.0000	0.	214.0	-0.1	3.0	46.4	14.5	3312.	22172.	33160.	0.	0.0000	0.0000
84	8.300	11.31000	0.00000	1063.9	760.	1999.5	306.9	0.0000	0.	189.6	-0.4	2.8	46.4	14.5	3342.	22447.	33560.	0.	0.0000	0.0000
85	8.400	11.23000	0.00000	1063.9	758.	2009.4	306.9	0.0000	0.	164.6	-0.7	2.6	46.4	14.5	3372.	22722.	33960.	0.	0.0000	0.0000
86	8.500	11.14000	0.00000	1063.9	756.	2019.3	306.9	0.0000	0.	139.0	-1.0	2.4	46.4	14.5	3402.	22997.	34360.	0.	0.0000	0.0000
87	8.600	11.04000	0.00000	1063.9	754.	2029.2	306.9	0.0000	0.	112.8	-1.3	2.2	46.4	14.5	3432.	23272.	34760.	0.	0.0000	0.0000
88	8.700	10.93000	0.00000	1063.9	752.	2039.1	306.9	0.0000	0.	86.0	-1.6	2.0	46.4	14.5	3462.	23547.	35160.	0.	0.0000	0.0000
89	8.800	10.81000	0.00000	1063.9	750.	2049.0	306.9	0.0000	0.	58.6	-1.9	1.8	46.4	14.5	3492.	23822.	35560.	0.	0.0000	0.0000
90	8.900	10.68000	0.00000	1063.9	748.	2058.9	306.9	0.0000	0.	30.6	-2.2	1.6	46.4	14.5	3522.	24097.	35960.	0.	0.0000	0.0000
91	9.000	10.54000	0.00000	1063.9	746.	2068.8	306.9	0.0000	0.	2.0	-2.5	1.4	46.4	14.5	3552.	24372.	36360.	0.	0.0000	0.0000
92	9.100	10.39000	0.00000	1063.9	744.	2078.7	306.9	0.0000	0.	-27.0	-2.8	1.2	46.4	14.5	3582.	24647.	36760.	0.	0.0000	0.0000
93	9.200	10.23000	0.00000	1063.9	742.	2088.6	306.9	0.0000	0.	-57.0	-3.1	1.0	46.4	14.5	3612.	24922.	37160.	0.	0.0000	0.0000
94	9.300	10.05000	0.00000	1063.9	740.	2098.5	306.9	0.0000	0.	-87.8	-3.4	0.8	46.4	14.5	3642.	25197.	37560.	0.	0.0000	0.0000
95	9.400	9.87000	0.00000	1063.9	738.	2108.4	306.9	0.0000	0.	-119.4	-3.7	0.6	46.4	14.5	3672.	25472.	37960.	0.	0.0000	0.0000
96	9.500	9.68000	0.00000	1063.9	736.	2118.3	306.9	0.0000	0.	-151.6	-4.0	0.4	46.4	14.5	3702.	25747.	38360.	0.	0.0000	0.0000
97	9.600	9.48000	0.00000	1063.9	734.	2128.2	306.9	0.0000	0.	-184.4	-4.3	0.2	46.4	14.5	3732.	26022.	38760.	0.	0.0000	0.0000
98	9.700	9.27000	0.00000	1063.9	732.	2138.1	306.9	0.0000	0.	-217.8	-4.6	0.0	46.4	14.5	3762.	26297.	39160.	0.	0.0000	0.0000
99	9.800	9.05000	0.00000	1063.9	730.	2148.0	306.9	0.0000	0.	-251.8	-4.9	-0.2	46.4	14.5	3792.	26572.	39560.	0.	0.0000	0.0000
100	9.900	8.82000	0.00000	1063.9	728.	2157.9	306.9	0.0000	0.	-286.4	-5.2	-0.4	46.4	14.5	3822.	26847.	39960.	0.	0.0000	0.0000
101	10.000	8.58000	0.00000	1063.9	726.	2167.8	306.9	0.0000	0.	-321.6	-5.5	-0.6	46.4	14.5	3852.	27122.	40360.	0.	0.0000	0.0000
102	10.100	8.33000	0.00000	1063.9	724.	2177.7	306.9	0.0000	0.	-357.4	-5.8	-0.8	46.4	14.5	3882.	27397.	40760.	0.	0.0000	0.0000
103	10.200	8.07000	0.00000	1063.9	722.	2187.6	306.9	0.0000	0.	-393.8	-6.1	-1.0	46.4	14.5	3912.	27672.	41160.	0.	0.0000	0.0000
104	10.300	7.80000	0.00000	1063.9	720.	2197.5	306.9	0.0000	0.	-430.8	-6.4	-1.2	46.4	14.5	3942.	27947.	41560.	0.	0.0000	0.0000
105	10.400	7.52000	0.00000	1063.9	718.	2207.4	306.9	0.0000	0.	-468.4	-6.7	-1.4	46.4	14.5	3972.	28222.	41960.	0.	0.0000	0.0000
106	10.500	7.23000	0.00000	1063.9	716.	2217.3	306.9	0.0000	0.	-506.6	-7.0	-1.6	46.4	14.5	4002.	28497.	42360.	0.	0.0000	0.0000
107	10.600	6.93000	0.00000	1063.9	714.	2227.2	306.9	0.0000	0.	-545.4	-7.3	-1.8	46.4	14.5	4032.	28772.	42760.	0.	0.0000	0.0000
108	10.700	6.63000	0.00000	1063.9	712.	2237.1	306.9	0.0000	0.	-584.8	-7.6	-2.0	46.4	14.5	4062.	29047.	43160.	0.	0.0000	0.0000
109	10.800	6.32000	0.00000	1063.9	710.	2247.0	306.9	0.0000	0.	-624.8	-7.9	-2.2	46.4	14.5	4092.	29322.	43560.	0.	0.0000	0.0000
110	10.900	6.00000	0.00000	1063.9	708.	2256.9	306.9	0.0000	0.	-665.4	-8.2	-2.4	46.4	14.5	4122.	29597.	43960.	0.	0.0000	0.0000
111	11.000	5.67000	0.00000	1063.9	706.	2266.8	306.9	0.0000	0.	-706.6	-8.5	-2.6	46.4	14.5	4152.	29872.	44360.	0.	0.0000	0.0000
112	11.100	5.33000	0.00000	1063.9	704.	2276.7	306.9	0.0000	0.	-748.4	-8.8	-2.8	46.4	14.5	4182.	30147.	44760.	0.	0.0000	0.0000
113	11.200	4.98000	0.00000	1063.9	702.	2286.6	306.9	0.0000	0.	-790.8	-9.1	-3.0	46.4	14.5	4212.	30422.	45160.	0.	0.0000	0.0000
114	11.300	4.63000	0.00000	1063.9	700.	2296.5	306.9	0.0000	0.	-833.8	-9.4	-3.2	46.4	14.5	4242.	30697.	45560.	0.	0.0000	0.0000
115	11.400	4.27000	0.00000	1063.9	698.	2306.4	306.9	0.0000	0.	-877.4	-9.7	-3.4	46.4	14.5	4272.	30972.	45960.	0.	0.0000	0.0000
116	11.500	3.90000	0.00000	1063.9	696.	2316.3	306.9	0.0000	0.	-921.6	-10.0	-3.6	46.4	14.5	4302.	31247.	46360.	0.	0.0000	0.0000
117	11.600	3.52000	0.00000	1063.9	694.	2326.2	306.9	0.0000	0.	-966.4	-10.3	-3.8	46.4	14.5	4332.	31522.	46760.	0.	0.0000	0.0000
118	11.700	3.13000	0.00000	1063.9	692.	2336.1	306.9	0.0000	0.	-1011.8	-10.6	-4.0	46.4	14.5	4362.	31797.	47160.	0.	0.0000	0.0000
119	11.800	2.73000	0.00000	1063.9	690.	2346.0	306.9	0.0000	0.	-1057.8	-10.9	-4.2	46.4	14.5	4392.	32072.	47560.	0.	0.0000	0.0000
120	11.900	2.32000	0.00000	1063.9	688.	2355.9	306.9	0.0000	0.	-1104.4	-11.2	-4.4	46.4	14.5	4422.	32347.	47960.	0.	0.0000	0.0000
121	12.000	1.90000	0.00000	1063.9	686.	2365.8	306.9	0.0000	0.	-1151.6	-11.5	-4.6	46.4	14.5	4452.	32622.	48360.	0.	0.0000	0.0000
122	12.100	1.47000	0.00000	1063.9	684.	2375.7	306.9	0.0000	0.	-1199.4	-11.8	-4.8	46.4	14.5	4482.	32897.	48760.	0.	0.0000	0.0000
123	12.200	1.03000	0.00000	1063.9	682.	2385.6	306.9	0.0000	0.	-1247.8	-12.1	-5.0	46.4	14.5	4512.	33172.	49160.	0.	0.0000	0.0000
124	12.300	0.58000	0.00000	1063.9	680.	2395.5	306.9	0.0000	0.	-1296.8	-12.4	-5.2	46.4	14.5	4542.	33447.	49560.	0.	0.0000	0.0000
125	12.400	0.12000	0.00000	1063.9	678.	2405.4	306.9	0.0000	0.	-1346.4	-12.7	-5.4	46.4	14.5	4572.	33722.	49960.	0.	0.0000	0.0000

ASH FUSION STARTS AT XF = 0.7103 AT HEIGHT (FROM TOP OF BURNING ZONE) = 2.025 M

HEIGHT OF THE BURNING ZONE = 2.290 M

TABLE F.2 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 2 (A)

(DPS=0.068 M)

RESULTS OF ANALYSIS

I	Z(M)	TE(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	480.50	1182.60	304.10	11.3	55.2	7955.0	0.0
3	0.100	473.33	1163.96	304.00	11.3	55.2	7821.2	19.6
5	0.200	466.27	1145.55	303.88	11.3	55.2	7688.6	38.5
7	0.300	459.33	1127.34	303.75	11.3	55.2	7557.4	56.6
9	0.400	452.49	1109.35	303.62	11.3	55.2	7427.4	73.9
11	0.500	445.76	1091.57	303.46	11.3	55.2	7298.7	90.5
13	0.600	439.14	1074.01	303.36	11.3	55.2	7171.3	106.3
15	0.700	432.62	1056.65	303.24	11.3	55.2	7045.2	121.4
17	0.800	426.21	1039.51	303.11	11.3	55.2	6920.3	135.8
19	0.900	419.90	1022.58	302.99	11.3	55.2	6796.8	149.5
21	1.000	413.70	1005.85	302.87	11.3	55.2	6674.5	162.5
23	1.100	407.60	989.34	302.74	11.3	55.2	6553.5	174.8
25	1.200	401.60	973.03	302.62	11.3	55.2	6433.8	186.4
27	1.300	395.71	956.93	302.50	11.3	55.2	6315.4	197.4
29	1.400	389.91	941.04	302.38	11.2	55.2	6198.3	207.7
31	1.500	384.21	925.35	302.26	11.2	55.2	6082.4	217.4
33	1.600	378.61	909.86	302.14	11.2	55.2	5967.9	226.5
35	1.700	373.10	894.58	302.02	11.2	55.2	5854.6	234.9
37	1.800	367.70	879.50	301.90	11.2	55.2	5742.6	242.8
39	1.900	362.38	864.63	301.79	11.2	55.2	5632.0	250.0
41	2.000	357.17	849.95	301.67	11.2	55.2	5522.6	256.7
43	2.100	352.04	835.48	301.55	11.2	55.2	5414.5	262.8
45	2.200	347.01	821.21	301.43	11.2	55.2	5307.7	268.4
47	2.300	342.06	807.13	301.31	11.2	55.2	5202.2	273.4
49	2.400	337.21	793.26	301.20	11.2	55.2	5098.0	277.8
51	2.500	332.45	779.58	301.08	11.2	55.2	4995.1	281.8
53	2.600	327.77	766.10	300.96	11.2	55.2	4893.5	285.2
55	2.700	323.18	752.82	300.83	11.2	55.2	4793.2	288.1
57	2.800	318.68	739.73	300.71	11.1	55.2	4694.2	290.5
59	2.900	314.26	726.83	300.58	11.1	55.2	4596.5	292.4
61	3.000	309.93	714.13	300.45	11.1	55.2	4500.1	293.8
63	3.100	305.68	701.62	300.31	11.1	55.2	4405.0	294.7
65	3.200	301.51	689.30	300.16	11.1	55.2	4311.3	295.2
66	3.250	299.45	683.21	300.07	11.1	55.2	4264.9	295.3

HEIGHT OF THE COOLING ZONE=3.250M

TABLE P.2 (81)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 2 (8)

(DPS=0.112 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELHTL
1	0.000		740.00	300.00	300.00	312.00	4.80	25.07	18.29	35.87	11.18	0.0	0.0	0.0	0.0
3	0.100		757.50	300.00	300.00	315.12	6.00	25.10	18.31	35.87	11.18	102.0	-1207.9	-1553.5	135.1
5	0.200		775.00	300.00	300.00	319.54	8.16	25.16	18.31	35.87	11.18	244.8	-1136.1	-1548.9	275.1
7	0.300		792.50	300.00	300.00	316.87	9.48	25.09	18.29	35.87	11.18	230.4	-1139.9	-1504.5	417.2
9	0.400		810.00	300.00	300.00	316.87	9.48	25.09	18.29	35.87	11.18	216.7	-1128.8	-1463.5	562.7	
11	0.500		827.50	300.00	300.00	316.87	10.77	25.07	18.29	35.87	11.18	203.5	-1122.0	-1429.5	710.5	
13	0.600		845.00	300.00	300.00	316.87	12.11	25.07	18.29	35.87	11.18	190.7	-1056.6	-1375.5	861.0	
15	0.700		862.50	300.00	300.00	316.87	14.01	25.07	18.29	35.87	11.18	178.4	-976.7	-1356.0	1015.4	
17	0.800		880.00	300.00	300.00	316.87	16.19	25.07	18.29	35.87	11.18	166.7	-925.5	-1331.0	1171.9	
19	0.900		897.50	300.00	300.00	316.87	18.13	25.07	18.29	35.87	11.18	155.4	-874.4	-1295.0	1331.7	
21	1.000		915.00	300.00	300.00	316.87	21.34	25.07	18.29	35.87	11.18	144.6	-824.3	-1253.0	1493.8	
23	1.100		932.50	300.00	300.00	316.87	23.63	25.07	18.29	35.87	11.18	134.3	-774.9	-1193.0	1657.3	
25	1.200		950.00	300.00	300.00	316.87	26.57	25.07	18.29	35.87	11.18	124.4	-726.4	-1143.0	1822.3	
27	1.300		967.50	300.00	300.00	316.87	29.44	25.07	18.29	35.87	11.18	115.0	-678.7	-1095.0	1988.7	
29	1.400		985.00	300.00	300.00	316.87	32.43	25.07	18.29	35.87	11.18	106.1	-631.8	-1045.0	2156.6	
31	1.500		1002.50	300.00	300.00	316.87	35.54	25.07	18.29	35.87	11.18	97.7	-585.7	-1000.0	2325.9	
33	1.600		1020.00	300.00	300.00	316.87	38.77	25.07	18.29	35.87	11.18	89.7	-540.4	-955.0	2496.7	
35	1.700		1037.50	300.00	300.00	316.87	41.20	25.07	18.29	35.87	11.18	82.2	-495.9	-910.0	2668.9	
37	1.800		1055.00	300.00	300.00	316.87	43.11	25.07	18.29	35.87	11.18	75.1	-452.1	-865.0	2842.6	
39	1.900		1072.50	300.00	300.00	316.87	45.01	25.07	18.29	35.87	11.18	68.4	-409.1	-820.0	3017.7	
41	2.000		1090.00	300.00	300.00	316.87	46.91	25.07	18.29	35.87	11.18	62.1	-366.8	-775.0	3194.2	
43	2.100		1107.50	300.00	300.00	316.87	48.80	25.07	18.29	35.87	11.18	56.3	-325.2	-730.0	3372.2	
45	2.200		1125.00	300.00	300.00	316.87	50.70	25.07	18.29	35.87	11.18	50.8	-284.3	-685.0	3551.6	
47	2.300		1142.50	300.00	300.00	316.87	52.59	25.07	18.29	35.87	11.18	45.7	-244.1	-640.0	3732.5	
49	2.400		1160.00	300.00	300.00	316.87	54.49	25.07	18.29	35.87	11.18	41.0	-204.6	-595.0	3914.8	
51	2.500		1177.50	300.00	300.00	316.87	56.38	25.07	18.29	35.87	11.18	36.7	-165.7	-550.0	4098.6	
53	2.600		1195.00	300.00	300.00	316.87	58.28	25.07	18.29	35.87	11.18	32.8	-127.5	-505.0	4283.8	
55	2.700		1212.50	300.00	300.00	316.87	60.17	25.07	18.29	35.87	11.18	29.2	-90.0	-460.0	4470.5	
57	2.800		1230.00	300.00	300.00	316.87	62.07	25.07	18.29	35.87	11.18	26.0	-53.1	-415.0	4658.6	
59	2.900		1247.50	300.00	300.00	316.87	63.96	25.07	18.29	35.87	11.18	23.1	-16.9	-370.0	4848.2	
61	3.000		1265.00	300.00	300.00	316.87	65.86	25.07	18.29	35.87	11.18	20.6	19.5	-325.0	5039.2	
63	3.100		1282.50	300.00	300.00	316.87	67.75	25.07	18.29	35.87	11.18	18.4	54.9	-280.0	5231.7	
65	3.200		1300.00	300.00	300.00	316.87	69.65	25.07	18.29	35.87	11.18	16.5	89.6	-235.0	5425.6	
67	3.300		1317.50	300.00	300.00	316.87	71.54	25.07	18.29	35.87	11.18	14.9	123.6	-190.0	5621.0	
69	3.400		1335.00	300.00	300.00	316.87	73.44	25.07	18.29	35.87	11.18	13.6	156.9	-145.0	5817.8	
71	3.500		1352.50	300.00	300.00	316.87	75.33	25.07	18.29	35.87	11.18	12.6	189.5	-100.0	6016.1	
73	3.600		1370.00	300.00	300.00	316.87	77.23	25.07	18.29	35.87	11.18	11.8	221.4	-55.0	6215.8	
75	3.700		1387.50	300.00	300.00	316.87	79.12	25.07	18.29	35.87	11.18	11.3	252.6	-10.0	6417.0	
77	3.800		1405.00	300.00	300.00	316.87	81.02	25.07	18.29	35.87	11.18	11.0	283.1	35.0	6619.6	
79	3.900		1422.50	300.00	300.00	316.87	82.91	25.07	18.29	35.87	11.18	10.9	312.9	80.0	6823.7	
81	4.000		1440.00	300.00	300.00	316.87	84.81	25.07	18.29	35.87	11.18	11.0	342.0	125.0	7029.2	
83	4.100		1457.50	300.00	300.00	316.87	86.70	25.07	18.29	35.87	11.18	11.3	370.4	170.0	7236.2	
85	4.200		1475.00	300.00	300.00	316.87	88.60	25.07	18.29	35.87	11.18	11.8	398.1	215.0	7444.6	
87	4.300		1492.50	300.00	300.00	316.87	90.49	25.07	18.29	35.87	11.18	12.6	425.1	260.0	7654.5	
89	4.400		1510.00	300.00	300.00	316.87	92.39	25.07	18.29	35.87	11.18	13.6	451.4	305.0	7865.8	
91	4.500		1527.50	300.00	300.00	316.87	94.28	25.07	18.29	35.87	11.18	14.9	477.0	350.0	8078.6	
93	4.600		1545.00	300.00	300.00	316.87	96.18	25.07	18.29	35.87	11.18	16.5	501.9	395.0	8292.8	
95	4.700		1562.50	300.00	300.00	316.87	98.07	25.07	18.29	35.87	11.18	18.4	526.2	440.0	8508.5	
97	4.800		1580.00	300.00	300.00	316.87	99.97	25.07	18.29	35.87	11.18	20.6	549.8	485.0	8725.6	
99	4.900		1597.50	300.00	300.00	316.87	101.86	25.07	18.29	35.87	11.18	23.1	572.8	530.0	8944.2	
101	5.000		1615.00	300.00	300.00	316.87	103.76	25.07	18.29	35.87	11.18	26.0	595.2	575.0	9164.2	
103	5.100		1632.50	300.00	300.00	316.87	105.65	25.07	18.29	35.87	11.18	29.2	617.0	620.0	9385.7	
105	5.200		1650.00	300.00	300.00	316.87	107.55	25.07	18.29	35.87	11.18	32.8	638.2	665.0	9608.6	
107	5.300		1667.50	300.00	300.00	316.87	109.44	25.07	18.29	35.87	11.18	36.7	658.8	710.0	9833.0	
109	5.400		1685.00	300.00	300.00	316.87	111.34	25.07	18.29	35.87	11.18	41.0	678.9	755.0	10058.8	
111	5.500	0.17316	1071.99	948.97	940.46	328.59	106.70	24.56	17.22	35.07	11.18	99.7	-375.3	-445.7	10053.9

VM COMBUSTION STARTS AT XF = 0.1732 AND AT HEIGHT (FROM TOP) = 5.500 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 5.500 M

TABLE P.2 (B2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 2 (9)

(DPS=0.112 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XL	TG(K)	TF(K)	TS(K)	TL(K)	RSHL	HD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PC2G	PC02G
1	0.000	0.1731	0.0000	1276.0	946.0	946.0	946.0	0.0000	0.0000	0.	1066.6	24.5	17.8	35.9	11.2	131.	-374.	-445.	0.	0.0000	0.0000
2	0.114	0.1953	0.0000	1069.4	1151.7	1012.6	1012.6	0.0000	0.0000	0.	1062.9	24.1	17.6	35.8	11.2	130.	-387.	-221.	22.	0.0000	0.0000
3	0.228	0.2161	0.0000	1060.4	1125.1	1057.6	1057.6	0.0000	0.0000	0.	1051.9	24.1	17.4	35.8	11.2	129.	-374.	44.	44.	0.0000	0.0000
4	0.342	0.2342	0.0000	1050.0	1111.1	1057.6	1057.6	0.0000	0.0000	0.	1041.5	24.1	17.3	35.8	11.2	129.	-349.	349.	66.	0.0000	0.0000
5	0.456	0.2505	0.0000	1040.0	1101.1	1057.6	1057.6	0.0000	0.0000	1.	1031.2	24.1	17.0	35.8	11.2	129.	-331.	441.	88.	0.0000	0.0000
6	0.570	0.2650	0.0000	1030.0	1091.1	1057.6	1057.6	0.0000	0.0000	1.	1020.9	24.1	16.9	35.8	11.2	129.	-317.	550.	110.	0.0000	0.0000
7	0.684	0.2781	0.0000	1020.0	1081.1	1057.6	1057.6	0.0000	0.0000	1.	1010.6	24.1	16.9	35.8	11.2	129.	-307.	660.	132.	0.0000	0.0000
8	0.798	0.2900	0.0000	1010.0	1071.1	1057.6	1057.6	0.0000	0.0000	1.	1000.3	24.1	16.8	35.8	11.2	129.	-299.	770.	154.	0.0000	0.0000
9	0.912	0.3010	0.0000	1000.0	1061.1	1057.6	1057.6	0.0000	0.0000	1.	990.0	24.1	16.8	35.8	11.2	129.	-292.	880.	176.	0.0000	0.0000
10	1.026	0.3113	0.0000	990.0	1051.1	1057.6	1057.6	0.0000	0.0000	1.	979.7	24.1	16.8	35.8	11.2	129.	-286.	990.	198.	0.0000	0.0000
11	1.140	0.3211	0.0000	980.0	1041.1	1057.6	1057.6	0.0000	0.0000	1.	969.4	24.1	16.8	35.8	11.2	129.	-281.	1100.	220.	0.0000	0.0000
12	1.254	0.3304	0.0000	970.0	1031.1	1057.6	1057.6	0.0000	0.0000	1.	959.1	24.1	16.8	35.8	11.2	129.	-276.	1210.	242.	0.0000	0.0000
13	1.368	0.3393	0.0000	960.0	1021.1	1057.6	1057.6	0.0000	0.0000	1.	948.8	24.1	16.8	35.8	11.2	129.	-272.	1320.	264.	0.0000	0.0000
14	1.482	0.3479	0.0000	950.0	1011.1	1057.6	1057.6	0.0000	0.0000	1.	938.5	24.1	16.8	35.8	11.2	129.	-268.	1430.	286.	0.0000	0.0000
15	1.596	0.3562	0.0000	940.0	1001.1	1057.6	1057.6	0.0000	0.0000	1.	928.2	24.1	16.8	35.8	11.2	129.	-265.	1540.	308.	0.0000	0.0000
16	1.710	0.3644	0.0000	930.0	991.1	1057.6	1057.6	0.0000	0.0000	1.	917.9	24.1	16.8	35.8	11.2	129.	-262.	1650.	330.	0.0000	0.0000
17	1.824	0.3725	0.0000	920.0	981.1	1057.6	1057.6	0.0000	0.0000	1.	907.6	24.1	16.8	35.8	11.2	129.	-260.	1760.	352.	0.0000	0.0000
18	1.938	0.3806	0.0000	910.0	971.1	1057.6	1057.6	0.0000	0.0000	1.	897.3	24.1	16.8	35.8	11.2	129.	-258.	1870.	374.	0.0000	0.0000
19	2.052	0.3888	0.0000	900.0	961.1	1057.6	1057.6	0.0000	0.0000	1.	887.0	24.1	16.8	35.8	11.2	129.	-256.	1980.	396.	0.0000	0.0000
20	2.166	0.3972	0.0000	890.0	951.1	1057.6	1057.6	0.0000	0.0000	1.	876.7	24.1	16.8	35.8	11.2	129.	-255.	2090.	418.	0.0000	0.0000
21	2.280	0.4059	0.0000	880.0	941.1	1057.6	1057.6	0.0000	0.0000	1.	866.4	24.1	16.8	35.8	11.2	129.	-254.	2200.	440.	0.0000	0.0000
22	2.394	0.4150	0.0000	870.0	931.1	1057.6	1057.6	0.0000	0.0000	1.	856.1	24.1	16.8	35.8	11.2	129.	-253.	2310.	462.	0.0000	0.0000
23	2.508	0.4246	0.0000	860.0	921.1	1057.6	1057.6	0.0000	0.0000	1.	845.8	24.1	16.8	35.8	11.2	129.	-252.	2420.	484.	0.0000	0.0000
24	2.622	0.4348	0.0000	850.0	911.1	1057.6	1057.6	0.0000	0.0000	1.	835.5	24.1	16.8	35.8	11.2	129.	-252.	2530.	506.	0.0000	0.0000
25	2.736	0.4458	0.0000	840.0	901.1	1057.6	1057.6	0.0000	0.0000	1.	825.2	24.1	16.8	35.8	11.2	129.	-252.	2640.	528.	0.0000	0.0000
26	2.850	0.4577	0.0000	830.0	891.1	1057.6	1057.6	0.0000	0.0000	1.	814.9	24.1	16.8	35.8	11.2	129.	-252.	2750.	550.	0.0000	0.0000
27	2.964	0.4708	0.0000	820.0	881.1	1057.6	1057.6	0.0000	0.0000	1.	804.6	24.1	16.8	35.8	11.2	129.	-252.	2860.	572.	0.0000	0.0000
28	3.078	0.4854	0.0000	810.0	871.1	1057.6	1057.6	0.0000	0.0000	1.	794.3	24.1	16.8	35.8	11.2	129.	-253.	2970.	594.	0.0000	0.0000
29	3.192	0.5020	0.0000	800.0	861.1	1057.6	1057.6	0.0000	0.0000	1.	784.0	24.1	16.8	35.8	11.2	129.	-253.	3080.	616.	0.0000	0.0000
30	3.306	0.5211	0.0000	790.0	851.1	1057.6	1057.6	0.0000	0.0000	1.	773.7	24.1	16.8	35.8	11.2	129.	-254.	3190.	638.	0.0000	0.0000
31	3.420	0.5435	0.0000	780.0	841.1	1057.6	1057.6	0.0000	0.0000	1.	763.4	24.1	16.8	35.8	11.2	129.	-255.	3300.	660.	0.0000	0.0000
32	3.534	0.5703	0.0000	770.0	831.1	1057.6	1057.6	0.0000	0.0000	1.	753.1	24.1	16.8	35.8	11.2	129.	-256.	3410.	682.	0.0000	0.0000
33	3.648	0.6031	0.0000	760.0	821.1	1057.6	1057.6	0.0000	0.0000	1.	742.8	24.1	16.8	35.8	11.2	129.	-258.	3520.	704.	0.0000	0.0000
34	3.762	0.6441	0.0000	750.0	811.1	1057.6	1057.6	0.0000	0.0000	1.	732.5	24.1	16.8	35.8	11.2	129.	-260.	3630.	726.	0.0000	0.0000
35	3.876	0.6956	0.0000	740.0	801.1	1057.6	1057.6	0.0000	0.0000	1.	722.2	24.1	16.8	35.8	11.2	129.	-262.	3740.	748.	0.0000	0.0000
36	3.990	0.7611	0.0000	730.0	791.1	1057.6	1057.6	0.0000	0.0000	1.	711.9	24.1	16.8	35.8	11.2	129.	-265.	3850.	770.	0.0000	0.0000
37	4.104	0.8466	0.0000	720.0	781.1	1057.6	1057.6	0.0000	0.0000	1.	701.6	24.1	16.8	35.8	11.2	129.	-268.	3960.	792.	0.0000	0.0000
38	4.218	0.9600	0.0000	710.0	771.1	1057.6	1057.6	0.0000	0.0000	1.	691.3	24.1	16.8	35.8	11.2	129.	-272.	4070.	814.	0.0000	0.0000
39	4.332	1.0000	0.0000	700.0	761.1	1057.6	1057.6	0.0000	0.0000	1.	681.0	24.1	16.8	35.8	11.2	129.	-276.	4180.	836.	0.0000	0.0000
40	4.446	1.0000	0.0000	690.0	751.1	1057.6	1057.6	0.0000	0.0000	1.	670.7	24.1	16.8	35.8	11.2	129.	-281.	4290.	858.	0.0000	0.0000
41	4.560	1.0000	0.0000	680.0	741.1	1057.6	1057.6	0.0000	0.0000	1.	660.4	24.1	16.8	35.8	11.2	129.	-286.	4400.	880.	0.0000	0.0000
42	4.674	1.0000	0.0000	670.0	731.1	1057.6	1057.6	0.0000	0.0000	1.	650.1	24.1	16.8	35.8	11.2	129.	-292.	4510.	902.	0.0000	0.0000
43	4.788	1.0000	0.0000	660.0	721.1	1057.6	1057.6	0.0000	0.0000	1.	639.8	24.1	16.8	35.8	11.2	129.	-299.	4620.	924.	0.0000	0.0000
44	4.902	1.0000	0.0000	650.0	711.1	1057.6	1057.6	0.0000	0.0000	1.	629.5	24.1	16.8	35.8	11.2	129.	-307.	4730.	946.	0.0000	0.0000
45	5.016	1.0000	0.0000	640.0	701.1	1057.6	1057.6	0.0000	0.0000	1.	619.2	24.1	16.8	35.8	11.2	129.	-317.	4840.	968.	0.0000	0.0000
46	5.130	1.0000	0.0000	630.0	691.1	1057.6	1057.6	0.0000	0.0000	1.	608.9	24.1	16.8	35.8	11.2	129.	-331.	4950.	990.	0.0000	0.0000
47	5.244	1.0000	0.0000	620.0	681.1	1057.6	1057.6	0.0000	0.0000	1.	598.6	24.1	16.8	35.8	11.2	129.	-349.	5060.	1012.	0.0000	0.0000
48	5.358	1.0000	0.0000	610.0	671.1	1057.6	1057.6	0.0000	0.0000	1.	588.3	24.1	16.8	35.8	11.2	129.	-374.	5170.	1034.	0.0000	0.0000
49	5.472	1.0000	0.0000	600.0	661.1	1057.6	1057.6	0.0000	0.0000	1.	578.0	24.1	16.8	35.8	11.2	129.	-408.	5280.	1056.	0.0000	0.0000
50	5.586	1.0000	0.0000	590.0	651.1	1057.6	1057.6	0.0000	0.0000	1.	567.7	24.1	16.8	35.8	11.2	129.	-453.	5390.	1078.	0.0000	0.0000
51	5.700	1.0000	0.0000	580.0	641.1	1057.6	1057.6	0.0000	0.0000	1.	557.4	24.1	16.8	35.8	11.2	129.	-513.	5500.	1100.	0.0000	0.0000
52	5.814	1.0000	0.0000	570.0	631.1	1057.6	1057.6	0.0000	0.0000	1.	547.1	24.1	16.8	35.8	11.2	129.	-594.	5610.	1122.	0.0000	0.0000
53	5.928	1.0000	0.0000	560.0	621.1	1057.6	1057.6	0.0000	0.0000	1.	536.8	24.1	16.8	35.8	11.2	129.	-700.	5720.	1144.	0.0000	0.0000

ASH FUSION STARTS AT XF = 0.6831 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.895 M

HEIGHT OF THE BURNING ZONE = 2.280 M

TABLE R2 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 2 (S)

(DPS=0.112 M)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	GSG	DELHTL
1	0.000	313.30	1200.80	305.30	10.1	45.4	7037.1	0.0
3	0.100	[illegible]	1193.25	305.30	10.1	45.4	6955.5	26.1
5	[illegible]	[illegible]	1179.87	[illegible]	10.1	45.4	6884.5	51.6
7	[illegible]	307.31	1166.57	[illegible]	10.1	45.4	6779.2	76.4
9	[illegible]	307.79	1155.40	[illegible]	10.1	45.4	6694.4	100.6
11	[illegible]	307.52	1146.33	[illegible]	10.1	45.4	6610.3	124.1
13	[illegible]	[illegible]	1127.34	[illegible]	10.1	45.4	6520.8	147.1
15	[illegible]	[illegible]	1114.35	[illegible]	10.1	45.4	6443.9	169.5
17	[illegible]	[illegible]	1101.00	[illegible]	10.1	45.4	6361.7	191.2
19	[illegible]	[illegible]	1087.26	[illegible]	10.1	45.4	6282.0	212.4
21	[illegible]	[illegible]	1076.73	[illegible]	10.1	45.4	6199.0	233.0
23	[illegible]	[illegible]	1064.30	[illegible]	10.1	45.4	6111.0	253.2
25	[illegible]	[illegible]	1053.26	[illegible]	10.1	45.4	6038.8	272.4
27	[illegible]	[illegible]	1042.97	[illegible]	10.1	45.4	5959.0	291.2
29	[illegible]	[illegible]	1027.76	[illegible]	10.1	45.4	5861.1	309.5
31	[illegible]	[illegible]	1015.70	[illegible]	10.1	45.4	5803.1	327.3
33	[illegible]	[illegible]	1004.14	[illegible]	10.1	45.4	5725.8	344.5
35	[illegible]	[illegible]	992.43	[illegible]	10.1	45.4	5649.1	361.2
37	[illegible]	[illegible]	979.33	[illegible]	10.1	45.4	5573.0	377.3
39	[illegible]	[illegible]	967.47	[illegible]	10.1	45.4	5497.5	392.9
41	[illegible]	[illegible]	956.70	[illegible]	10.1	45.4	5422.6	408.1
43	[illegible]	[illegible]	945.54	[illegible]	10.1	45.4	5346.4	422.6
45	[illegible]	[illegible]	934.46	[illegible]	10.1	45.4	5274.7	436.7
47	[illegible]	[illegible]	923.55	[illegible]	10.1	45.4	5201.7	450.3
49	[illegible]	[illegible]	913.59	[illegible]	10.1	45.4	5129.3	463.5
51	[illegible]	[illegible]	902.71	[illegible]	10.1	45.4	5057.5	476.1
53	[illegible]	[illegible]	891.98	[illegible]	10.1	45.4	4986.3	488.2
55	[illegible]	[illegible]	881.57	[illegible]	10.1	45.4	4915.8	499.9
57	[illegible]	[illegible]	870.68	[illegible]	10.1	45.4	4845.8	511.1
59	[illegible]	[illegible]	860.40	[illegible]	10.1	45.4	4776.5	521.9
61	[illegible]	[illegible]	850.15	[illegible]	10.1	45.4	4707.8	532.2
63	[illegible]	[illegible]	839.97	[illegible]	10.1	45.4	4639.7	542.0
65	[illegible]	[illegible]	829.89	[illegible]	10.1	45.4	4572.3	551.4
67	[illegible]	[illegible]	819.91	[illegible]	10.1	45.4	4505.5	560.4
69	[illegible]	[illegible]	810.04	[illegible]	10.1	45.4	4439.3	569.0
71	[illegible]	[illegible]	800.27	[illegible]	10.1	45.4	4373.6	577.1
73	[illegible]	[illegible]	790.61	[illegible]	10.1	45.4	4308.6	584.8
75	[illegible]	[illegible]	781.05	[illegible]	10.1	45.4	4244.2	592.1
77	[illegible]	[illegible]	771.60	[illegible]	10.1	45.4	4180.4	599.0
79	[illegible]	[illegible]	762.26	[illegible]	10.1	45.4	4117.3	605.6
81	[illegible]	[illegible]	753.02	[illegible]	10.1	45.4	4054.7	611.7
83	[illegible]	[illegible]	743.89	[illegible]	10.1	45.4	3992.8	617.4
85	[illegible]	[illegible]	734.86	[illegible]	10.1	45.4	3931.5	622.7
87	[illegible]	[illegible]	725.94	[illegible]	10.1	45.4	3870.8	627.7
89	[illegible]	[illegible]	717.12	[illegible]	10.1	45.4	3810.8	632.3
91	[illegible]	[illegible]	708.41	[illegible]	10.1	45.4	3751.3	636.5
93	[illegible]	[illegible]	699.80	[illegible]	10.1	45.4	3692.5	640.4
95	[illegible]	[illegible]	691.30	[illegible]	10.1	45.4	3634.2	643.9
97	[illegible]	[illegible]	682.91	[illegible]	10.1	45.4	3576.6	647.1
99	[illegible]	[illegible]	674.62	[illegible]	10.1	45.4	3519.5	650.0
101	[illegible]	[illegible]	666.43	[illegible]	10.1	45.4	3463.0	652.4
103	[illegible]	[illegible]	658.35	[illegible]	10.1	45.4	3407.1	654.6
105	[illegible]	[illegible]	650.37	[illegible]	10.1	45.4	3351.7	656.4
107	[illegible]	[illegible]	642.49	[illegible]	10.1	45.4	3296.9	657.9
109	[illegible]	[illegible]	634.71	[illegible]	10.1	45.4	3242.6	659.2
111	[illegible]	[illegible]	627.03	[illegible]	9.9	45.4	3188.9	660.1
113	[illegible]	[illegible]	619.45	[illegible]	9.9	45.4	3135.7	660.8
115	5.700	[illegible]	611.97	[illegible]	9.9	45.4	3083.1	661.2
116	5.750	295.35	607.40	300.33	9.9	45.4	3059.7	661.0

HEIGHT OF THE COOLING ZONE=5.750M

TABLE P.3 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 3 (A)

(DPF=0.044)

/ RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TB(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELNTL
1	0.000	0.00000	748.00	300.00	300.00	318.00	5.00	26.42	15.08	40.22	12.54	0.0	0.0	0.0	0.0
2	0.100	0.01200	781.39	335.11	326.68	318.96	7.14	26.45	15.10	40.22	12.54	224.6	-135.2	-185.3	134.1
3	0.200	0.01250	774.20	407.02	331.26	319.46	8.86	26.44	15.09	40.22	12.54	268.1	-135.2	-175.5	272.2
4	0.300	0.01500	786.61	426.14	376.76	319.79	10.56	26.43	15.07	40.22	12.54	290.5	-131.5	-171.9	413.5
5	0.400	0.01750	798.66	440.40	403.06	320.19	12.27	26.42	15.06	40.22	12.54	296.1	-126.9	-164.3	558.4
6	0.500	0.02000	810.39	460.58	420.16	320.51	14.00	26.41	15.04	40.22	12.54	291.3	-122.5	-161.4	706.6
7	0.600	0.02500	821.39	508.03	449.74	320.86	16.65	26.44	15.06	40.22	12.54	549.2	-115.1	-155.2	857.1
8	0.700	0.03000	831.78	537.54	474.38	321.21	18.96	26.47	15.09	40.22	12.54	697.0	-103.4	-152.2	1010.1
9	0.800	0.03500	841.72	555.07	498.78	321.53	21.16	26.49	15.09	40.22	12.54	708.4	-104.3	-140.2	1166.0
10	0.900	0.04000	851.27	577.03	522.33	321.84	23.32	26.51	15.11	40.22	12.54	710.7	-101.2	-140.4	1325.0
11	1.000	0.04500	860.47	593.91	544.84	322.14	25.51	26.54	15.12	40.22	12.54	697.4	-99.8	-134.8	1487.3
12	1.100	0.05000	869.35	610.17	566.66	322.42	27.76	26.56	15.14	40.22	12.54	678.6	-98.3	-129.5	1652.7
13	1.200	0.05500	877.91	626.03	588.70	322.71	30.07	26.58	15.15	40.22	12.54	658.8	-93.4	-124.6	1821.2
14	1.300	0.06000	886.18	641.54	610.98	322.98	32.45	26.60	15.17	40.22	12.54	638.9	-90.6	-119.9	1992.9
15	1.400	0.06500	894.17	656.88	634.77	323.23	34.85	26.62	15.18	40.22	12.54	619.4	-88.0	-115.4	2167.8
16	1.500	0.07000	901.88	671.45	658.53	323.48	37.27	26.64	15.19	40.22	12.54	600.5	-85.5	-111.2	2345.8
17	1.600	0.07500	909.31	685.11	681.44	323.72	39.55	26.66	15.20	40.22	12.54	582.1	-83.2	-107.1	2526.9
18	1.700	0.08000	916.48	698.04	704.09	323.94	41.57	26.66	15.20	40.22	12.54	564.2	-80.9	-103.2	2711.2
19	1.800	0.08504	923.40	706.29	688.16	324.14	43.80	26.67	15.20	40.22	12.54	523.3	-80.4	-98.3	2897.3
20	1.900	0.09078	930.36	713.84	701.03	324.34	46.07	26.67	15.20	40.22	12.54	498.4	-78.8	-95.7	3086.3
21	2.000	0.09583	937.07	724.75	713.67	324.53	48.35	26.67	15.19	40.22	12.54	485.6	-77.1	-93.3	3277.3
22	2.100	0.10088	943.44	735.88	726.76	324.71	50.66	26.67	15.19	40.22	12.54	476.6	-75.4	-91.0	3470.3
23	2.200	0.10593	949.75	746.76	737.38	324.89	52.96	26.67	15.19	40.22	12.54	467.8	-73.7	-88.8	3665.2
24	2.300	0.11098	955.90	757.36	748.06	325.07	55.25	26.67	15.18	40.22	12.54	466.9	-72.0	-86.6	3862.0
25	2.400	0.11604	961.90	767.93	759.01	325.24	57.57	26.67	15.18	40.22	12.54	462.2	-70.4	-84.6	4060.8
26	2.500	0.12109	967.78	778.14	770.27	325.40	59.88	26.67	15.18	40.22	12.54	455.7	-68.8	-82.6	4261.5
27	2.600	0.12614	973.47	788.03	780.65	325.56	62.17	26.67	15.17	40.22	12.54	449.7	-67.3	-80.6	4464.2
28	2.700	0.13378	979.05	797.98	790.73	325.72	64.46	26.67	15.17	40.22	12.54	443.7	-65.9	-78.7	4668.9
29	2.800	0.13799	984.49	807.87	800.52	325.87	66.73	26.67	15.17	40.22	12.54	437.8	-64.4	-76.9	4875.5
30	2.900	0.14204	989.80	816.22	810.04	326.02	68.99	26.67	15.17	40.22	12.54	432.0	-63.1	-75.2	5084.1
31	3.000	0.14661	994.99	825.14	819.30	326.16	71.24	26.67	15.16	40.22	12.54	426.4	-61.7	-73.5	5294.6
32	3.100	0.15069	1000.07	833.84	828.31	326.30	73.48	26.67	15.16	40.22	12.54	420.9	-60.4	-71.8	5507.1
33	3.200	0.15567	1005.02	842.31	837.06	326.44	75.70	26.68	15.16	40.22	12.54	415.6	-59.1	-70.3	5721.5
34	3.300	0.16037	1009.87	850.58	845.61	326.57	77.90	26.68	15.16	40.22	12.54	410.4	-57.9	-68.7	5937.9
35	3.400	0.16497	1014.61	858.69	853.93	326.70	80.09	26.68	15.15	40.22	12.54	405.3	-56.7	-67.2	6156.2
36	3.500	0.16950	1019.25	866.51	862.05	326.82	82.27	26.68	15.15	40.22	12.54	400.4	-55.5	-65.8	6376.5
37	3.600	0.17394	1023.79	874.19	869.92	326.95	84.42	26.68	15.15	40.22	12.54	395.6	-54.4	-64.4	6598.7
38	3.700	0.17830	1028.22	881.66	877.62	327.07	86.56	26.68	15.15	40.22	12.54	390.9	-53.3	-63.0	6822.9
39	3.800	0.18259	1032.57	888.99	885.13	327.19	88.68	26.68	15.14	40.22	12.54	386.3	-52.2	-61.7	7049.0
40	3.900	0.18679	1036.82	896.13	892.45	327.30	90.78	26.68	15.14	40.22	12.54	381.8	-51.2	-60.4	7277.1
41	4.000	0.19093	1040.99	903.10	899.59	327.41	92.87	26.68	15.14	40.22	12.54	377.4	-50.2	-59.2	7507.1
42	4.100	0.19500	1045.07	909.91	906.56	327.52	94.93	26.68	15.14	40.22	12.54	373.1	-49.2	-58.0	7739.1
43	4.200	0.19904	1049.07	916.57	913.36	327.63	96.98	26.68	15.14	40.22	12.54	368.8	-48.3	-56.8	7973.0
44	4.300	0.20300	1053.00	923.07	920.00	327.73	99.00	26.68	15.13	40.22	12.54	364.7	-47.3	-55.7	8208.9
45	4.400	0.20689	1056.84	929.42	926.49	327.84	101.01	26.68	15.13	40.22	12.54	360.6	-46.4	-54.6	8446.8
46	4.500	0.21072	1060.61	935.63	932.82	327.94	102.99	26.68	15.13	40.22	12.54	356.7	-45.5	-53.5	8686.6
47	4.600	0.21450	1064.31	941.70	939.02	328.04	104.96	26.68	15.13	40.22	12.54	352.8	-44.7	-52.5	8928.4
48	4.700	0.21823	1067.94	947.63	945.07	328.13	106.91	26.68	15.13	40.22	12.54	348.9	-43.8	-51.5	9172.1
49	4.750	0.21957	1069.72	950.55	948.04	328.18	107.87	26.90	15.60	40.22	12.54	113.1	-42.9	-50.5	8936.4

VM COMBUSTION STARTS AT XF = 0.1726 AND AT HEIGHT (FROM TOP) = 4.750 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.750 M

TABLE P.3 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 3 (A)

(DPF=0.044 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TK(K)	RSHLHD	DELSHT	HFS	HFS	HSG	ASEZ	AFSZ	GFS	QFG	QSG	DELMTL	PC2G	PCO2G
1	0.000	0.17257	0.000000	1069.7	950.5	946.0	328.2	0.0000	0.	107.7	25.3	18.6	40.2	12.5	151.	-429.	-505.	0.	0.054	0.242
2	0.050	0.16201	0.000000	1069.6	1124.7	970.0	327.9	0.0000	0.	143.6	25.7	18.5	40.2	12.5	1235.	-298.	-589.	0.	0.057	0.249
3	0.100	0.15200	0.000000	1067.6	1164.2	1017.0	327.9	0.0000	0.	181.9	25.7	18.4	40.2	12.5	8826.	-191.	-634.	0.	0.057	0.249
4	0.150	0.14201	0.000000	1065.6	1158.2	1058.0	327.7	0.0000	0.	166.0	25.6	18.3	40.2	12.5	9667.	-331.	-634.	0.	0.057	0.249
5	0.200	0.13201	0.000000	1063.6	1180.2	1094.0	327.5	0.0000	0.	181.8	25.6	18.2	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
6	0.250	0.12202	0.000000	1061.6	1187.2	1127.0	327.3	0.0000	0.	188.8	25.5	18.1	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
7	0.300	0.11202	0.000000	1059.6	1204.5	1161.0	327.1	0.0000	0.	211.0	25.5	18.1	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
8	0.350	0.10203	0.000000	1057.6	1204.5	1173.0	326.9	0.0000	0.	211.0	25.5	18.0	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
9	0.400	0.09203	0.000000	1055.6	1204.5	1173.0	326.7	0.0000	0.	211.0	25.5	17.9	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
10	0.450	0.08204	0.000000	1053.6	1204.5	1173.0	326.5	0.0000	1.	211.0	25.5	17.8	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
11	0.500	0.07204	0.000000	1051.6	1204.5	1173.0	326.3	0.0000	2.	211.0	25.5	17.7	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
12	0.550	0.06205	0.000000	1049.6	1204.5	1173.0	326.1	0.0000	2.	211.0	25.5	17.6	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
13	0.600	0.05205	0.000000	1047.6	1204.5	1173.0	325.9	0.0000	2.	211.0	25.5	17.4	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
14	0.650	0.04206	0.000000	1045.6	1204.5	1173.0	325.7	0.0000	2.	211.0	25.5	17.3	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
15	0.700	0.03206	0.000000	1043.6	1204.5	1173.0	325.5	0.0000	2.	211.0	25.5	17.2	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
16	0.750	0.02207	0.000000	1041.6	1204.5	1173.0	325.3	0.0000	2.	211.0	25.5	17.1	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
17	0.800	0.01207	0.000000	1039.6	1204.5	1173.0	325.1	0.0000	2.	211.0	25.5	17.0	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
18	0.850	0.00208	0.000000	1037.6	1204.5	1173.0	324.9	0.0000	2.	211.0	25.5	16.9	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
19	0.900	0.00208	0.000000	1035.6	1204.5	1173.0	324.7	0.0000	2.	211.0	25.5	16.8	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
20	0.950	0.00208	0.000000	1033.6	1204.5	1173.0	324.5	0.0000	2.	211.0	25.5	16.7	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
21	1.000	0.00208	0.000000	1031.6	1204.5	1173.0	324.3	0.0000	2.	211.0	25.5	16.5	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
22	1.050	0.00208	0.000000	1029.6	1204.5	1173.0	324.1	0.0000	2.	211.0	25.5	16.4	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
23	1.100	0.00208	0.000000	1027.6	1204.5	1173.0	323.9	0.0000	2.	211.0	25.5	16.3	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
24	1.150	0.00208	0.000000	1025.6	1204.5	1173.0	323.7	0.0000	2.	211.0	25.5	16.2	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
25	1.200	0.00208	0.000000	1023.6	1204.5	1173.0	323.5	0.0000	2.	211.0	25.5	16.1	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
26	1.250	0.00208	0.000000	1021.6	1204.5	1173.0	323.3	0.0000	2.	211.0	25.5	16.0	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
27	1.300	0.00208	0.000000	1019.6	1204.5	1173.0	323.1	0.0000	2.	211.0	25.5	15.9	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
28	1.350	0.00208	0.000000	1017.6	1204.5	1173.0	322.9	0.0000	2.	211.0	25.5	15.8	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
29	1.400	0.00208	0.000000	1015.6	1204.5	1173.0	322.7	0.0000	2.	211.0	25.5	15.7	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
30	1.450	0.00208	0.000000	1013.6	1204.5	1173.0	322.5	0.0000	2.	211.0	25.5	15.6	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
31	1.500	0.00208	0.000000	1011.6	1204.5	1173.0	322.3	0.0000	2.	211.0	25.5	15.5	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
32	1.550	0.00208	0.000000	1009.6	1204.5	1173.0	322.1	0.0000	2.	211.0	25.5	15.4	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
33	1.600	0.00208	0.000000	1007.6	1204.5	1173.0	321.9	0.0000	2.	211.0	25.5	15.3	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
34	1.650	0.00208	0.000000	1005.6	1204.5	1173.0	321.7	0.0000	2.	211.0	25.5	15.2	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
35	1.700	0.00208	0.000000	1003.6	1204.5	1173.0	321.5	0.0000	2.	211.0	25.5	15.1	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
36	1.750	0.00208	0.000000	1001.6	1204.5	1173.0	321.3	0.0000	2.	211.0	25.5	15.0	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
37	1.800	0.00208	0.000000	999.6	1204.5	1173.0	321.1	0.0000	2.	211.0	25.5	14.9	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
38	1.850	0.00208	0.000000	997.6	1204.5	1173.0	320.9	0.0000	2.	211.0	25.5	14.8	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
39	1.900	0.00208	0.000000	995.6	1204.5	1173.0	320.7	0.0000	2.	211.0	25.5	14.7	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
40	1.950	0.00208	0.000000	993.6	1204.5	1173.0	320.5	0.0000	2.	211.0	25.5	14.6	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
41	1.975	0.00208	0.000000	992.6	1204.5	1173.0	320.4	0.0000	2.	211.0	25.5	14.6	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
42	1.995	0.00208	0.000000	991.6	1204.5	1173.0	320.3	0.0000	2.	211.0	25.5	14.5	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
43	1.815	0.00208	0.000000	990.6	1204.5	1173.0	320.2	0.0000	2.	211.0	25.5	14.5	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
44	1.835	0.00208	0.000000	989.6	1204.5	1173.0	320.1	0.0000	2.	211.0	25.5	14.4	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
45	1.855	0.00208	0.000000	988.6	1204.5	1173.0	320.0	0.0000	2.	211.0	25.5	14.4	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249
46	1.875	0.00208	0.000000	987.6	1204.5	1173.0	319.9	0.0000	2.	211.0	25.5	14.3	40.2	12.5	9971.	-225.	-634.	0.	0.057	0.249

ASH FUSION STARTS AT XF = 0.6730 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.545 M

HEIGHT OF THE BURNING ZONE = 1.875 M

TABLE F.3 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 3 (A)

(DPF=0.0-4 M)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	GSG	DELHTC
1	0.000	[illegible].70	12[illegible]2.4[illegible]	304.[illegible]	10.7	51.1	744[illegible].7	0.0
3	0.100	[illegible].50	11[illegible].31	30[illegible]	10.7	51.1	7341.1	23.9
5	0.200	[illegible].38	117[illegible]	304.[illegible]	10.7	51.1	72[illegible]	47.0
7	0.300	4[illegible]7.34	115[illegible]	304.4[illegible]	10.7	51.1	71[illegible].0	69.4
9	0.400	[illegible]1.35	1139.[illegible]	30[illegible]	10.7	51.1	7020.7	91.2
11	0.500	[illegible]	1123.[illegible]	304.24	10.7	51.1	[illegible]	112.[illegible]
13	0.600	4[illegible]9.75	110[illegible]	304.13	10.7	51.1	[illegible]811.6	132.[illegible]
15	0.700	464.0[illegible]	1[illegible]	304.01	10.7	51.1	[illegible]700.7	152.2
17	0.800	[illegible]	1075.[illegible]	303.[illegible]	10.7	51.1	[illegible]600.5	171.5
19	0.900	[illegible]	1063.[illegible]	303.80	10.6	51.1	6505.2	189.5
21	1.000	447.37	1048.81	303.[illegible]	10.6	51.1	6404.9	207.2
23	1.100	441.98	10[illegible].33	303.58	10.6	51.1	6305.4	224.[illegible]
25	1.200	4[illegible]	10[illegible].01	303.47	10.6	51.1	6206.9	240.7
27	1.300	[illegible]1.4[illegible]	1[illegible]	303.37	10.6	51.1	6109.[illegible]	256.4
29	1.400	4[illegible].27	[illegible]1.[illegible]	303.2[illegible]	10.6	51.1	6012.6	271.6
31	1.500	421.1[illegible]	[illegible]77.97	303.15	10.6	51.1	5916.[illegible]	2[illegible].2
33	1.600	416.17	[illegible]64.2[illegible]	303.[illegible]	10.6	51.1	5821.9	30[illegible]
35	1.700	411.2[illegible]	[illegible].73	30[illegible].95	10.6	51.1	5727.9	31[illegible]
37	1.800	[illegible]	[illegible]37.33	302.[illegible]	10.6	51.1	5634.8	32[illegible]
39	1.900	[illegible]1.[illegible]	[illegible]24.10	302.74	10.6	51.1	5542.7	338.7
41	2.000	[illegible]	[illegible]11.01	302.64	10.6	51.1	5451.5	350.[illegible]
43	2.100	3[illegible]2.2[illegible]	[illegible]98.05	302.54	10.6	51.1	5361.2	361.5
45	2.200	3[illegible]7.07	[illegible]5.30	302.44	10.6	51.1	5271.8	372.1
47	2.300	3[illegible].17	[illegible]72.67	302.3[illegible]	10.6	51.1	5183.3	382.2
49	2.400	37[illegible]	[illegible]60.19	302.24	10.6	51.1	5095.7	391.8
51	2.500	374.3[illegible]	[illegible]47.97	302.14	10.6	51.1	5009.0	400.[illegible]
53	2.600	370.1[illegible]	[illegible]35.[illegible]	302.0[illegible]	10.6	51.1	4923.3	409.[illegible]
55	2.700	3[illegible]	[illegible]23.[illegible]	301.95	10.6	51.1	4838.5	417.4
57	2.800	361.72	[illegible]11.73	301.[illegible]	10.6	51.1	4754.6	424.9
59	2.900	357.6[illegible]	[illegible]00.05	301.75	10.6	51.1	4671.6	431.9
61	3.000	353.62	788.47	301.[illegible]5	10.5	51.1	4589.5	438.5
63	3.100	349.[illegible]	777.03	301.56	10.5	51.1	4508.4	444.[illegible]
65	3.200	34[illegible].77	765.7[illegible]	301.4[illegible]	10.5	51.1	4428.1	450.[illegible]
67	3.300	341.9[illegible]	754.60	301.36	10.5	51.1	4348.8	455.5
69	3.400	338.1[illegible]	743.60	301.27	10.5	51.1	4270.4	460.2
71	3.500	334.49	732.74	301.17	10.5	51.1	4192.9	464.6
73	3.600	330.[illegible]	722.03	301.07	10.5	51.1	4116.4	468.4
75	3.700	327.22	711.46	300.98	10.5	51.1	4040.7	471.9
77	3.800	323.77	701.04	[illegible]	10.5	51.1	3966.0	475.0
79	3.900	320.32	690.76	300.78	10.5	51.1	3892.2	477.6
81	4.000	31[illegible].9[illegible]	680.61	300.68	10.5	51.1	3819.2	479.8
83	4.100	31[illegible]	670.61	300.58	10.5	51.1	3747.2	481.7
85	4.200	310.32	660.75	300.47	10.5	51.1	3676.1	483.2
87	4.300	307.11	651.03	300.36	10.5	51.1	3606.0	484.3
89	4.400	303.95	641.44	300.25	10.5	51.1	3536.7	485.0
91	4.500	300.[illegible]	631.99	300.12	10.5	51.1	3468.3	485.3
92	4.550	299.32	627.32	300.05	10.5	51.1	3434.5	485.4

HEIGHT OF THE COOLING ZONE=4.550M

TABLE E.3 (B1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 3 (E)

(DFF=0.056)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELNTL
1	0.000	0.00000	742.00	366.00	300.00	318.00	4.66	23.94	15.08	40.70	12.69	0.0	0.0	0.0	0.0
3	0.100	0.00000	751.01	377.15	326.77	319.99	0.87	23.97	15.10	40.70	12.69	195.3	-1296.2	-1875.7	134.4
5	0.200	0.00000	751.01	388.30	350.16	321.99	8.44	23.97	15.09	40.70	12.69	212.3	-1256.2	-1857.2	274.4
7	0.300	0.00000	751.01	399.44	370.14	323.99	10.03	23.97	15.07	40.70	12.69	221.6	-1222.1	-1838.7	419.7
9	0.400	0.00000	751.01	410.59	388.51	325.99	11.69	23.97	15.05	40.70	12.69	227.6	-1192.1	-1820.2	569.8
11	0.500	0.00000	751.01	421.73	405.80	327.99	13.43	23.97	15.03	40.70	12.69	231.6	-1164.8	-1801.7	724.8
13	0.600	0.00000	751.01	432.88	422.31	329.99	15.26	23.97	15.01	40.70	12.69	234.6	-1139.2	-1783.2	884.8
15	0.700	0.00000	751.01	444.02	438.26	331.99	17.19	23.97	14.99	40.70	12.69	236.9	-1114.7	-1764.7	1049.9
17	0.800	0.00000	751.01	455.17	453.82	333.99	19.21	23.97	14.97	40.70	12.69	238.7	-1091.0	-1746.2	1220.0
19	0.900	0.00000	751.01	466.31	469.09	335.99	21.33	23.97	14.95	40.70	12.69	240.2	-1067.9	-1727.7	1395.1
21	1.000	0.00000	751.01	477.46	484.14	337.99	23.55	23.97	14.93	40.70	12.69	241.5	-1045.2	-1709.2	1575.2
23	1.100	0.00000	751.01	488.60	499.04	339.99	25.87	23.97	14.91	40.70	12.69	242.6	-1022.8	-1690.7	1760.3
25	1.200	0.00000	751.01	499.75	513.84	341.99	28.29	23.97	14.89	40.70	12.69	243.5	-1000.6	-1672.2	1950.4
27	1.300	0.00000	751.01	510.89	528.59	343.99	30.82	23.97	14.87	40.70	12.69	244.3	-978.5	-1653.7	2145.5
29	1.400	0.00000	751.01	522.04	543.32	345.99	33.45	23.97	14.85	40.70	12.69	245.0	-956.5	-1635.2	2345.6
31	1.500	0.00000	751.01	533.18	558.06	347.99	36.19	23.97	14.83	40.70	12.69	245.6	-934.5	-1616.7	2550.7
33	1.600	0.00000	751.01	544.33	572.83	349.99	39.04	23.97	14.81	40.70	12.69	246.1	-912.5	-1598.2	2760.8
35	1.700	0.00000	751.01	555.47	587.64	351.99	42.00	23.97	14.79	40.70	12.69	246.6	-890.5	-1579.7	2975.9
37	1.800	0.00000	751.01	566.62	602.52	353.99	45.08	23.97	14.77	40.70	12.69	247.0	-868.4	-1561.2	3196.0
39	1.900	0.00000	751.01	577.76	617.49	355.99	48.28	23.97	14.75	40.70	12.69	247.4	-846.3	-1542.7	3421.1
41	2.000	0.00000	751.01	588.91	632.57	357.99	51.60	23.97	14.73	40.70	12.69	247.7	-824.1	-1524.2	3651.2
43	2.100	0.00000	751.01	600.05	647.79	359.99	55.05	23.97	14.71	40.70	12.69	248.0	-801.8	-1505.7	3886.3
45	2.200	0.00000	751.01	611.20	663.16	361.99	58.64	23.97	14.69	40.70	12.69	248.2	-779.4	-1487.2	4126.4
47	2.300	0.00000	751.01	622.34	678.71	363.99	62.37	23.97	14.67	40.70	12.69	248.4	-756.9	-1468.7	4371.5
49	2.400	0.00000	751.01	633.49	694.46	365.99	66.24	23.97	14.65	40.70	12.69	248.6	-734.3	-1450.2	4621.6
51	2.500	0.00000	751.01	644.63	710.43	367.99	70.27	23.97	14.63	40.70	12.69	248.7	-711.5	-1431.7	4876.7
53	2.600	0.00000	751.01	655.78	726.65	369.99	74.46	23.97	14.61	40.70	12.69	248.8	-688.6	-1413.2	5136.8
55	2.700	0.00000	751.01	666.92	743.13	371.99	78.82	23.97	14.59	40.70	12.69	248.9	-665.5	-1394.7	5401.9
57	2.800	0.00000	751.01	678.07	759.91	373.99	83.36	23.97	14.57	40.70	12.69	248.9	-642.2	-1376.2	5672.0
59	2.900	0.00000	751.01	689.21	777.01	375.99	88.09	23.97	14.55	40.70	12.69	248.9	-618.7	-1357.7	5947.1
61	3.000	0.00000	751.01	700.36	794.46	377.99	93.03	23.97	14.53	40.70	12.69	248.9	-594.9	-1339.2	6227.2
63	3.100	0.00000	751.01	711.50	812.31	379.99	98.19	23.97	14.51	40.70	12.69	248.8	-570.9	-1320.7	6512.3
65	3.200	0.00000	751.01	722.65	830.58	381.99	103.58	23.97	14.49	40.70	12.69	248.7	-546.6	-1302.2	6802.4
67	3.300	0.00000	751.01	733.79	849.31	383.99	109.23	23.97	14.47	40.70	12.69	248.6	-522.0	-1283.7	7097.5
69	3.400	0.00000	751.01	744.94	868.54	385.99	115.15	23.97	14.45	40.70	12.69	248.4	-497.0	-1265.2	7397.6
71	3.500	0.00000	751.01	756.08	888.31	387.99	121.37	23.97	14.43	40.70	12.69	248.2	-471.7	-1246.7	7702.7
73	3.600	0.00000	751.01	767.23	908.67	389.99	127.92	23.97	14.41	40.70	12.69	247.9	-446.0	-1228.2	8012.8
75	3.700	0.00000	751.01	778.37	929.67	391.99	134.82	23.97	14.39	40.70	12.69	247.6	-419.8	-1209.7	8327.9
77	3.800	0.00000	751.01	789.52	951.36	393.99	142.12	23.97	14.37	40.70	12.69	247.3	-393.2	-1191.2	8648.0
79	3.900	0.00000	751.01	800.66	973.80	395.99	149.85	23.97	14.35	40.70	12.69	246.9	-366.1	-1172.7	8973.1
81	4.000	0.00000	751.01	811.81	997.05	397.99	158.06	23.97	14.33	40.70	12.69	246.5	-338.5	-1154.2	9303.2
83	4.100	0.00000	751.01	822.95	1021.19	399.99	166.80	23.97	14.31	40.70	12.69	246.0	-310.3	-1135.7	9638.3
85	4.200	0.00000	751.01	834.10	1046.30	401.99	176.14	23.97	14.29	40.70	12.69	245.4	-281.5	-1117.2	9978.4
87	4.300	0.00000	751.01	845.24	1072.49	403.99	186.16	23.97	14.27	40.70	12.69	244.8	-252.0	-1098.7	10323.5
89	4.400	0.00000	751.01	856.39	1099.91	405.99	196.97	23.97	14.25	40.70	12.69	244.1	-221.8	-1080.2	10673.6
91	4.500	0.00000	751.01	867.53	1128.74	407.99	208.72	23.97	14.23	40.70	12.69	243.3	-190.8	-1061.7	11028.7
93	4.600	0.00000	751.01	878.68	1159.21	409.99	221.62	23.97	14.21	40.70	12.69	242.4	-159.0	-1043.2	11388.8
95	4.700	0.00000	751.01	889.82	1191.61	411.99	235.97	23.97	14.19	40.70	12.69	241.4	-126.3	-1024.7	11753.9
97	4.800	0.00000	751.01	900.97	1226.32	413.99	252.24	23.97	14.17	40.70	12.69	240.3	-92.7	-1006.2	12124.0
98	4.850	0.17193	1069.31	948.45	946.38	328.22	106.79	23.43	12.60	40.70	12.69	93.7	-399.2	-517.1	9140.8

VM COMBUSTION STARTS AT XF = 0.1719 AND AT HEIGHT (FROM TOP) = 4.850 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.850 M

TABLE P.3 (B2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 3 (B)

(DPF=0.056 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TL(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PC2G	PCO2G
1	0.000	0.17193	0.00000	1064.3	948.6	946.4	328.2	0.00000	0.	106.6	23.4	18.6	40.7	12.7	124.	-398.	-516.	0.	0.	0.
2	0.055	0.18264	0.00000	1069.2	1123.3	969.1	328.2	0.00000	0.	146.7	33.1	18.5	40.7	12.7	1288.	1.	-418.	0.	0.	0.
3	0.110	0.17654	0.00000	1067.4	1122.0	1015.3	327.7	0.00000	0.	151.1	33.1	18.3	40.7	12.7	1287.	172.	-214.	0.	0.	0.
4	0.165	0.17654	0.00000	1067.1	1157.0	1054.4	327.7	0.00000	0.	167.2	33.1	18.2	40.7	12.7	1287.	1305.	-45.	0.	0.	0.
5	0.220	0.17654	0.00000	1066.8	1196.0	1092.4	327.7	0.00000	0.	181.2	33.1	18.2	40.7	12.7	1287.	2345.	125.	0.	0.	0.
6	0.275	0.17654	0.00000	1066.5	1220.4	1127.6	327.7	0.00000	0.	196.3	33.1	18.1	40.7	12.7	1287.	2461.	295.	0.	0.	0.
7	0.330	0.17654	0.00000	1066.2	1235.4	1161.7	327.7	0.00000	0.	211.4	33.1	18.1	40.7	12.7	1287.	2539.	465.	0.	0.	0.
8	0.385	0.17654	0.00000	1065.9	1246.4	1173.2	327.7	0.00000	0.	217.6	33.1	17.9	40.7	12.7	1287.	2576.	556.	0.	0.	0.
9	0.440	0.17654	0.00000	1065.6	1249.4	1173.2	327.7	0.00000	1.	218.0	33.1	17.8	40.7	12.7	1287.	2576.	556.	0.	0.	0.
10	0.495	0.17654	0.00000	1065.3	1248.4	1174.2	327.7	0.00000	2.	218.0	33.1	17.8	40.7	12.7	1287.	2576.	556.	0.	0.	0.
11	0.550	0.17654	0.00000	1064.8	1246.4	1174.7	327.7	0.00000	3.	218.0	33.1	17.8	40.7	12.7	1287.	2576.	556.	0.	0.	0.
12	0.555	0.17654	0.00000	1064.4	1243.4	1175.0	327.7	0.00000	4.	218.0	33.1	17.8	40.7	12.7	1287.	2576.	556.	0.	0.	0.
13	0.560	0.17654	0.00000	1064.0	1239.4	1175.2	327.7	0.00000	5.	217.9	33.1	17.8	40.8	12.7	1287.	2576.	556.	0.	0.	0.
14	0.565	0.17654	0.00000	1063.5	1236.4	1175.4	327.7	0.00000	6.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
15	0.570	0.17654	0.00000	1063.1	1234.4	1175.5	327.7	0.00000	7.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
16	0.575	0.17654	0.00000	1062.6	1232.4	1175.7	327.7	0.00000	8.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
17	0.580	0.17654	0.00000	1062.2	1230.4	1175.8	327.7	0.00000	9.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
18	0.585	0.17654	0.00000	1061.7	1228.4	1175.9	327.7	0.00000	10.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
19	0.590	0.17654	0.00000	1061.3	1226.4	1176.0	327.7	0.00000	11.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
20	0.595	0.17654	0.00000	1060.8	1224.4	1176.1	327.7	0.00000	12.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
21	1.000	0.17654	0.00000	1060.4	1222.4	1176.2	327.7	0.00000	13.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
22	1.005	0.17654	0.00000	1059.9	1220.4	1176.3	327.7	0.00000	14.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
23	1.010	0.17654	0.00000	1059.5	1218.4	1176.4	327.7	0.00000	15.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
24	1.015	0.17654	0.00000	1059.0	1216.4	1176.5	327.7	0.00000	16.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
25	1.020	0.17654	0.00000	1058.6	1214.4	1176.6	327.7	0.00000	17.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
26	1.025	0.17654	0.00000	1058.1	1212.4	1176.7	327.7	0.00000	18.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
27	1.030	0.17654	0.00000	1057.7	1210.4	1176.8	327.7	0.00000	19.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
28	1.035	0.17654	0.00000	1057.2	1208.4	1176.9	327.7	0.00000	20.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
29	1.040	0.17654	0.00000	1056.8	1206.4	1177.0	327.7	0.00000	21.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
30	1.045	0.17654	0.00000	1056.3	1204.4	1177.1	327.7	0.00000	22.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
31	1.050	0.17654	0.00000	1055.9	1202.4	1177.2	327.7	0.00000	23.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
32	1.055	0.17654	0.00000	1055.4	1200.4	1177.3	327.7	0.00000	24.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
33	1.060	0.17654	0.00000	1055.0	1198.4	1177.4	327.7	0.00000	25.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
34	1.065	0.17654	0.00000	1054.5	1196.4	1177.5	327.7	0.00000	26.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
35	1.070	0.17654	0.00000	1054.1	1194.4	1177.6	327.7	0.00000	27.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
36	1.075	0.17654	0.00000	1053.6	1192.4	1177.7	327.7	0.00000	28.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
37	1.080	0.17654	0.00000	1053.2	1190.4	1177.8	327.7	0.00000	29.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
38	1.085	0.17654	0.00000	1052.7	1188.4	1177.9	327.7	0.00000	30.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
39	1.090	0.17654	0.00000	1052.3	1186.4	1178.0	327.7	0.00000	31.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
40	1.095	0.17654	0.00000	1051.8	1184.4	1178.1	327.7	0.00000	32.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
41	1.100	0.17654	0.00000	1051.4	1182.4	1178.2	327.7	0.00000	33.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
42	1.105	0.17654	0.00000	1050.9	1180.4	1178.3	327.7	0.00000	34.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
43	1.110	0.17654	0.00000	1050.5	1178.4	1178.4	327.7	0.00000	35.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
44	1.115	0.17654	0.00000	1050.0	1176.4	1178.5	327.7	0.00000	36.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
45	1.120	0.17654	0.00000	1049.6	1174.4	1178.6	327.7	0.00000	37.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
46	1.125	0.17654	0.00000	1049.1	1172.4	1178.7	327.7	0.00000	38.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
47	1.130	0.17654	0.00000	1048.7	1170.4	1178.8	327.7	0.00000	39.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
48	1.135	0.17654	0.00000	1048.2	1168.4	1178.9	327.7	0.00000	40.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
49	1.140	0.17654	0.00000	1047.8	1166.4	1179.0	327.7	0.00000	41.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
50	1.145	0.17654	0.00000	1047.3	1164.4	1179.1	327.7	0.00000	42.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
51	1.150	0.17654	0.00000	1046.9	1162.4	1179.2	327.7	0.00000	43.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
52	1.155	0.17654	0.00000	1046.4	1160.4	1179.3	327.7	0.00000	44.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
53	1.160	0.17654	0.00000	1046.0	1158.4	1179.4	327.7	0.00000	45.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
54	1.165	0.17654	0.00000	1045.5	1156.4	1179.5	327.7	0.00000	46.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
55	1.170	0.17654	0.00000	1045.1	1154.4	1179.6	327.7	0.00000	47.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
56	1.175	0.17654	0.00000	1044.6	1152.4	1179.7	327.7	0.00000	48.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
57	1.180	0.17654	0.00000	1044.2	1150.4	1179.8	327.7	0.00000	49.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
58	1.185	0.17654	0.00000	1043.7	1148.4	1179.9	327.7	0.00000	50.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
59	1.190	0.17654	0.00000	1043.3	1146.4	1180.0	327.7	0.00000	51.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
60	1.195	0.17654	0.00000	1042.8	1144.4	1180.1	327.7	0.00000	52.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
61	1.200	0.17654	0.00000	1042.4	1142.4	1180.2	327.7	0.00000	53.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
62	1.205	0.17654	0.00000	1041.9	1140.4	1180.3	327.7	0.00000	54.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
63	1.210	0.17654	0.00000	1041.5	1138.4	1180.4	327.7	0.00000	55.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.
64	1.215	0.17654	0.00000	1041.0	1136.4	1180.5	327.7	0.00000	56.	217.9	33.1	17.8	40.9	12.7	1287.	2576.	556.	0.	0.	0.

ASH FUSION STARTS AT XF = 0.7204 AT HEIGHT (FROM TOP OF BURNING ZONE) = 2.470 M

HEIGHT OF THE BURNING ZONE = 2.725 M

TABLE F.3 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 3 (B)

(DFF=0.056 M)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TA(K)	HSG	ASCZ	GSG	DELHTL
1	0.000	471.30	1192.40	304.50	10.7	47.4	7466.7	0.0
3	0.100	465.50	1177.35	304.44	10.7	47.4	7387.9	22.2
5	0.200	479.77	1162.45	304.32	10.7	47.4	7287.0	43.7
7	0.300	474.11	1147.66	304.21	10.7	47.4	7156.9	64.5
9	0.400	468.53	1133.07	304.10	10.7	47.4	7027.5	84.7
11	0.500	463.02	1118.54	303.99	10.7	47.4	6899.0	104.2
13	0.600	457.57	1104.19	303.89	10.7	47.4	6771.2	123.1
15	0.700	452.20	1089.97	303.78	10.7	47.4	6754.2	141.4
17	0.800	446.90	1075.90	303.68	10.6	47.4	6698.0	159.0
19	0.900	441.67	1061.95	303.57	10.6	47.4	6602.8	176.0
21	1.000	436.51	1048.10	303.47	10.6	47.4	6576.0	192.4
23	1.100	431.41	1034.50	303.36	10.6	47.4	6414.2	208.1
25	1.200	426.38	1014.25	303.21	10.6	47.4	6275.0	230.7
28	1.350	418.98	1000.55	303.11	10.6	47.4	6183.1	245.0
30	1.450	414.12	987.75	303.01	10.6	47.4	6092.1	258.7
32	1.550	409.33	974.70	302.91	10.6	47.4	6001.8	271.9
34	1.650	404.60	961.79	302.81	10.6	47.4	5912.3	284.5
36	1.750	399.94	949.01	302.71	10.6	47.4	5823.6	296.6
38	1.850	395.34	936.36	302.61	10.6	47.4	5735.7	308.1
40	1.950	390.81	923.85	302.51	10.6	47.4	5648.6	319.0
42	2.050	386.34	911.47	302.41	10.6	47.4	5562.3	329.5
43	2.100	384.13	905.33	302.36	10.6	47.4	5519.5	334.5
45	2.200	379.76	893.15	302.26	10.6	47.4	5434.3	344.2
47	2.300	375.45	881.10	302.17	10.6	47.4	5350.0	353.3
49	2.400	371.20	869.18	302.07	10.6	47.4	5266.5	362.0
51	2.500	367.01	857.40	301.97	10.6	47.4	5183.7	370.1
53	2.600	362.89	845.74	301.88	10.6	47.4	5101.8	377.8
55	2.700	358.82	834.22	301.78	10.6	47.4	5020.6	385.0
57	2.800	354.81	822.83	301.68	10.6	47.4	4940.3	391.7
59	2.900	350.87	811.56	301.59	10.6	47.4	4860.7	398.0
61	3.000	346.98	800.43	301.49	10.5	47.4	4781.9	403.8
63	3.100	343.15	789.43	301.39	10.5	47.4	4704.0	409.1
65	3.200	339.38	778.55	301.30	10.5	47.4	4626.8	414.0
67	3.300	335.66	767.80	301.20	10.5	47.4	4550.4	418.4
69	3.400	332.01	757.16	301.11	10.5	47.4	4474.9	422.5
71	3.500	328.40	746.68	301.01	10.5	47.4	4400.1	426.1
73	3.600	324.86	736.32	300.91	10.5	47.4	4326.1	429.3
75	3.700	321.37	726.08	300.81	10.5	47.4	4252.9	432.0
77	3.800	317.93	715.96	300.71	10.5	47.4	4180.5	434.4
79	3.900	314.55	705.97	300.61	10.5	47.4	4109.0	436.4
81	4.000	311.22	696.10	300.50	10.5	47.4	4038.2	437.9
83	4.100	307.95	686.36	300.39	10.5	47.4	3968.2	439.1
85	4.200	304.74	676.74	300.28	10.5	47.4	3899.0	439.9
86	4.250	303.13	671.98	300.22	10.5	47.4	3864.7	440.2
87	4.300	301.55	667.24	300.15	10.5	47.4	3830.6	440.4
88	4.350	299.98	662.54	300.08	10.5	47.4	3796.7	440.5

HEIGHT OF THE COOLING ZONE=4.350M

TABLE P.4 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 4 (A)

[PS=2.0 T/(SQM)(DAY)]

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELNTL
1	0.000	0.000000	740.00	300.00	300.00	318.00	4.93	23.89	18.25	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.000000	761.95	303.80	326.60	318.87	7.13	23.92	18.27	40.11	12.50	245.3	-1413.4	-1985.9	137.9
5	0.200	0.012500	775.37	406.39	357.01	319.32	8.88	23.91	18.26	40.11	12.50	285.3	-1371.9	-1914.1	279.6
7	0.300	0.025000	788.31	427.33	383.96	319.78	10.64	23.90	18.24	40.11	12.50	301.7	-1340.9	-1846.1	425.5
9	0.400	0.037500	800.85	446.34	409.49	320.09	12.41	23.89	18.23	40.11	12.50	301.4	-1316.1	-1788.0	574.3
11	0.500	0.050000	813.05	466.47	433.67	320.46	14.23	23.88	18.21	40.11	12.50	291.3	-1292.9	-1731.8	727.0
13	0.600	0.050000	824.44	511.79	456.31	320.82	16.09	23.90	18.23	40.11	12.50	567.5	-1167.9	-1672.8	882.9
15	0.700	0.050000	835.23	540.46	477.00	321.18	17.94	23.91	18.24	40.11	12.50	684.4	-1102.2	-1606.3	1040.4
17	0.800	0.050000	845.55	562.07	496.26	321.51	19.41	23.93	18.26	40.11	12.50	716.4	-1061.0	-1539.3	1200.5
19	0.900	0.050000	855.41	580.95	513.49	321.82	21.70	23.94	18.28	40.11	12.50	711.5	-1028.3	-1474.9	1361.5
21	1.000	0.050000	864.92	598.70	529.55	322.14	23.99	23.97	18.29	40.11	12.50	693.5	-996.3	-1413.3	1523.6
23	1.100	0.050000	874.07	615.90	545.45	322.44	26.32	24.00	18.31	40.11	12.50	672.6	-966.9	-1356.5	1711.2
25	1.200	0.050000	882.88	632.65	560.72	322.72	28.74	24.02	18.31	40.11	12.50	651.6	-939.9	-1305.9	1868.6
27	1.300	0.050000	891.37	648.96	575.37	322.99	31.20	24.04	18.32	40.11	12.50	628.3	-911.4	-1251.4	2026.2
29	1.400	0.050000	899.55	664.77	589.34	323.28	33.71	24.06	18.33	40.11	12.50	608.3	-885.2	-1203.1	2184.2
31	1.500	0.050000	907.43	680.18	603.93	323.55	36.27	24.07	18.35	40.11	12.50	589.1	-859.9	-1157.4	2342.4
33	1.600	0.050305	915.05	695.26	617.74	323.80	38.86	24.09	18.36	40.11	12.50	573.1	-836.9	-1115.4	2500.8
35	1.700	0.050664	922.34	709.94	631.19	324.05	41.02	24.10	18.36	40.11	12.50	557.5	-815.9	-1082.1	2659.4
37	1.800	0.050420	929.49	711.66	700.50	324.16	43.26	24.10	18.36	40.11	12.50	327.5	-839.9	-1052.1	2795.4
39	1.900	0.050949	936.43	763.38	715.08	324.46	45.64	24.10	18.35	40.11	12.50	318.8	-820.2	-1025.6	2984.1
41	2.000	0.050662	943.22	754.97	728.55	324.55	48.03	24.10	18.35	40.11	12.50	292.6	-802.4	-997.0	3174.6
43	2.100	0.050803	949.81	746.67	741.46	324.73	50.43	24.10	18.35	40.11	12.50	271.6	-784.2	-967.4	3367.1
45	2.200	0.050502	956.42	757.90	750.21	324.91	52.82	24.10	18.34	40.11	12.50	271.3	-764.9	-971.9	3561.4
47	2.300	0.050967	962.46	774.45	762.75	325.08	55.27	24.10	18.34	40.11	12.50	265.8	-746.7	-947.0	3757.5
49	2.400	0.054597	968.55	774.45	772.75	325.25	57.68	24.09	18.33	40.11	12.50	257.5	-729.2	-922.9	3955.4
51	2.500	0.059319	974.47	759.74	783.48	325.41	60.08	24.09	18.33	40.11	12.50	250.7	-712.1	-899.7	4154.9
53	2.600	0.103651	980.25	797.77	795.91	325.57	62.48	24.09	18.33	40.11	12.50	244.4	-695.5	-877.4	4355.1
55	2.700	0.105001	985.98	809.53	804.02	325.73	64.88	24.09	18.32	40.11	12.50	237.9	-679.5	-855.9	4556.0
57	2.800	0.112241	991.37	819.05	815.85	325.88	67.22	24.09	18.32	40.11	12.50	231.5	-663.9	-835.2	4758.1
59	2.900	0.116371	996.73	825.26	823.39	326.04	69.58	24.09	18.32	40.11	12.50	225.5	-648.8	-815.2	4960.8
61	3.000	0.120391	1001.97	837.27	832.00	326.17	71.92	24.09	18.31	40.11	12.50	219.6	-634.2	-795.8	5164.3
63	3.100	0.124311	1007.07	846.03	841.66	326.30	74.24	24.09	18.31	40.11	12.50	213.8	-620.0	-777.1	5368.0
65	3.200	0.128131	1012.06	854.56	850.45	326.44	76.55	24.09	18.31	40.11	12.50	208.2	-606.2	-759.1	5572.1
67	3.300	0.131861	1016.94	862.87	858.98	326.57	78.84	24.09	18.31	40.11	12.50	202.7	-592.9	-741.6	5776.6
69	3.400	0.135511	1021.70	870.96	867.28	326.70	81.11	24.09	18.30	40.11	12.50	197.4	-580.0	-724.7	5981.4
71	3.500	0.139086	1026.35	878.85	875.36	326.82	83.37	24.09	18.30	40.11	12.50	192.2	-567.4	-708.4	6186.4
73	3.600	0.142594	1030.91	886.54	883.23	326.94	85.60	24.09	18.30	40.11	12.50	187.0	-555.2	-692.6	6391.8
75	3.700	0.146046	1035.36	894.04	890.89	327.06	87.81	24.09	18.29	40.11	12.50	182.0	-543.3	-677.3	6597.4
77	3.800	0.149446	1039.71	901.35	898.36	327.18	90.01	24.09	18.29	40.11	12.50	177.1	-531.9	-662.4	6803.2
79	3.900	0.152801	1043.96	908.48	905.63	327.29	92.18	24.09	18.29	40.11	12.50	172.3	-520.8	-648.1	7009.2
81	4.000	0.156119	1048.15	915.43	912.73	327.40	94.33	24.09	18.29	40.11	12.50	167.6	-510.0	-634.2	7215.3
83	4.100	0.159402	1052.23	922.22	919.64	327.51	96.46	24.09	18.28	40.11	12.50	162.9	-499.5	-620.7	7421.5
85	4.200	0.162654	1056.23	928.84	926.39	327.61	98.57	24.08	18.28	40.11	12.50	158.4	-489.3	-607.6	7627.8
87	4.300	0.165878	1060.15	935.46	932.97	327.72	100.65	24.08	18.28	40.11	12.50	153.9	-479.5	-595.0	7834.2
89	4.400	0.169076	1064.00	941.82	939.44	327.82	102.74	24.08	18.28	40.11	12.50	159.8	-469.3	-582.7	8040.7
91	4.500	0.172049	1067.77	948.05	945.77	327.91	104.80	23.98	18.28	40.11	12.50	155.8	-459.8	-570.6	8247.1
		0.170437	1067.77	948.05	945.77	327.91	106.83	23.39	17.78	40.11	12.50	114.0	-437.5	-543.7	8665.6

VR COMBUSTION STARTS AT XF = 0.1704 AND AT HEIGHT (FROM TOP) = 4.500 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.500 M

TABLE P.4 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 4 (A)

[PS=2.0T/(SQM)(DAY)]

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TL(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	GFS	QFG	QSG	DELHTL	PC2S	PC02S
1	0.000	0.17037	0.00000	1067.5	945.0	945.0	337.9	0.0000	0.	109.7	23.3	17.8	40.1	12.5	152.	-437.	-543.	0.	0.0000	0.0000
2	0.050	0.18063	0.00000	1067.7	1111.4	970.6	337.8	0.0000	0.	142.6	23.3	17.5	40.1	12.5	1325.	183.	-411.	113.	0.0000	0.0000
3	0.100	0.19133	0.00000	1068.0	1111.4	1016.7	337.8	0.0000	0.	149.9	23.3	17.6	40.1	12.5	1870.	164.	-1.	225.	0.0000	0.0000
4	0.150	0.20217	0.00000	1068.2	1115.8	1056.7	337.8	0.0000	0.	160.9	23.3	17.7	40.1	12.5	1002.	534.	411.	336.	0.0000	0.0000
5	0.200	0.21316	0.00000	1068.4	1118.0	1093.4	337.8	0.0000	0.	169.9	23.3	17.7	40.1	12.5	918.	418.	823.	448.	0.0000	0.0000
6	0.250	0.22431	0.00000	1068.5	1120.1	1131.1	337.8	0.0000	0.	180.9	23.3	17.7	40.1	12.5	918.	534.	1234.	560.	0.0000	0.0000
7	0.300	0.23561	0.00000	1068.6	1121.1	1164.4	337.8	0.0000	0.	191.9	23.3	17.7	40.1	12.5	918.	534.	1645.	672.	0.0000	0.0000
8	0.350	0.24701	0.00000	1068.7	1121.8	1173.3	337.8	0.0000	0.	202.9	23.3	17.7	40.1	12.5	918.	534.	2056.	784.	0.0000	0.0000
9	0.400	0.25854	0.00000	1068.8	1122.4	1174.1	337.8	0.0000	0.	213.9	23.3	17.7	40.1	12.5	918.	534.	2467.	896.	0.0000	0.0000
10	0.450	0.27020	0.00000	1068.9	1122.9	1174.1	337.8	0.0000	0.	216.7	23.3	17.7	40.1	12.5	918.	534.	2878.	1008.	0.0000	0.0000
11	0.500	0.28207	0.00000	1068.9	1123.3	1174.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	3289.	1120.	0.0000	0.0000
12	0.550	0.29407	0.00000	1068.9	1123.6	1174.6	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	3700.	1232.	0.0000	0.0000
13	0.600	0.30614	0.00000	1068.9	1123.8	1175.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	4111.	1344.	0.0000	0.0000
14	0.650	0.31829	0.00000	1068.9	1124.0	1176.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	4522.	1456.	0.0000	0.0000
15	0.700	0.33047	0.00000	1068.9	1124.1	1176.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	4933.	1568.	0.0000	0.0000
16	0.750	0.34264	0.00000	1068.9	1124.2	1177.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	5344.	1680.	0.0000	0.0000
17	0.800	0.35478	0.00000	1068.9	1124.3	1178.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	5755.	1792.	0.0000	0.0000
18	0.850	0.36688	0.00000	1068.9	1124.4	1178.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	6166.	1904.	0.0000	0.0000
19	0.900	0.37895	0.00000	1068.9	1124.5	1179.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	6577.	2016.	0.0000	0.0000
20	0.950	0.39102	0.00000	1068.9	1124.6	1180.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	6988.	2128.	0.0000	0.0000
21	1.000	0.40307	0.00000	1068.9	1124.7	1180.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	7399.	2240.	0.0000	0.0000
22	1.050	0.41507	0.00000	1068.9	1124.8	1181.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	7810.	2352.	0.0000	0.0000
23	1.100	0.42701	0.00000	1068.9	1124.9	1182.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	8221.	2464.	0.0000	0.0000
24	1.150	0.43891	0.00000	1068.9	1125.0	1182.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	8632.	2576.	0.0000	0.0000
25	1.200	0.45078	0.00000	1068.9	1125.1	1183.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	9043.	2688.	0.0000	0.0000
26	1.250	0.46263	0.00000	1068.9	1125.2	1184.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	9454.	2800.	0.0000	0.0000
27	1.300	0.47446	0.00000	1068.9	1125.3	1184.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	9865.	2912.	0.0000	0.0000
28	1.350	0.48628	0.00000	1068.9	1125.4	1185.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	10276.	3024.	0.0000	0.0000
29	1.400	0.49808	0.00000	1068.9	1125.5	1186.2	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	10687.	3136.	0.0000	0.0000
30	1.450	0.50987	0.00000	1068.9	1125.6	1186.9	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	11098.	3248.	0.0000	0.0000
31	1.500	0.52165	0.00000	1068.9	1125.7	1187.6	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	11509.	3360.	0.0000	0.0000
32	1.550	0.53343	0.00000	1068.9	1125.8	1188.3	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	11920.	3472.	0.0000	0.0000
33	1.600	0.54520	0.00000	1068.9	1125.9	1189.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	12331.	3584.	0.0000	0.0000
34	1.650	0.55696	0.00000	1068.9	1126.0	1189.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	12742.	3696.	0.0000	0.0000
35	1.700	0.56872	0.00000	1068.9	1126.1	1190.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	13153.	3808.	0.0000	0.0000
36	1.750	0.58048	0.00000	1068.9	1126.2	1191.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	13564.	3920.	0.0000	0.0000
37	1.800	0.59224	0.00000	1068.9	1126.3	1191.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	13975.	4032.	0.0000	0.0000
38	1.850	0.60400	0.00000	1068.9	1126.4	1192.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	14386.	4144.	0.0000	0.0000
39	1.900	0.61576	0.00000	1068.9	1126.5	1193.2	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	14797.	4256.	0.0000	0.0000
40	1.950	0.62752	0.00000	1068.9	1126.6	1193.9	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15208.	4368.	0.0000	0.0000
41	1.980	0.63455	0.00000	1068.9	1126.7	1194.3	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15460.	4440.	0.0000	0.0000
42	1.990	0.63690	0.00000	1068.9	1126.7	1194.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15544.	4464.	0.0000	0.0000
43	2.000	0.63927	0.00000	1068.9	1126.7	1194.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15628.	4488.	0.0000	0.0000
44	2.010	0.64164	0.00000	1068.9	1126.7	1194.6	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15712.	4512.	0.0000	0.0000
45	2.020	0.64401	0.00000	1068.9	1126.7	1194.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15796.	4536.	0.0000	0.0000
46	2.030	0.64638	0.00000	1068.9	1126.7	1194.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15880.	4560.	0.0000	0.0000
47	2.040	0.64875	0.00000	1068.9	1126.7	1194.9	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	15964.	4584.	0.0000	0.0000
48	2.050	0.65112	0.00000	1068.9	1126.7	1195.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16048.	4608.	0.0000	0.0000
49	2.060	0.65349	0.00000	1068.9	1126.7	1195.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16132.	4632.	0.0000	0.0000
50	2.070	0.65586	0.00000	1068.9	1126.7	1195.2	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16216.	4656.	0.0000	0.0000
51	2.080	0.65823	0.00000	1068.9	1126.7	1195.3	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16300.	4680.	0.0000	0.0000
52	2.090	0.66060	0.00000	1068.9	1126.7	1195.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16384.	4704.	0.0000	0.0000
53	2.100	0.66297	0.00000	1068.9	1126.7	1195.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16468.	4728.	0.0000	0.0000
54	2.110	0.66534	0.00000	1068.9	1126.7	1195.6	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16552.	4752.	0.0000	0.0000
55	2.120	0.66771	0.00000	1068.9	1126.7	1195.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16636.	4776.	0.0000	0.0000
56	2.130	0.67008	0.00000	1068.9	1126.7	1195.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16720.	4800.	0.0000	0.0000
57	2.140	0.67245	0.00000	1068.9	1126.7	1195.9	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16804.	4824.	0.0000	0.0000
58	2.150	0.67482	0.00000	1068.9	1126.7	1196.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16888.	4848.	0.0000	0.0000
59	2.160	0.67719	0.00000	1068.9	1126.7	1196.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	16972.	4872.	0.0000	0.0000
60	2.170	0.67956	0.00000	1068.9	1126.7	1196.2	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17056.	4896.	0.0000	0.0000
61	2.180	0.68193	0.00000	1068.9	1126.7	1196.3	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17140.	4920.	0.0000	0.0000
62	2.190	0.68430	0.00000	1068.9	1126.7	1196.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17224.	4944.	0.0000	0.0000
63	2.200	0.68667	0.00000	1068.9	1126.7	1196.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17308.	4968.	0.0000	0.0000
64	2.210	0.68904	0.00000	1068.9	1126.7	1196.6	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17392.	4992.	0.0000	0.0000
65	2.220	0.69141	0.00000	1068.9	1126.7	1196.7	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17476.	5016.	0.0000	0.0000
66	2.230	0.69378	0.00000	1068.9	1126.7	1196.8	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17560.	5040.	0.0000	0.0000
67	2.240	0.69615	0.00000	1068.9	1126.7	1196.9	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17644.	5064.	0.0000	0.0000
68	2.250	0.69852	0.00000	1068.9	1126.7	1197.0	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17728.	5088.	0.0000	0.0000
69	2.260	0.70089	0.00000	1068.9	1126.7	1197.1	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17812.	5112.	0.0000	0.0000
70	2.270	0.70326	0.00000	1068.9	1126.7	1197.2	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17896.	5136.	0.0000	0.0000
71	2.280	0.70563	0.00000	1068.9	1126.7	1197.3	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	17980.	5160.	0.0000	0.0000
72	2.290	0.70800	0.00000	1068.9	1126.7	1197.4	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	18064.	5184.	0.0000	0.0000
73	2.300	0.71037	0.00000	1068.9	1126.7	1197.5	337.8	0.0000	0.	217.1	23.3	17.7	40.1	12.5	918.	534.	18148.	5208.	0.0000	0.0000

-SM FUSION STARTS AT XF = 0.6940 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.785 M

HEIGHT OF THE BURNING ZONE = 2.060 M

TABLE F.4 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 4 (A)

(PS=2.0T/(SQM)(DAY))

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	GSG	DELHTL
1	0.000	501.90	1201.20	304.20	10.1	49.5	7066.3	0.0
3	0.100	445.55	1134.47	304.20	10.1	49.5	6959.1	22.1
5	0.200	440.19	1107.99	304.15	10.1	49.5	6852.8	43.4
7	0.300	440.97	1151.55	304.07	10.1	49.5	6747.4	64.1
9	0.400	447.64	1135.55	304.06	10.1	49.5	6643.0	84.0
11	0.500	447.85	1119.48	304.05	10.1	49.5	6539.6	103.3
13	0.600	446.85	1102.45	304.04	10.1	49.5	6437.0	122.0
15	0.700	445.57	1085.71	304.04	10.1	49.5	6335.5	139.9
17	0.800	445.13	1067.35	304.03	10.1	49.5	6234.9	157.3
19	0.900	447.48	1050.76	304.03	10.1	49.5	6135.2	173.9
21	1.000	444.84	1031.11	304.02	10.1	49.5	6036.5	190.0
23	1.100	446.84	1012.04	304.02	10.1	49.5	5938.7	205.5
25	1.200	444.99	992.11	304.01	10.1	49.5	5841.8	220.3
27	1.300	445.56	972.90	304.01	10.1	49.5	5745.9	234.5
29	1.400	442.26	952.79	304.01	10.1	49.5	5651.0	248.2
31	1.500	441.56	932.56	304.01	10.1	49.5	5557.0	261.2
33	1.600	439.94	911.84	304.01	10.1	49.5	5463.9	273.7
35	1.700	444.99	890.04	304.01	10.1	49.5	5371.8	285.7
37	1.800	439.99	868.20	304.01	10.1	49.5	5280.6	297.1
39	1.900	437.12	846.12	304.01	10.1	49.5	5190.3	307.9
41	2.000	435.99	823.91	304.01	10.1	49.5	5101.0	318.2
43	2.100	434.38	801.38	304.01	10.1	49.5	5012.7	327.9
45	2.200	433.73	778.71	304.01	10.1	49.5	4925.2	337.2
47	2.300	432.47	755.87	304.01	10.1	49.5	4838.8	345.9
49	2.400	431.71	732.87	304.01	10.1	49.5	4753.2	354.2
51	2.500	430.72	709.64	304.01	10.1	49.5	4668.6	361.9
53	2.600	429.74	686.20	304.01	10.1	49.5	4585.0	369.2
55	2.700	428.76	662.57	304.01	10.1	49.5	4502.3	376.0
57	2.800	427.77	638.74	304.01	10.1	49.5	4420.5	382.3
59	2.900	426.78	614.72	304.01	10.1	49.5	4339.7	388.1
61	3.000	425.79	590.51	304.01	10.1	49.5	4259.9	393.5
63	3.100	424.80	566.12	304.01	10.1	49.5	4181.0	398.5
65	3.200	423.81	541.55	304.01	10.1	49.5	4103.0	403.0
67	3.300	422.82	516.80	304.01	10.1	49.5	4025.9	407.1
69	3.400	421.83	491.88	304.01	9.9	49.5	3949.8	410.7
71	3.500	420.84	466.79	304.01	9.9	49.5	3874.7	414.0
73	3.600	419.85	441.53	304.01	9.9	49.5	3800.5	416.8
75	3.700	418.86	416.10	304.01	9.9	49.5	3727.2	419.2
77	3.800	417.87	390.51	304.01	9.9	49.5	3654.9	421.3
79	3.900	416.88	364.75	304.01	9.9	49.5	3583.5	423.0
81	4.000	415.89	338.84	304.01	9.9	49.5	3513.0	424.2
83	4.100	414.90	312.76	304.00	9.9	49.5	3443.5	425.2
85	4.200	413.91	286.53	304.00	9.9	49.5	3374.9	425.7
87	4.300	412.92	260.14	304.00	9.9	49.5	3307.2	425.9

HEIGHT OF THE COOLING ZONE=4.300M

TABLE P.4 (81).

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 4 (9)

[PS=2.5T/(SQM)(DAY)]

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TL(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELNTL
1	0.000	0.0000	745.00	300.00	300.00	315.00	4.93	20.19	19.87	40.11	12.50	0.	0.	0.	0.
3	0.150	0.0045	766.33	375.46	324.74	315.09	6.35	20.21	19.89	40.11	12.50	173.	0.	0.	13.
5	0.300	0.0090	776.66	395.95	349.22	315.51	8.36	20.20	19.87	40.11	12.50	195.	-20.	0.	26.
7	0.450	0.0135	783.51	414.21	372.97	315.87	9.66	20.19	19.86	40.11	12.50	206.	-12.	0.	40.
9	0.600	0.0180	788.11	431.66	394.75	316.22	11.45	20.17	19.84	40.11	12.50	213.	-11.	0.	54.
11	0.750	0.0225	791.14	447.12	413.94	316.55	12.96	20.16	19.83	40.11	12.50	219.	-11.	0.	67.
13	0.900	0.0270	793.27	461.44	431.59	316.86	14.35	20.15	19.82	40.11	12.50	224.	-11.	0.	81.
15	1.050	0.0315	794.83	474.63	447.70	317.16	15.65	20.14	19.81	40.11	12.50	228.	-11.	0.	95.
17	1.200	0.0360	795.98	486.83	462.39	317.45	16.91	20.13	19.80	40.11	12.50	232.	-11.	0.	108.
19	1.350	0.0405	796.84	498.16	475.80	317.73	18.14	20.12	19.79	40.11	12.50	235.	-11.	0.	122.
21	1.500	0.0450	797.49	508.74	488.03	318.00	19.36	20.11	19.78	40.11	12.50	238.	-11.	0.	136.
23	1.650	0.0495	797.98	518.68	499.17	318.27	20.57	20.10	19.77	40.11	12.50	241.	-11.	0.	149.
25	1.800	0.0540	798.35	528.08	509.32	318.53	21.78	20.09	19.76	40.11	12.50	243.	-11.	0.	163.
27	1.950	0.0585	798.63	537.03	518.56	318.79	23.00	20.08	19.75	40.11	12.50	245.	-11.	0.	177.
29	2.100	0.0630	798.85	545.61	526.96	319.05	24.23	20.07	19.74	40.11	12.50	247.	-11.	0.	190.
31	2.250	0.0675	799.02	553.89	534.59	319.31	25.48	20.06	19.73	40.11	12.50	249.	-11.	0.	204.
33	2.400	0.0720	799.16	561.94	541.51	319.57	26.76	20.05	19.72	40.11	12.50	251.	-11.	0.	218.
35	2.550	0.0765	799.27	569.82	547.78	319.83	28.07	20.04	19.71	40.11	12.50	252.	-11.	0.	231.
37	2.700	0.0810	799.36	577.59	553.46	320.09	29.42	20.03	19.70	40.11	12.50	253.	-11.	0.	245.
39	2.850	0.0855	799.43	585.29	558.59	320.35	30.82	20.02	19.69	40.11	12.50	254.	-11.	0.	259.
41	3.000	0.0900	799.49	592.98	563.22	320.61	32.28	20.01	19.68	40.11	12.50	255.	-11.	0.	272.
43	3.150	0.0945	799.54	600.70	567.39	320.87	33.80	20.00	19.67	40.11	12.50	256.	-11.	0.	286.
45	3.300	0.0990	799.58	608.49	571.13	321.13	35.40	19.99	19.66	40.11	12.50	257.	-11.	0.	300.
47	3.450	0.1035	799.61	616.39	574.48	321.39	37.08	19.98	19.65	40.11	12.50	258.	-11.	0.	313.
49	3.600	0.1080	799.64	624.44	577.47	321.65	38.86	19.97	19.64	40.11	12.50	259.	-11.	0.	327.
51	3.750	0.1125	799.67	632.68	580.13	321.91	40.75	19.96	19.63	40.11	12.50	260.	-11.	0.	341.
53	3.900	0.1170	799.69	641.15	582.49	322.17	42.77	19.95	19.62	40.11	12.50	261.	-11.	0.	354.
55	4.050	0.1215	799.71	649.89	584.57	322.43	44.94	19.94	19.61	40.11	12.50	262.	-11.	0.	368.
57	4.200	0.1260	799.73	658.94	586.40	322.69	47.28	19.93	19.60	40.11	12.50	263.	-11.	0.	382.
59	4.350	0.1305	799.74	668.34	588.00	322.95	49.82	19.92	19.59	40.11	12.50	264.	-11.	0.	395.
61	4.500	0.1350	799.75	678.14	589.40	323.21	52.58	19.91	19.58	40.11	12.50	265.	-11.	0.	409.
63	4.650	0.1395	799.76	688.39	590.62	323.47	55.61	19.90	19.57	40.11	12.50	266.	-11.	0.	423.
65	4.800	0.1440	799.77	699.15	591.68	323.73	58.94	19.89	19.56	40.11	12.50	267.	-11.	0.	436.
67	4.950	0.1485	799.77	710.49	592.61	323.99	62.62	19.88	19.55	40.11	12.50	268.	-11.	0.	450.
69	5.100	0.1530	799.78	722.49	593.43	324.25	66.71	19.87	19.54	40.11	12.50	269.	-11.	0.	464.
71	5.250	0.1575	799.78	735.26	594.16	324.51	71.29	19.86	19.53	40.11	12.50	270.	-11.	0.	477.
73	5.400	0.1620	799.79	748.92	594.82	324.77	76.46	19.85	19.52	40.11	12.50	271.	-11.	0.	491.
75	5.550	0.1665	799.79	763.66	595.43	325.03	82.36	19.84	19.51	40.11	12.50	272.	-11.	0.	505.
77	5.700	0.1710	799.79	779.77	596.00	325.29	89.22	19.83	19.50	40.11	12.50	273.	-11.	0.	518.
79	5.850	0.1755	799.80	797.75	596.55	325.55	97.36	19.82	19.49	40.11	12.50	274.	-11.	0.	532.
81	6.000	0.1800	799.80	818.30	597.09	325.81	107.30	19.81	19.48	40.11	12.50	275.	-11.	0.	546.
83	6.150	0.1845	799.80	842.47	597.64	326.07	119.88	19.80	19.47	40.11	12.50	276.	-11.	0.	559.
85	6.300	0.1890	799.80	872.19	598.22	326.33	136.57	19.79	19.46	40.11	12.50	277.	-11.	0.	573.
87	6.450	0.1935	799.80	911.05	598.87	326.59	160.77	19.78	19.45	40.11	12.50	278.	-11.	0.	587.
89	6.600	0.1980	799.80	966.40	599.64	326.85	201.59	19.77	19.44	40.11	12.50	279.	-11.	0.	600.
91	6.750	0.2025	799.80	1060.75	600.62	327.11	300.41	19.76	19.43	40.11	12.50	280.	-11.	0.	614.
93	6.900	0.2070	799.80	1411.71	602.05	327.37	1111.05	19.75	19.42	40.11	12.50	281.	-11.	0.	628.
95	7.050	0.2115	799.80	9126.05	604.55	327.63	2067.87	19.74	19.41	40.11	12.50	282.	-11.	0.	641.
97	7.200	0.2160	799.80	9141.10	609.24	327.89	104.69	19.73	19.40	40.11	12.50	283.	-11.	0.	655.
99	7.350	0.2205	799.80	9150.05	617.24	328.15	26.45	19.72	19.39	40.11	12.50	284.	-11.	0.	669.
101	7.500	0.2250	799.80	9155.81	633.10	328.41	32.34	19.71	19.38	40.11	12.50	285.	-11.	0.	682.
103	7.650	0.2295	799.80	9161.45	944.45	328.67	104.69	19.70	19.37	40.11	12.50	286.	-11.	0.	696.
	5.100	0.1734	1069.27	946.97	944.47	328.44	104.69	26.45	19.93	40.11	12.50	133.1	-404.1	-456.8	940.

VM COMBUSTION STARTS AT XF = 0.1746 AND AT HEIGHT (FROM TOP) = 5.150 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 5.150 M

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 4 (B)

[FS=2.5T/(SQM)(DAY)]

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFE	QSG	DELMTL	PC2G	PCO2G
1	0.000	0.17455	0.00000	1070.9	949.7	947.2	328.5	0.0000	0.	107.2	25.6	19.3	40.1	12.5	131.	-398.	-480.	0.	0.055	0.242
2	0.050	0.18402	0.00000	1070.8	1129.6	967.9	328.3	0.0000	0.	143.9	25.5	19.2	40.1	12.5	11642.	188.	-357.	108.	0.058	0.240
3	0.100	0.19406	0.00000	1069.0	1129.2	1012.8	328.2	0.0000	0.	152.6	25.4	19.2	40.1	12.5	8854.	191.	-216.	210.	0.061	0.239
4	0.150	0.20471	0.00000	1066.7	1102.2	[illegible]	[illegible]	0.0000	0.	167.7	25.3	19.1	40.1	12.5	9354.	302.	-61.	323.	0.064	0.238
5	0.200	0.21475	0.00000	[illegible]	1186.5	[illegible]	[illegible]	0.0000	0.	181.5	25.2	19.0	40.1	12.5	8964.	387.	92.	429.	0.067	0.237
6	0.250	0.22473	0.00000	1060.0	1212.5	1122.6	[illegible]	0.0000	0.	196.0	25.1	18.9	40.1	12.5	8817.	479.	237.	534.	0.070	0.235
7	0.300	[illegible]	0.00000	1055.0	1237.4	[illegible]	[illegible]	0.0000	0.	210.6	25.0	18.8	40.1	12.5	8598.	569.	378.	638.	0.073	[illegible]
8	0.350	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	327.1	0.0000	0.	219.2	[illegible]	18.7	40.1	12.5	[illegible]	636.	465.	741.	0.076	[illegible]
9	0.400	[illegible]	[illegible]	[illegible]	[illegible]	1173.7	326.7	0.0001	1.	220.1	24.7	18.6	40.1	12.5	[illegible]	661.	490.	842.	0.080	[illegible]
10	0.450	[illegible]	[illegible]	[illegible]	1256.1	[illegible]	[illegible]	0.0002	2.	220.1	24.6	18.4	40.1	12.5	8955.	678.	515.	941.	[illegible]	[illegible]
11	0.500	0.27500	[illegible]	1027.7	[illegible]	[illegible]	[illegible]	0.0003	4.	[illegible]	24.4	18.3	40.1	12.5	8968.	698.	541.	1039.	0.086	0.221
12	0.550	0.28450	0.10017	1021.5	1261.0	[illegible]	[illegible]	0.0004	[illegible]	[illegible]	24.4	18.2	40.2	12.4	9146.	706.	556.	1135.	0.088	0.217
13	0.600	0.29421	[illegible]	[illegible]	[illegible]	1176.0	[illegible]	[illegible]	1.	[illegible]	[illegible]	18.1	40.4	12.2	9225.	712.	575.	1230.	0.091	0.213
14	0.650	0.30415	0.14105	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.	[illegible]	[illegible]	18.0	40.5	12.1	9455.	720.	592.	1323.	[illegible]	[illegible]
15	0.700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.9	40.6	12.0	9662.	728.	610.	1414.	[illegible]	[illegible]
16	0.750	0.32474	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0010	[illegible]	[illegible]	[illegible]	17.7	40.8	11.8	9879.	734.	628.	1504.	[illegible]	[illegible]
17	0.800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0012	34.	[illegible]	[illegible]	17.6	40.9	11.7	10097.	741.	647.	1593.	0.100	0.195
18	0.850	[illegible]	[illegible]	979.5	[illegible]	[illegible]	[illegible]	0.0014	44.	227.6	[illegible]	17.5	41.1	11.5	10320.	746.	666.	1680.	[illegible]	0.190
19	0.900	[illegible]	[illegible]	971.3	[illegible]	[illegible]	[illegible]	0.0017	[illegible]	[illegible]	[illegible]	17.3	41.2	11.3	10544.	750.	685.	1765.	[illegible]	0.185
20	0.950	[illegible]	[illegible]	962.7	1291.7	[illegible]	[illegible]	0.0019	55.	230.7	[illegible]	17.2	41.4	11.1	10770.	754.	705.	1848.	0.108	0.180
21	1.000	[illegible]	[illegible]	953.7	[illegible]	[illegible]	[illegible]	0.0022	[illegible]	[illegible]	[illegible]	17.1	41.5	11.0	10999.	756.	725.	1929.	0.111	0.175
22	1.050	0.39247	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0026	104.	[illegible]	[illegible]	16.9	41.7	10.8	11227.	757.	745.	2008.	0.114	0.170
23	1.100	0.40406	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0029	[illegible]	[illegible]	[illegible]	16.8	41.9	10.6	11457.	757.	765.	2086.	0.117	[illegible]
24	1.150	0.41712	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0034	[illegible]	[illegible]	[illegible]	16.6	42.1	10.4	11685.	755.	785.	2161.	0.120	[illegible]
25	1.200	[illegible]	[illegible]	913.1	[illegible]	[illegible]	[illegible]	0.0038	[illegible]	[illegible]	[illegible]	16.5	42.3	10.1	11911.	753.	806.	2235.	0.123	[illegible]
26	1.250	[illegible]	[illegible]	901.7	[illegible]	[illegible]	[illegible]	0.0044	[illegible]	[illegible]	[illegible]	16.3	42.5	9.9	12134.	743.	827.	2306.	0.126	0.147
27	1.300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0050	[illegible]	[illegible]	[illegible]	16.2	42.7	9.7	12355.	742.	848.	2375.	0.130	0.141
28	1.350	0.46901	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0056	301.	251.3	[illegible]	16.0	42.9	9.4	12565.	734.	869.	2442.	0.133	0.136
29	1.400	[illegible]	[illegible]	[illegible]	1561.1	[illegible]	[illegible]	0.0063	[illegible]	[illegible]	[illegible]	[illegible]	43.1	9.1	12766.	725.	890.	2506.	0.137	[illegible]
30	1.450	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0072	413.	[illegible]	[illegible]	15.7	43.3	8.9	12960.	713.	911.	2568.	0.140	0.121
31	1.500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	317.5	0.0081	[illegible]	261.9	[illegible]	15.5	43.5	8.6	13132.	699.	932.	2628.	0.144	0.115
32	1.550	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	316.9	0.0092	561.	265.9	[illegible]	15.3	43.7	8.3	13290.	653.	953.	2685.	0.148	0.108
33	1.600	[illegible]	[illegible]	[illegible]	[illegible]	1209.9	[illegible]	0.0105	[illegible]	270.4	[illegible]	15.2	44.0	7.9	[illegible]	665.	974.	2740.	0.152	0.101
34	1.650	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0119	755.	[illegible]	[illegible]	15.0	44.2	7.6	[illegible]	644.	994.	2792.	0.155	0.094
35	1.700	[illegible]	[illegible]	[illegible]	[illegible]	1221.7	314.4	0.0136	875.	[illegible]	[illegible]	14.8	44.5	7.2	13627.	621.	1014.	2842.	0.159	0.087
36	1.750	[illegible]	[illegible]	[illegible]	[illegible]	1226.4	313.7	0.0155	1011.	[illegible]	[illegible]	14.6	44.7	6.9	13667.	596.	1034.	2889.	0.164	[illegible]
37	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1231.4	[illegible]	0.0179	1107.	[illegible]	[illegible]	14.5	45.0	6.5	13662.	560.	1053.	2933.	0.168	0.072
38	1.850	[illegible]	[illegible]	713.9	1400.[illegible]	[illegible]	[illegible]	0.0205	[illegible]	[illegible]	[illegible]	[illegible]	45.2	6.0	[illegible]	537.	1071.	2974.	0.172	[illegible]
39	1.900	[illegible]	[illegible]	[illegible]	1477.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.1	45.5	[illegible]	13474.	504.	1089.	3013.	0.176	0.057
40	1.950	0.64717	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45.7	5.1	13265.	469.	1106.	3049.	0.180	0.050
41	2.000	0.66224	[illegible]	[illegible]	1517.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46.0	4.7	12969.	431.	1122.	3083.	0.184	[illegible]
42	2.045	0.67557	[illegible]	[illegible]	1535.0	[illegible]	[illegible]	0.0326	[illegible]	[illegible]	[illegible]	13.6	46.2	4.2	11334.	356.	1024.	3113.	[illegible]	[illegible]
43	2.0[illegible]5	0.68715	[illegible]	613.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.5	46.4	[illegible]	9740.	239.	920.	3139.	0.191	0.031
44	2.120	0.69700	[illegible]	597.5	[illegible]	1261.3	[illegible]	0.0446	[illegible]	[illegible]	[illegible]	13.4	46.6	[illegible]	8193.	232.	812.	3160.	[illegible]	0.026
45	2.155	[illegible]	[illegible]	[illegible]	1581.7	[illegible]	[illegible]	0.0513	[illegible]	[illegible]	[illegible]	13.4	46.7	[illegible]	7630.	214.	815.	3177.	0.197	0.022
46	2.185	0.71371	[illegible]	[illegible]	[illegible]	[illegible]	307.6	0.0645	3373.	[illegible]	[illegible]	13.3	46.8	[illegible]	5985.	170.	699.	3193.	0.199	0.018
47	2.215	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0703	3611.	351.9	[illegible]	13.2	46.8	[illegible]	5462.	157.	697.	3207.	0.201	0.015
48	2.245	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	306.7	[illegible]	[illegible]	340.3	[illegible]	13.1	46.9	[illegible]	4874.	145.	695.	3219.	0.202	0.012
49	2.270	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.1	47.0	[illegible]	3651.	113.	577.	3231.	0.203	0.010
50	2.295	[illegible]	[illegible]	[illegible]	1522.1	[illegible]	[illegible]	0.0857	4195.	[illegible]	[illegible]	[illegible]	47.0	[illegible]	3229.	106.	573.	3240.	0.205	0.008
51	2.320	[illegible]	[illegible]	[illegible]	1499.1	[illegible]	[illegible]	0.0891	4344.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	2301.	99.	569.	3249.	0.206	0.007
52	2.345	0.74144	[illegible]	520.7	1471.5	[illegible]	305.7	0.0910	4474.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	1963.	93.	563.	3258.	0.206	0.005
53	2.370	0.74390	[illegible]	515.6	[illegible]	[illegible]	[illegible]	0.0903	4577.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	1567.	87.	556.	3266.	0.207	0.004
54	2.395	[illegible]	0.98411	511.7	1401.[illegible]	[illegible]	[illegible]	[illegible]	4657.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	1114.	82.	548.	3275.	0.208	0.003
55	2.420	[illegible]	[illegible]	[illegible]	1357.5	[illegible]	[illegible]	0.0762	4707.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	[illegible]	77.	539.	3283.	0.208	[illegible]
56	2.445	0.74849	[illegible]	[illegible]	1311.5	[illegible]	305.3	0.0607	4733.	[illegible]	[illegible]	[illegible]	47.1	[illegible]	[illegible]	72.	522.	3291.	0.208	[illegible]
57	2.470	0.74922	[illegible]	[illegible]	1261.5	[illegible]	[illegible]	0.0390	4740.	[illegible]	[illegible]	[illegible]	47.1	2.1	519.	67.	518.	3298.	0.208	0.002
58	2.490	0.75000	[illegible]	501.6	1208.9	1174.5	305.2	0.0146	4741.	220.9	28.4	12.8	47.1	2.1	194.	50.	406.	3306.	0.209	0.002

ASH FUSION STARTS AT XF = 0.6970 AT HEIGHT (FROM TOP OF BURNING ZONE) = 2.120 M

HEIGHT OF THE BURNING ZONE = 2.490 M

TABLE P.4 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 4 (B)

[PS=2.5T/(SQM)(DAY)]

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	498.10	1186.00	305.20	11.2	50.4	7732.7	0.0
3	0.100	492.37	1170.94	304.87	11.2	50.4	7624.9	24.4
5	0.200	486.71	1156.02	304.75	11.2	50.4	7517.9	47.7
7	0.300	481.12	1141.25	304.63	11.2	50.4	7411.9	70.5
9	0.400	475.62	1126.62	304.52	11.2	50.4	7306.7	92.6
11	0.500	470.19	1112.14	304.41	11.2	50.4	7202.5	114.1
13	0.600	464.86	1097.81	304.30	11.2	50.4	7099.1	134.8
15	0.700	459.53	1083.62	304.19	11.2	50.4	6996.5	154.9
17	0.800	454.31	1069.57	304.08	11.2	50.4	6894.9	174.4
19	0.900	449.16	1055.66	303.97	11.2	50.4	6794.1	193.2
21	1.000	444.08	1041.90	303.86	11.2	50.4	6694.2	211.4
23	1.100	439.07	1028.28	303.75	11.2	50.4	6595.2	228.9
25	1.200	434.12	1014.80	303.65	11.2	50.4	6497.0	245.8
27	1.300	429.26	1001.46	303.54	11.2	50.4	6399.8	262.2
29	1.400	424.45	988.27	303.43	11.2	50.4	6303.3	277.9
31	1.500	419.72	975.21	303.33	11.2	50.4	6207.8	293.0
33	1.600	415.05	962.29	303.23	11.2	50.4	6113.2	307.6
35	1.700	410.44	949.51	303.12	11.2	50.4	6019.4	321.6
37	1.800	405.91	936.87	303.02	11.2	50.4	5926.5	335.0
39	1.900	401.43	924.37	302.92	11.2	50.4	5834.4	347.8
41	2.000	397.03	912.01	302.82	11.2	50.4	5743.3	360.1
43	2.100	392.68	899.78	302.72	11.1	50.4	5653.0	371.9
45	2.200	388.40	887.69	302.62	11.1	50.4	5563.5	383.1
47	2.300	384.19	875.74	302.52	11.1	50.4	5475.0	393.8
49	2.400	380.03	863.92	302.42	11.1	50.4	5387.3	404.0
51	2.500	375.94	852.24	302.32	11.1	50.4	5300.5	413.7
53	2.600	371.91	840.69	302.22	11.1	50.4	5214.6	422.9
55	2.700	367.94	829.28	302.12	11.1	50.4	5129.6	431.5
57	2.800	364.04	818.00	302.03	11.1	50.4	5045.4	439.7
59	2.900	360.19	806.85	301.93	11.1	50.4	4962.1	447.5
61	3.000	356.40	795.84	301.83	11.1	50.4	4879.7	454.7
63	3.100	352.67	784.95	301.74	11.1	50.4	4798.1	461.5
65	3.200	349.00	774.21	301.64	11.1	50.4	4717.4	467.8
67	3.300	345.38	763.59	301.54	11.1	50.4	4637.6	473.7
69	3.400	341.83	753.11	301.45	11.1	50.4	4558.7	479.1
71	3.500	338.32	742.75	301.35	11.1	50.4	4480.6	484.1
73	3.600	334.86	732.52	301.26	11.1	50.4	4403.4	488.7
75	3.700	331.45	722.43	301.16	11.1	50.4	4327.1	492.8
77	3.800	328.10	712.46	301.06	11.1	50.4	4251.7	496.5
79	3.900	324.80	702.62	300.97	11.1	50.4	4177.1	499.9
81	4.000	321.65	692.90	300.87	11.1	50.4	4103.4	502.8
83	4.100	318.48	683.32	300.77	11.0	50.4	4030.6	505.3
85	4.200	315.36	673.86	300.67	11.0	50.4	3958.6	507.5
87	4.300	312.29	664.52	300.57	11.0	50.4	3887.5	509.2
89	4.400	309.28	655.31	300.46	11.0	50.4	3817.2	510.6
91	4.500	306.31	646.22	300.35	11.0	50.4	3747.8	511.7
93	4.600	303.40	637.26	300.24	11.0	50.4	3679.3	512.3
95	4.700	300.53	628.42	300.11	11.0	50.4	3611.6	512.6
96	4.750	299.12	624.04	300.03	11.0	50.4	3578.1	512.7

HEIGHT OF THE COOLING ZONE=4.750M

TABLE P.5 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 5 (A)

(XRINFO=5.0)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TA(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.0000	740.00	300.00	300.00	318.00	4.93	25.68	19.66	39.52	13.55	0.0	0.0	0.0	0.0
3	0.167	0.0000	760.79	300.55	356.99	319.14	7.01	25.91	19.68	39.52	13.55	226.1	-1483.2	-1974.0	135.8
5	0.333	0.0000	778.15	402.68	353.79	319.58	8.68	25.99	19.66	39.52	13.55	261.6	-1435.5	-1809.9	275.4
7	0.500	0.0000	794.97	423.91	379.29	319.99	10.34	25.89	19.65	39.52	13.55	277.9	-1407.1	-1749.6	418.3
9	0.667	0.0000	811.51	444.00	403.49	320.39	12.01	25.87	19.63	39.52	13.55	279.0	-1386.6	-1695.1	564.4
11	0.833	0.0000	827.73	463.96	426.46	320.80	13.71	25.86	19.61	39.52	13.55	270.5	-1366.1	-1641.2	713.1
13	1.000	0.0000	843.64	483.84	448.30	321.22	15.41	25.85	19.60	39.52	13.55	254.5	-1345.6	-1586.8	864.3
15	1.167	0.0000	859.26	503.64	469.06	321.66	17.13	25.85	19.58	39.52	13.55	232.5	-1325.1	-1532.0	1017.8
17	1.333	0.0000	874.61	523.38	488.80	322.12	18.87	25.85	19.57	39.52	13.55	205.4	-1304.5	-1476.8	1173.4
19	1.500	0.0000	889.70	543.07	507.57	322.60	20.63	25.86	19.55	39.52	13.55	174.0	-1283.9	-1421.1	1331.1
21	1.667	0.0000	904.55	562.74	525.41	323.11	22.42	25.87	19.54	39.52	13.55	139.0	-1263.3	-1364.9	1490.8
23	1.833	0.0000	919.17	582.39	542.38	323.65	24.24	25.89	19.52	39.52	13.55	101.2	-1242.6	-1308.1	1652.5
25	2.000	0.0000	933.57	602.03	558.51	324.22	26.09	25.91	19.51	39.52	13.55	61.3	-1221.8	-1250.6	1816.1
27	2.167	0.0000	947.76	621.67	573.85	324.82	27.98	25.94	19.49	39.52	13.55	20.0	-1201.0	-1192.5	1981.6
29	2.333	0.0000	961.75	641.32	588.44	325.46	29.91	25.98	19.47	39.52	13.55	-21.8	-1180.1	-1133.8	2148.9
31	2.500	0.0000	975.55	660.98	602.32	326.14	31.89	26.03	19.45	39.52	13.55	-64.4	-1159.2	-1074.6	2317.9
33	2.667	0.0000	989.17	680.67	615.53	326.87	33.91	26.09	19.43	39.52	13.55	-107.9	-1138.2	-1014.9	2488.5
35	2.833	0.0000	1002.62	700.40	628.11	327.65	35.99	26.17	19.41	39.52	13.55	-152.2	-1117.1	-954.7	2660.6
37	3.000	0.0000	1015.91	720.18	640.09	328.49	38.13	26.27	19.39	39.52	13.55	-197.2	-1096.0	-894.0	2834.2
39	3.167	0.0000	1029.05	740.03	651.51	329.40	40.34	26.40	19.36	39.52	13.55	-242.8	-1074.8	-832.8	3009.2
41	3.333	0.0000	1042.05	759.96	662.40	330.38	42.63	26.55	19.33	39.52	13.55	-288.9	-1053.5	-771.0	3185.5
43	3.500	0.0000	1054.92	779.98	672.80	331.44	45.00	26.73	19.30	39.52	13.55	-335.4	-1032.1	-708.7	3363.1
45	3.667	0.0000	1067.67	800.11	682.74	332.59	47.47	26.95	19.26	39.52	13.55	-382.3	-1010.6	-645.8	3541.9
47	3.833	0.0000	1080.31	820.36	692.26	333.84	50.05	27.21	19.22	39.52	13.55	-429.4	-989.0	-582.2	3721.8
49	4.000	0.0000	1092.85	840.74	701.39	335.20	52.76	27.52	19.17	39.52	13.55	-476.7	-967.3	-518.0	3902.8
51	4.167	0.0000	1105.30	861.26	710.17	336.68	55.62	27.89	19.12	39.52	13.55	-524.2	-945.5	-453.1	4084.8
53	4.333	0.0000	1117.68	881.94	718.64	338.30	58.64	28.33	19.06	39.52	13.55	-571.8	-923.6	-387.5	4267.8
55	4.500	0.0000	1129.99	902.80	726.83	340.08	61.85	28.86	18.99	39.52	13.55	-619.4	-901.6	-321.2	4451.7
57	4.667	0.0000	1142.25	923.85	734.78	342.04	65.26	29.50	18.91	39.52	13.55	-667.0	-879.5	-254.2	4636.5
59	4.833	0.0000	1154.48	945.12	742.53	344.21	68.91	30.28	18.82	39.52	13.55	-714.6	-857.2	-186.4	4822.2
61	5.000	0.0000	1166.68	966.62	750.12	346.62	72.83	31.24	18.71	39.52	13.55	-762.1	-834.8	-117.8	5008.7
63	5.167	0.0000	1178.87	988.39	757.59	349.31	77.06	32.42	18.58	39.52	13.55	-809.5	-812.2	-48.4	5196.0
65	5.333	0.0000	1191.06	1010.46	764.98	352.33	81.66	33.89	18.43	39.52	13.55	-856.8	-789.4	22.8	5384.1
67	5.500	0.0000	1203.26	1032.87	772.34	355.76	86.70	35.74	18.25	39.52	13.55	-903.9	-766.4	95.0	5572.9
69	5.667	0.0000	1215.49	1055.67	779.72	359.70	92.28	38.11	18.03	39.52	13.55	-950.8	-743.2	168.0	5762.4
71	5.833	0.0000	1227.76	1078.92	787.18	364.27	98.54	41.19	17.77	39.52	13.55	-997.4	-719.8	242.0	5952.6
73	6.000	0.0000	1240.09	1102.69	794.79	369.66	105.67	45.31	19.14	39.52	13.55	-1043.7	-696.2	317.1	6143.5
75	6.167	0.0000	1252.50	1127.05	802.62	376.11	113.90	50.98	19.14	39.52	13.55	-1089.7	-672.3	393.3	6335.1
77	6.333	0.0000	1265.00	1152.09	810.76	383.94	123.58	58.98	19.14	39.52	13.55	-1135.3	-648.2	470.8	6527.3
79	6.500	0.0000	1277.62	1177.92	819.32	393.58	135.31	70.64	19.14	39.52	13.55	-1180.5	-623.8	549.8	6720.1
81	6.667	0.0000	1290.39	1204.69	828.44	405.72	150.34	88.64	19.14	39.52	13.55	-1225.2	-599.0	630.5	6913.5
83	6.833	0.0000	1303.34	1232.58	838.32	422.64	172.00	119.64	19.14	39.52	13.55	-1269.4	-573.9	713.2	7107.4
85	7.000	0.0000	1316.52	1261.82	849.26	448.71	205.34	175.64	19.14	39.52	13.55	-1312.9	-548.4	798.2	7301.8
87	7.167	0.0000	1329.97	1292.69	861.71	491.39	259.80	287.64	19.14	39.52	13.55	-1355.8	-522.4	885.9	7496.8
89	7.333	0.0000	1343.76	1325.52	876.41	570.08	360.00	511.64	19.14	39.52	13.55	-1398.0	-495.8	976.8	7692.2
91	7.500	0.0000	1357.96	1360.77	894.61	734.77	564.21	1015.64	19.14	39.52	13.55	-1439.4	-468.6	1071.5	7888.1
93	7.667	0.0000	1372.66	1399.04	919.01	1079.46	1000.42	2039.64	19.14	39.52	13.55	-1480.0	-440.7	1170.7	8084.4
95	7.833	0.0000	1387.99	1441.21	953.17	1727.15	1892.63	4063.64	19.14	39.52	13.55	-1519.7	-412.0	1276.1	8281.1
97	8.000	0.0000	1404.12	1489.07	1004.31	3051.85	3783.84	8087.64	19.14	39.52	13.55	-1558.4	-382.5	1389.8	8478.2
99	8.167	0.0000	1421.21	1544.21	1083.51	6048.45	7559.05	16111.64	19.14	39.52	13.55	-1596.0	-352.1	1514.1	8675.6
101	5.000	0.1731	1054.73	950.09	942.10	328.05	107.57	25.31	19.14	39.52	13.55	96.7	-398.8	-448.1	9440.8

VM COMBUSTION STARTS AT XF = 0.1731 AND AT HEIGHT (FROM TOP) = 5.000 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 5.000 M

TABLE F.5 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 5 (A)

(XRINPC=5.C)

RESULTS OF ANALYSIS

I	Z(M)	XF	AS	TS(K)	TF(K)	TS(K)	TA(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	GFS	QFG	QSG	DELHTL	PC2G	PCC2G
1	0.000	0.1711	0.000000	1[illegible]	[illegible]	[illegible]	[illegible]	0.0000	0.	107.4	2	19.1	99	1	12[illegible]	[illegible]	[illegible]	0.	[illegible]	[illegible]
2	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
38	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
56	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ASH FUSION STARTS AT XF = 0.0765 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.895 M

HEIGHT OF THE BURNING ZONE = 2.270 M

TABLE P.5 (A3)

SIMULATION OF LIME SHAFT KILN.
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 5 (A)

(XRINFD=5.0)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	GSG	DELHTL
			1608.00	303.50	11.1	49.8	13016.9	0.0
1	0.000	439.50	1595.41	303.70	11.1	49.8	12925.7	8.7
2	0.050	434.64	1582.88	303.52	11.1	49.8	12834.9	17.0
3	0.100	429.92	1570.41	303.44	11.1	49.8	12744.4	25.1
4	0.150	425.02	1558.00	303.33	11.1	49.8	12654.3	32.8
5	0.200	420.25	1545.65	303.23	11.1	49.8	12564.5	40.3
6	0.250	415.50	1533.37	303.12	11.1	49.8	12475.1	47.4
7	0.300	410.79	1521.14	303.02	11.1	49.8	12386.0	54.3
8	0.350	406.10	1508.97	302.92	11.1	49.8	12297.3	60.9
9	0.400	401.44	1496.86	302.81	11.1	49.8	12208.9	67.1
10	0.450	396.81	1484.81	302.71	11.1	49.8	12120.9	73.1
11	0.500	392.21	1472.82	302.60	11.1	49.8	12033.2	78.8
12	0.550	387.63	1460.88	302.50	11.1	49.8	11945.8	84.3
13	0.600	383.08	1449.01	302.39	11.1	49.8	11858.7	89.4
14	0.650	378.56	1437.19	302.29	11.1	49.8	11772.0	94.3
15	0.700	374.07	1425.43	302.18	11.1	49.8	11685.5	98.8
16	0.750	369.60	1413.73	302.07	11.1	49.8	11599.4	103.1
17	0.800	365.16	1402.08	301.96	11.1	49.8	11513.6	107.2
18	0.850	360.75	1390.50	301.85	11.1	49.8	11428.1	110.9
19	0.900	356.36	1378.96	301.74	11.0	49.8	11342.9	114.4
20	0.950	352.00	1367.49	301.63	11.0	49.8	11258.0	117.6
21	1.000	347.66	1356.07	301.52	11.0	49.6	11173.4	120.5
22	1.050	343.35	1344.71	301.41	11.0	49.8	11089.1	123.2
23	1.100	339.06	1333.40	301.29	11.0	49.8	11005.1	125.6
24	1.150	334.81	1322.15	301.18	11.0	49.8	10921.3	127.8
25	1.200	330.57	1310.96	301.06	11.0	49.8	10837.9	129.6
26	1.250	326.36	1299.82	300.95	11.0	49.8	10754.7	131.3
27	1.300	322.18	1288.74	300.81	11.0	49.6	10671.8	132.6
28	1.350	318.02	1277.71	300.68	11.0	49.8	10589.1	133.7
29	1.400	313.89	1266.74	300.55	11.0	49.8	10506.8	134.6
30	1.450	309.78	1255.82	300.41	11.0	49.8	10424.6	135.2
31	1.500	305.69	1244.96	300.25	11.0	49.8	10342.8	135.5
32	1.550	301.63	1234.15	300.08	11.0	49.8	10261.2	135.6
33	1.600	297.59						

HEIGHT OF THE COOLING ZONE=1.6COM

TABLE P.5 (61)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 5 (9)

(XRINFO=0.0)

RESULTS OF ANALYSIS

I	Z(M)	XF	Tg(I)	TF(I)	Ts(I)	Ta(K)	HFS	HFG	HSG	ASPZ	AFPZ	DFS	DFG	DSG	DELNTL
1	0.000	0.0000	746.00	300.00	300.00	316.00	0.00	24.26	16.55	40.62	11.60	0.0	0.0	0.0	0.0
3	0.100	0.0000	761.00	300.00	300.00	316.00	0.92	24.26	16.55	40.62	11.60	150.4	-1205.6	-1822.0	0.0
5	0.300	0.0000	774.00	300.00	300.00	316.00	0.92	24.26	16.55	40.62	11.60	211.9	-1115.5	-1772.0	0.0
7	0.500	0.0000	791.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	252.4	-1113.7	-1760.7	0.0
9	0.700	0.0000	811.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	284.8	-1112.1	-1753.3	0.0
11	0.900	0.0000	834.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	311.9	-1110.7	-1747.6	0.0
13	1.100	0.0000	860.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	335.6	-1109.4	-1743.0	0.0
15	1.300	0.0000	889.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	356.9	-1108.3	-1739.2	0.0
17	1.500	0.0000	921.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	376.2	-1107.3	-1736.0	0.0
19	1.700	0.0000	956.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	393.6	-1106.4	-1733.3	0.0
21	1.900	0.0000	994.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	409.5	-1105.6	-1730.9	0.0
23	2.100	0.0000	1035.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	424.1	-1104.9	-1728.8	0.0
25	2.300	0.0000	1079.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	437.7	-1104.2	-1726.9	0.0
27	2.500	0.0000	1126.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	450.3	-1103.6	-1725.2	0.0
29	2.700	0.0000	1176.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	462.1	-1103.0	-1723.6	0.0
31	2.900	0.0000	1230.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	473.2	-1102.5	-1722.2	0.0
33	3.100	0.0000	1287.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	483.6	-1102.0	-1720.8	0.0
35	3.300	0.0000	1348.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	493.5	-1101.5	-1719.6	0.0
37	3.500	0.0000	1412.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	502.8	-1101.1	-1718.4	0.0
39	3.700	0.0000	1480.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	511.7	-1100.7	-1717.3	0.0
41	3.900	0.0000	1552.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	520.1	-1100.3	-1716.3	0.0
43	4.100	0.0000	1628.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	528.2	-1099.9	-1715.3	0.0
45	4.300	0.0000	1708.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	535.9	-1099.6	-1714.4	0.0
47	4.500	0.0000	1792.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	543.3	-1099.3	-1713.5	0.0
49	4.700	0.0000	1881.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	550.4	-1099.0	-1712.7	0.0
51	4.900	0.0000	1974.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	557.3	-1098.7	-1712.0	0.0
53	5.100	0.0000	2072.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	564.0	-1098.4	-1711.3	0.0
55	5.300	0.0000	2175.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	570.5	-1098.2	-1710.6	0.0
57	5.500	0.0000	2283.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	576.8	-1098.0	-1710.0	0.0
61	5.900	0.0000	2509.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	588.9	-1097.6	-1708.9	0.0
63	6.100	0.0000	2628.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	594.7	-1097.4	-1708.4	0.0
65	6.300	0.0000	2753.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	600.4	-1097.2	-1707.9	0.0
67	6.500	0.0000	2884.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	605.9	-1097.1	-1707.4	0.0
69	6.700	0.0000	3020.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	611.3	-1096.9	-1706.9	0.0
71	6.900	0.0000	3163.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	616.5	-1096.8	-1706.5	0.0
73	7.100	0.0000	3312.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	621.6	-1096.6	-1706.0	0.0
75	7.300	0.0000	3468.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	626.5	-1096.5	-1705.6	0.0
77	7.500	0.0000	3631.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	631.3	-1096.4	-1705.2	0.0
79	7.700	0.0000	3802.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	636.0	-1096.3	-1704.8	0.0
81	7.900	0.0000	3980.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	640.6	-1096.2	-1704.4	0.0
83	8.100	0.0000	4167.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	645.0	-1096.1	-1704.1	0.0
85	8.300	0.0000	4362.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	649.4	-1096.0	-1703.7	0.0
87	8.500	0.0000	4567.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	653.7	-1095.9	-1703.4	0.0
89	8.700	0.0000	4782.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	657.9	-1095.8	-1703.1	0.0
91	8.900	0.0000	5007.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	662.0	-1095.8	-1702.8	0.0
93	9.100	0.0000	5243.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	666.1	-1095.7	-1702.5	0.0
95	9.300	0.0000	5491.00	300.00	300.00	316.00	1.79	24.26	16.55	40.62	11.60	670.1	-1095.6	-1702.2	0.0

VM COMBUSTION STARTS AT XF = 0.1738 AND AT HEIGHT (FROM TOP) = 4.750 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.750 M

TABLE P.5 (B2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 5 (B)

(XRINFO=6.0)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TL(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	BFS	BFG	BSG	DELMTL	PC2S	PCO2S
1	0.000	0.17382	0.00000	1065.3	950.5	948.0	328.4	0.0000	0.	107.5	23.8	18.1	40.6	11.6	140.	-414.	-361.	0.	0.0	251.
2	0.250	0.16394	0.00000	1065.5	1166.8	969.2	328.2	0.0000	0.	142.7	23.8	18.0	40.6	11.6	129.	-114.	-473.	0.	0.0	244.
3	0.500	0.19466	0.00000	1064.2	1117.5	1012.2	328.1	0.0000	0.	150.0	23.7	17.9	40.6	11.6	112.	104.	-139.	0.	0.0	237.
4	0.750	0.20417	0.00000	1062.4	1152.7	1048.0	327.9	0.0000	0.	165.8	23.7	17.8	40.6	11.6	89.	183.	114.	0.	0.0	230.
5	0.250	0.21441	0.00000	1079.9	1174.9	1083.4	327.7	0.0000	0.	157.8	23.6	17.8	40.6	11.6	69.	253.	346.	0.	0.0	223.
6	0.250	0.22441	0.00000	1078.7	1200.7	1116.5	327.5	0.0000	0.	191.7	23.6	17.7	40.6	11.6	49.	323.	578.	0.	0.0	216.
7	0.300	0.23453	0.00000	1078.9	1224.5	1148.5	327.3	0.0000	0.	205.3	23.5	17.6	40.6	11.6	29.	393.	810.	0.	0.0	209.
8	0.350	0.24465	0.00000	1067.1	1245.7	1173.6	327.0	0.0000	0.	217.3	23.5	17.5	40.6	11.6	8.	463.	1042.	0.	0.0	202.
9	0.400	0.25476	0.00000	1066.6	1245.7	1173.6	326.7	0.0000	0.	216.1	23.4	17.4	40.6	11.6	8.	534.	1274.	0.	0.0	195.
10	0.450	0.26486	0.00000	1064.9	1244.2	1174.4	326.3	0.0000	0.	218.5	23.4	17.2	40.6	11.6	8.	604.	1506.	0.	0.0	188.
11	0.500	0.27497	0.00000	1047.9	1244.2	1174.4	326.0	0.0000	0.	218.5	23.4	17.1	40.6	11.6	8.	675.	1738.	0.	0.0	181.
12	0.550	0.28508	0.00000	1060.9	1246.2	1175.0	325.6	0.0000	0.	222.4	23.4	17.0	40.6	11.6	8.	746.	1970.	0.	0.0	174.
13	0.600	0.29519	0.00000	1060.3	1246.2	1175.7	325.3	0.0000	0.	222.4	23.4	17.0	40.6	11.6	8.	816.	2202.	0.	0.0	167.
14	0.650	0.30530	0.00000	1060.7	1247.2	1176.2	324.9	0.0000	0.	224.0	23.4	16.9	40.7	11.6	8.	887.	2434.	0.	0.0	160.
15	0.700	0.31540	0.00000	1060.7	1247.2	1176.7	324.6	0.0000	0.	224.0	23.4	16.7	41.0	11.6	8.	957.	2666.	0.	0.0	153.
16	0.750	0.32551	0.00000	1061.5	1247.2	1177.1	324.2	0.0000	0.	225.3	23.4	16.5	41.3	11.6	8.	1028.	2898.	0.	0.0	146.
17	0.000	0.33562	0.00000	1061.5	1247.2	1177.5	323.8	0.0000	0.	226.4	23.4	16.3	41.6	11.6	8.	1098.	3130.	0.	0.0	139.
18	0.000	0.34573	0.00000	1061.5	1247.2	1177.9	323.4	0.0000	0.	227.4	23.4	16.2	41.8	11.6	8.	1169.	3362.	0.	0.0	132.
19	0.000	0.35584	0.00000	1061.5	1247.2	1178.3	323.0	0.0000	0.	228.4	23.4	16.1	41.9	11.6	8.	1239.	3594.	0.	0.0	125.
20	0.000	0.36595	0.00000	1061.5	1247.2	1178.7	322.6	0.0000	0.	229.4	23.4	16.0	42.0	11.6	8.	1310.	3826.	0.	0.0	118.
21	0.000	0.37606	0.00000	1061.5	1247.2	1179.1	322.2	0.0000	0.	230.4	23.4	15.9	42.1	11.6	8.	1380.	4058.	0.	0.0	111.
22	0.000	0.38617	0.00000	1061.5	1247.2	1179.5	321.8	0.0000	0.	231.4	23.4	15.8	42.2	11.6	8.	1451.	4290.	0.	0.0	104.
23	0.000	0.39628	0.00000	1061.5	1247.2	1179.9	321.4	0.0000	0.	232.4	23.4	15.7	42.3	11.6	8.	1521.	4522.	0.	0.0	97.
24	0.000	0.40639	0.00000	1061.5	1247.2	1180.3	321.0	0.0000	0.	233.4	23.4	15.6	42.4	11.6	8.	1592.	4754.	0.	0.0	90.
25	0.000	0.41650	0.00000	1061.5	1247.2	1180.7	320.6	0.0000	0.	234.4	23.4	15.5	42.5	11.6	8.	1662.	4986.	0.	0.0	83.
26	0.000	0.42661	0.00000	1061.5	1247.2	1181.1	320.2	0.0000	0.	235.4	23.4	15.4	42.6	11.6	8.	1733.	5218.	0.	0.0	76.
27	0.000	0.43672	0.00000	1061.5	1247.2	1181.5	319.8	0.0000	0.	236.4	23.4	15.3	42.7	11.6	8.	1803.	5450.	0.	0.0	69.
28	0.000	0.44683	0.00000	1061.5	1247.2	1181.9	319.4	0.0000	0.	237.4	23.4	15.2	42.8	11.6	8.	1874.	5682.	0.	0.0	62.
29	0.000	0.45694	0.00000	1061.5	1247.2	1182.3	319.0	0.0000	0.	238.4	23.4	15.1	42.9	11.6	8.	1944.	5914.	0.	0.0	55.
30	0.000	0.46705	0.00000	1061.5	1247.2	1182.7	318.6	0.0000	0.	239.4	23.4	15.0	43.0	11.6	8.	2015.	6146.	0.	0.0	48.
31	0.000	0.47716	0.00000	1061.5	1247.2	1183.1	318.2	0.0000	0.	240.4	23.4	14.9	43.1	11.6	8.	2085.	6378.	0.	0.0	41.
32	0.000	0.48727	0.00000	1061.5	1247.2	1183.5	317.8	0.0000	0.	241.4	23.4	14.8	43.2	11.6	8.	2156.	6610.	0.	0.0	34.
33	0.000	0.49738	0.00000	1061.5	1247.2	1183.9	317.4	0.0000	0.	242.4	23.4	14.7	43.3	11.6	8.	2226.	6842.	0.	0.0	27.
34	0.000	0.50749	0.00000	1061.5	1247.2	1184.3	317.0	0.0000	0.	243.4	23.4	14.6	43.4	11.6	8.	2297.	7074.	0.	0.0	20.
35	0.000	0.51760	0.00000	1061.5	1247.2	1184.7	316.6	0.0000	0.	244.4	23.4	14.5	43.5	11.6	8.	2367.	7306.	0.	0.0	13.
36	0.000	0.52771	0.00000	1061.5	1247.2	1185.1	316.2	0.0000	0.	245.4	23.4	14.4	43.6	11.6	8.	2438.	7538.	0.	0.0	6.
37	0.000	0.53782	0.00000	1061.5	1247.2	1185.5	315.8	0.0000	0.	246.4	23.4	14.3	43.7	11.6	8.	2508.	7770.	0.	0.0	0.
38	0.000	0.54793	0.00000	1061.5	1247.2	1185.9	315.4	0.0000	0.	247.4	23.4	14.2	43.8	11.6	8.	2579.	8002.	0.	0.0	0.
39	0.000	0.55804	0.00000	1061.5	1247.2	1186.3	315.0	0.0000	0.	248.4	23.4	14.1	43.9	11.6	8.	2649.	8234.	0.	0.0	0.
40	0.000	0.56815	0.00000	1061.5	1247.2	1186.7	314.6	0.0000	0.	249.4	23.4	14.0	44.0	11.6	8.	2720.	8466.	0.	0.0	0.
41	0.000	0.57826	0.00000	1061.5	1247.2	1187.1	314.2	0.0000	0.	250.4	23.4	13.9	44.1	11.6	8.	2790.	8698.	0.	0.0	0.
42	0.000	0.58837	0.00000	1061.5	1247.2	1187.5	313.8	0.0000	0.	251.4	23.4	13.8	44.2	11.6	8.	2861.	8930.	0.	0.0	0.
43	0.000	0.59848	0.00000	1061.5	1247.2	1187.9	313.4	0.0000	0.	252.4	23.4	13.7	44.3	11.6	8.	2931.	9162.	0.	0.0	0.
44	0.000	0.60859	0.00000	1061.5	1247.2	1188.3	313.0	0.0000	0.	253.4	23.4	13.6	44.4	11.6	8.	3002.	9394.	0.	0.0	0.
45	0.000	0.61870	0.00000	1061.5	1247.2	1188.7	312.6	0.0000	0.	254.4	23.4	13.5	44.5	11.6	8.	3072.	9626.	0.	0.0	0.
46	0.000	0.62881	0.00000	1061.5	1247.2	1189.1	312.2	0.0000	0.	255.4	23.4	13.4	44.6	11.6	8.	3143.	9858.	0.	0.0	0.
47	0.000	0.63892	0.00000	1061.5	1247.2	1189.5	311.8	0.0000	0.	256.4	23.4	13.3	44.7	11.6	8.	3213.	10090.	0.	0.0	0.
48	0.000	0.64903	0.00000	1061.5	1247.2	1189.9	311.4	0.0000	0.	257.4	23.4	13.2	44.8	11.6	8.	3284.	10322.	0.	0.0	0.
49	0.000	0.65914	0.00000	1061.5	1247.2	1190.3	311.0	0.0000	0.	258.4	23.4	13.1	44.9	11.6	8.	3354.	10554.	0.	0.0	0.
50	0.000	0.66925	0.00000	1061.5	1247.2	1190.7	310.6	0.0000	0.	259.4	23.4	13.0	45.0	11.6	8.	3425.	10786.	0.	0.0	0.
51	0.000	0.67936	0.00000	1061.5	1247.2	1191.1	310.2	0.0000	0.	260.4	23.4	12.9	45.1	11.6	8.	3495.	11018.	0.	0.0	0.
52	0.000	0.68947	0.00000	1061.5	1247.2	1191.5	309.8	0.0000	0.	261.4	23.4	12.8	45.2	11.6	8.	3566.	11250.	0.	0.0	0.
53	0.000	0.69958	0.00000	1061.5	1247.2	1191.9	309.4	0.0000	0.	262.4	23.4	12.7	45.3	11.6	8.	3636.	11482.	0.	0.0	0.
54	0.000	0.70969	0.00000	1061.5	1247.2	1192.3	309.0	0.0000	0.	263.4	23.4	12.6	45.4	11.6	8.	3707.	11714.	0.	0.0	0.
55	0.000	0.71980	0.00000	1061.5	1247.2	1192.7	308.6	0.0000	0.	264.4	23.4	12.5	45.5	11.6	8.	3777.	11946.	0.	0.0	0.
56	0.000	0.72991	0.00000	1061.5	1247.2	1193.1	308.2	0.0000	0.	265.4	23.4	12.4	45.6	11.6	8.	3848.	12178.	0.	0.0	0.
57	0.000	0.74002	0.00000	1061.5	1247.2	1193.5	307.8	0.0000	0.	266.4	23.4	12.3	45.7	11.6	8.	3918.	12410.	0.	0.0	0.
58	0.000	0.75013	0.00000	1061.5	1247.2	1193.9	307.4	0.0000	0.	267.4	23.4	12.2	45.8	11.6	8.	3989.	12642.	0.	0.0	0.

ASH FUSION STARTS AT XF = 0.7010 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.965 M

HEIGHT OF THE BURNING ZONE = 2.265 M

TABLE P.5 (E3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 5 (5)

(XRINFD=0.0)

RESULTS OF ANALYSIS

I	Z(M)	TC(K)	TS(K)	Tm(K)	PSG	ASCZ	GSG	DELMTL
1	0.000	566.00	1191.40	355.70	10.2	48.6	6294.0	0.0
3	0.100	561.85	1165.96	355.56	10.2	48.6	6266.1	29.5
5	0.200	556.13	1150.66	355.45	10.2	48.6	6146.6	58.5
7	0.300	550.37	1144.19	355.40	10.2	48.6	6072.7	86.8
9	0.400	544.64	1132.25	355.31	10.2	48.6	6001.2	114.5
11	0.500	538.94	1120.22	355.22	10.2	48.6	5929.1	141.7
13	0.600	533.27	1108.25	355.17	10.2	48.6	5857.6	168.3
15	0.700	527.63	1096.45	355.04	10.2	48.6	5786.5	194.3
17	0.800	522.01	1084.72	354.95	10.2	48.6	5715.9	219.7
19	0.900	516.43	1073.09	354.89	10.2	48.6	5645.8	244.6
21	1.000	510.87	1061.55	354.78	10.2	48.6	5576.1	269.0
23	1.100	505.34	1050.11	354.69	10.2	48.6	5507.0	292.8
25	1.200	499.84	1038.75	354.61	10.2	48.6	5438.3	316.1
27	1.300	494.37	1027.52	354.52	10.2	48.6	5370.1	338.8
29	1.400	488.93	1016.40	354.44	10.2	48.6	5302.4	361.0
31	1.500	483.52	1005.36	354.36	10.2	48.6	5235.1	382.7
33	1.600	478.14	994.42	354.27	10.2	48.6	5168.4	403.9
35	1.700	472.79	983.59	354.19	10.2	48.6	5102.1	424.6
37	1.800	467.47	972.84	354.11	10.2	48.6	5036.4	444.7
39	1.900	462.18	962.20	354.03	10.2	48.6	4971.1	464.4
41	2.000	456.92	951.65	353.95	10.2	48.6	4906.3	483.6
43	2.100	451.69	941.20	353.87	10.2	48.6	4842.0	502.3
45	2.200	446.49	930.84	353.79	10.2	48.6	4778.2	520.6
47	2.300	441.32	920.58	353.71	10.2	48.6	4714.9	538.3
49	2.400	436.18	910.42	353.64	10.2	48.6	4652.0	555.6
51	2.500	431.07	900.37	353.57	10.2	48.6	4589.7	572.5
53	2.600	425.99	890.41	353.50	10.2	48.6	4527.9	588.9
55	2.700	420.94	880.54	353.43	10.2	48.6	4466.5	604.8
57	2.800	415.92	870.77	353.36	10.2	48.6	4405.7	620.4
59	2.900	410.93	861.10	353.29	10.2	48.6	4345.4	635.4
61	3.000	405.97	851.52	353.23	10.1	48.6	4285.5	650.1
63	3.100	401.04	842.04	353.17	10.1	48.6	4226.3	664.3
65	3.200	396.14	832.66	353.11	10.1	48.6	4167.5	678.1
67	3.300	391.27	823.37	353.05	10.1	48.6	4109.2	691.5
69	3.400	386.43	814.18	352.99	10.1	48.6	4051.2	704.5
73	3.600	376.84	796.08	352.87	10.1	48.6	3937.0	729.2
77	3.800	367.36	778.31	352.76	10.1	48.6	3824.9	752.4
81	4.000	357.99	760.87	352.65	10.1	48.6	3714.7	774.1
85	4.200	348.74	743.75	352.55	10.1	48.6	3606.6	794.3
89	4.400	339.60	726.96	352.45	10.1	48.6	3500.6	813.1
93	4.600	330.58	710.50	352.35	10.1	48.6	3396.5	830.5
97	4.800	321.68	694.35	352.26	10.1	48.6	3294.5	846.5
101	5.000	312.90	678.52	352.17	10.1	48.6	3194.6	861.2
105	5.200	304.24	663.00	352.08	10.1	48.6	3096.9	874.3
109	5.400	295.70	647.79	351.99	10.1	48.6	3001.5	886.0
113	5.600	287.28	632.89	351.91	10.1	48.6	2908.4	896.2
117	5.800	278.98	618.30	351.83	10.1	48.6	2817.7	905.0
121	6.000	270.80	604.01	351.75	10.1	48.6	2729.4	912.4
125	6.200	262.74	590.03	351.68	10.1	48.6	2643.5	918.4
129	6.400	254.80	576.34	351.61	10.1	48.6	2560.0	923.0
133	6.600	246.98	562.95	351.54	10.1	48.6	2479.0	926.2
137	6.800	239.28	549.86	351.47	10.1	48.6	2400.5	928.0
141	7.000	231.70	537.06	351.41	10.1	48.6	2324.5	928.4
145	7.200	224.24	524.56	351.35	10.1	48.6	2251.0	927.4
149	7.400	216.90	512.35	351.29	10.1	48.6	2179.9	925.0
153	7.600	209.68	500.43	351.24	10.1	48.6	2111.4	921.2
155	7.700	206.14	494.57	351.21	10.1	48.6	2078.0	918.7

HEIGHT OF THE COOLING ZONE=7.700M

TABLE P.6 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 6 (A)

(XFV=0.15)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TL(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.00000	746.00	300.00	300.00	318.00						0.0	0.0	0.0	0.0
3	0.100	0.00000	761.36	378.32	326.15	321.32	4.93	24.72	16.83	40.11	12.50	0.0	0.0	0.0	0.0
5	0.200	0.00125	774.47	400.87	352.16	319.34	6.95	24.75	16.80	40.11	12.50	33.2	-11.6	-18.8	12.1
7	0.300	0.00633	786.67	419.26	376.98	319.71	8.71	24.73	16.81	40.11	12.50	44.5	-15.4	-24.9	16.1
9	0.400	0.01641	797.08	435.38	400.35	320.41	10.43	24.71	16.78	40.11	12.50	53.4	-18.4	-29.7	19.3
11	0.500	0.03164	805.84	449.72	422.27	321.41	12.15	24.69	16.76	40.11	12.50	60.6	-20.9	-33.7	21.9
13	0.600	0.05215	813.08	462.77	442.76	322.67	13.87	24.67	16.76	40.11	12.50	66.5	-22.9	-37.0	24.0
15	0.700	0.07805	818.93	474.79	461.85	324.16	15.60	24.75	16.78	40.11	12.50	71.3	-24.6	-39.7	25.8
17	0.800	0.10947	823.52	485.98	479.57	325.86	17.34	24.77	16.81	40.11	12.50	75.2	-25.9	-41.9	27.2
19	0.900	0.14652	826.98	496.52	495.96	327.74	19.09	24.77	16.83	40.11	12.50	78.3	-27.0	-43.7	28.4
21	1.000	0.18931	829.44	506.56	511.06	329.77	20.85	24.77	16.85	40.11	12.50	80.8	-27.9	-45.1	29.3
23	1.100	0.23795	831.03	516.23	525.00	331.94	22.61	24.77	16.86	40.11	12.50	82.8	-28.6	-46.2	30.0
25	1.200	0.29253	831.89	525.63	538.82	334.23	24.39	24.77	16.87	40.11	12.50	84.4	-29.1	-47.1	30.6
27	1.300	0.35314	832.14	534.84	552.56	336.62	26.17	24.77	16.88	40.11	12.50	85.6	-29.5	-47.8	31.0
29	1.400	0.41985	831.91	543.93	566.26	339.11	27.96	24.77	16.89	40.11	12.50	86.6	-29.8	-48.3	31.3
31	1.500	0.49272	831.31	552.96	579.96	341.68	29.76	24.77	16.89	40.11	12.50	87.3	-30.0	-48.7	31.5
33	1.600	0.57182	830.45	561.98	593.70	344.33	31.57	24.77	16.90	40.11	12.50	87.8	-30.2	-48.9	31.6
35	1.700	0.65720	829.40	571.04	607.52	347.05	33.38	24.77	16.90	40.11	12.50	88.1	-30.3	-49.1	31.7
37	1.800	0.74891	828.21	580.19	621.46	349.84	35.21	24.77	16.90	40.11	12.50	88.3	-30.3	-49.2	31.7
39	1.900	0.84700	826.92	589.48	635.56	352.69	37.04	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
41	2.000	0.95151	825.58	598.96	649.87	355.60	38.88	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
43	2.100	1.06248	824.22	608.68	664.44	358.57	40.73	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
45	2.200	1.17993	822.87	618.68	679.32	361.60	42.59	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
47	2.300	1.30388	821.57	629.01	694.57	364.68	44.46	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
49	2.400	1.43433	820.34	639.72	710.26	367.81	46.34	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
51	2.500	1.57126	819.19	650.87	726.46	370.99	48.23	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
53	2.600	1.71464	818.15	662.53	743.26	374.21	50.13	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
55	2.700	1.86441	817.24	674.78	760.76	377.47	52.04	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
57	2.800	2.02049	816.47	687.71	779.07	380.77	53.96	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
59	2.900	2.18277	815.87	701.44	798.34	384.11	55.89	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
61	3.000	2.35111	815.45	716.09	818.75	387.48	57.83	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
63	3.100	2.52534	815.23	731.83	840.52	390.88	59.78	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
65	3.200	2.70525	815.23	748.87	863.94	394.31	61.74	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
67	3.300	2.89060	815.46	767.44	889.34	397.77	63.71	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
69	3.400	3.08107	816.00	787.80	917.19	401.25	65.69	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
71	3.500	3.27631	816.92	810.27	948.05	404.76	67.68	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
73	3.600	3.47592	818.32	835.23	982.61	408.30	69.68	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
75	3.700	3.67941	820.32	863.13	1021.78	411.86	71.69	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
77	3.800	3.88624	823.08	894.52	1066.74	415.44	73.71	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
79	3.900	4.09580	826.80	929.98	1118.99	419.05	75.74	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
81	4.000	4.30741	831.71	970.21	1180.54	422.68	77.78	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
83	4.100	4.52027	838.09	1016.04	1253.36	426.33	79.83	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
85	4.200	4.73350	846.30	1069.50	1340.61	430.00	81.89	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
87	4.300	4.94605	856.80	1133.00	1446.00	433.70	83.96	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
89	4.400	5.15671	870.15	1209.61	1574.00	437.41	86.04	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
91	4.500	5.36413	887.05	1303.00	1729.00	441.14	88.13	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
93	4.600	5.56681	908.41	1417.00	1917.00	444.89	90.23	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7
94	4.650	5.66600	921.00	1482.00	2024.00	446.77	91.28	24.77	16.90	40.11	12.50	88.4	-30.4	-49.2	31.7

VM COMBUSTION STARTS AT XF = 0.1319 AND AT HEIGHT (FROM TOP) = 4.650 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.650 M

TABLE P-6 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 6 (A)

(XFV=0.15)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT
1	0.000	0.13193	0.00000	1073.5	950.4	947.3	328.2	0.0000	0.
2	0.050	0.13874	0.00000	1074.0	1090.1	965.6	328.0	0.0000	0.
3	0.100	0.14554	0.00000	1073.4	1098.1	1003.2	328.0	0.0000	0.
4	0.150	0.15235	0.00000	1072.4	1125.6	1035.9	327.9	0.0000	0.
5	0.200	0.15916	0.00000	1070.5	1148.6	1067.8	327.7	0.0000	0.
6	0.250	0.16596	0.00000	1068.7	1172.3	1097.9	327.6	0.0000	0.
7	0.300	0.17277	0.00000	1066.0	1195.0	1126.7	327.5	0.0000	0.
8	0.350	0.17958	0.00000	1062.6	1217.1	1154.2	327.3	0.0000	0.
9	0.400	0.18638	0.01596	1057.9	1234.4	1173.1	327.1	0.0000	0.
10	0.450	0.19319	0.03273	1052.6	1236.4	1173.5	326.9	0.0001	0.
11	0.500	0.20000	0.04953	1047.0	1237.3	1173.8	326.6	0.0001	1.
12	0.550	0.20785	0.06550	1042.0	1237.7	1174.1	326.3	0.0002	2.
13	0.600	0.21590	0.08255	1037.0	1240.0	1174.5	326.1	0.0003	3.
14	0.650	0.22417	0.10091	1031.7	1242.6	1174.9	325.8	0.0003	5.
15	0.700	0.23266	0.11765	1026.2	1245.5	1175.3	325.6	0.0004	7.
16	0.750	0.24135	0.13691	1020.4	1248.5	1175.8	325.3	0.0005	10.
17	0.800	0.25034	0.15591	1014.4	1251.6	1176.3	325.0	0.0006	14.
18	0.850	0.25954	0.17479	1008.0	1254.9	1176.9	324.7	0.0008	18.
19	0.900	0.26699	0.19445	1001.4	1258.3	1177.5	324.4	0.0009	23.
20	0.950	0.27670	0.21401	994.5	1261.9	1178.6	324.0	0.0011	30.
21	1.000	0.28607	0.23525	987.6	1265.5	1179.0	323.7	0.0012	37.
22	1.050	0.29590	0.25647	979.6	1269.9	1179.9	323.4	0.0014	46.
23	1.100	0.30742	0.27719	971.5	1274.1	1180.7	323.0	0.0016	57.
24	1.150	0.32021	[illegible]	963.1	1278.6	1181.7	322.6	0.0019	69.
25	1.200	0.33130	0.32022	954.3	1283.4	1182.8	322.2	0.0021	84.
26	1.250	0.34268	0.34056	944.0	1288.5	1183.9	321.8	0.0024	101.
27	1.300	0.35436	0.37045	935.2	1293.8	1185.3	321.4	0.0027	120.
28	1.350	0.36035	0.39459	924.9	1299.5	1186.7	321.0	0.0031	143.
29	1.400	0.37005	0.41959	914.1	1305.6	1188.5	320.5	0.0036	170.
30	1.450	0.39128	0.44344	902.7	1312.0	1190.0	320.0	0.0041	201.
31	1.500	0.40420	0.47153	890.7	1318.5	1191.9	319.6	0.0046	237.
32	1.550	0.41746	0.49517	876.0	1325.1	1194.0	319.0	0.0052	279.
33	1.600	0.43105	0.52036	864.7	1333.9	1196.3	318.5	0.0060	327.
34	1.650	0.44490	0.55293	850.6	1342.1	1198.9	318.0	0.0068	384.
35	1.700	0.45920	0.58114	835.3	1351.0	1201.7	317.4	0.0079	449.
36	1.750	0.47376	0.60974	820.1	1360.4	1204.6	316.8	0.0089	526.
37	1.800	0.48864	0.63876	803.5	1370.5	1208.3	316.2	0.0102	614.
38	1.850	0.50382	0.66613	786.0	1381.4	1212.1	315.6	0.0117	718.
39	1.900	0.51930	0.69750	767.6	1393.1	1216.6	314.9	0.0136	840.
40	1.950	0.53506	0.72709	746.1	1405.7	1221.3	314.2	0.0155	982.
41	2.000	0.55107	0.75771	727.6	1419.4	1226.6	313.5	0.0185	1150.
43	2.100	0.58374	0.81703	683.3	1450.5	1240.2	312.1	0.0261	1586.
45	2.200	0.61098	0.87226	634.5	1488.4	1256.4	310.5	0.0369	2225.
47	2.300	0.65027	0.93153	581.5	1537.0	1280.0	308.9	0.0550	3220.
49	2.395	0.68124	0.97719	528.0	1605.3	1339.1	307.3	0.1404	4967.
51	2.460	0.70132	1.00000	491.4	1658.7	1409.6	305.6	0.1077	6533.
53	2.520	0.71700	1.00000	467.1	1692.4	1459.6	304.7	1.0000	6533.
55	2.580	0.73021	1.00000	444.8	1724.3	1546.2	304.1	1.0000	6533.
57	2.630	0.73809	1.00000	428.5	1728.5	1581.9	303.8	1.0000	6533.
59	2.660	0.74258	1.00000	420.2	1719.4	1595.1	302.9	1.0000	6533.
61	2.690	0.74557	1.00000	412.9	1702.1	1603.5	302.8	1.0000	6533.
63	2.720	0.74772	1.00000	406.5	1677.6	1607.1	302.7	1.0000	6533.
65	2.750	0.74908	1.00000	401.1	1648.6	1606.4	302.5	1.0000	6533.
66	2.765	0.75000	1.00000	396.8	1621.4	1604.3	302.5	1.0000	6533.

I	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PC2G	PCO2G
1	107.5	24.2	18.4	40.1	12.5	156.	-414.	-516.	0.	0.043	0.262
2	135.6	24.2	18.3	40.1	12.5	9385.	54.	-443.	110.	0.046	0.261
3	144.3	24.1	18.3	40.1	12.5	7611.	83.	-266.	220.	0.048	0.261
4	156.6	24.1	18.2	40.1	12.5	7803.	175.	-145.	330.	0.050	0.260
5	168.4	24.0	18.2	40.1	12.5	7505.	259.	-12.	439.	0.052	0.259
6	180.6	23.9	18.1	40.1	12.5	7405.	345.	113.	547.	0.054	0.258
7	192.6	23.9	18.1	40.1	12.5	7314.	428.	244.	654.	0.056	0.257
8	205.0	23.8	18.0	40.1	12.5	7167.	510.	367.	761.	0.058	0.256
9	214.1	23.7	17.9	40.1	12.5	7290.	531.	480.	867.	0.061	0.254
10	215.4	23.6	17.8	40.1	12.5	7774.	609.	490.	972.	0.063	0.251
11	215.2	23.5	17.7	40.1	12.5	7592.	621.	501.	1075.	0.065	0.249
12	215.4	23.4	17.6	40.2	12.4	7525.	626.	517.	1178.	0.067	0.245
13	216.1	23.4	17.6	40.3	12.3	7699.	636.	532.	1279.	0.069	0.242
14	217.0	23.3	17.5	40.4	12.2	7904.	647.	549.	1379.	0.071	0.238
15	217.8	23.3	17.4	40.5	12.1	8112.	658.	565.	1477.	0.073	0.234
16	218.8	23.2	17.3	40.6	12.0	8325.	669.	582.	1574.	0.075	0.231
17	219.7	23.1	17.2	40.7	11.9	8544.	679.	600.	1670.	0.077	0.227
18	220.5	23.1	17.1	40.8	11.8	8765.	689.	615.	1764.	0.079	0.223
19	221.9	23.0	17.0	40.9	11.7	8995.	699.	637.	1857.	0.081	0.218
20	223.1	22.9	16.9	41.0	11.5	9233.	708.	650.	1948.	0.084	0.214
21	224.3	22.9	16.7	41.2	11.4	9471.	717.	675.	2038.	0.086	0.210
22	225.7	22.8	16.6	41.3	11.3	9719.	725.	695.	2126.	0.089	0.205
23	227.1	22.7	16.5	41.4	11.1	9969.	733.	715.	2212.	0.091	0.200
24	228.6	22.7	16.4	41.5	11.0	10225.	740.	730.	2297.	0.094	0.195
25	230.3	22.6	16.3	41.7	10.8	10485.	740.	756.	2380.	0.097	0.190
26	232.0	22.5	16.1	41.8	10.7	10749.	751.	780.	2461.	0.099	0.185
27	233.9	22.5	16.0	42.0	10.5	11017.	756.	802.	2540.	0.102	0.179
28	235.9	22.4	15.9	42.1	10.3	11288.	759.	825.	2617.	0.105	0.174
29	238.1	22.4	15.7	42.3	10.1	11562.	762.	849.	2692.	0.109	0.168
30	240.4	22.3	15.6	42.4	9.9	11837.	763.	872.	2765.	0.112	0.162
31	242.9	22.2	15.4	42.6	9.7	12112.	763.	896.	2836.	0.115	0.156
32	245.7	22.2	15.3	42.8	9.5	12387.	761.	921.	2904.	0.119	0.150
33	248.6	22.1	15.1	42.9	9.3	12662.	758.	946.	2970.	0.122	0.143
34	251.6	22.1	15.0	43.1	9.1	12929.	753.	972.	3034.	0.126	0.136
35	255.3	22.0	14.8	43.3	8.8	13192.	746.	995.	3095.	0.130	0.129
36	259.1	22.0	14.7	43.5	8.6	13444.	737.	1024.	3154.	0.133	0.122
37	263.2	22.0	14.5	43.7	8.3	13677.	726.	1051.	3210.	0.137	0.115
38	267.7	22.0	14.3	43.9	8.0	13904.	713.	1078.	3263.	0.142	0.108
39	272.7	21.9	14.2	44.1	7.7	14106.	698.	1109.	3314.	0.145	0.100
40	278.2	22.0	14.0	44.4	7.4	14287.	680.	1134.	3362.	0.150	0.092
41	284.4	22.0	13.8	44.6	7.1	14431.	650.	1162.	3407.	0.155	0.084
43	298.9	22.1	13.4	45.1	6.3	14594.	611.	1220.	3458.	0.164	0.068
45	318.0	22.4	13.1	45.5	5.5	14514.	551.	1283.	3557.	0.173	0.051
47	345.0	23.0	12.7	46.0	4.6	14073.	479.	1356.	3614.	0.183	0.035
49	390.7	24.0	12.4	46.5	3.6	11783.	363.	1315.	3658.	0.192	0.020
51	430.9	24.0	12.2	46.7	3.2	6455.	213.	951.	3687.	0.197	0.012
53	489.0	24.2	12.1	46.9	2.8	5594.	136.	1024.	3704.	0.201	0.008
55	520.9	24.4	12.0	47.0	2.3	4405.	158.	1074.	3718.	0.204	0.005
57	548.8	24.7	11.9	47.1	2.0	2207.	92.	735.	3731.	0.205	0.003
59	550.0	24.9	11.9	47.2	1.9	1315.	64.	556.	3737.	0.207	0.002
61	546.0	25.1	11.9	47.2	1.8	976.	60.	560.	3742.	0.208	0.001
63	535.3	25.4	11.8	47.2	1.7	657.	56.	562.	3747.	0.209	0.001
65	521.3	25.7	11.8	47.3	1.7	370.	54.	562.	3752.	0.209	0.000
66	521.3	25.7	11.8	47.3	1.6	147.	52.	561.	3754.	0.209	0.000

ASH FUSION STARTS AT XF = 0.6812 AT HEIGHT (FROM TOP OF BURNING ZONE) = 2.395 M

HEIGHT OF THE BURNING ZONE = 2.765 M

TABLE P.6 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 6 (A)

(XFV=0.15)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	MSG	ASCZ	QSG	DELHTL
1	0.000	398.60	1605.50	302.50	10.4	48.9	12534.3	0.0
2	0.050	393.27	1593.50	302.60	10.4	48.9	12458.7	5.6
3	0.100	387.96	1581.55	302.43	10.4	48.9	12383.2	10.9
4	0.150	382.68	1569.64	302.35	10.4	48.9	12307.9	15.8
5	0.200	377.42	1557.78	302.22	10.4	48.9	12232.8	20.5
6	0.250	372.19	1545.97	302.10	10.4	48.9	12157.8	24.9
7	0.300	366.98	1534.20	301.96	10.4	48.9	12082.9	29.0
8	0.350	361.79	1522.47	301.87	10.3	48.9	12008.2	32.8
9	0.400	356.63	1510.80	301.75	10.3	48.9	11933.7	36.3
10	0.450	351.49	1499.17	301.63	10.3	48.9	11859.2	39.5
11	0.500	346.37	1487.58	301.51	10.3	48.9	11784.9	42.4
12	0.550	341.28	1476.04	301.38	10.3	48.9	11710.7	45.0
13	0.600	336.20	1464.55	301.26	10.3	48.9	11636.6	47.3
14	0.650	331.15	1453.10	301.13	10.3	48.9	11562.5	49.3
15	0.700	326.13	1441.70	301.00	10.3	48.9	11488.6	51.1
16	0.750	321.12	1430.34	300.86	10.3	48.9	11414.8	52.6
17	0.800	316.13	1419.03	300.72	10.3	48.9	11341.0	53.8
18	0.850	311.17	1407.76	300.57	10.3	48.9	11267.3	54.7
19	0.900	306.23	1396.54	300.42	10.3	48.9	11193.6	55.3
20	0.950	301.32	1385.36	300.25	10.3	48.9	11120.0	55.6
21	1.000	296.40	1374.23	300.06	10.2	48.9	11046.4	55.7

HEIGHT OF THE COOLING ZONE=1.000M

TABLE 2.6 (B1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 6 (B)

(XFV=0.30)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELHTL
1	0.000	0.00000	748.00	300.00	300.00	318.00	4.93	25.41	19.32	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.00000	760.78	380.22	326.60	319.04	7.00	25.44	19.35	40.11	12.50	207.5	-1344.9	-1870.8	134.6
5	0.200	0.00125	773.05	403.32	353.33	319.48	8.56	25.44	19.34	40.11	12.50	237.7	-1306.4	-1808.4	273.6
7	0.300	0.00250	784.98	423.33	378.52	319.85	10.13	25.43	19.32	40.11	12.50	252.1	-1277.4	-1750.0	415.6
9	0.400	0.00375	796.53	441.55	402.47	320.21	11.72	25.42	19.31	40.11	12.50	254.3	-1253.9	-1695.6	561.5
11	0.500	0.00500	807.77	458.75	425.22	320.56	13.35	25.41	19.30	40.11	12.50	248.2	-1231.7	-1644.9	710.5
13	0.600	0.00625	818.29	504.76	446.46	320.90	15.00	25.43	19.32	40.11	12.50	500.4	-1107.7	-1591.9	862.1
15	0.700	0.00750	828.23	534.20	472.67	321.25	16.30	25.46	19.33	40.11	12.50	626.3	-1039.6	-1531.6	1015.6
17	0.800	0.00875	837.72	565.69	496.74	321.55	20.45	25.48	19.35	40.11	12.50	669.1	-998.2	-1470.0	1171.2
19	0.900	0.01000	846.84	573.74	519.99	321.85	22.57	25.50	19.36	40.11	12.50	674.1	-907.2	-1410.2	1328.2
21	1.000	0.01125	855.61	570.40	542.20	322.14	24.71	25.52	19.38	40.11	12.50	661.9	-940.2	-1353.3	1486.7
23	1.100	0.01250	864.07	606.42	563.34	322.42	26.90	25.54	19.39	40.11	12.50	663.9	-914.4	-1299.4	1646.3
25	1.200	0.01375	872.09	637.20	583.54	322.68	29.15	25.56	19.41	40.11	12.50	684.3	-886.4	-1248.6	1806.9
27	1.300	0.01500	879.87	652.14	620.93	322.94	31.44	25.58	19.42	40.11	12.50	685.7	-864.8	-1200.5	1968.3
29	1.400	0.01625	887.42	666.64	638.38	323.19	33.77	25.60	19.43	40.11	12.50	687.3	-837.6	-1155.5	2130.5
31	1.500	0.01750	894.81	677.53	654.98	323.42	36.14	25.62	19.44	40.11	12.50	680.0	-812.6	-1111.8	2293.4
33	1.600	0.01875	902.01	684.29	669.79	323.65	38.32	25.63	19.45	40.11	12.50	665.9	-799.3	-1070.8	2456.8
35	1.700	0.02000	909.04	694.35	683.86	323.86	40.15	25.63	19.45	40.11	12.50	655.5	-795.6	-1036.2	2620.7
37	1.800	0.02125	915.91	715.21	697.23	324.05	42.19	25.63	19.45	40.11	12.50	673.9	-787.5	-1009.1	2784.9
41	2.000	0.02375	928.96	715.21	722.66	324.40	46.38	25.63	19.44	40.11	12.50	679.1	-758.8	-960.2	3113.6
43	2.100	0.02500	934.54	715.71	734.88	324.56	48.51	25.63	19.43	40.11	12.50	680.1	-745.6	-937.5	3278.3
45	2.200	0.02625	940.07	730.03	746.99	324.71	50.64	25.63	19.43	40.11	12.50	697.9	-728.0	-916.0	3443.4
47	2.300	0.02750	945.45	746.12	758.99	324.86	52.77	25.62	19.42	40.11	12.50	710.2	-713.7	-895.5	3608.7
49	2.400	0.02875	950.68	755.98	770.94	325.00	54.89	25.62	19.42	40.11	12.50	690.8	-696.3	-875.9	3774.3
51	2.500	0.03000	955.81	765.61	782.97	325.11	57.02	25.62	19.41	40.11	12.50	684.3	-683.9	-857.2	4014.3
53	2.600	0.03125	960.84	775.00	794.72	325.22	59.15	25.62	19.41	40.11	12.50	676.7	-670.9	-837.2	4207.7
55	2.700	0.03250	965.78	784.15	806.15	325.32	61.28	25.61	19.41	40.11	12.50	673.4	-656.3	-819.2	4400.0
57	2.800	0.03375	970.63	793.07	817.44	325.42	63.33	25.61	19.40	40.11	12.50	668.1	-643.9	-801.7	4595.5
59	2.900	0.03500	975.39	801.75	828.72	325.51	65.43	25.61	19.40	40.11	12.50	663.1	-629.1	-784.9	4795.5
61	3.000	0.03625	980.07	810.24	839.86	325.60	67.52	25.61	19.39	40.11	12.50	664.6	-617.1	-768.4	4994.5
63	3.100	0.03750	984.68	818.90	850.99	325.68	69.60	25.61	19.39	40.11	12.50	662.1	-604.8	-752.4	5194.5
65	3.200	0.03875	989.22	827.05	861.98	325.76	71.66	25.61	19.39	40.11	12.50	658.1	-592.2	-736.5	5396.0
67	3.300	0.04000	993.69	835.00	872.85	325.83	73.71	25.61	19.38	40.11	12.50	654.2	-581.2	-721.1	5598.2
69	3.400	0.04125	998.10	842.76	883.54	325.90	75.75	25.60	19.38	40.11	12.50	650.6	-570.1	-706.1	5802.2
71	3.500	0.04250	1002.46	850.34	894.09	325.96	77.77	25.60	19.38	40.11	12.50	646.1	-559.2	-692.9	6008.2
73	3.600	0.04375	1006.76	857.74	904.52	326.02	79.77	25.60	19.37	40.11	12.50	641.9	-548.5	-679.1	6214.7
75	3.700	0.04500	1011.01	865.00	914.83	326.07	81.76	25.60	19.37	40.11	12.50	637.8	-538.0	-665.8	6422.6
77	3.800	0.04625	1015.21	872.12	925.02	326.12	83.74	25.59	19.36	40.11	12.50	633.7	-528.0	-652.9	6631.9
79	3.900	0.04750	1019.36	879.04	935.09	326.17	85.71	25.59	19.36	40.11	12.50	629.5	-518.2	-640.2	6841.5
81	4.000	0.04875	1023.46	885.84	945.04	326.21	87.67	25.59	19.36	40.11	12.50	625.5	-508.7	-627.9	7052.3
83	4.100	0.05000	1027.52	892.48	954.88	326.25	89.61	25.59	19.36	40.11	12.50	621.2	-498.7	-615.9	7264.4
85	4.200	0.05125	1031.53	898.96	964.60	326.29	91.53	25.59	19.35	40.11	12.50	617.2	-489.5	-604.2	7477.6
87	4.300	0.05250	1035.50	905.30	974.21	326.33	93.43	25.59	19.35	40.11	12.50	613.2	-480.7	-592.9	7691.9
89	4.400	0.05375	1039.42	911.49	983.72	326.36	95.32	25.59	19.35	40.11	12.50	609.2	-472.1	-581.9	7907.1
91	4.500	0.05500	1043.30	917.55	993.12	326.39	97.19	25.59	19.34	40.11	12.50	605.3	-463.5	-571.2	8123.4
93	4.600	0.05625	1047.13	923.48	1002.43	326.42	99.05	25.58	19.34	40.11	12.50	601.4	-455.1	-560.8	8340.6
95	4.700	0.05750	1050.92	929.29	1011.64	326.45	100.89	25.58	19.34	40.11	12.50	597.5	-447.1	-550.5	8558.8
97	4.800	0.05875	1054.67	934.98	1020.76	326.47	102.72	25.58	19.34	40.11	12.50	593.7	-439.2	-540.6	8777.8
99	4.900	0.06000	1058.38	940.56	1029.79	326.49	104.55	25.58	19.33	40.11	12.50	589.9	-431.7	-531.0	8997.8
101	5.000	0.06148	1062.19	940.72	1038.94	326.11	104.55	25.58	19.33	40.11	12.50	586.2	-424.0	-521.6	9219.0
102	5.050	0.21646	1067.20	948.97	947.23	326.25	107.21	24.68	18.69	40.11	12.50	584.6	-405.5	-500.8	9440.8

VM COMBUSTION STARTS AT XF = 0.2165 AND AT HEIGHT (FROM TOP) = 5.050 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 5.050 M

TABLE B.6 (B2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 6 (B)

(XFV=0.30)

RESULTS OF ANALYSIS

I	Z(M)	XF	XE	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PC26	PCO26
1	0.000	0.21046	0.00000	1067.3	946.0	947.1	328.3	0.0000	0.	107.1	24.7	18.7	40.1	12.5	103.	-406.	-501.	0.	0.065	0.223
2	0.000	0.42092	0.00000	1066.6	1126.7	1270.4	327.6	0.0000	0.	144.4	24.6	18.6	40.1	12.5	1276.	-216.	-369.	110.	0.065	0.221
3	0.100	0.42092	0.00000	1066.1	1111.1	1017.4	327.1	0.0000	0.	151.1	24.5	18.5	40.1	12.5	846.	184.	-193.	220.	0.065	0.219
4	0.150	0.63138	0.00000	1065.1	1153.1	1035.1	326.1	0.0000	0.	107.5	24.4	18.4	40.1	12.5	774.	332.	-27.	335.	0.065	0.218
5	0.200	0.63138	0.00000	1065.2	1182.5	1035.1	326.2	0.0000	0.	151.0	24.4	18.3	40.1	12.5	696.	415.	142.	435.	0.065	0.216
6	0.250	0.84184	0.00000	1065.6	1160.6	1156.6	326.6	0.0000	0.	151.1	24.4	18.1	40.1	12.5	655.	521.	301.	540.	0.065	0.215
7	0.300	0.84184	0.00000	1067.1	1185.1	1159.6	327.0	0.0000	0.	210.6	24.4	18.0	40.1	12.5	606.	620.	451.	646.	0.065	0.214
8	0.350	1.05230	0.00000	1065.5	1246.6	1175.7	326.5	0.0000	0.	217.7	24.6	17.7	40.1	12.5	557.	683.	562.	746.	0.065	0.213
9	0.400	1.05230	0.00000	1065.5	1247.1	1174.1	326.5	0.0000	0.	217.7	24.6	17.7	40.1	12.5	508.	709.	562.	846.	0.065	0.212
10	0.450	1.26276	0.00000	1065.4	1247.1	1174.1	326.4	0.0000	0.	217.7	24.6	17.6	40.1	12.5	459.	730.	594.	944.	0.065	0.211
11	0.500	1.26276	0.00000	1065.2	1247.4	1174.4	326.2	0.0000	0.	217.7	24.6	17.6	40.1	12.5	410.	753.	622.	1043.	0.065	0.211
12	0.550	1.47322	0.00000	1064.4	1247.4	1175.4	325.4	0.0000	0.	217.7	24.6	17.5	40.1	12.5	361.	774.	644.	1143.	0.065	0.210
13	0.600	1.47322	0.00000	1064.0	1247.7	1177.7	325.0	0.0000	0.	217.7	24.6	17.3	40.1	12.5	312.	794.	669.	1243.	0.065	0.209
14	0.650	1.68368	0.00000	1063.9	1247.7	1176.1	324.9	0.0000	0.	217.7	24.6	17.1	40.1	12.5	263.	834.	690.	1344.	0.065	0.208
15	0.700	1.68368	0.00000	1063.9	1294.7	1179.7	324.9	0.0000	0.	217.7	24.6	16.9	40.1	12.5	214.	846.	714.	1401.	0.065	0.207
16	0.750	1.89414	0.00000	1063.9	1301.1	1181.1	324.9	0.0000	0.	217.7	24.6	16.8	40.1	12.5	165.	845.	737.	1456.	0.065	0.206
17	0.800	1.89414	0.00000	1063.2	1300.7	1182.7	324.2	0.0000	0.	217.7	24.6	16.6	40.1	12.5	116.	841.	760.	1568.	0.065	0.205
18	0.850	2.10460	0.00000	1062.7	1310.4	1184.4	323.7	0.0000	0.	217.7	24.6	16.4	40.1	12.5	67.	834.	783.	1625.	0.065	0.204
19	0.900	2.10460	0.00000	1062.4	1322.4	1185.0	323.4	0.0000	0.	217.7	24.6	16.2	41.7	10.8	18.	825.	805.	1682.	0.065	0.203
20	0.950	2.31506	0.00000	1062.4	1335.4	1186.4	323.4	0.0000	0.	217.7	24.6	16.0	42.3	10.5	1969.	816.	828.	1800.	0.065	0.202
21	1.000	2.31506	0.41000	1062.7	1356.6	1193.1	323.7	0.0000	0.	217.7	24.6	15.8	42.3	10.1	1920.	797.	851.	1858.	0.065	0.201
22	1.050	2.52552	0.41001	1063.1	1356.6	1195.7	324.1	0.0000	0.	217.7	24.6	15.7	42.3	9.8	1871.	779.	872.	1916.	0.065	0.200
23	1.100	2.52552	0.41001	1063.1	1375.6	1196.6	324.1	0.0000	0.	217.7	24.6	15.5	43.0	9.4	1822.	757.	893.	1975.	0.065	0.199
24	1.150	2.73598	0.41001	1063.1	1387.9	1201.7	324.1	0.0000	0.	217.7	24.6	15.3	43.1	9.1	1773.	732.	914.	2034.	0.065	0.198
25	1.200	2.73598	0.41001	1063.0	1401.7	1205.0	324.0	0.0000	0.	217.7	24.6	15.1	43.4	8.7	1724.	703.	933.	2093.	0.065	0.197
26	1.250	2.94644	0.41001	1062.9	1414.0	1206.0	323.9	0.0000	0.	217.7	24.6	14.9	43.8	8.2	1675.	671.	951.	2153.	0.065	0.196
27	1.300	2.94644	0.41001	1062.9	1414.0	1206.0	323.9	0.0000	0.	217.7	24.6	14.7	44.1	7.8	1626.	634.	968.	2213.	0.065	0.195
28	1.350	3.15690	0.41001	1062.9	1412.6	1210.1	323.9	0.0000	0.	217.7	24.6	14.4	44.4	7.3	1577.	595.	984.	2273.	0.065	0.194
29	1.400	3.15690	0.41001	1062.9	1431.4	1211.1	323.9	0.0000	0.	217.7	24.6	14.2	44.8	6.8	1528.	551.	998.	2334.	0.065	0.193
30	1.450	3.36736	0.41001	1062.9	1451.4	1212.1	323.9	0.0000	0.	217.7	24.6	14.0	45.1	6.2	1479.	504.	1010.	2394.	0.065	0.192
31	1.500	3.36736	0.41001	1062.9	1471.7	1213.0	323.9	0.0000	0.	217.7	24.6	13.8	45.5	5.6	1430.	454.	1017.	2454.	0.065	0.191
32	1.550	3.57782	0.41001	1062.9	1491.7	1213.0	323.9	0.0000	0.	217.7	24.6	13.6	45.8	5.1	1381.	414.	1023.	2514.	0.065	0.190
33	1.600	3.57782	0.41001	1062.9	1512.7	1213.0	323.9	0.0000	0.	217.7	24.6	13.5	46.1	4.6	1332.	374.	1028.	2574.	0.065	0.189
34	1.650	3.78828	0.41001	1062.9	1532.6	1213.0	323.9	0.0000	0.	217.7	24.6	13.4	46.3	4.1	1283.	334.	1032.	2634.	0.065	0.188
35	1.700	3.78828	0.41001	1062.9	1552.6	1213.0	323.9	0.0000	0.	217.7	24.6	13.2	46.5	3.6	1234.	294.	1036.	2694.	0.065	0.187
36	1.750	3.99874	0.41001	1062.9	1572.6	1213.0	323.9	0.0000	0.	217.7	24.6	13.1	46.7	3.1	1185.	255.	1039.	2754.	0.065	0.186
37	1.800	3.99874	0.41001	1062.9	1592.6	1213.0	323.9	0.0000	0.	217.7	24.6	13.0	46.8	2.6	1136.	215.	1041.	2814.	0.065	0.185
38	1.850	4.20920	0.41001	1062.9	1612.6	1213.0	323.9	0.0000	0.	217.7	24.6	13.0	46.9	2.1	1087.	175.	1043.	2874.	0.065	0.184
39	1.900	4.20920	0.41001	1062.9	1632.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.9	46.9	1.6	1038.	136.	1044.	2934.	0.065	0.183
40	1.950	4.41966	0.41001	1062.9	1652.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.9	47.0	1.1	989.	96.	1045.	2994.	0.065	0.182
41	1.970	4.41966	0.41001	1062.9	1672.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.6	940.	57.	1045.	3054.	0.065	0.181
42	1.990	4.41966	0.41001	1062.9	1692.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.1	891.	17.	1045.	3114.	0.065	0.180
43	2.010	4.41966	0.41001	1062.9	1712.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.0	842.	-22.	1045.	3174.	0.065	0.179
44	2.030	4.41966	0.41001	1062.9	1732.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.0	793.	-62.	1045.	3234.	0.065	0.178
45	2.050	4.41966	0.41001	1062.9	1752.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.0	744.	-102.	1045.	3294.	0.065	0.177
46	2.070	4.41966	0.41001	1062.9	1772.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.0	695.	-142.	1045.	3354.	0.065	0.176
47	2.090	4.41966	0.41001	1062.9	1792.6	1213.0	323.9	0.0000	0.	217.7	24.6	12.8	47.0	0.0	646.	-182.	1045.	3414.	0.065	0.175

ASH FUSION STARTS AT XF = 0.7101 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.635 M

HEIGHT OF THE BURNING ZONE = 1.890 M

TABLE F.6 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 6 (B)

(XFV=0.30)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	621.10	1176.70	307.00	11.0	49.1	6123.0	0.0
5	0.200	611.84	1155.90	306.83	11.0	49.1	5971.4	76.5
9	0.400	602.80	1133.51	306.67	11.0	49.1	5822.1	150.7
13	0.600	593.98	1111.53	306.52	11.0	49.1	5675.2	222.8
17	0.800	585.36	1089.96	306.36	11.0	49.1	5530.9	292.7
21	1.000	576.96	1068.79	306.21	11.0	49.1	5388.3	360.6
25	1.200	568.76	1048.03	306.06	11.0	49.1	5246.3	426.5
29	1.400	560.78	1027.67	305.92	10.9	49.1	5110.9	490.4
33	1.600	553.01	1007.70	305.78	10.9	49.1	4975.2	552.4
37	1.800	545.37	988.14	305.64	10.9	49.1	4842.1	612.6
41	2.000	537.97	968.96	305.50	10.9	49.1	4711.3	670.9
45	2.200	530.75	950.18	305.36	10.9	49.1	4582.8	727.5
49	2.400	523.73	931.78	305.23	10.9	49.1	4456.7	782.3
53	2.600	516.89	913.77	305.11	10.9	49.1	4332.8	835.4
57	2.800	510.23	896.14	304.98	10.9	49.1	4211.2	886.9
61	3.000	503.76	878.88	304.85	10.9	49.1	4092.0	936.9
65	3.200	497.45	862.01	304.73	10.9	49.1	3975.0	985.2
69	3.400	491.33	845.50	304.61	10.9	49.1	3860.2	1032.1
73	3.600	485.37	829.37	304.50	10.9	49.1	3747.8	1077.5
77	3.800	479.58	813.60	304.39	10.9	49.1	3637.6	1121.5
81	4.000	473.95	798.19	304.28	10.9	49.1	3529.7	1164.1
85	4.200	468.49	783.14	304.17	10.9	49.1	3424.1	1205.4
89	4.400	463.18	768.45	304.06	10.9	49.1	3320.7	1245.3
93	4.600	458.02	754.10	303.96	10.9	49.1	3219.5	1284.0
97	4.800	453.02	740.11	303.86	10.9	49.1	3120.5	1321.5
101	5.000	448.17	726.46	303.76	10.9	49.1	3023.8	1357.8
105	5.200	443.46	713.14	303.66	10.9	49.1	2929.2	1392.9
109	5.400	438.90	700.17	303.57	10.9	49.1	2836.8	1426.9
113	5.600	434.47	687.52	303.48	10.9	49.1	2746.5	1459.8
117	5.800	430.18	675.20	303.39	10.9	49.1	2658.4	1491.6
121	6.000	426.02	663.20	303.30	10.8	49.1	2572.5	1522.4
125	6.200	422.00	651.52	303.21	10.8	49.1	2488.6	1552.3
129	6.400	418.11	640.15	303.13	10.8	49.1	2406.8	1581.2
133	6.600	414.34	629.09	303.05	10.8	49.1	2327.0	1609.1
137	6.800	410.68	618.34	302.97	10.8	49.1	2249.3	1636.2
141	7.000	407.15	607.88	302.90	10.8	49.1	2173.6	1662.4
145	7.200	403.73	597.72	302.82	10.8	49.1	2099.9	1687.7
149	7.400	400.43	587.85	302.75	10.8	49.1	2028.2	1712.2
153	7.600	397.23	578.26	302.68	10.8	49.1	1958.4	1736.0
157	7.800	394.14	568.94	302.61	10.8	49.1	1890.5	1759.0
161	8.000	391.16	559.91	302.54	10.8	49.1	1824.5	1781.2
165	8.200	388.28	551.14	302.48	10.8	49.1	1760.4	1802.8
169	8.400	385.50	542.63	302.41	10.8	49.1	1698.0	1823.6
173	8.600	382.81	534.39	302.35	10.8	49.1	1637.5	1843.8
177	8.800	380.22	526.39	302.29	10.8	49.1	1578.7	1863.4
181	9.000	377.72	518.65	302.24	10.8	49.1	1521.7	1882.4
185	9.200	375.30	511.14	302.18	10.8	49.1	1466.3	1900.7
189	9.400	372.97	503.88	302.13	10.8	49.1	1412.7	1918.5
193	9.600	370.73	496.84	302.07	10.8	49.1	1360.6	1935.7
197	9.800	368.57	490.03	302.02	10.8	49.1	1310.2	1952.4
201	10.000	366.48	483.45	301.97	10.8	49.1	1261.4	1968.6
205	10.200	364.47	477.08	301.92	10.8	49.1	1214.1	1984.3
209	10.400	362.54	470.92	301.88	10.8	49.1	1168.3	1999.5
213	10.600	360.67	464.97	301.83	10.8	49.1	1124.0	2014.3
217	10.800	358.88	459.21	301.79	10.8	49.1	1081.1	2028.6
221	11.000	357.15	453.66	301.75	10.8	49.1	1039.6	2042.5
229	11.400	353.89	443.11	301.66	10.8	49.1	960.8	2069.1
237	11.800	350.87	433.29	301.59	10.8	49.1	887.2	2094.2
245	12.200	348.08	424.15	301.52	10.8	49.1	818.6	2117.8
250	12.450	346.45	418.77	301.48	10.8	49.1	778.1	2131.9

WEIGHT OF THE COOLING ZONE=******M

TABLE P.7 (A)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 7 (A)

(XEA=0.00)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELNTL
1	0.000	0.000000	746.00	300.00	300.00	316.00	4.93	24.23	18.49	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.000000	761.74	376.98	345.70	318.79	6.90	24.26	18.51	40.11	12.50	196.7	-1296.9	-1798.0	1384.8
5	0.200	0.001255	775.07	348.32	351.24	319.23	8.47	24.25	18.50	40.11	12.50	251.6	-1269.2	-1747.8	2608.5
7	0.300	0.002509	786.03	417.29	375.58	319.63	10.35	24.24	18.48	40.11	12.50	293.7	-1233.1	-1693.9	4009.2
9	0.400	0.003764	796.07	434.92	398.78	320.01	11.84	24.23	18.47	40.11	12.50	328.7	-1215.0	-1653.9	5399.6
11	0.500	0.005018	804.62	451.86	420.93	320.37	13.27	24.22	18.45	40.11	12.50	358.2	-1181.1	-1611.8	6799.2
13	0.600	0.006273	812.82	467.71	443.00	320.74	15.81	24.25	18.47	40.11	12.50	384.5	-1101.1	-1561.8	8199.6
15	0.700	0.007527	820.80	482.75	464.11	321.10	18.05	24.27	18.49	40.11	12.50	408.5	-1038.1	-1516.8	9599.9
17	0.800	0.008782	828.64	497.26	484.32	321.44	20.20	24.30	18.51	40.11	12.50	430.7	-1000.0	-1468.8	11000.3
19	0.900	0.010036	836.38	511.36	503.77	321.77	22.30	24.32	18.52	40.11	12.50	451.4	-946.1	-1424.8	12400.6
21	1.000	0.011291	844.05	525.13	522.56	322.09	24.43	24.35	18.54	40.11	12.50	470.8	-907.1	-1378.8	13801.0
23	1.100	0.012545	851.66	538.63	540.66	322.39	26.61	24.37	18.56	40.11	12.50	489.2	-864.1	-1336.8	15201.3
25	1.200	0.013800	859.23	551.91	558.10	322.69	28.86	24.39	18.57	40.11	12.50	506.8	-827.1	-1294.8	16601.7
27	1.300	0.015054	866.77	565.01	575.50	322.98	31.17	24.41	18.59	40.11	12.50	523.7	-795.2	-1251.8	18002.0
29	1.400	0.016309	874.29	577.96	592.96	323.25	33.53	24.43	18.60	40.11	12.50	540.1	-767.2	-1210.8	19402.4
31	1.500	0.017563	881.79	590.78	610.72	323.52	35.95	24.45	18.62	40.11	12.50	556.0	-739.2	-1168.8	20802.7
33	1.600	0.018818	889.28	603.49	628.04	323.77	38.40	24.48	18.63	40.11	12.50	571.5	-711.2	-1126.8	22203.1
35	1.700	0.020072	896.76	616.10	644.80	324.02	40.90	24.49	18.63	40.11	12.50	586.7	-684.2	-1085.8	23603.4
37	1.800	0.021327	904.23	628.62	661.89	324.26	42.57	24.49	18.63	40.11	12.50	601.6	-657.2	-1044.8	25003.8
39	1.900	0.022581	911.68	641.06	678.36	324.49	44.84	24.49	18.63	40.11	12.50	616.2	-630.2	-1003.8	26404.1
41	2.000	0.023836	919.13	653.44	695.31	324.72	47.12	24.49	18.63	40.11	12.50	630.6	-603.3	-962.8	27804.5
43	2.100	0.025090	926.57	665.75	711.78	324.94	49.45	24.49	18.63	40.11	12.50	644.8	-576.3	-921.8	29204.8
45	2.200	0.026345	934.00	678.00	728.06	325.15	51.78	24.49	18.63	40.11	12.50	658.8	-549.3	-880.8	30605.2
47	2.300	0.027599	941.42	690.20	744.27	325.36	54.13	24.49	18.62	40.11	12.50	672.7	-522.3	-839.8	32005.5
49	2.400	0.028854	948.84	702.35	760.59	325.56	56.48	24.49	18.62	40.11	12.50	686.5	-495.4	-798.8	33405.9
51	2.500	0.030108	956.25	714.45	776.84	325.76	58.86	24.49	18.62	40.11	12.50	700.2	-468.4	-757.8	34806.2
53	2.600	0.031363	963.65	726.51	793.03	325.95	61.23	24.49	18.61	40.11	12.50	713.8	-441.4	-716.8	36206.6
55	2.700	0.032617	971.06	738.53	809.25	326.14	63.63	24.49	18.61	40.11	12.50	727.3	-414.4	-675.8	37606.9
57	2.800	0.033872	978.46	750.51	825.47	326.33	65.96	24.50	18.61	40.11	12.50	740.8	-387.5	-634.8	39007.3
59	2.900	0.035126	985.86	762.46	841.72	326.51	68.33	24.50	18.60	40.11	12.50	754.2	-360.5	-593.8	40407.6
61	3.000	0.036381	993.26	774.38	857.98	326.68	70.69	24.50	18.60	40.11	12.50	767.5	-333.5	-552.8	41808.0
63	3.100	0.037635	1000.66	786.27	874.26	326.86	73.04	24.50	18.60	40.11	12.50	780.8	-306.5	-511.8	43208.3
65	3.200	0.038890	1008.06	798.14	890.56	327.03	75.39	24.50	18.60	40.11	12.50	794.0	-279.6	-470.8	44608.7
67	3.300	0.040144	1015.46	809.98	906.87	327.20	77.74	24.50	18.60	40.11	12.50	807.2	-252.6	-429.8	46009.0
69	3.400	0.041399	1022.86	821.80	923.20	327.36	80.08	24.50	18.60	40.11	12.50	820.3	-225.6	-388.8	47409.4
71	3.500	0.042653	1030.26	833.60	939.55	327.52	82.41	24.50	18.59	40.11	12.50	833.4	-198.6	-347.8	48809.7
73	3.600	0.043908	1037.66	845.38	955.91	327.68	84.73	24.50	18.59	40.11	12.50	846.4	-171.7	-306.8	50210.1
75	3.700	0.045162	1045.06	857.14	972.29	327.84	87.04	24.50	18.59	40.11	12.50	859.4	-144.7	-265.8	51610.4
77	3.800	0.046417	1052.46	868.89	988.69	327.99	89.34	24.50	18.59	40.11	12.50	872.3	-117.7	-224.8	53010.8
79	3.900	0.047671	1059.86	880.62	1005.10	328.14	91.63	24.50	18.59	40.11	12.50	885.2	-90.7	-183.8	54411.1
81	4.000	0.048926	1067.26	892.34	1021.52	328.29	93.91	24.50	18.58	40.11	12.50	898.1	-63.8	-142.8	55811.5
83	4.100	0.050180	1074.66	904.05	1037.96	328.44	96.19	24.50	18.58	40.11	12.50	910.9	-36.8	-101.8	57211.8
85	4.200	0.051435	1082.06	915.74	1054.41	328.58	98.47	24.50	18.58	40.11	12.50	923.7	-9.8	-60.8	58612.2
87	4.300	0.052689	1089.46	927.42	1070.87	328.72	100.74	24.50	18.58	40.11	12.50	936.5	17.2	-19.8	60012.5
89	4.400	0.053944	1096.86	939.09	1087.34	328.86	103.00	24.50	18.58	40.11	12.50	949.2	44.2	21.2	61412.9
91	4.500	0.055198	1104.26	950.75	1103.83	329.00	105.26	24.50	18.57	40.11	12.50	961.9	71.2	62.2	62813.2
93	4.600	0.056453	1111.66	962.40	1120.33	329.13	107.52	24.50	18.57	40.11	12.50	974.6	98.2	103.2	64213.6

VM COMBUSTION STARTS AT XF = 0.1722 AND AT HEIGHT (FROM TOP) = 4.600 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.600 M

TABLE F.7 (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 7 (4)
(XEA=0.00)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TL(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFS	QSG	DELHTL	PC2S	PCO2S
1	0.000	0.17217	0.00200	1063.8	949.6	947.0	326.9	0.0000		107.1	23.7	18.0	40.1	12.5	158.	-76.	-55.	0.	0.	29.
2	0.025	0.18455	0.00200	1063.1	1126.7	970.6	326.4	0.0000		143.7	23.7	17.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
3	0.100	0.19774	0.00200	1062.0	1125.0	1017.5	326.3	0.0000		152.3	23.7	17.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
4	0.150	0.21183	0.00200	1060.9	1124.1	1055.1	326.1	0.0000		165.7	23.7	17.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
5	0.200	0.22693	0.00200	1059.8	1123.1	1081.1	325.9	0.0000		193.0	23.7	17.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
6	0.250	0.24306	0.00200	1058.7	1122.1	1101.1	325.7	0.0000		213.7	23.7	17.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.
7	0.300	0.26021	0.00200	1057.6	1121.1	1117.1	325.5	0.0000		218.6	23.7	17.4	40.1	12.5	1257.	101.	-54.	124.	0.	29.
8	0.350	0.27841	0.00200	1056.5	1120.1	1132.7	325.3	0.0000		219.2	23.7	17.3	40.1	12.5	1257.	101.	-54.	124.	0.	29.
9	0.400	0.29766	0.00200	1055.4	1119.1	1147.7	325.1	0.0000		219.7	23.7	17.2	40.1	12.5	1257.	101.	-54.	124.	0.	29.
10	0.450	0.31797	0.00200	1054.3	1118.1	1162.7	324.9	0.0000		219.7	23.7	17.1	40.1	12.5	1257.	101.	-54.	124.	0.	29.
11	0.500	0.33933	0.00200	1053.2	1117.1	1173.7	324.7	0.0000		219.7	23.7	17.0	40.1	12.5	1257.	101.	-54.	124.	0.	29.
12	0.550	0.36175	0.00200	1052.1	1116.1	1179.7	324.5	0.0000		217.2	23.7	16.9	40.1	12.5	1257.	101.	-54.	124.	0.	29.
13	0.600	0.38525	0.00200	1051.1	1115.1	1184.7	324.3	0.0000		214.7	23.7	16.8	40.1	12.5	1257.	101.	-54.	124.	0.	29.
14	0.650	0.40986	0.00200	1050.0	1114.1	1188.7	324.1	0.0000		211.7	23.7	16.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
15	0.700	0.43560	0.00200	1048.9	1113.1	1192.7	323.9	0.0000		208.2	23.7	16.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
16	0.750	0.46250	0.00200	1047.8	1112.1	1195.7	323.7	0.0000		204.2	23.7	16.6	40.1	12.5	1257.	101.	-54.	124.	0.	29.
17	0.800	0.49060	0.00200	1046.7	1111.1	1198.7	323.5	0.0000		199.7	23.7	16.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.
18	0.850	0.52000	0.00200	1045.6	1110.1	1201.7	323.3	0.0000		194.7	23.7	16.4	40.1	12.5	1257.	101.	-54.	124.	0.	29.
19	0.900	0.55071	0.00200	1044.5	1109.1	1204.7	323.1	0.0000		189.2	23.7	16.3	40.1	12.5	1257.	101.	-54.	124.	0.	29.
20	0.950	0.58277	0.00200	1043.4	1108.1	1207.7	322.9	0.0000		183.2	23.7	16.2	40.1	12.5	1257.	101.	-54.	124.	0.	29.
21	1.000	0.61614	0.00200	1042.3	1107.1	1210.7	322.7	0.0000		176.7	23.7	16.1	40.1	12.5	1257.	101.	-54.	124.	0.	29.
22	1.050	0.65087	0.00200	1041.2	1106.1	1213.7	322.5	0.0000		169.7	23.7	16.0	40.1	12.5	1257.	101.	-54.	124.	0.	29.
23	1.100	0.68707	0.00200	1040.1	1105.1	1216.7	322.3	0.0000		162.2	23.7	15.9	40.1	12.5	1257.	101.	-54.	124.	0.	29.
24	1.150	0.72477	0.00200	1039.0	1104.1	1219.7	322.1	0.0000		154.2	23.7	15.8	40.1	12.5	1257.	101.	-54.	124.	0.	29.
25	1.200	0.76500	0.00200	1037.9	1103.1	1222.7	321.9	0.0000		145.7	23.7	15.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
26	1.250	0.80777	0.00200	1036.8	1102.1	1225.7	321.7	0.0000		136.7	23.7	15.6	40.1	12.5	1257.	101.	-54.	124.	0.	29.
27	1.300	0.85317	0.00200	1035.7	1101.1	1228.7	321.5	0.0000		127.2	23.7	15.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.
28	1.350	0.90126	0.00200	1034.6	1100.1	1231.7	321.3	0.0000		117.2	23.7	15.4	40.1	12.5	1257.	101.	-54.	124.	0.	29.
29	1.400	0.95214	0.00200	1033.5	1099.1	1234.7	321.1	0.0000		106.7	23.7	15.3	40.1	12.5	1257.	101.	-54.	124.	0.	29.
30	1.450	0.00000	0.00200	1032.4	1098.1	1237.7	320.9	0.0000		95.7	23.7	15.2	40.1	12.5	1257.	101.	-54.	124.	0.	29.
31	1.500	0.00000	0.00200	1031.3	1097.1	1240.7	320.7	0.0000		84.2	23.7	15.1	40.1	12.5	1257.	101.	-54.	124.	0.	29.
32	1.550	0.00000	0.00200	1030.2	1096.1	1243.7	320.5	0.0000		72.2	23.7	15.0	40.1	12.5	1257.	101.	-54.	124.	0.	29.
33	1.600	0.00000	0.00200	1029.1	1095.1	1246.7	320.3	0.0000		59.7	23.7	14.9	40.1	12.5	1257.	101.	-54.	124.	0.	29.
34	1.650	0.00000	0.00200	1028.0	1094.1	1249.7	320.1	0.0000		46.7	23.7	14.8	40.1	12.5	1257.	101.	-54.	124.	0.	29.
35	1.700	0.00000	0.00200	1026.9	1093.1	1252.7	319.9	0.0000		33.2	23.7	14.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
36	1.750	0.00000	0.00200	1025.8	1092.1	1255.7	319.7	0.0000		19.2	23.7	14.6	40.1	12.5	1257.	101.	-54.	124.	0.	29.
37	1.800	0.00000	0.00200	1024.7	1091.1	1258.7	319.5	0.0000		4.7	23.7	14.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.
38	1.850	0.00000	0.00200	1023.6	1090.1	1261.7	319.3	0.0000		0.0	23.7	14.4	40.1	12.5	1257.	101.	-54.	124.	0.	29.
39	1.900	0.00000	0.00200	1022.5	1089.1	1264.7	319.1	0.0000		0.0	23.7	14.3	40.1	12.5	1257.	101.	-54.	124.	0.	29.
40	1.950	0.00000	0.00200	1021.4	1088.1	1267.7	318.9	0.0000		0.0	23.7	14.2	40.1	12.5	1257.	101.	-54.	124.	0.	29.
41	2.000	0.00000	0.00200	1020.3	1087.1	1270.7	318.7	0.0000		0.0	23.7	14.1	40.1	12.5	1257.	101.	-54.	124.	0.	29.
42	2.050	0.00000	0.00200	1019.2	1086.1	1273.7	318.5	0.0000		0.0	23.7	14.0	40.1	12.5	1257.	101.	-54.	124.	0.	29.
43	2.100	0.00000	0.00200	1018.1	1085.1	1276.7	318.3	0.0000		0.0	23.7	13.9	40.1	12.5	1257.	101.	-54.	124.	0.	29.
44	2.150	0.00000	0.00200	1017.0	1084.1	1279.7	318.1	0.0000		0.0	23.7	13.8	40.1	12.5	1257.	101.	-54.	124.	0.	29.
45	2.200	0.00000	0.00200	1015.9	1083.1	1282.7	317.9	0.0000		0.0	23.7	13.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
46	2.250	0.00000	0.00200	1014.8	1082.1	1285.7	317.7	0.0000		0.0	23.7	13.6	40.1	12.5	1257.	101.	-54.	124.	0.	29.
47	2.300	0.00000	0.00200	1013.7	1081.1	1288.7	317.5	0.0000		0.0	23.7	13.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.
48	2.350	0.00000	0.00200	1012.6	1080.1	1291.7	317.3	0.0000		0.0	23.7	13.4	40.1	12.5	1257.	101.	-54.	124.	0.	29.
49	2.400	0.00000	0.00200	1011.5	1079.1	1294.7	317.1	0.0000		0.0	23.7	13.3	40.1	12.5	1257.	101.	-54.	124.	0.	29.
50	2.450	0.00000	0.00200	1010.4	1078.1	1297.7	316.9	0.0000		0.0	23.7	13.2	40.1	12.5	1257.	101.	-54.	124.	0.	29.
51	2.500	0.00000	0.00200	1009.3	1077.1	1300.7	316.7	0.0000		0.0	23.7	13.1	40.1	12.5	1257.	101.	-54.	124.	0.	29.
52	2.550	0.00000	0.00200	1008.2	1076.1	1303.7	316.5	0.0000		0.0	23.7	13.0	40.1	12.5	1257.	101.	-54.	124.	0.	29.
53	2.600	0.00000	0.00200	1007.1	1075.1	1306.7	316.3	0.0000		0.0	23.7	12.9	40.1	12.5	1257.	101.	-54.	124.	0.	29.
54	2.650	0.00000	0.00200	1006.0	1074.1	1309.7	316.1	0.0000		0.0	23.7	12.8	40.1	12.5	1257.	101.	-54.	124.	0.	29.
55	2.700	0.00000	0.00200	1004.9	1073.1	1312.7	315.9	0.0000		0.0	23.7	12.7	40.1	12.5	1257.	101.	-54.	124.	0.	29.
56	2.750	0.00000	0.00200	1003.8	1072.1	1315.7	315.7	0.0000		0.0	23.7	12.6	40.1	12.5	1257.	101.	-54.	124.	0.	29.
57	2.800	0.00000	0.00200	1002.7	1071.1	1318.7	315.5	0.0000		0.0	23.7	12.5	40.1	12.5	1257.	101.	-54.	124.	0.	29.

ASH FUSION STARTS AT XF = 0.6964 AT HEIGHT (FROM TOP OF BURNING ZONE) = 2.080 M

HEIGHT OF THE BURNING ZONE = 2.400 M

TABLE B.7 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 7 (A)

(XEA=0.00)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	Tw(K)	HSG	ASCZ	QSG	DELMTL
1	0.0	485.70	1243.20	304.20	10.1	49.2	7646.2	0.0
2	[illegible]	[illegible]	1235.23	304.11	10.1	49.2	7599.0	10.1
3	[illegible]	[illegible]	1227.36	304.05	10.1	49.2	7551.8	19.9
4	[illegible]	[illegible]	1219.39	303.99	10.1	49.2	7504.9	29.6
5	[illegible]	471.55	1211.51	303.93	10.1	49.2	7458.1	39.1
6	[illegible]	468.56	1203.67	303.87	10.1	49.2	7411.4	48.4
7	[illegible]	[illegible]	1195.66	303.81	10.1	49.2	7364.9	57.5
8	[illegible]	[illegible]	1188.09	303.74	10.1	49.2	7318.5	66.4
9	[illegible]	[illegible]	1180.34	303.68	10.1	49.2	7272.3	75.2
10	[illegible]	[illegible]	1172.63	303.62	10.1	49.2	7226.2	83.8
11	[illegible]	1.90	1164.95	303.56	10.1	49.2	7180.2	92.2
12	[illegible]	[illegible]	1157.30	303.50	10.1	49.2	7134.4	100.4
13	[illegible]	[illegible]	1149.68	303.44	10.1	49.2	7088.8	108.4
14	[illegible]	[illegible]	1142.10	303.38	10.1	49.2	7043.2	116.3
15	[illegible]	[illegible]	1134.55	303.32	10.1	49.2	6997.9	124.0
16	[illegible]	[illegible]	1127.03	303.26	10.1	49.2	6952.7	131.5
17	[illegible]	[illegible]	1119.54	303.20	10.1	49.2	6907.6	138.8
18	[illegible]	[illegible]	1112.08	303.13	10.1	49.2	6862.6	146.0
19	[illegible]	[illegible]	1104.66	303.07	10.0	49.2	6817.9	153.0
20	[illegible]	[illegible]	1097.26	303.01	10.0	49.2	6773.2	159.8
21	[illegible]	419.97	1089.90	302.95	10.0	49.2	6728.7	166.4
22	[illegible]	416.88	1082.57	302.89	10.0	49.2	6684.4	172.9
23	[illegible]	[illegible]	1075.27	302.83	10.0	49.2	6640.1	179.2
24	[illegible]	410.75	1068.01	302.77	10.0	49.2	6596.1	185.4
25	[illegible]	407.71	1060.77	302.71	10.0	49.2	6552.2	191.3
26	[illegible]	404.69	1053.57	302.65	10.0	49.2	6508.4	197.2
27	[illegible]	401.69	1046.40	302.59	10.0	49.2	6464.8	202.8
28	[illegible]	398.71	1039.26	302.53	10.0	49.2	6421.3	208.3
29	[illegible]	395.74	1032.15	302.47	10.0	49.2	6377.9	213.6
30	[illegible]	392.80	1025.07	302.41	10.0	49.2	6334.8	218.8
31	[illegible]	389.87	1018.02	302.35	10.0	49.2	6291.7	223.8
32	[illegible]	386.96	1011.01	302.29	10.0	49.2	6248.8	228.7
33	[illegible]	384.06	1004.03	302.23	10.0	49.2	6206.1	233.3
34	[illegible]	381.18	997.07	302.17	10.0	49.2	6163.5	237.9
35	[illegible]	378.33	990.15	302.11	10.0	49.2	6121.0	242.3
36	[illegible]	375.48	983.27	302.05	10.0	49.2	6078.7	246.5
37	[illegible]	372.66	976.41	301.99	10.0	49.2	6036.5	250.5
38	[illegible]	369.85	969.58	301.93	10.0	49.2	5994.5	254.5
39	[illegible]	367.06	962.79	301.87	10.0	49.2	5952.6	258.2
40	1.950	364.29	956.02	301.81	10.0	49.2	5910.9	261.8
43	2.100	356.07	935.92	301.63	10.0	49.2	5786.6	271.8
45	2.200	350.68	922.67	301.50	10.0	49.2	5704.5	277.7
47	2.300	345.36	909.55	301.38	10.0	49.2	5623.0	283.0
49	2.400	340.10	896.55	301.25	10.0	49.2	5542.1	287.7
51	2.500	334.91	883.67	301.13	10.0	49.2	5461.8	291.9
53	2.600	329.78	870.92	301.00	9.9	49.2	5382.1	295.5
55	2.700	324.72	858.29	300.87	9.9	49.2	5303.0	298.5
57	2.800	319.73	845.79	300.74	9.9	49.2	5224.5	301.1
59	2.900	314.79	833.41	300.60	9.9	49.2	5146.6	303.0
62	3.050	307.51	815.07	300.36	9.9	49.2	5030.9	305.0
63	3.100	305.12	809.02	300.30	9.9	49.2	4992.6	305.4
65	3.200	300.38	797.01	300.12	9.9	49.2	4916.6	305.8
66	3.250	298.03	791.05	300.02	9.9	49.2	4878.8	305.8

HEIGHT OF THE COOLING ZONE=3.250M

TABLE F.7 (E1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 7 (B)

(XEA=0.25)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELHTL
1	0.000	0.00000	745.00	300.00	300.00	318.00	4.93	25.87	19.65	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.00000	760.47	351.48	327.23	319.15	7.04	25.90	19.67	40.11	12.50	212.3	-1303.3	-1809.0	135.9
5	0.200	0.01250	772.42	405.16	354.16	319.58	8.73	25.89	19.66	40.11	12.50	247.3	-1320.7	-1831.8	275.6
7	0.300	0.02500	785.97	425.23	379.72	319.94	10.40	25.88	19.64	40.11	12.50	[illegible]	-1259.2	-1768.9	418.5
9	0.400	0.03750	795.10	443.37	403.95	320.28	12.07	25.86	19.62	40.11	12.50	[illegible]	-1203.7	-1710.5	564.6
11	0.500	0.05000	800.03	460.42	426.93	320.61	13.77	25.85	19.60	40.11	12.50	[illegible]	-1240.5	-1655.7	713.7
13	0.600	0.05000	810.22	505.70	450.27	320.95	16.40	25.87	19.62	40.11	12.50	[illegible]	-1115.5	-1599.6	865.8
15	0.700	0.05000	825.55	534.91	474.59	321.27	18.72	25.89	19.63	40.11	12.50	627.5	-1046.5	-1536.5	1020.9
17	0.800	0.05000	834.96	556.29	498.67	321.57	20.89	25.92	19.65	40.11	12.50	666.5	-1003.2	-1472.4	1178.8
19	0.900	0.05000	843.73	574.37	521.68	321.87	23.01	25.94	19.66	40.11	12.50	671.0	-970.5	-1410.3	1339.5
21	1.000	0.05000	852.15	591.05	544.01	322.15	25.16	25.96	19.68	40.11	12.50	657.6	-941.5	-1351.3	1502.8
23	1.100	0.05000	860.30	607.07	565.05	322.41	27.35	25.98	19.69	40.11	12.50	636.6	-913.8	-1285.5	1668.7
26	1.250	0.05000	871.92	630.27	594.67	322.80	30.73	26.00	19.71	40.11	12.50	600.0	-872.9	-1217.8	1922.0
28	1.350	0.05000	879.32	645.26	613.23	323.04	33.04	26.02	19.72	40.11	12.50	587.9	-846.0	-1169.5	2093.7
30	1.450	0.05000	886.45	659.84	630.91	323.27	35.37	26.04	19.74	40.11	12.50	568.5	-819.6	-1123.7	2267.7
32	1.550	0.05000	893.32	674.01	647.79	323.50	37.74	26.06	19.75	40.11	12.50	549.7	-792.7	-1080.3	2443.7
34	1.650	0.05345	899.91	687.79	663.51	323.70	39.69	26.06	19.75	40.11	12.50	503.1	-777.5	-1040.3	2621.9
36	1.750	0.05767	906.31	691.24	677.32	323.90	41.71	26.06	19.75	40.11	12.50	[illegible]	-775.6	-1007.6	2801.9
38	1.850	0.06207	912.54	702.41	689.94	324.08	43.87	26.06	19.74	40.11	12.50	[illegible]	-760.7	-979.3	2983.6
40	1.950	0.06757	918.00	713.09	702.26	324.26	46.01	26.06	19.74	40.11	12.50	[illegible]	-744.0	-951.6	3167.0
42	2.050	0.07247	924.43	723.83	714.15	324.43	48.19	26.06	19.74	40.11	12.50	[illegible]	-726.0	-925.0	3352.1
44	2.150	0.07733	930.21	734.41	725.50	324.60	50.36	26.06	19.73	40.11	12.50	[illegible]	-708.0	-900.1	3538.5
46	2.250	0.08200	935.78	744.71	736.46	324.76	52.52	26.06	19.73	40.11	12.50	[illegible]	-691.7	-870.3	3727.0
48	2.350	0.08600	941.20	754.73	747.05	324.91	54.67	26.06	19.73	40.11	12.50	[illegible]	-675.0	-853.2	3916.7
50	2.450	0.09114	946.49	764.59	757.30	325.06	56.82	26.06	19.72	40.11	12.50	[illegible]	[illegible]	-831.1	4107.9
52	2.550	0.09540	951.63	774.26	767.33	325.21	58.97	26.06	19.72	40.11	12.50	227.0	[illegible]	-809.8	4300.5
54	2.650	[illegible]	956.04	783.55	777.04	325.35	61.10	26.06	19.72	40.11	12.50	221.1	-626.0	-789.0	4494.5
56	2.750	[illegible]	961.55	792.59	786.46	325.49	63.21	26.06	19.71	40.11	12.50	210.4	-611.4	-769.0	4689.8
58	2.850	0.10751	966.09	801.38	795.59	325.62	65.31	26.06	19.71	40.11	12.50	[illegible]	[illegible]	-749.6	4886.5
60	2.950	0.11132	970.92	809.92	804.46	325.76	67.38	26.05	19.71	40.11	12.50	[illegible]	[illegible]	-731.0	5084.4
62	3.050	[illegible]	975.46	818.23	813.07	325.88	69.45	26.05	19.70	40.11	12.50	[illegible]	[illegible]	-712.9	5283.5
64	3.150	[illegible]	979.68	826.32	821.44	326.01	71.49	26.05	19.70	40.11	12.50	[illegible]	[illegible]	-695.5	5483.9
66	3.250	0.12215	984.14	834.19	829.57	326.13	73.51	26.05	19.70	40.11	12.50	[illegible]	[illegible]	-678.7	5685.4
68	3.350	[illegible]	988.40	841.85	837.47	326.25	75.51	26.05	19.69	40.11	12.50	[illegible]	[illegible]	-662.4	5888.1
70	3.450	[illegible]	992.51	849.31	845.15	326.36	77.50	26.05	19.69	40.11	12.50	[illegible]	-516.2	-646.6	6091.9
72	3.550	0.13215	996.52	856.58	852.62	326.47	79.46	26.05	19.69	40.11	12.50	[illegible]	-506.0	-631.4	6296.8
74	3.650	[illegible]	1000.44	863.66	859.89	326.58	81.40	26.05	19.69	40.11	12.50	[illegible]	[illegible]	-616.0	6502.7
76	3.750	0.13830	1004.22	870.55	866.97	326.69	83.32	26.05	19.68	40.11	12.50	[illegible]	[illegible]	-602.0	6709.7
78	3.850	0.14140	1008.02	877.27	873.86	326.79	85.22	26.05	19.68	40.11	12.50	161.0	-471.1	-588.0	6917.7
80	3.950	0.14434	1011.69	883.82	880.56	326.89	87.09	26.05	19.68	40.11	12.50	157.5	-460.7	-575.0	7126.7
82	4.050	0.14721	1015.27	890.20	887.10	326.99	88.95	26.05	19.68	40.11	12.50	[illegible]	-452.7	-562.0	7336.7
84	4.150	0.15001	1018.78	896.43	893.46	327.09	90.78	26.05	19.68	40.11	12.50	[illegible]	-442.7	-549.4	7547.6
86	4.250	0.15275	1022.21	902.50	899.67	327.18	92.59	26.05	19.67	40.11	12.50	145.7	-435.1	-537.2	7759.5
88	4.350	0.15542	1025.56	908.42	905.71	327.27	94.38	26.05	19.67	40.11	12.50	[illegible]	-423.0	-525.6	7972.2
90	4.450	0.15804	1028.85	914.20	911.61	327.36	96.15	26.05	19.67	40.11	12.50	130.0	-414.8	-514.9	8185.4
92	4.550	0.16060	1032.07	919.84	917.36	327.45	97.89	26.05	19.67	40.11	12.50	[illegible]	-406.1	-502.7	8400.0
94	4.650	0.16310	1035.22	925.35	922.97	327.54	99.61	26.05	19.67	40.11	12.50	131.4	-397.0	-491.9	8615.6
96	4.750	0.16555	1038.32	930.72	928.44	327.62	101.31	26.05	19.67	40.11	12.50	126.0	-389.3	-481.4	8831.8
98	4.850	0.16794	1041.34	935.97	933.79	327.70	102.99	26.05	19.66	40.11	12.50	124.6	-381.3	-471.3	9048.3
100	4.950	0.17028	1044.31	941.09	939.00	327.78	104.65	26.05	19.66	40.11	12.50	121.0	-373.5	-461.4	9266.5
102	5.050	0.17258	1047.22	946.10	944.09	327.86	106.28	26.05	19.66	40.11	12.50	118.4	-365.4	-451.8	9485.1
103	5.100	0.17371	1048.66	948.56	946.59	327.90	107.09	25.29	19.12	40.11	12.50	87.7	-351.6	-434.9	9594.6

VM COMBUSTION STARTS AT XF = 0.1737 AND AT HEIGHT (FROM TOP) = 5.100 M

-HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 5.100 M

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 7 (B)
(XEA=0.25)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PG26	PCO26
1	0.000	0.17371	0.00000	1048.7	946.6	946.6	327.9	0.0000	0.	109.9	25.2	19.1	40.1	12.5	117.	-351.	-474.	0.	0.	0.
2	0.050	0.16154	0.00000	1048.5	1119.5	946.6	327.7	0.0000	0.	142.0	25.1	19.0	40.1	12.5	119224.	-349.	-473.	0.	0.	0.
3	0.100	0.19397	0.00000	1048.3	1119.2	946.6	327.6	0.0000	0.	150.4	25.0	18.9	40.1	12.5	97557.	-348.	-471.	0.	0.	0.
4	0.150	0.20411	0.00000	1048.2	1118.9	946.6	327.4	0.0000	0.	165.7	24.9	18.8	40.1	12.5	89923.	-347.	-469.	0.	0.	0.
5	0.200	0.21463	0.00000	1048.1	1117.6	1087.4	327.4	0.0000	0.	179.2	24.9	18.7	40.1	12.5	88815.	-346.	-468.	0.	0.	0.
6	0.250	0.22536	0.00000	1048.0	1122.8	1154.4	327.0	0.0000	0.	193.6	24.8	18.7	40.1	12.5	88545.	-345.	-466.	0.	0.	0.
7	0.300	0.23630	0.00000	1047.9	1124.4	1173.6	326.7	0.0000	0.	207.9	24.7	18.6	40.1	12.5	87725.	-344.	-465.	0.	0.	0.
8	0.350	0.24461	0.00000	1047.8	1124.5	1173.6	326.4	0.0000	0.	217.1	24.5	18.4	40.1	12.5	87655.	-343.	-463.	0.	0.	0.
9	0.400	0.25474	0.00000	1047.7	1124.5	1173.6	326.1	0.0000	0.0001	218.0	24.5	18.3	40.1	12.5	88065.	-342.	-462.	0.	0.	0.
10	0.450	0.26467	0.00000	1047.6	1111.0	1174.1	325.7	0.0000	0.0002	216.0	24.2	18.2	40.1	12.5	88911.	-341.	-460.	0.	0.	0.
11	0.500	0.27500	0.00000	1047.5	1124.6	1174.6	325.4	0.0000	0.0003	216.3	24.1	18.1	40.1	12.5	89936.	-340.	-459.	0.	0.	0.
12	0.550	0.28571	0.00000	1047.4	1124.7	1175.5	325.1	0.0000	0.0004	225.8	24.0	18.0	40.3	12.3	122211.	-339.	-457.	0.	0.	0.
13	0.600	0.29722	0.00000	1047.3	1127.4	1176.0	324.8	0.0000	0.0009	225.2	24.0	17.9	40.6	12.0	119588.	-338.	-456.	0.	0.	0.
14	0.650	0.30911	0.00000	1047.2	1127.7	1176.5	324.5	0.0000	0.0011	227.2	23.9	17.7	40.8	11.8	119144.	-337.	-454.	0.	0.	0.
15	0.700	0.32156	0.00000	1047.1	1128.1	1176.6	324.2	0.0000	0.0011	228.7	23.8	17.5	40.8	11.8	121107.	-336.	-453.	0.	0.	0.
16	0.750	0.33456	0.00000	1047.0	1128.4	1179.7	323.9	0.0000	0.0013	230.5	23.7	17.4	41.1	11.6	123966.	-335.	-451.	0.	0.	0.
17	0.800	0.35116	0.00000	1046.9	1128.7	1181.1	323.6	0.0000	0.0016	233.4	23.7	17.2	41.3	11.4	128550.	-334.	-450.	0.	0.	0.
18	0.850	0.36971	0.00000	1046.8	1129.1	1182.2	323.3	0.0000	0.0019	235.6	23.6	17.1	41.3	11.2	129926.	-333.	-448.	0.	0.	0.
19	0.900	0.38997	0.00000	1046.7	1129.4	1183.5	323.0	0.0000	0.0022	236.6	23.6	17.1	41.3	11.2	129926.	-332.	-447.	0.	0.	0.
20	0.950	0.41324	0.00000	1046.6	1129.7	1184.8	322.7	0.0000	0.0027	238.6	23.6	16.9	41.5	11.0	131944.	-331.	-445.	0.	0.	0.
21	1.000	0.44010	0.00000	1046.5	1130.0	1186.1	322.4	0.0000	0.0031	239.9	23.5	16.7	41.7	10.8	134466.	-330.	-444.	0.	0.	0.
22	1.050	0.47135	0.00000	1046.4	1130.3	1187.4	322.1	0.0000	0.0037	241.4	23.4	16.6	42.0	10.5	137266.	-329.	-442.	0.	0.	0.
23	1.100	0.50855	0.00000	1046.3	1130.6	1188.9	321.8	0.0000	0.0045	244.4	23.4	16.4	42.2	10.2	139866.	-328.	-441.	0.	0.	0.
24	1.150	0.55976	0.00000	1046.2	1130.9	1190.4	321.5	0.0000	0.0059	247.1	23.4	16.2	42.4	10.0	142239.	-327.	-439.	0.	0.	0.
25	1.200	0.64030	0.00000	1046.1	1131.2	1191.9	321.2	0.0000	0.0076	249.3	23.3	16.1	42.6	9.9	144566.	-326.	-438.	0.	0.	0.
26	1.250	0.76595	0.00000	1046.0	1131.5	1193.4	320.9	0.0000	0.0099	251.3	23.3	15.9	42.8	9.7	146711.	-325.	-436.	0.	0.	0.
27	1.300	0.96096	0.00000	1045.9	1131.8	1194.9	320.6	0.0000	0.0135	253.5	23.3	15.7	43.0	9.5	148921.	-324.	-435.	0.	0.	0.
28	1.350	1.25161	0.00000	1045.8	1132.1	1196.4	320.3	0.0000	0.0196	255.7	23.2	15.5	43.2	9.3	151158.	-323.	-433.	0.	0.	0.
29	1.400	1.65306	0.00000	1045.7	1132.4	1197.9	320.0	0.0000	0.0301	257.9	23.2	15.3	43.4	9.1	153497.	-322.	-432.	0.	0.	0.
30	1.450	2.32255	0.00000	1045.6	1132.7	1199.4	319.7	0.0000	0.0457	260.2	23.2	15.1	43.6	8.9	155927.	-321.	-430.	0.	0.	0.
31	1.500	3.37043	0.00000	1045.5	1133.0	1200.9	319.4	0.0000	0.0717	262.5	23.1	14.9	43.8	8.7	158455.	-320.	-429.	0.	0.	0.
32	1.550	5.56706	0.00000	1045.4	1133.3	1202.4	319.1	0.0000	0.1135	264.8	23.1	14.8	44.0	8.6	161085.	-319.	-427.	0.	0.	0.
33	1.600	9.51911	0.00000	1045.3	1133.6	1203.9	318.8	0.0000	0.1857	267.1	23.1	14.6	44.2	8.4	163821.	-318.	-426.	0.	0.	0.
34	1.650	16.22270	0.00000	1045.2	1133.9	1205.4	318.5	0.0000	0.3163	269.4	23.0	14.4	44.4	8.2	166665.	-317.	-424.	0.	0.	0.
35	1.700	27.66400	0.00000	1045.1	1134.2	1206.9	318.2	0.0000	0.5214	271.7	23.0	14.2	44.6	8.0	169621.	-316.	-423.	0.	0.	0.
36	1.750	47.16576	0.00000	1045.0	1134.5	1208.4	317.9	0.0000	0.8599	274.0	23.0	14.0	44.8	7.8	172691.	-315.	-421.	0.	0.	0.
37	1.800	80.42445	0.00000	1044.9	1134.8	1209.9	317.6	0.0000	0.0355	276.3	22.9	13.8	45.0	7.6	175881.	-314.	-420.	0.	0.	0.
38	1.850	137.14211	0.00000	1044.8	1135.1	1211.4	317.3	0.0000	0.0418	278.6	22.9	13.6	45.2	7.4	179196.	-313.	-418.	0.	0.	0.
39	1.900	233.84537	0.00000	1044.7	1135.4	1212.9	317.0	0.0000	0.0466	280.9	22.8	13.5	45.4	7.2	182642.	-312.	-417.	0.	0.	0.
40	1.950	398.69444	0.00000	1044.6	1135.7	1214.4	316.7	0.0000	0.0521	283.2	22.8	13.3	45.7	7.1	186224.	-311.	-415.	0.	0.	0.
41	1.975	679.71370	0.00000	1044.5	1136.0	1215.9	316.4	0.0000	0.0583	285.5	22.8	13.2	45.9	6.9	189944.	-310.	-414.	0.	0.	0.
42	1.990	1158.72110	0.00000	1044.4	1136.3	1217.4	316.1	0.0000	0.0653	287.8	22.7	13.1	46.1	6.7	193803.	-309.	-412.	0.	0.	0.
43	1.995	1974.72671	0.00000	1044.3	1136.6	1218.9	315.8	0.0000	0.0732	290.1	22.7	13.0	46.3	6.5	197803.	-308.	-411.	0.	0.	0.
44	2.000	3367.73100	0.00000	1044.2	1136.9	1220.4	315.5	0.0000	0.0822	292.4	22.7	12.8	46.5	6.3	201946.	-307.	-409.	0.	0.	0.
45	2.005	5739.73515	0.00000	1044.1	1137.2	1221.9	315.2	0.0000	0.0924	294.7	22.6	12.7	46.7	6.1	206236.	-306.	-408.	0.	0.	0.
46	2.010	9784.73824	0.00000	1044.0	1137.5	1223.4	314.9	0.0000	0.1040	297.0	22.6	12.5	46.9	5.9	210671.	-305.	-406.	0.	0.	0.
47	2.015	16678.74092	0.00000	1043.9	1137.8	1224.9	314.6	0.0000	0.1170	299.3	22.6	12.4	47.1	5.7	215254.	-304.	-405.	0.	0.	0.
48	2.020	28441.74321	0.00000	1043.8	1138.1	1226.4	314.3	0.0000	0.1316	301.6	22.5	12.2	47.3	5.5	219986.	-303.	-403.	0.	0.	0.
49	2.025	48511.74510	0.00000	1043.7	1138.4	1227.9	314.0	0.0000	0.1482	303.9	22.5	12.1	47.5	5.3	224869.	-302.	-402.	0.	0.	0.
50	2.030	82766.74683	0.00000	1043.6	1138.7	1229.4	313.7	0.0000	0.1670	306.2	22.5	11.9	47.7	5.1	229902.	-301.	-400.	0.	0.	0.
51	2.035	141159.74826	0.00000	1043.5	1139.0	1230.9	313.4	0.0000	0.1884	308.5	22.4	11.8	47.9	4.9	235089.	-300.	-399.	0.	0.	0.
52	2.040	240783.74947	0.00000	1043.4	1139.3	1232.4	313.1	0.0000	0.2128	310.8	22.4	11.6	48.1	4.7	240431.	-299.	-397.	0.	0.	0.
53	2.045	410465.75050	0.00000	1043.3	1139.6	1233.9	312.8	0.0000	0.2406	313.1	22.4	11.5	48.3	4.5	245938.	-298.	-396.	0.	0.	0.
54	2.050	699420.75136	0.00000	1043.2	1139.9	1235.4	312.5	0.0000	0.2722	315.4	22.3	11.3	48.5	4.3	251609.	-297.	-394.	0.	0.	0.
55	2.055	1192318.75208	0.00000	1043.1	1140.2	1236.9	312.2	0.0000	0.3080	317.7	22.3	11.2	48.7	4.1	257447.	-296.	-393.	0.	0.	0.
56	2.060	2032420.75269	0.00000	1043.0	1140.5	1238.4	311.9	0.0000	0.3487	320.0	22.3	11.0	48.9	3.9	263463.	-295.	-391.	0.	0.	0.
57	2.065	3465465.75322	0.00000	1042.9	1140.8	1239.9	311.6	0.0000	0.3950	322.3	22.2	10.8	49.1	3.7	269661.	-294.	-390.	0.	0.	0.
58	2.070	5907465.75368	0.00000	1042.8	1141.1	1241.4	311.3	0.0000	0.4480	324.6	22.2	10.7	49.3	3.5	276045.	-293.	-388.	0.	0.	0.
59	2.075	10074465.75408	0.00000	1042.7	1141.4	1242.9	311.0	0.0000	0.5092	326.9	22.2	10.5	49.5	3.3	282619.	-292.	-387.	0.	0.	0.
60	2.080	17181465.75443	0.00000	1042.6	1141.7	1244.4	310.7	0.0000	0.5800	329.2	22.1	10.3	49.7	3.1	289384.	-291.	-385.	0.	0.	0.
61	2.085	29301465.75474	0.00000	1042.5	1142.0	1245.9	310.4	0.0000	0.6618	331.5	22.1	10.2	49.9	2.9	296344.	-290.	-384.	0.	0.	0.
62	2.090	49965465.75501	0.00000	1042.4	1142.3	1247.4	310.1	0.0000	0.7560	333.8	22.1	10.0	50.1	2.7	303504.	-289.	-382.	0.	0.	0.
63	2.095	85201465.75525	0.00000	1042.3	1142.6	1248.9	309.8	0.0000	0.8643	336.1	22.0	9.8	50.3	2.5	310866.	-288.	-381.	0.	0.	0.
64	2.100	145301465.75545	0.00000	1042.2	1142.9	1250.4	309.5	0.0000	0.9876	338.4	22.0	9.7	50.5	2.3	318438.	-287.	-379.	0.	0.	0.
65	2.105	247801465.75562	0.00000	1042.1	1143.2	1251.9	309.2	0.0000	1.1282	340.7	22.0	9.5	50.7	2.1	326227.	-286.	-378.	0.	0.	0.
66	2.110	422665465.75577	0.00000	1042.0	1143.5	1253.4	308.9	0.0000	1.2885	343.0	21.9	9.3	50.9	1.9	334236.	-285.	-376.	0.	0.	0.
67	2.115	720865465.75589	0.00000	1041.9	1143.8	1254.9	308.6	0.0000	1.4713	345.3	21.9	9.2	51.1	1.7	342472.	-284.	-375.	0.	0.	0.
68	2.120	1229465465.75600	0.00000	1041.8	1144.1	1256.4	308.3	0.0000	1.6800	347.6	21.9	9.0	51.3	1.5	350941.	-283.	-373.	0.	0.	0.
69	2.125	2096465465.75608	0.00000	1041.7	1144.4	1257.9	308.0	0.0000	1.9185	349.9	21.8	8.8	51.5	1.3	359647.	-282.	-372.	0.	0.	0.
70	2.130	3574465465.75615	0.00000	1041.6	1144.7	1259.4	307.7	0.0000	2.1885	352.2	21.8	8.7	51.7	1.1	368593.	-281.	-370.	0.	0.	0.
71	2.135	6094465465.75621	0.00000	1041.5	1145.0	1260.9	307.4	0.0000	2.4924	354.5	21.8	8.5	51.9	0.9	377781.	-280.	-369.	0.	0.	0.
72	2.140	10391465465.75625	0.00000	1041.4	1145.3	1262.4	307.1	0.0000	2.8327	356.8	21.7	8.3	52.1	0.7	387213.	-279.	-367.	0.	0.	0.
73	2.145	17719465465.75629	0.00000	1041.3	1145.6	1263.9	306.8	0.0000	3.2127	359.1	21.7	8.2	52.3	0.5	396897.	-278.	-366.	0.	0.	0.
74	2.150	30215465465.75632	0.00000	1041.2	1145.9	1265.4	306.5	0.0000	3.6357	361.4	21.7	8.0	52.5	0.3	406837.	-277.	-364.	0.	0.	0.
75	2.155	51515465465.75634	0.00000	1041.1	1146.2	1266.9	306.2	0.0000	4.1055	363.7	21.6	7.8	52.7	0.1	417038.	-276.	-363.	0.	0.	0.
76	2.160	87815465465.75636	0.00000	1041.0	1146.5	1268.4	305.9	0.0000	4.6264	366.0	21.6	7.7	52.9	-0.1	427506.	-275.	-361.	0.	0.	0.
77	2.165	149715465465.75637	0.00000	1040.9	1146.8	1269.9	305.6	0.0000	5.2030	368.3	21.6	7.5	53.1	-0.3	438246.	-274.	-360.	0.	0.	0.
78	2.170	255215465465.75638	0.00000	1040.8	1147.1	1271.4	305.3	0.0000	5.8408	370.6	21.5	7.3	53.3	-0.5	449262.	-273.	-358.	0.	0.	0.
79	2.175	435115465465.75639	0.00000	1040.7	1147.4	1272.9	305.0	0.0000	6.5464	372.9	21.5	7.2	53.5	-0.7	460560.	-272.	-357.	0.	0.	0.
80	2.180	741715465465.75640	0.00000	1040.6	1147.7	1274.4	304.7	0.0000	7.3270	375.2	21.5	7.0	53.7	-0.9	472149.	-271.	-355.	0.	0.	0.
81	2.185	1264715465465.75641	0.00000	1040.5	1148.0	1275.9	304.4	0.0000	8.2900	377.5	21.4	6.8	53.9	-1.1	484035.	-270.	-354.	0.	0.	0.
82	2.190	2156715465465.75642	0.00000	1040.4	1148.3	1277.4	304.1	0.0000	9.3427	379.8	21.4	6.7	54.1	-1.3	496220.	-269.	-352.	0.	0.	0.

ASH FUSION STARTS AT XF = 0.6965 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.870 M

HEIGHT OF THE BURNING ZONE = 2.190 M

TABLE P.7 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 7 (B)

(XEA=0.25)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TA(K)	HSG	ASCZ	QSG	DELNTL
1	0.000	520.00	1193.00	305.30	11.3	49.2	7575.8	0.0
3	0.100	514.54	1177.25	305.24	11.3	49.2	7457.7	27.4
5	0.200	509.16	1161.73	305.14	11.2	49.2	7340.8	54.0
7	0.300	503.87	1146.36	305.03	11.2	49.2	7225.0	80.0
9	0.400	498.65	1131.17	304.93	11.2	49.2	7110.4	105.4
11	0.500	493.51	1116.15	304.83	11.2	49.2	6997.0	130.1
13	0.600	488.44	1101.30	304.73	11.2	49.2	6884.7	154.1
15	0.700	483.45	1086.62	304.63	11.2	49.2	6773.5	177.5
17	0.800	478.54	1072.11	304.53	11.2	49.2	6663.5	200.3
19	0.900	473.71	1057.78	304.43	11.2	49.2	6554.7	222.5
21	1.000	468.94	1043.61	304.33	11.2	49.2	6447.0	244.0
23	1.100	464.26	1029.62	304.23	11.2	49.2	6340.4	265.0
25	1.200	459.64	1015.79	304.14	11.2	49.2	6234.9	285.4
27	1.300	455.10	1002.12	304.04	11.2	49.2	6130.6	305.2
29	1.400	450.63	988.65	303.95	11.2	49.2	6027.4	324.4
31	1.500	446.23	975.30	303.86	11.2	49.2	5925.3	343.1
33	1.600	441.91	962.13	303.77	11.2	49.2	5824.4	361.2
35	1.700	437.65	949.13	303.68	11.2	49.2	5724.5	378.8
37	1.800	433.46	936.30	303.59	11.2	49.2	5625.8	395.9
39	1.900	429.34	923.62	303.50	11.2	49.2	5528.3	412.4
41	2.000	425.29	911.11	303.41	11.2	49.2	5431.8	428.4
43	2.100	421.30	898.76	303.32	11.2	49.2	5336.4	443.9
45	2.200	417.39	886.56	303.24	11.2	49.2	5242.2	458.9
47	2.300	413.53	874.53	303.15	11.2	49.2	5149.0	473.4
49	2.400	409.74	862.66	303.07	11.2	49.2	5057.0	487.5
51	2.500	406.02	850.94	302.98	11.2	49.2	4966.1	501.1
53	2.600	402.36	839.35	302.90	11.2	49.2	4876.3	514.2
55	2.700	398.77	827.98	302.82	11.2	49.2	4787.5	526.8
57	2.800	395.23	816.73	302.74	11.2	49.2	4699.9	539.0
59	2.900	391.76	805.64	302.66	11.1	49.2	4613.4	550.8
61	3.000	388.35	794.70	302.58	11.1	49.2	4527.9	562.1
65	3.200	381.71	773.27	302.42	11.1	49.2	4360.3	583.5
69	3.400	375.30	752.45	302.27	11.1	49.2	4196.9	603.2
73	3.600	369.12	732.23	302.12	11.1	49.2	4037.9	621.3
77	3.800	363.17	712.59	301.97	11.1	49.2	3883.2	638.0
81	4.000	357.44	693.54	301.83	11.1	49.2	3732.6	653.1
85	4.200	351.92	675.06	301.69	11.1	49.2	3586.3	666.9
89	4.400	346.61	657.14	301.55	11.1	49.2	3444.1	679.3
93	4.600	341.50	639.78	301.41	11.1	49.2	3306.1	690.4
95	4.700	339.02	631.31	301.35	11.1	49.2	3238.6	695.4
97	4.800	336.59	622.97	301.28	11.1	49.2	3172.1	700.2
99	4.900	334.21	614.77	301.21	11.1	49.2	3106.6	704.6
101	5.000	331.87	606.70	301.15	11.1	49.2	3042.1	708.8
105	5.200	327.34	590.95	301.02	11.1	49.2	2916.1	716.3
109	5.400	322.99	575.75	300.89	11.1	49.2	2794.1	722.6
113	5.600	318.82	561.02	300.76	11.0	49.2	2675.9	727.9
117	5.800	314.82	546.81	300.63	11.0	49.2	2561.5	732.2
121	6.000	310.99	533.10	300.50	11.0	49.2	2450.9	735.5
125	6.200	307.31	519.86	300.37	11.0	49.2	2343.9	737.8
129	6.400	303.80	507.10	300.23	11.0	49.2	2240.6	739.3
133	6.600	300.43	494.80	300.05	11.0	49.2	2140.9	739.9
134	6.650	299.61	491.79	300.03	11.0	49.2	2116.5	739.9

HEIGHT OF THE COOLING ZONE=6.650M

ENTHALPIES OF PRODUCT LIME AND ASH/CINDERS AT BOTTOM OF KILN = 21268.2 KCAL/HR

TABLE P.E (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 8 (A)

(DTHICK = 0.09 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TL(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.000000	746.00	300.00	300.00	316.00	4.93	25.07	19.08	40.11	12.55	0.0	0.0	0.0	0.0
3	0.100	0.000000	761.09	379.61	326.45	322.15	6.97	25.10	19.10	40.11	12.55	204.7	-1331.7	-165.9	147.1
5	0.200	0.001256	773.71	401.34	352.73	344.90	8.60	25.09	19.09	40.11	12.55	233.7	-1295.7	-173.3	293.1
7	0.300	0.002509	785.94	421.42	377.70	363.35	10.22	25.08	19.07	40.11	12.55	248.5	-1266.9	-173.8	439.1
9	0.400	0.003759	797.83	439.31	401.44	323.78	11.86	25.06	19.05	40.11	12.55	249.5	-1244.2	-169.3	585.1
11	0.500	0.005007	809.46	456.35	424.02	324.16	13.53	25.05	19.04	40.11	12.55	242.2	-1222.6	-161.4	731.1
13	0.600	0.006253	820.85	501.88	447.00	324.60	16.12	25.05	19.00	40.11	12.55	227.1	-1196.7	-152.7	877.1
15	0.700	0.007497	832.57	531.56	471.15	325.00	18.41	25.10	19.07	40.11	12.55	217.3	-1100.2	-146.3	1023.1
17	0.800	0.008740	844.40	553.19	495.13	325.56	20.56	25.12	19.09	40.11	12.55	206.3	-972.2	-141.6	1169.1
19	0.900	0.009981	856.49	571.49	518.34	325.75	22.67	25.15	19.11	40.11	12.55	195.9	-920.3	-135.5	1315.1
21	1.000	0.011220	868.97	588.37	540.56	326.10	24.81	25.17	19.12	40.11	12.55	186.2	-871.1	-132.4	1461.1
23	1.100	0.012458	881.78	604.56	561.74	326.44	27.00	25.16	19.14	40.11	12.55	176.9	-824.4	-128.5	1607.1
25	1.200	0.013695	894.85	620.35	581.98	326.76	29.25	25.21	19.15	40.11	12.55	168.1	-780.1	-124.4	1753.1
27	1.300	0.014931	908.47	635.77	601.22	327.08	31.55	25.23	19.16	40.11	12.55	159.7	-738.1	-120.4	1899.1
29	1.400	0.016166	922.40	650.86	619.64	327.36	33.92	25.25	19.18	40.11	12.55	151.8	-698.3	-116.5	2045.1
31	1.500	0.017400	936.87	665.65	637.45	327.67	36.36	25.27	19.19	40.11	12.55	144.2	-660.7	-112.7	2191.1
33	1.600	0.018634	951.78	680.19	654.10	327.95	38.89	25.28	19.20	40.11	12.55	137.0	-625.1	-109.0	2337.1
35	1.700	0.019867	967.45	694.51	669.81	328.21	41.50	25.29	19.20	40.11	12.55	130.1	-591.4	-105.4	2483.1
37	1.800	0.021100	983.96	708.64	684.69	328.46	44.21	25.29	19.20	40.11	12.55	123.6	-559.5	-101.9	2629.1
39	1.900	0.022332	1001.34	722.61	698.88	328.71	47.02	25.30	19.21	40.11	12.55	117.4	-529.3	-98.5	2775.1
41	2.000	0.023564	1019.64	736.45	712.52	328.96	49.94	25.30	19.21	40.11	12.55	111.5	-500.8	-95.2	2921.1
43	2.100	0.024795	1038.91	750.19	725.67	329.21	52.98	25.30	19.21	40.11	12.55	105.9	-473.8	-92.0	3067.1
45	2.200	0.026026	1059.21	763.86	738.41	329.46	56.15	25.30	19.21	40.11	12.55	100.6	-448.3	-88.9	3213.1
47	2.300	0.027257	1080.61	777.49	750.82	329.71	59.46	25.30	19.21	40.11	12.55	95.5	-424.2	-85.9	3359.1
49	2.400	0.028487	1103.19	791.11	762.96	329.96	62.94	25.30	19.21	40.11	12.55	90.8	-401.4	-83.0	3505.1
51	2.500	0.029717	1127.03	804.76	774.90	330.21	66.61	25.30	19.21	40.11	12.55	86.2	-379.8	-80.2	3651.1
53	2.600	0.030947	1152.23	818.47	786.70	330.46	70.49	25.30	19.21	40.11	12.55	81.9	-359.4	-77.5	3797.1
55	2.700	0.032176	1178.91	832.27	798.41	330.71	74.62	25.30	19.21	40.11	12.55	77.8	-340.1	-74.8	3943.1
57	2.800	0.033405	1207.21	846.19	810.08	330.96	79.03	25.30	19.21	40.11	12.55	73.9	-321.8	-72.3	4089.1
59	2.900	0.034634	1237.29	860.26	821.75	331.21	83.77	25.30	19.21	40.11	12.55	70.2	-304.5	-69.8	4235.1
61	3.000	0.035863	1269.33	874.52	833.48	331.46	88.89	25.30	19.21	40.11	12.55	66.7	-288.1	-67.4	4381.1
63	3.100	0.037092	1303.53	889.00	845.32	331.71	94.46	25.30	19.21	40.11	12.55	63.4	-272.5	-65.1	4527.1
65	3.200	0.038321	1340.11	903.74	857.33	331.96	100.54	25.30	19.21	40.11	12.55	60.2	-257.8	-62.9	4673.1
67	3.300	0.039550	1379.33	918.79	869.57	332.21	107.22	25.30	19.21	40.11	12.55	57.2	-243.8	-60.7	4819.1
69	3.400	0.040780	1421.49	934.19	882.09	332.46	114.62	25.30	19.21	40.11	12.55	54.4	-230.6	-58.6	4965.1
71	3.500	0.042011	1466.96	949.99	894.96	332.71	122.90	25.30	19.21	40.11	12.55	51.7	-218.1	-56.6	5111.1
73	3.600	0.043243	1516.19	966.24	908.24	332.96	132.26	25.30	19.21	40.11	12.55	49.1	-206.2	-54.6	5257.1
75	3.700	0.044476	1569.72	982.99	921.99	333.21	142.94	25.30	19.21	40.11	12.55	46.7	-194.9	-52.7	5403.1
77	3.800	0.045711	1628.23	1000.31	936.30	333.46	155.26	25.30	19.21	40.11	12.55	44.4	-184.2	-50.8	5549.1
79	3.900	0.046947	1692.58	1018.27	951.27	333.71	169.68	25.30	19.21	40.11	12.55	42.2	-174.0	-49.0	5695.1
81	4.000	0.048186	1763.85	1036.97	967.04	333.96	186.95	25.30	19.21	40.11	12.55	40.1	-164.3	-47.2	5841.1
83	4.100	0.049428	1843.41	1056.54	983.79	334.21	208.19	25.30	19.21	40.11	12.55	38.1	-155.1	-45.5	5987.1
85	4.200	0.050675	1932.99	1077.16	1001.81	334.46	235.00	25.30	19.21	40.11	12.55	36.2	-146.4	-43.8	6133.1
87	4.300	0.051929	2035.91	1099.04	1021.47	334.71	270.84	25.30	19.21	40.11	12.55	34.4	-138.1	-42.2	6279.1
89	4.400	0.053193	2156.37	1122.47	1043.31	334.96	321.04	25.30	19.21	40.11	12.55	32.7	-130.2	-40.6	6425.1
91	4.500	0.054471	2300.77	1147.87	1068.07	335.21	393.41	25.30	19.21	40.11	12.55	31.1	-122.7	-39.0	6571.1
93	4.600	0.055768	2479.81	1175.84	1096.81	335.46	502.97	25.30	19.21	40.11	12.55	29.5	-115.6	-37.4	6717.1
95	4.700	0.057091	2711.49	1207.32	1130.49	335.71	674.14	25.30	19.21	40.11	12.55	28.0	-108.8	-35.9	6863.1
97	4.800	0.058465	3035.11	1244.03	1170.11	335.96	955.83	25.30	19.21	40.11	12.55	26.6	-102.3	-34.4	7009.1

VM COMBUSTION STARTS AT XF = 0.1709 AND AT HEIGHT (FROM TOP) = 4.800 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.800 M

TABLE P.7 (AZ)

SIMULATION OF A LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 8 (A)
(WTHICK=0.09 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	GFS	QFG	QSG	DELHTL	PC2G	PCO2G
1	0.000	0.17065	0.00006	1070.1	946.0	945.7	373.3	0.0000	0.	106.7	24.5	18.8	40.1	12.5	138.	-419.	-515.	0.	0.0	2.1
2	0.050	0.16164	0.00006	1070.0	1126.1	968.6	373.3	0.0000	0.	141.7	24.4	18.8	40.1	12.5	1259.	-191.	-418.	121.	0.0	2.4
3	0.100	0.15191	0.00006	1069.9	1124.4	1015.5	373.3	0.0000	0.	151.7	24.4	18.8	40.1	12.5	1259.	133.	-215.	241.	0.0	2.4
4	0.150	0.14211	0.00006	1069.8	1120.1	1060.1	373.3	0.0000	0.	160.7	24.4	18.8	40.1	12.5	1259.	317.	-46.	362.	0.0	2.4
5	0.200	0.13231	0.00006	1069.7	1116.4	1102.2	373.3	0.0000	0.	169.7	24.4	18.8	40.1	12.5	1259.	408.	123.	483.	0.0	2.4
6	0.250	0.12251	0.00006	1069.6	1112.7	1144.0	373.3	0.0000	0.	178.7	24.4	18.8	40.1	12.5	1259.	512.	288.	604.	0.0	2.4
7	0.300	0.11271	0.00006	1069.4	1109.0	1185.8	373.3	0.0000	0.	187.7	24.4	18.8	40.1	12.5	1259.	611.	437.	725.	0.0	2.4
8	0.350	0.10291	0.00006	1069.3	1105.3	1227.6	373.3	0.0000	0.	196.7	24.4	18.8	40.1	12.5	1259.	671.	555.	846.	0.0	2.4
9	0.400	0.09317	0.00006	1069.2	1101.6	1269.4	373.3	0.0000	0.	205.7	24.4	18.8	40.1	12.5	1259.	691.	655.	967.	0.0	2.4
10	0.450	0.08342	0.00006	1069.1	1097.9	1311.2	373.3	0.0000	0.	214.7	24.4	18.8	40.1	12.5	1259.	712.	755.	1088.	0.0	2.4
11	0.500	0.07368	0.00006	1069.0	1094.2	1353.0	373.3	0.0000	0.	223.7	24.4	18.8	40.1	12.5	1259.	733.	855.	1209.	0.0	2.4
12	0.550	0.06394	0.00006	1068.9	1090.5	1394.8	373.3	0.0000	0.	232.7	24.4	18.8	40.1	12.5	1259.	754.	955.	1330.	0.0	2.4
13	0.600	0.05419	0.00006	1068.8	1086.8	1436.6	373.3	0.0000	0.	241.7	24.4	18.8	40.1	12.5	1259.	775.	1055.	1451.	0.0	2.4
14	0.650	0.04445	0.00006	1068.7	1083.1	1478.4	373.3	0.0000	0.	250.7	24.4	18.8	40.1	12.5	1259.	796.	1155.	1572.	0.0	2.4
15	0.700	0.03471	0.00006	1068.6	1079.4	1520.2	373.3	0.0000	0.	259.7	24.4	18.8	40.1	12.5	1259.	817.	1255.	1693.	0.0	2.4
16	0.750	0.02496	0.00006	1068.5	1075.7	1562.0	373.3	0.0000	0.	268.7	24.4	18.8	40.1	12.5	1259.	838.	1355.	1814.	0.0	2.4
17	0.800	0.01522	0.00006	1068.4	1072.0	1603.8	373.3	0.0000	0.	277.7	24.4	18.8	40.1	12.5	1259.	859.	1455.	1935.	0.0	2.4
18	0.850	0.00548	0.00006	1068.3	1068.3	1645.6	373.3	0.0000	0.	286.7	24.4	18.8	40.1	12.5	1259.	880.	1555.	2056.	0.0	2.4
19	0.900	0.00000	0.00006	1068.2	1064.6	1687.4	373.3	0.0000	0.	295.7	24.4	18.8	40.1	12.5	1259.	901.	1655.	2177.	0.0	2.4
20	0.950	0.00000	0.00006	1068.1	1060.9	1729.2	373.3	0.0000	0.	304.7	24.4	18.8	40.1	12.5	1259.	922.	1755.	2298.	0.0	2.4
21	1.000	0.00000	0.00006	1068.0	1057.2	1771.0	373.3	0.0000	0.	313.7	24.4	18.8	40.1	12.5	1259.	943.	1855.	2419.	0.0	2.4
22	1.050	0.00000	0.00006	1067.9	1053.5	1812.8	373.3	0.0000	0.	322.7	24.4	18.8	40.1	12.5	1259.	964.	1955.	2540.	0.0	2.4
23	1.100	0.00000	0.00006	1067.8	1049.8	1854.6	373.3	0.0000	0.	331.7	24.4	18.8	40.1	12.5	1259.	985.	2055.	2661.	0.0	2.4
24	1.150	0.00000	0.00006	1067.7	1046.1	1896.4	373.3	0.0000	0.	340.7	24.4	18.8	40.1	12.5	1259.	1006.	2155.	2782.	0.0	2.4
25	1.200	0.00000	0.00006	1067.6	1042.4	1938.2	373.3	0.0000	0.	349.7	24.4	18.8	40.1	12.5	1259.	1027.	2255.	2903.	0.0	2.4
26	1.250	0.00000	0.00006	1067.5	1038.7	1980.0	373.3	0.0000	0.	358.7	24.4	18.8	40.1	12.5	1259.	1048.	2355.	3024.	0.0	2.4
27	1.300	0.00000	0.00006	1067.4	1035.0	2021.8	373.3	0.0000	0.	367.7	24.4	18.8	40.1	12.5	1259.	1069.	2455.	3145.	0.0	2.4
28	1.350	0.00000	0.00006	1067.3	1031.3	2063.6	373.3	0.0000	0.	376.7	24.4	18.8	40.1	12.5	1259.	1090.	2555.	3266.	0.0	2.4
29	1.400	0.00000	0.00006	1067.2	1027.6	2105.4	373.3	0.0000	0.	385.7	24.4	18.8	40.1	12.5	1259.	1111.	2655.	3387.	0.0	2.4
30	1.450	0.00000	0.00006	1067.1	1023.9	2147.2	373.3	0.0000	0.	394.7	24.4	18.8	40.1	12.5	1259.	1132.	2755.	3508.	0.0	2.4
31	1.500	0.00000	0.00006	1067.0	1020.2	2189.0	373.3	0.0000	0.	403.7	24.4	18.8	40.1	12.5	1259.	1153.	2855.	3629.	0.0	2.4
32	1.550	0.00000	0.00006	1066.9	1016.5	2230.8	373.3	0.0000	0.	412.7	24.4	18.8	40.1	12.5	1259.	1174.	2955.	3750.	0.0	2.4
33	1.600	0.00000	0.00006	1066.8	1012.8	2272.6	373.3	0.0000	0.	421.7	24.4	18.8	40.1	12.5	1259.	1195.	3055.	3871.	0.0	2.4
34	1.650	0.00000	0.00006	1066.7	1009.1	2314.4	373.3	0.0000	0.	430.7	24.4	18.8	40.1	12.5	1259.	1216.	3155.	3992.	0.0	2.4
35	1.700	0.00000	0.00006	1066.6	1005.4	2356.2	373.3	0.0000	0.	439.7	24.4	18.8	40.1	12.5	1259.	1237.	3255.	4113.	0.0	2.4
36	1.750	0.00000	0.00006	1066.5	1001.7	2398.0	373.3	0.0000	0.	448.7	24.4	18.8	40.1	12.5	1259.	1258.	3355.	4234.	0.0	2.4
37	1.800	0.00000	0.00006	1066.4	998.0	2439.8	373.3	0.0000	0.	457.7	24.4	18.8	40.1	12.5	1259.	1279.	3455.	4355.	0.0	2.4
38	1.850	0.00000	0.00006	1066.3	994.3	2481.6	373.3	0.0000	0.	466.7	24.4	18.8	40.1	12.5	1259.	1300.	3555.	4476.	0.0	2.4
39	1.900	0.00000	0.00006	1066.2	990.6	2523.4	373.3	0.0000	0.	475.7	24.4	18.8	40.1	12.5	1259.	1321.	3655.	4597.	0.0	2.4
40	1.950	0.00000	0.00006	1066.1	986.9	2565.2	373.3	0.0000	0.	484.7	24.4	18.8	40.1	12.5	1259.	1342.	3755.	4718.	0.0	2.4
41	1.970	0.00000	0.00006	1066.0	985.4	2582.0	373.3	0.0000	0.	488.3	24.4	18.8	40.1	12.5	1259.	1351.	3795.	4767.	0.0	2.4
42	2.000	0.00000	0.00006	1065.9	983.2	2607.0	373.3	0.0000	0.	493.7	24.4	18.8	40.1	12.5	1259.	1363.	3855.	4839.	0.0	2.4
43	2.050	0.00000	0.00006	1065.8	979.5	2648.8	373.3	0.0000	0.	502.7	24.4	18.8	40.1	12.5	1259.	1384.	3955.	4960.	0.0	2.4
44	2.100	0.00000	0.00006	1065.7	975.8	2690.6	373.3	0.0000	0.	511.7	24.4	18.8	40.1	12.5	1259.	1405.	4055.	5081.	0.0	2.4
45	2.150	0.00000	0.00006	1065.6	972.1	2732.4	373.3	0.0000	0.	520.7	24.4	18.8	40.1	12.5	1259.	1426.	4155.	5202.	0.0	2.4
46	2.200	0.00000	0.00006	1065.5	968.4	2774.2	373.3	0.0000	0.	529.7	24.4	18.8	40.1	12.5	1259.	1447.	4255.	5323.	0.0	2.4
47	2.250	0.00000	0.00006	1065.4	964.7	2816.0	373.3	0.0000	0.	538.7	24.4	18.8	40.1	12.5	1259.	1468.	4355.	5444.	0.0	2.4
48	2.275	0.00000	0.00006	1065.3	963.0	2836.9	373.3	0.0000	0.	543.2	24.4	18.8	40.1	12.5	1259.	1478.	4405.	5505.	0.0	2.4
49	2.300	0.00000	0.00006	1065.2	961.0	2857.8	373.3	0.0000	0.	547.7	24.4	18.8	40.1	12.5	1259.	1489.	4455.	5565.	0.0	2.4
50	2.325	0.00000	0.00006	1065.1	959.3	2878.7	373.3	0.0000	0.	552.2	24.4	18.8	40.1	12.5	1259.	1499.	4505.	5626.	0.0	2.4
51	2.350	0.00000	0.00006	1065.0	957.6	2899.6	373.3	0.0000	0.	556.7	24.4	18.8	40.1	12.5	1259.	1510.	4555.	5686.	0.0	2.4
52	2.375	0.00000	0.00006	1064.9	955.9	2920.5	373.3	0.0000	0.	561.2	24.4	18.8	40.1	12.5	1259.	1520.	4605.	5747.	0.0	2.4
53	2.400	0.00000	0.00006	1064.8	954.2	2941.4	373.3	0.0000	0.	565.7	24.4	18.8	40.1	12.5	1259.	1531.	4655.	5807.	0.0	2.4
54	2.425	0.00000	0.00006	1064.7	952.5	2962.3	373.3	0.0000	0.	570.2	24.4	18.8	40.1	12.5	1259.	1541.	4705.	5868.	0.0	2.4
55	2.275	0.75000	0.99366	501.9	1247.8	1186.3	305.4	0.0530	5256.	230.1	31.1	12.2	47.2	1.9	359.	59.	427.	3343.	0.2	0.0

ASH FUSION STARTS AT XF = 0.7012 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.970 M

HEIGHT OF THE BURNING ZONE = 2.275 M

TABLE B.8 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 8 (A)

(ΔTHICK=0.69 M)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	501.90	1195.80	305.40	10.7	49.1	7460.7	0.0
3	0.100	495.93	1184.24	305.22	10.7	49.1	7355.3	24.2
5	0.200	490.03	1166.83	305.05	10.7	49.1	7250.8	47.8
7	0.300	484.21	1151.57	304.9[illegible]	10.7	49.1	7147.1	70.6
9	0.400	478.47	1136.46	304.64	10.7	49.1	7044.3	92.7
11	0.500	472.81	1123.51	304.72	10.7	49.1	6942.4	114.1
13	0.600	467.22	1108.70	304.59	10.7	49.1	6841.4	134.8
15	0.700	461.71	1094.05	304.47	10.7	49.1	6741.2	154.9
17	0.800	456.27	1079.55	304.35	10.7	49.1	6641.8	174.2
19	0.900	450.91	1065.19	304.23	10.7	49.1	6543.4	193.0
21	1.000	445.62	1050.98	304.11	10.6	49.1	6445.7	211.0
23	1.100	440.41	1036.92	304.00	10.6	49.1	6349.0	228.5
25	1.200	435.26	1023.01	303.88	10.6	49.1	6253.1	245.3
27	1.300	430.19	1009.25	303.76	10.6	49.1	6158.0	261.4
29	1.400	425.19	995.63	303.65	10.6	49.1	6063.9	277.0
31	1.500	420.27	982.16	303.53	10.6	49.1	5970.5	292.0
33	1.600	415.41	968.84	303.42	10.6	49.1	5878.1	306.3
35	1.700	410.62	955.66	303.31	10.6	49.1	5786.5	320.1
37	1.800	405.91	942.62	303.19	10.6	49.1	5695.7	333.3
39	1.900	401.26	929.73	303.08	10.6	49.1	5605.8	345.9
41	2.000	396.68	916.98	302.97	10.6	49.1	5516.8	358.0
43	2.100	392.17	904.38	302.86	10.6	49.1	5428.6	369.5
45	2.200	387.71	891.91	302.75	10.6	49.1	5341.3	380.5
47	2.300	383.34	879.60	302.64	10.6	49.1	5254.9	390.9
49	2.400	379.03	867.42	302.53	10.6	49.1	5169.3	400.8
51	2.500	374.78	855.38	302.42	10.6	49.1	5084.6	410.2
53	2.600	370.60	843.49	302.31	10.6	49.1	5000.7	419.1
55	2.700	366.48	831.73	302.21	10.6	49.1	4917.7	427.4
57	2.800	362.43	820.12	302.10	10.6	49.1	4835.6	435.3
59	2.900	358.44	808.64	301.99	10.6	49.1	4754.3	442.7
61	3.000	354.51	797.30	301.89	10.6	49.1	4673.9	449.6
63	3.100	350.64	786.10	301.78	10.6	49.1	4594.3	456.0
65	3.200	346.84	775.04	301.67	10.5	49.1	4515.6	462.0
67	3.300	343.09	764.12	301.57	10.5	49.1	4437.8	467.5
69	3.400	339.41	753.33	301.46	10.5	49.1	4360.8	472.5
71	3.500	335.79	742.68	301.36	10.5	49.1	4284.7	477.1
73	3.600	332.22	732.16	301.25	10.5	49.1	4209.5	481.3
75	3.700	328.71	721.78	301.14	10.5	49.1	4135.1	485.1
77	3.800	325.26	711.54	301.04	10.5	49.1	4061.6	488.4
79	3.900	321.87	701.42	300.93	10.5	49.1	3988.9	491.3
81	4.000	318.53	691.44	300.82	10.5	49.1	3917.1	493.8
83	4.100	315.25	681.59	300.71	10.5	49.1	3846.1	495.9
85	4.200	312.03	671.88	300.59	10.5	49.1	3776.0	497.6
87	4.300	308.86	662.29	300.48	10.5	49.1	3706.8	499.0
89	4.400	305.74	652.84	300.35	10.5	49.1	3638.4	499.9
91	4.500	302.68	643.51	300.22	10.5	49.1	3570.9	500.5
93	4.600	299.67	634.31	300.07	10.5	49.1	3504.2	500.8

HEIGHT OF THE COOLING ZONE=4.600M

TABLE 8.5 (E1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 8 (8)
(WTHICK = 1.15 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TL(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELHTL
1	0.000	0.000000	746.00	300.00	300.00	318.00	4.93	25.07	19.08	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.000000	761.04	379.66	329.44	316.57	6.97	25.10	19.10	40.11	12.50	104.6	-133.5	-184.0	124.4
5	0.200	0.012500	775.62	461.83	352.75	316.82	8.60	25.08	19.09	40.11	12.50	204.4	-179.0	-179.2	225.3
7	0.300	0.037500	789.80	421.39	377.09	317.14	10.22	25.06	19.07	40.11	12.50	304.3	-167.4	-174.3	326.1
9	0.400	0.075000	797.04	439.66	401.42	317.45	11.86	25.06	19.05	40.11	12.50	404.2	-142.0	-169.3	426.9
11	0.500	0.125000	807.16	458.65	423.76	317.76	13.52	25.05	19.04	40.11	12.50	504.0	-110.8	-163.7	527.7
13	0.600	0.187500	819.99	501.30	447.00	318.06	16.11	25.08	19.05	40.11	12.50	610.7	-104.1	-155.2	634.4
15	0.700	0.262500	833.21	531.35	471.09	318.35	18.41	25.10	19.07	40.11	12.50	652.2	-100.1	-146.9	740.1
17	0.800	0.350000	839.94	553.07	496.04	318.63	20.55	25.15	19.09	40.11	12.50	698.1	-97.1	-139.9	845.8
19	0.900	0.450000	847.38	571.39	519.27	318.90	22.65	25.15	19.10	40.11	12.50	698.1	-94.5	-133.9	951.5
21	1.000	0.562500	856.44	588.20	540.46	319.15	24.79	25.17	19.12	40.11	12.50	641.4	-91.9	-130.2	1057.2
23	1.100	0.687500	867.17	604.37	561.56	319.40	26.98	25.19	19.13	40.11	12.50	642.9	-89.4	-126.7	1162.9
25	1.200	0.825000	875.80	620.16	581.75	319.64	29.22	25.21	19.15	40.11	12.50	604.4	-86.9	-120.7	1268.6
27	1.300	0.975000	883.74	635.51	601.06	319.88	31.51	25.23	19.16	40.11	12.50	564.2	-84.5	-115.3	1374.3
29	1.400	1.137500	891.01	650.54	619.38	320.00	33.85	25.25	19.18	40.11	12.50	550.7	-82.1	-111.5	1480.0
31	1.500	1.312500	897.61	665.26	636.95	320.30	36.23	25.26	19.19	40.11	12.50	501.7	-79.7	-106.1	1585.7
33	1.600	1.500000	904.55	679.72	653.77	320.50	38.03	25.28	19.20	40.11	12.50	420.7	-78.5	-101.4	1691.4
35	1.700	1.700000	911.81	693.27	669.96	320.69	40.02	25.29	19.20	40.11	12.50	378.5	-76.9	-98.8	1797.1
37	1.800	1.912500	918.40	706.86	685.69	320.87	42.09	25.29	19.20	40.11	12.50	378.5	-75.4	-95.4	1902.8
39	1.900	2.137500	927.19	720.16	700.94	321.04	44.90	25.29	19.20	40.11	12.50	378.5	-73.8	-93.9	2008.5
41	2.000	2.375000	933.76	733.44	715.77	321.20	47.10	25.29	19.20	40.11	12.50	378.5	-72.2	-91.6	2114.2
43	2.100	2.625000	940.09	746.50	730.36	321.36	49.34	25.29	19.19	40.11	12.50	378.5	-70.6	-89.2	2219.9
45	2.200	2.887500	946.30	759.56	744.66	321.51	51.58	25.29	19.19	40.11	12.50	378.5	-69.1	-87.0	2325.6
47	2.300	3.162500	952.42	772.61	758.72	321.66	53.81	25.29	19.18	40.11	12.50	378.5	-67.5	-84.8	2431.3
49	2.400	3.450000	958.29	785.50	772.53	321.81	56.05	25.29	19.18	40.11	12.50	378.5	-66.0	-82.7	2537.0
51	2.500	3.750000	964.01	798.26	786.12	321.95	58.30	25.29	19.18	40.11	12.50	378.5	-64.4	-80.5	2642.7
53	2.600	4.062500	969.64	811.09	799.57	322.09	60.54	25.29	19.18	40.11	12.50	378.5	-62.9	-78.4	2748.4
55	2.700	4.387500	975.12	823.80	812.84	322.22	62.76	25.29	19.17	40.11	12.50	378.5	-61.3	-76.3	2854.1
57	2.800	4.725000	980.46	836.38	825.93	322.35	64.98	25.29	19.17	40.11	12.50	378.5	-59.8	-74.2	2959.8
59	2.900	5.075000	985.76	848.96	838.84	322.48	67.18	25.29	19.17	40.11	12.50	378.5	-58.2	-72.1	3065.5
61	3.000	5.437500	990.83	861.31	851.61	322.60	69.38	25.29	19.17	40.11	12.50	378.5	-56.7	-70.0	3171.2
63	3.100	5.812500	995.83	873.66	864.24	322.72	71.58	25.29	19.16	40.11	12.50	378.5	-55.1	-67.9	3276.9
65	3.200	6.201562	1000.78	885.86	876.74	322.84	73.78	25.29	19.16	40.11	12.50	378.5	-53.6	-65.8	3382.6
67	3.300	6.603125	1005.58	898.07	889.14	322.96	75.98	25.29	19.16	40.11	12.50	378.5	-52.0	-63.7	3488.3
69	3.400	7.017188	1010.17	910.28	901.47	323.07	78.18	25.29	19.16	40.11	12.50	378.5	-50.5	-61.6	3594.0
71	3.500	7.443750	1014.74	922.34	913.72	323.18	80.14	25.29	19.15	40.11	12.50	378.5	-48.9	-59.5	3699.7
73	3.600	7.882812	1019.26	934.39	925.91	323.29	82.55	25.29	19.15	40.11	12.50	378.5	-47.4	-57.4	3805.4
75	3.700	8.334375	1023.59	946.44	938.05	323.39	84.34	25.29	19.15	40.11	12.50	378.5	-45.8	-55.3	3911.1
77	3.800	8.798438	1027.88	958.34	950.11	323.49	86.41	25.29	19.15	40.11	12.50	378.5	-44.3	-53.2	4016.8
79	3.900	9.275000	1032.06	970.24	962.13	323.59	88.47	25.29	19.14	40.11	12.50	378.5	-42.7	-51.1	4122.5
81	4.000	9.764062	1036.19	982.14	974.09	323.69	90.50	25.29	19.14	40.11	12.50	378.5	-41.2	-49.0	4228.2
83	4.100	10.265625	1040.22	993.89	985.99	323.78	92.52	25.29	19.14	40.11	12.50	378.5	-39.6	-46.9	4333.9
85	4.200	10.779688	1044.17	1005.64	997.84	323.87	94.53	25.29	19.14	40.11	12.50	378.5	-38.1	-44.8	4439.6
87	4.300	11.306250	1048.04	1017.39	1009.64	323.96	96.51	25.29	19.14	40.11	12.50	378.5	-36.5	-42.7	4545.3
89	4.400	11.845312	1051.84	1029.14	1021.39	324.05	98.47	25.29	19.13	40.11	12.50	378.5	-35.0	-40.6	4651.0
91	4.500	12.396875	1055.58	1040.89	1033.09	324.14	100.42	25.29	19.13	40.11	12.50	378.5	-33.4	-38.5	4756.7
93	4.600	12.960938	1059.27	1052.64	1044.74	324.22	102.34	25.29	19.13	40.11	12.50	378.5	-31.9	-36.4	4862.4
95	4.700	13.537500	1062.92	1064.39	1056.35	324.31	104.25	25.29	19.13	40.11	12.50	378.5	-30.3	-34.3	4968.1
97	4.800	14.126563	1066.53	1076.14	1067.92	324.39	106.14	25.29	19.13	40.11	12.50	378.5	-28.8	-32.2	5073.8
98	4.850	14.421094	1068.32	1082.01	1073.69	324.43	107.08	24.55	18.00	40.11	12.50	378.5	-28.0	-31.1	5126.7

VM COMBUSTION STARTS AT XF = 0.1713 AND AT HEIGHT (FROM TOP) = 4.850 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 4.850 M

TABLE P.2 (E2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 2 (E)
(WTHICK = 1.15 M)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TL(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELWTL	PC2G	PCO2G
1	0.000	0.17134	0.00000	1000.0	946.8	946.5	324.4	0.0000	0.	106.9	24.5	18.6	40.1	12.5	135.	-406.	-503.	0.	0.	0.
2	0.038	0.16171	0.00000	1067.8	1129.7	969.2	324.3	0.0000	0.	143.3	24.4	18.5	40.1	12.5	1246.	190.	-472.	102.	0.	0.
3	0.076	0.17200	0.00000	1166.0	1016.1	1014.2	324.2	0.0000	0.	151.7	24.3	18.4	40.1	12.5	1297.	1131.	-441.	205.	0.	0.
4	0.114	0.16644	0.00000	1165.8	1154.3	1054.0	324.0	0.0000	0.	167.9	24.1	18.3	40.1	12.5	1345.	1145.	-424.	307.	0.	0.
5	0.152	0.16317	0.00000	1166.0	1182.0	1096.7	323.9	0.0000	0.	181.9	24.1	18.1	40.1	12.5	1396.	1159.	-407.	409.	0.	0.
6	0.190	0.16317	0.00000	1166.0	1211.4	1123.4	323.7	0.0000	0.	197.1	24.0	18.1	40.1	12.5	1447.	1173.	-390.	511.	0.	0.
7	0.228	0.16317	0.00000	1166.0	1230.5	1145.4	323.6	0.0000	0.	212.0	23.9	18.1	40.1	12.5	1498.	1187.	-373.	613.	0.	0.
8	0.266	0.16317	0.00000	1166.0	1245.0	1162.4	323.5	0.0000	0.	226.2	23.8	17.9	40.1	12.5	1549.	1201.	-356.	715.	0.	0.
9	0.304	0.16317	0.00000	1166.0	1257.7	1174.7	323.4	0.0000	0.	240.5	23.7	17.8	40.1	12.5	1600.	1215.	-339.	817.	0.	0.
10	0.342	0.16317	0.00000	1166.0	1268.4	1184.6	323.3	0.0000	0.	254.7	23.6	17.7	40.1	12.5	1651.	1229.	-322.	919.	0.	0.
11	0.380	0.16317	0.00000	1166.0	1277.7	1193.7	323.2	0.0000	0.	269.0	23.5	17.6	40.1	12.5	1702.	1243.	-305.	1021.	0.	0.
12	0.418	0.16317	0.00000	1166.0	1286.1	1201.7	323.1	0.0000	0.	283.2	23.4	17.4	40.2	12.4	1753.	1257.	-288.	1123.	0.	0.
13	0.456	0.16317	0.00000	1166.0	1294.0	1208.7	323.0	0.0000	0.	297.5	23.3	17.3	40.3	12.3	1804.	1271.	-271.	1225.	0.	0.
14	0.494	0.16317	0.00000	1166.0	1301.4	1215.4	322.9	0.0000	0.	311.7	23.2	17.2	40.4	12.2	1855.	1285.	-254.	1327.	0.	0.
15	0.532	0.16317	0.00000	1166.0	1308.4	1221.7	322.8	0.0000	0.	326.0	23.1	17.1	40.5	12.1	1906.	1299.	-237.	1429.	0.	0.
16	0.570	0.16317	0.00000	1166.0	1315.0	1227.7	322.7	0.0000	0.	340.2	23.0	17.0	40.6	12.0	1957.	1313.	-220.	1531.	0.	0.
17	0.608	0.16317	0.00000	1166.0	1321.3	1233.4	322.6	0.0000	0.	354.5	22.9	16.9	40.7	11.9	2008.	1327.	-203.	1633.	0.	0.
18	0.646	0.16317	0.00000	1166.0	1327.3	1238.8	322.5	0.0000	0.	368.7	22.8	16.8	40.8	11.8	2059.	1341.	-186.	1735.	0.	0.
19	0.684	0.16317	0.00000	1166.0	1332.9	1243.9	322.4	0.0000	0.	383.0	22.7	16.7	40.9	11.7	2110.	1355.	-169.	1837.	0.	0.
20	0.722	0.16317	0.00000	1166.0	1338.2	1248.7	322.3	0.0000	0.	397.2	22.6	16.6	41.0	11.6	2161.	1369.	-152.	1939.	0.	0.
21	0.760	0.16317	0.00000	1166.0	1343.2	1253.2	322.2	0.0000	0.	411.5	22.5	16.5	41.1	11.5	2212.	1383.	-135.	2041.	0.	0.
22	0.798	0.16317	0.00000	1166.0	1347.9	1257.5	322.1	0.0000	0.	425.7	22.4	16.4	41.2	11.4	2263.	1397.	-118.	2143.	0.	0.
23	0.836	0.16317	0.00000	1166.0	1352.3	1261.6	322.0	0.0000	0.	440.0	22.3	16.3	41.3	11.3	2314.	1411.	-101.	2245.	0.	0.
24	0.874	0.16317	0.00000	1166.0	1356.5	1265.5	321.9	0.0000	0.	454.2	22.2	16.2	41.4	11.2	2365.	1425.	-84.	2347.	0.	0.
25	0.912	0.16317	0.00000	1166.0	1360.4	1269.2	321.8	0.0000	0.	468.5	22.1	16.1	41.5	11.1	2416.	1439.	-67.	2449.	0.	0.
26	0.950	0.16317	0.00000	1166.0	1364.1	1272.7	321.7	0.0000	0.	482.7	22.0	16.0	41.6	11.0	2467.	1453.	-50.	2551.	0.	0.
27	0.988	0.16317	0.00000	1166.0	1367.6	1276.0	321.6	0.0000	0.	497.0	21.9	15.9	41.7	10.9	2518.	1467.	-33.	2653.	0.	0.
28	1.026	0.16317	0.00000	1166.0	1370.9	1279.1	321.5	0.0000	0.	511.2	21.8	15.8	41.8	10.8	2569.	1481.	-16.	2755.	0.	0.
29	1.064	0.16317	0.00000	1166.0	1374.0	1282.1	321.4	0.0000	0.	525.5	21.7	15.7	41.9	10.7	2620.	1495.	1.	2857.	0.	0.
30	1.102	0.16317	0.00000	1166.0	1377.0	1284.9	321.3	0.0000	0.	539.7	21.6	15.6	42.0	10.6	2671.	1509.	18.	2959.	0.	0.
31	1.140	0.16317	0.00000	1166.0	1379.8	1287.6	321.2	0.0000	0.	554.0	21.5	15.5	42.1	10.5	2722.	1523.	35.	3061.	0.	0.
32	1.178	0.16317	0.00000	1166.0	1382.5	1290.1	321.1	0.0000	0.	568.2	21.4	15.4	42.2	10.4	2773.	1537.	52.	3163.	0.	0.
33	1.216	0.16317	0.00000	1166.0	1385.0	1292.5	321.0	0.0000	0.	582.5	21.3	15.3	42.3	10.3	2824.	1551.	69.	3265.	0.	0.
34	1.254	0.16317	0.00000	1166.0	1387.4	1294.8	320.9	0.0000	0.	596.7	21.2	15.2	42.4	10.2	2875.	1565.	86.	3367.	0.	0.
35	1.292	0.16317	0.00000	1166.0	1389.7	1297.0	320.8	0.0000	0.	611.0	21.1	15.1	42.5	10.1	2926.	1579.	103.	3469.	0.	0.
36	1.330	0.16317	0.00000	1166.0	1391.9	1299.1	320.7	0.0000	0.	625.2	21.0	15.0	42.6	10.0	2977.	1593.	120.	3571.	0.	0.
37	1.368	0.16317	0.00000	1166.0	1394.0	1301.1	320.6	0.0000	0.	639.5	20.9	14.9	42.7	9.9	3028.	1607.	137.	3673.	0.	0.
38	1.406	0.16317	0.00000	1166.0	1396.0	1303.0	320.5	0.0000	0.	653.7	20.8	14.8	42.8	9.8	3079.	1621.	154.	3775.	0.	0.
39	1.444	0.16317	0.00000	1166.0	1397.9	1304.8	320.4	0.0000	0.	668.0	20.7	14.7	42.9	9.7	3130.	1635.	171.	3877.	0.	0.
40	1.482	0.16317	0.00000	1166.0	1399.8	1306.6	320.3	0.0000	0.	682.2	20.6	14.6	43.0	9.6	3181.	1649.	188.	3979.	0.	0.
41	1.520	0.16317	0.00000	1166.0	1401.6	1308.3	320.2	0.0000	0.	696.5	20.5	14.5	43.1	9.5	3232.	1663.	205.	4081.	0.	0.
42	1.558	0.16317	0.00000	1166.0	1403.3	1309.9	320.1	0.0000	0.	710.7	20.4	14.4	43.2	9.4	3283.	1677.	222.	4183.	0.	0.
43	1.596	0.16317	0.00000	1166.0	1404.9	1311.4	320.0	0.0000	0.	725.0	20.3	14.3	43.3	9.3	3334.	1691.	239.	4285.	0.	0.
44	1.634	0.16317	0.00000	1166.0	1406.4	1312.9	319.9	0.0000	0.	739.2	20.2	14.2	43.4	9.2	3385.	1705.	256.	4387.	0.	0.
45	1.672	0.16317	0.00000	1166.0	1407.9	1314.3	319.8	0.0000	0.	753.5	20.1	14.1	43.5	9.1	3436.	1719.	273.	4489.	0.	0.
46	1.710	0.16317	0.00000	1166.0	1409.3	1315.7	319.7	0.0000	0.	767.7	20.0	14.0	43.6	9.0	3487.	1733.	290.	4591.	0.	0.
47	1.748	0.16317	0.00000	1166.0	1410.7	1317.0	319.6	0.0000	0.	782.0	19.9	13.9	43.7	8.9	3538.	1747.	307.	4693.	0.	0.
48	1.786	0.16317	0.00000	1166.0	1412.0	1318.3	319.5	0.0000	0.	796.2	19.8	13.8	43.8	8.8	3589.	1761.	324.	4795.	0.	0.
49	1.824	0.16317	0.00000	1166.0	1413.3	1319.5	319.4	0.0000	0.	810.5	19.7	13.7	43.9	8.7	3640.	1775.	341.	4897.	0.	0.
50	1.862	0.16317	0.00000	1166.0	1414.5	1320.7	319.3	0.0000	0.	824.7	19.6	13.6	44.0	8.6	3691.	1789.	358.	4999.	0.	0.
51	1.900	0.16317	0.00000	1166.0	1415.7	1321.8	319.2	0.0000	0.	839.0	19.5	13.5	44.1	8.5	3742.	1803.	375.	5101.	0.	0.
52	1.938	0.16317	0.00000	1166.0	1416.8	1322.9	319.1	0.0000	0.	853.2	19.4	13.4	44.2	8.4	3793.	1817.	392.	5203.	0.	0.
53	1.976	0.16317	0.00000	1166.0	1417.9	1323.9	319.0	0.0000	0.	867.5	19.3	13.3	44.3	8.3	3844.	1831.	409.	5305.	0.	0.
54	2.014	0.16317	0.00000	1166.0	1418.9	1324.9	318.9	0.0000	0.	881.7	19.2	13.2	44.4	8.2	3895.	1845.	426.	5407.	0.	0.
55	2.052	0.16317	0.00000	1166.0	1419.9	1325.8	318.8	0.0000	0.	896.0	19.1	13.1	44.5	8.1	3946.	1859.	443.	5509.	0.	0.
56	2.090	0.16317	0.00000	1166.0	1420.8	1326.7	318.7	0.0000	0.	910.2	19.0	13.0	44.6	8.0	3997.	1873.	460.	5611.	0.	0.
57	2.128	0.16317	0.00000	1166.0	1421.7	1327.5	318.6	0.0000	0.	924.5	18.9	12.9	44.7	7.9	4048.	1887.	477.	5713.	0.	0.
58	2.166	0.16317	0.00000	1166.0	1422.6	1328.3	318.5	0.0000	0.	938.7	18.8	12.8	44.8	7.8	4099.	1901.	494.	5815.	0.	0.
59	2.204	0.16317	0.00000	1166.0	1423.4	1329.1	318.4	0.0000	0.	953.0	18.7	12.7	44.9	7.7	4150.	1915.	511.	5917.	0.	0.
60	2.242	0.16317	0.00000	1166.0	1424.2	1329.8	318.3	0.0000	0.	967.2	18.6	12.6	45.0	7.6	4201.	1929.	528.	6019.	0.	0.
61	2.280	0.16317	0.00000	1166.0	1424.9	1330.5	318.2	0.0000	0.	981.5	18.5	12.5	45.1	7.5	4252.	1943.	545.	6121.	0.	0.

ASH FUSION STARTS AT XF = 0.7010 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.970 M

HEIGHT OF THE BURNING ZONE = 2.280 M

TABLE B.6 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 6 (B)

(WTHICK = 1.15 M)

RESULTS OF ANALYSIS

I	Z(M.)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	QSG	DELHTL
1	0.000	495.70	1193.70	304.10	10.7	49.1	7458.7	0.0
3	0.100	485.73	1178.14	304.05	10.7	49.1	7353.4	22.0
5	0.200	476.63	1162.73	303.95	10.7	49.1	7248.9	43.4
7	0.300	468.01	1147.48	303.85	10.7	49.1	7145.2	64.1
9	0.400	459.27	1132.37	303.75	10.7	49.1	7042.4	84.1
11	0.500	450.61	1117.42	303.65	10.7	49.1	6940.5	103.5
13	0.600	441.02	1102.61	303.56	10.7	49.1	6839.5	122.2
15	0.700	435.51	1087.96	303.46	10.7	49.1	6739.3	140.3
17	0.800	430.07	1073.46	303.36	10.7	49.1	6639.9	157.8
19	0.900	424.71	1059.10	303.27	10.6	49.1	6541.5	174.6
21	1.000	419.42	1044.89	303.17	10.6	49.1	6443.8	190.9
23	1.100	414.20	1030.83	303.08	10.6	49.1	6347.1	206.5
25	1.200	409.06	1016.92	302.98	10.6	49.1	6251.1	221.6
27	1.300	403.99	1003.16	302.89	10.6	49.1	6156.1	236.0
29	1.400	399.00	989.54	302.79	10.6	49.1	6061.9	249.9
31	1.500	394.08	976.06	302.70	10.6	49.1	5968.5	263.3
33	1.600	389.23	962.74	302.61	10.6	49.1	5876.0	276.0
35	1.700	384.45	949.55	302.51	10.6	49.1	5784.4	288.3
37	1.800	379.74	936.51	302.42	10.6	49.1	5693.6	299.9
39	1.900	375.09	923.62	302.34	10.6	49.1	5603.7	311.1
41	2.000	370.51	910.87	302.25	10.6	49.1	5514.6	321.7
43	2.100	365.99	898.26	302.16	10.6	49.1	5426.4	331.8
45	2.200	361.54	885.79	302.07	10.6	49.1	5339.1	341.4
47	2.300	357.15	873.47	301.98	10.6	49.1	5252.6	350.5
49	2.400	352.82	861.29	301.89	10.6	49.1	5167.0	359.1
51	2.500	348.55	849.25	301.81	10.6	49.1	5082.2	367.2
53	2.600	344.34	837.35	301.72	10.6	49.1	4998.3	374.8
55	2.700	340.19	825.59	301.64	10.6	49.1	4915.2	381.9
57	2.800	336.10	813.97	301.54	10.6	49.1	4833.1	388.6
59	2.900	332.07	802.48	301.46	10.6	49.1	4751.7	394.8
61	3.000	328.09	791.14	301.37	10.5	49.1	4671.3	400.6
63	3.100	324.17	779.94	301.28	10.5	49.1	4591.7	405.9
65	3.200	320.30	768.87	301.20	10.5	49.1	4512.9	410.8
67	3.300	316.48	757.94	301.11	10.5	49.1	4435.0	415.3
69	3.400	312.71	747.15	301.03	10.5	49.1	4357.9	419.3
71	3.500	308.99	736.49	300.94	10.5	49.1	4281.9	422.9
73	3.600	305.32	725.96	300.86	10.5	49.1	4206.6	426.2
75	3.700	301.70	715.56	300.76	10.5	49.1	4132.1	429.0
77	3.800	298.12	705.29	300.69	10.5	49.1	4058.6	431.4
79	3.900	294.59	695.15	300.57	10.5	49.1	3985.8	433.4
81	4.000	291.10	685.13	300.48	10.5	49.1	3914.0	435.1
83	4.100	287.66	675.36	300.38	10.5	49.1	3843.0	436.3
85	4.200	284.25	665.64	300.28	10.5	49.1	3772.8	437.3
87	4.300	280.89	656.04	300.17	10.5	49.1	3703.5	437.8
89	4.400	277.56	646.56	300.05	10.5	49.1	3635.1	438.0

HEIGHT OF THE COOLING ZONE=4.400M

TABLE P.9 (A1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 9 (A)

(TGO = 698 K)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TL(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.00000	698.00	300.00	300.00	316.00	4.93	24.96	18.99	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.00305	709.97	370.25	323.42	317.34	6.70	24.97	19.01	40.11	12.50	17.4	-117.4	-155.1	11.1
5	0.200	0.00625	720.88	401.64	347.31	317.67	8.24	24.98	19.01	40.11	12.50	24.8	-110.7	-154.1	14.7
7	0.300	0.01572	731.70	411.46	369.78	318.00	9.52	24.99	19.00	40.11	12.50	20.4	-111.0	-153.1	14.6
9	0.400	0.03128	746.36	422.97	390.77	318.33	10.64	24.99	18.98	40.11	12.50	19.3	-110.6	-152.1	14.2
11	0.500	0.04375	756.81	435.80	410.51	318.65	12.21	24.99	18.96	40.11	12.50	17.1	-110.7	-151.1	13.9
13	0.600	0.05625	766.38	449.02	429.57	318.96	14.08	24.94	18.96	40.11	12.50	17.0	-110.9	-150.1	13.6
15	0.700	0.06875	774.30	463.02	449.98	319.25	16.19	24.96	18.97	40.11	12.50	23.8	-110.2	-149.1	13.3
17	0.800	0.08125	781.82	477.77	471.77	319.55	18.09	24.98	18.99	40.11	12.50	24.5	-94.0	-148.1	13.0
19	0.900	0.09375	788.07	492.98	491.58	319.85	19.67	24.98	19.00	40.11	12.50	25.7	-99.5	-147.1	12.7
21	1.000	0.10625	793.83	508.78	511.53	320.15	21.64	25.00	19.02	40.11	12.50	25.7	-93.1	-146.1	12.4
23	1.100	0.11875	799.03	525.07	530.65	320.45	23.23	25.02	19.03	40.11	12.50	31.8	-88.3	-145.1	12.1
25	1.200	0.13125	803.71	541.67	548.91	320.67	24.52	25.04	19.04	40.11	12.50	31.7	-78.6	-144.1	11.8
27	1.300	0.14375	808.13	558.46	566.35	320.92	25.62	25.06	19.06	40.11	12.50	31.7	-76.5	-143.1	11.5
29	1.400	0.15625	812.21	575.36	583.01	321.18	26.58	25.08	19.07	40.11	12.50	30.3	-74.4	-142.1	11.2
31	1.500	0.16875	816.21	592.34	599.96	321.43	27.50	25.10	19.08	40.11	12.50	30.3	-72.3	-141.1	10.9
33	1.600	0.18125	820.14	609.37	616.23	321.68	28.36	25.11	19.08	40.11	12.50	30.3	-70.2	-140.1	10.6
35	1.700	0.19375	824.02	626.44	632.86	321.93	29.18	25.13	19.09	40.11	12.50	30.3	-68.2	-139.1	10.3
37	1.800	0.20625	827.86	643.54	648.87	322.18	29.96	25.14	19.09	40.11	12.50	30.3	-66.2	-138.1	10.0
39	1.900	0.21875	831.66	660.67	664.29	322.42	30.71	25.16	19.10	40.11	12.50	30.3	-64.1	-137.1	9.7
41	2.000	0.23125	835.43	677.82	679.14	322.67	31.43	25.17	19.11	40.11	12.50	30.3	-62.1	-136.1	9.4
43	2.100	0.24375	839.17	695.00	693.43	322.92	32.13	25.18	19.12	40.11	12.50	30.3	-60.1	-135.1	9.1
45	2.200	0.25625	842.89	712.19	707.19	323.17	32.80	25.18	19.12	40.11	12.50	30.3	-58.1	-134.1	8.8
47	2.300	0.26875	846.58	729.40	720.44	323.42	33.45	25.18	19.13	40.11	12.50	30.3	-56.1	-133.1	8.5
49	2.400	0.28125	850.26	746.63	733.21	323.67	34.08	25.18	19.12	40.11	12.50	30.3	-54.1	-132.1	8.2
51	2.500	0.29375	853.92	763.87	745.52	323.92	34.70	25.18	19.12	40.11	12.50	30.3	-52.1	-131.1	7.9
53	2.600	0.30625	857.57	781.12	757.40	324.17	35.30	25.18	19.12	40.11	12.50	30.3	-50.1	-130.1	7.6
55	2.700	0.31875	861.21	798.38	768.87	324.42	35.89	25.18	19.11	40.11	12.50	30.3	-48.1	-129.1	7.3
57	2.800	0.33125	864.84	815.65	779.95	324.67	36.47	25.18	19.11	40.11	12.50	30.3	-46.1	-128.1	7.0
59	2.900	0.34375	868.47	832.93	790.66	324.92	37.04	25.18	19.10	40.11	12.50	30.3	-44.1	-127.1	6.7
61	3.000	0.35625	872.09	850.21	801.02	325.17	37.60	25.19	19.10	40.11	12.50	30.3	-42.1	-126.1	6.4
63	3.100	0.36875	875.70	867.50	811.04	325.42	38.15	25.19	19.10	40.11	12.50	30.3	-40.1	-125.1	6.1
65	3.200	0.38125	879.31	884.79	820.74	325.67	38.70	25.19	19.10	40.11	12.50	30.3	-38.1	-124.1	5.8
67	3.300	0.39375	882.92	902.09	830.13	325.92	39.24	25.19	19.09	40.11	12.50	30.3	-36.1	-123.1	5.5
69	3.400	0.40625	886.52	919.39	839.23	326.17	39.77	25.19	19.09	40.11	12.50	30.3	-34.1	-122.1	5.2
71	3.500	0.41875	890.12	936.70	848.04	326.42	40.30	25.19	19.09	40.11	12.50	30.3	-32.1	-121.1	4.9
73	3.600	0.43125	893.72	954.01	856.58	326.67	40.82	25.19	19.09	40.11	12.50	30.3	-30.1	-120.1	4.6
75	3.700	0.44375	897.32	971.33	864.86	326.92	41.33	25.19	19.09	40.11	12.50	30.3	-28.1	-119.1	4.3
77	3.800	0.45625	900.92	988.65	872.89	327.17	41.84	25.19	19.08	40.11	12.50	30.3	-26.1	-118.1	4.0
79	3.900	0.46875	904.52	1005.98	880.69	327.42	42.34	25.19	19.08	40.11	12.50	30.3	-24.1	-117.1	3.7
81	4.000	0.48125	908.12	1023.31	888.27	327.67	42.84	25.19	19.08	40.11	12.50	30.3	-22.1	-116.1	3.4
83	4.100	0.49375	911.72	1040.64	895.64	327.92	43.33	25.19	19.07	40.11	12.50	30.3	-20.1	-115.1	3.1
85	4.200	0.50625	915.32	1057.98	902.81	328.17	43.82	25.19	19.07	40.11	12.50	30.3	-18.1	-114.1	2.8
87	4.300	0.51875	918.92	1075.31	909.80	328.42	44.30	25.19	19.07	40.11	12.50	30.3	-16.1	-113.1	2.5
89	4.400	0.53125	922.52	1092.65	916.62	328.67	44.78	25.19	19.07	40.11	12.50	30.3	-14.1	-112.1	2.2
91	4.500	0.54375	926.12	1109.98	923.27	328.92	45.25	25.19	19.07	40.11	12.50	30.3	-12.1	-111.1	1.9
93	4.600	0.55625	929.72	1127.32	929.77	329.17	45.72	25.19	19.07	40.11	12.50	30.3	-10.1	-110.1	1.6
95	4.700	0.56875	933.32	1144.65	936.13	329.42	46.18	25.19	19.07	40.11	12.50	30.3	-8.1	-109.1	1.3
97	4.800	0.58125	936.92	1161.99	942.34	329.67	46.64	25.19	19.07	40.11	12.50	30.3	-6.1	-108.1	1.0
101	5.000	0.60625	944.12	1196.66	954.36	330.17	47.55	25.19	19.07	40.11	12.50	30.3	-2.1	-106.1	0.4
105	5.200	0.63125	951.32	1231.33	965.99	330.67	48.44	25.19	19.07	40.11	12.50	30.3	1.9	-104.1	-0.2
109	5.400	0.65625	958.52	1266.00	977.24	331.17	49.31	25.19	19.07	40.11	12.50	30.3	5.9	-102.1	-0.8
113	5.600	0.68125	965.72	1300.67	988.13	331.67	50.16	25.19	19.07	40.11	12.50	30.3	9.9	-100.1	-1.4
117	5.800	0.70625	972.92	1335.34	998.67	332.17	50.99	25.19	19.07	40.11	12.50	30.3	13.9	-98.1	-2.0
121	6.000	0.73125	980.12	1370.01	1008.87	332.67	51.80	25.19	19.07	40.11	12.50	30.3	17.9	-96.1	-2.6
125	6.200	0.75625	987.32	1404.68	1018.75	333.17	52.60	25.19	19.07	40.11	12.50	30.3	21.9	-94.1	-3.2
128	6.350	0.77500	992.72	1430.68	1026.00	333.57	53.19	25.19	19.07	40.11	12.50	30.3	24.9	-92.6	-3.6

WH COMBUSTION STARTS AT XF = 0.1729 AND AT HEIGHT (FROM TOP) = 6.350 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 6.350 M

TABLE P.C (A2)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 9 (A)

(TGO = 698 K)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELHTL	PO2G	PCO2G
1	0.000	0.17391	0.00000	1068.7	946.6	946.1	327.0	0.0000	0.	107.3	14.4	18.5	40.1	12.5	88.	-268.	-324.	0.	0.2200	0.2419
2	0.030	0.17391	0.00000	1066.7	1122.6	1066.9	326.9	0.0000	0.	142.3	14.3	18.3	40.1	12.5	1268.	-324.	-324.	108.	0.2200	0.2419
3	0.090	0.17391	0.00000	1062.3	1117.4	1014.0	326.7	0.0000	0.	165.0	14.1	18.2	40.1	12.5	1268.	-324.	-324.	251.	0.2200	0.2419
4	0.150	0.17391	0.00000	1058.3	1153.7	1050.7	326.6	0.0000	0.	179.1	14.0	18.2	40.1	12.5	1268.	-324.	-324.	451.	0.2200	0.2419
5	0.210	0.17391	0.00000	1054.6	1117.7	1087.7	326.5	0.0000	0.	193.4	13.9	18.1	40.1	12.5	1268.	-324.	-324.	678.	0.2200	0.2419
6	0.270	0.17391	0.00000	1051.1	1100.3	1111.1	326.4	0.0000	0.	207.5	13.8	18.0	40.1	12.5	1268.	-324.	-324.	930.	0.2200	0.2419
7	0.330	0.17391	0.00000	1047.9	1093.7	1128.7	326.3	0.0000	0.	221.5	13.7	17.9	40.1	12.5	1268.	-324.	-324.	1208.	0.2200	0.2419
8	0.390	0.17391	0.00000	1044.9	1087.7	1141.1	326.2	0.0000	0.	235.4	13.6	17.8	40.1	12.5	1268.	-324.	-324.	1511.	0.2200	0.2419
9	0.450	0.17391	0.00000	1042.1	1082.0	1150.7	326.1	0.0000	0.	249.2	13.5	17.7	40.1	12.5	1268.	-324.	-324.	1838.	0.2200	0.2419
10	0.510	0.17391	0.00000	1039.5	1076.6	1158.7	326.0	0.0000	0.	262.9	13.4	17.6	40.1	12.5	1268.	-324.	-324.	2189.	0.2200	0.2419
11	0.570	0.17391	0.00000	1037.0	1071.5	1165.9	325.9	0.0000	0.	276.3	13.3	17.5	40.1	12.5	1268.	-324.	-324.	2563.	0.2200	0.2419
12	0.630	0.17391	0.00000	1034.7	1066.7	1172.4	325.8	0.0000	0.	289.6	13.2	17.4	40.1	12.5	1268.	-324.	-324.	2958.	0.2200	0.2419
13	0.690	0.17391	0.00000	1032.5	1062.2	1178.3	325.7	0.0000	0.	302.7	13.1	17.3	40.1	12.5	1268.	-324.	-324.	3374.	0.2200	0.2419
14	0.750	0.17391	0.00000	1030.5	1058.0	1183.6	325.6	0.0000	0.	315.6	13.0	17.2	40.1	12.5	1268.	-324.	-324.	3810.	0.2200	0.2419
15	0.810	0.17391	0.00000	1028.6	1054.1	1188.4	325.5	0.0000	0.	328.3	12.9	17.1	40.1	12.5	1268.	-324.	-324.	4264.	0.2200	0.2419
16	0.870	0.17391	0.00000	1026.8	1050.5	1192.7	325.4	0.0000	0.	340.8	12.8	17.0	40.1	12.5	1268.	-324.	-324.	4736.	0.2200	0.2419
17	0.930	0.17391	0.00000	1025.2	1047.2	1196.6	325.3	0.0000	0.	353.2	12.7	16.9	40.1	12.5	1268.	-324.	-324.	5225.	0.2200	0.2419
18	0.990	0.17391	0.00000	1023.7	1044.2	1200.1	325.2	0.0000	0.	365.4	12.6	16.8	40.1	12.5	1268.	-324.	-324.	5730.	0.2200	0.2419
19	1.050	0.17391	0.00000	1022.3	1041.5	1203.3	325.1	0.0000	0.	377.4	12.5	16.7	40.1	12.5	1268.	-324.	-324.	6251.	0.2200	0.2419
20	1.110	0.17391	0.00000	1021.1	1039.1	1206.2	325.0	0.0000	0.	389.3	12.4	16.6	40.1	12.5	1268.	-324.	-324.	6787.	0.2200	0.2419
21	1.170	0.17391	0.00000	1020.0	1037.0	1208.7	324.9	0.0000	0.	401.0	12.3	16.5	40.1	12.5	1268.	-324.	-324.	7338.	0.2200	0.2419
22	1.230	0.17391	0.00000	1019.1	1035.2	1210.9	324.8	0.0000	0.	412.5	12.2	16.4	40.1	12.5	1268.	-324.	-324.	7902.	0.2200	0.2419
23	1.290	0.17391	0.00000	1018.3	1033.7	1212.8	324.7	0.0000	0.	423.9	12.1	16.3	40.1	12.5	1268.	-324.	-324.	8479.	0.2200	0.2419
24	1.350	0.17391	0.00000	1017.6	1032.4	1214.4	324.6	0.0000	0.	435.1	12.0	16.2	40.1	12.5	1268.	-324.	-324.	9067.	0.2200	0.2419
25	1.410	0.17391	0.00000	1017.0	1031.2	1215.8	324.5	0.0000	0.	446.1	11.9	16.1	40.1	12.5	1268.	-324.	-324.	9665.	0.2200	0.2419
26	1.470	0.17391	0.00000	1016.5	1030.2	1217.0	324.4	0.0000	0.	457.0	11.8	16.0	40.1	12.5	1268.	-324.	-324.	10273.	0.2200	0.2419
27	1.530	0.17391	0.00000	1016.1	1029.4	1218.0	324.3	0.0000	0.	467.8	11.7	15.9	40.1	12.5	1268.	-324.	-324.	10890.	0.2200	0.2419
28	1.590	0.17391	0.00000	1015.8	1028.8	1218.8	324.2	0.0000	0.	478.5	11.6	15.8	40.1	12.5	1268.	-324.	-324.	11515.	0.2200	0.2419
29	1.650	0.17391	0.00000	1015.6	1028.4	1219.4	324.1	0.0000	0.	489.1	11.5	15.7	40.1	12.5	1268.	-324.	-324.	12147.	0.2200	0.2419
30	1.710	0.17391	0.00000	1015.5	1028.1	1219.8	324.0	0.0000	0.	499.6	11.4	15.6	40.1	12.5	1268.	-324.	-324.	12785.	0.2200	0.2419
31	1.770	0.17391	0.00000	1015.4	1028.0	1220.0	323.9	0.0000	0.	510.0	11.3	15.5	40.1	12.5	1268.	-324.	-324.	13427.	0.2200	0.2419
32	1.830	0.17391	0.00000	1015.4	1028.0	1220.1	323.8	0.0000	0.	520.3	11.2	15.4	40.1	12.5	1268.	-324.	-324.	14072.	0.2200	0.2419
33	1.890	0.17391	0.00000	1015.5	1028.1	1220.0	323.7	0.0000	0.	530.5	11.1	15.3	40.1	12.5	1268.	-324.	-324.	14719.	0.2200	0.2419
34	1.950	0.17391	0.00000	1015.6	1028.4	1219.8	323.6	0.0000	0.	540.6	11.0	15.2	40.1	12.5	1268.	-324.	-324.	15367.	0.2200	0.2419
35	2.010	0.17391	0.00000	1015.8	1028.8	1219.4	323.5	0.0000	0.	550.5	10.9	15.1	40.1	12.5	1268.	-324.	-324.	16015.	0.2200	0.2419
36	2.070	0.17391	0.00000	1016.1	1029.4	1218.8	323.4	0.0000	0.	560.4	10.8	15.0	40.1	12.5	1268.	-324.	-324.	16662.	0.2200	0.2419
37	2.130	0.17391	0.00000	1016.5	1030.2	1218.0	323.3	0.0000	0.	570.2	10.7	14.9	40.1	12.5	1268.	-324.	-324.	17307.	0.2200	0.2419
38	2.190	0.17391	0.00000	1017.0	1031.2	1217.0	323.2	0.0000	0.	579.9	10.6	14.8	40.1	12.5	1268.	-324.	-324.	17949.	0.2200	0.2419
39	2.250	0.17391	0.00000	1017.6	1032.4	1215.8	323.1	0.0000	0.	589.5	10.5	14.7	40.1	12.5	1268.	-324.	-324.	18587.	0.2200	0.2419
40	2.310	0.17391	0.00000	1018.3	1033.7	1214.4	323.0	0.0000	0.	599.0	10.4	14.6	40.1	12.5	1268.	-324.	-324.	19220.	0.2200	0.2419
41	2.370	0.17391	0.00000	1019.1	1035.2	1212.8	322.9	0.0000	0.	608.4	10.3	14.5	40.1	12.5	1268.	-324.	-324.	19847.	0.2200	0.2419
42	2.430	0.17391	0.00000	1020.0	1037.0	1210.9	322.8	0.0000	0.	617.7	10.2	14.4	40.1	12.5	1268.	-324.	-324.	20466.	0.2200	0.2419
43	2.490	0.17391	0.00000	1021.1	1039.1	1208.7	322.7	0.0000	0.	626.9	10.1	14.3	40.1	12.5	1268.	-324.	-324.	21076.	0.2200	0.2419
44	2.550	0.17391	0.00000	1022.3	1041.5	1206.2	322.6	0.0000	0.	636.0	10.0	14.2	40.1	12.5	1268.	-324.	-324.	21677.	0.2200	0.2419
45	2.610	0.17391	0.00000	1023.7	1044.2	1203.3	322.5	0.0000	0.	645.0	9.9	14.1	40.1	12.5	1268.	-324.	-324.	22268.	0.2200	0.2419
46	2.670	0.17391	0.00000	1025.2	1047.2	1200.1	322.4	0.0000	0.	653.9	9.8	14.0	40.1	12.5	1268.	-324.	-324.	22847.	0.2200	0.2419
47	2.730	0.17391	0.00000	1026.8	1050.5	1196.6	322.3	0.0000	0.	662.7	9.7	13.9	40.1	12.5	1268.	-324.	-324.	23411.	0.2200	0.2419
48	2.790	0.17391	0.00000	1028.6	1054.1	1192.7	322.2	0.0000	0.	671.5	9.6	13.8	40.1	12.5	1268.	-324.	-324.	23958.	0.2200	0.2419
49	2.850	0.17391	0.00000	1030.5	1058.0	1188.4	322.1	0.0000	0.	680.2	9.5	13.7	40.1	12.5	1268.	-324.	-324.	24487.	0.2200	0.2419
50	2.910	0.17391	0.00000	1032.5	1062.2	1183.6	322.0	0.0000	0.	688.8	9.4	13.6	40.1	12.5	1268.	-324.	-324.	24995.	0.2200	0.2419
51	2.970	0.17391	0.00000	1034.7	1066.7	1178.3	321.9	0.0000	0.	697.3	9.3	13.5	40.1	12.5	1268.	-324.	-324.	25480.	0.2200	0.2419
52	3.030	0.17391	0.00000	1037.0	1071.5	1172.4	321.8	0.0000	0.	705.7	9.2	13.4	40.1	12.5	1268.	-324.	-324.	25939.	0.2200	0.2419
53	3.090	0.17391	0.00000	1039.5	1076.6	1165.9	321.7	0.0000	0.	714.0	9.1	13.3	40.1	12.5	1268.	-324.	-324.	26370.	0.2200	0.2419
54	3.150	0.17391	0.00000	1042.1	1082.0	1158.7	321.6	0.0000	0.	722.2	9.0	13.2	40.1	12.5	1268.	-324.	-324.	26770.	0.2200	0.2419
55	3.210	0.17391	0.00000	1044.9	1087.7	1150.7	321.5	0.0000	0.	730.3	8.9	13.1	40.1	12.5	1268.	-324.	-324.	27136.	0.2200	0.2419
56	3.270	0.17391	0.00000	1047.9	1093.7	1141.1	321.4	0.0000	0.	738.3	8.8	13.0	40.1	12.5	1268.	-324.	-324.	27466.	0.2200	0.2419
57	3.330	0.17391	0.00000	1051.1	1100.3	1128.7	321.3	0.0000	0.	746.2	8.7	12.9	40.1	12.5	1268.	-324.	-324.	27758.	0.2200	0.2419
58	3.390	0.17391	0.00000	1054.6	1107.7	1111.1	321.2	0.0000	0.	754.0	8.6	12.8	40.1	12.5	1268.	-324.	-324.	28010.	0.2200	0.2419
59	3.450	0.17391	0.00000	1058.3	1117.7	1087.7	321.1	0.0000	0.	761.7	8.5	12.7	40.1	12.5	1268.	-324.	-324.	28220.	0.2200	0.2419
60	3.510	0.17391	0.00000	1062.3	1128.7	1050.7	321.0	0.0000	0.	769.3	8.4	12.6	40.1	12.5	1268.	-324.	-324.	28384.	0.2200	0.2419
61	3.570	0.17391	0.00000	1066.7	1141.0	1014.0	320.9	0.0000	0.	776.8	8.3	12.5	40.1	12.5	1268.	-324.	-324.	28500.	0.2200	0.2419
62	3.630	0.17391	0.00000	1071.5	1155.0	1000.0	320.8	0.0000	0.	784.2	8.2	12.4	40.1	12.5	1268.	-324.	-324.	28564.	0.2200	0.2419
63	3.690	0.17391	0.00000	1077.0	1171.0	1000.0	320.7	0.0000	0.	791.5	8.1	12.3	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
64	3.750	0.17391	0.00000	1083.3	1189.0	1000.0	320.6	0.0000	0.	798.7	8.0	12.2	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
65	3.810	0.17391	0.00000	1090.8	1209.0	1000.0	320.5	0.0000	0.	805.8	7.9	12.1	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
66	3.870	0.17391	0.00000	1099.6	1232.0	1000.0	320.4	0.0000	0.	812.8	7.8	12.0	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
67	3.930	0.17391	0.00000	1110.0	1259.0	1000.0	320.3	0.0000	0.	819.7	7.7	11.9	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
68	3.990	0.17391	0.00000	1122.5	1290.0	1000.0	320.2	0.0000	0.	826.5	7.6	11.8	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
69	4.050	0.17391	0.00000	1138.0	1328.0	1000.0	320.1	0.0000	0.	833.2	7.5	11.7	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
70	4.110	0.17391	0.00000	1157.4	1375.0	1000.0	320.0	0.0000	0.	839.8	7.4	11.6	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
71	4.170	0.17391	0.00000	1182.0	1435.0	1000.0	319.9	0.0000	0.	846.3	7.3	11.5	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
72	4.230	0.17391	0.00000	1214.1	1513.0	1000.0	319.8	0.0000	0.	852.7	7.2	11.4	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
73	4.290	0.17391	0.00000	1257.0	1617.0	1000.0	319.7	0.0000	0.	859.0	7.1	11.3	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
74	4.350	0.17391	0.00000	1317.0	1761.0	1000.0	319.6	0.0000	0.	865.2	7.0	11.2	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
75	4.410	0.17391	0.00000	1410.0	1986.0	1000.0	319.5	0.0000	0.	871.3	6.9	11.1	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
76	4.470	0.17391	0.00000	1564.0	2350.0	1000.0	319.4	0.0000	0.	877.3	6.8	11.0	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
77	4.530	0.17391	0.00000	1844.0	3000.0	1000.0	319.3	0.0000	0.	883.2	6.7	10.9	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
78	4.590	0.17391	0.00000	2400.0	4300.0	1000.0	319.2	0.0000	0.	889.0	6.6	10.8	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
79	4.650	0.17391	0.00000	3900.0	7500.0	1000.0	319.1	0.0000	0.	894.7	6.5	10.7	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
80	4.710	0.17391	0.00000	7500.0	15000.0	1000.0	319.0	0.0000	0.	900.3	6.4	10.6	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
81	4.770	0.17391	0.00000	15000.0	30000.0	1000.0	318.9	0.0000	0.	905.8	6.3	10.5	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
82	4.830	0.17391	0.00000	30000.0	60000.0	1000.0	318.8	0.0000	0.	911.2	6.2	10.4	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
83	4.890	0.17391	0.00000	60000.0	120000.0	1000.0	318.7	0.0000	0.	916.5	6.1	10.3	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
84	4.950	0.17391	0.00000	120000.0	240000.0	1000.0	318.6	0.0000	0.	921.7	6.0	10.2	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
85	5.010	0.17391	0.00000	240000.0	480000.0	1000.0	318.5	0.0000	0.	926.8	5.9	10.1	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
86	5.070	0.17391	0.00000	480000.0	960000.0	1000.0	318.4	0.0000	0.	931.8	5.8	10.0	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
87	5.130	0.17391	0.00000	960000.0	1920000.0	1000.0	318.3	0.0000	0.	936.7	5.7	9.9	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
88	5.190	0.17391	0.00000	1920000.0	3840000.0	1000.0	318.2	0.0000	0.	941.5	5.6	9.8	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
89	5.250	0.17391	0.00000	3840000.0	7680000.0	1000.0	318.1	0.0000	0.	946.2	5.5	9.7	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
90	5.310	0.17391	0.00000	7680000.0	15360000.0	1000.0	318.0	0.0000	0.	950.8	5.4	9.6	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
91	5.370	0.17391	0.00000	15360000.0	30720000.0	1000.0	317.9	0.0000	0.	955.4	5.3	9.5	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
92	5.430	0.17391	0.00000	30720000.0	61440000.0	1000.0	317.8	0.0000	0.	959.9	5.2	9.4	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
93	5.490	0.17391	0.00000	61440000.0	122880000.0	1000.0	317.7	0.0000	0.	964.3	5.1	9.3	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
94	5.550	0.17391	0.00000	122880000.0	245760000.0	1000.0	317.6	0.0000	0.	968.6	5.0	9.2	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
95	5.610	0.17391	0.00000	245760000.0	491520000.0	1000.0	317.5	0.0000	0.	972.8	4.9	9.1	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
96	5.670	0.17391	0.00000	491520000.0	983040000.0	1000.0	317.4	0.0000	0.	977.0	4.8	9.0	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
97	5.730	0.17391	0.00000	983040000.0	1966080000.0	1000.0	317.3	0.0000	0.	981.1	4.7	8.9	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
98	5.790	0.17391	0.00000	1966080000.0	3932160000.0	1000.0	317.2	0.0000	0.	985.1	4.6	8.8	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
99	5.850	0.17391	0.00000	3932160000.0	7864320000.0	1000.0	317.1	0.0000	0.	989.0	4.5	8.7	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419
100	5.910	0.17391	0.00000	7864320000.0	15728640000.0	1000.0	317.0	0.0000	0.	992.9	4.4	8.6	40.1	12.5	1268.	-324.	-324.	28574.	0.2200	0.2419

ASH FUSION STARTS AT XF = 0.6987 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.970 M

HEIGHT OF THE BURNING ZONE = 2.290 M

TABLE P .9 (A3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 9 (A)

(TGO = 698 K)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	Tw(K)	HSG	ASCZ	GSG	DELHTL
1	0.000	[illegible]	1181.70	302.60	10.0	46.2	8237.9	0.0
2	[illegible]	[illegible]	1173.25	[illegible]	10.0	46.2	8181.5	6.1
3	[illegible]	[illegible]	1164.03	[illegible]	10.0	46.2	8125.1	12.1
4	[illegible]	[illegible]	1150.45	[illegible]	10.0	46.2	8069.1	17.8
5	[illegible]	[illegible]	1142.12	[illegible]	10.0	46.2	8013.2	23.4
6	[illegible]	[illegible]	1133.81	[illegible]	10.0	46.2	7957.5	28.7
7	[illegible]	[illegible]	1131.35	[illegible]	10.0	46.2	7902.0	33.9
8	[illegible]	[illegible]	1123.13	[illegible]	10.0	46.2	7846.7	38.9
9	[illegible]	[illegible]	1115.13	[illegible]	10.0	46.2	7791.6	43.7
10	[illegible]	[illegible]	1107.37	[illegible]	10.0	46.2	7736.7	48.3
11	[illegible]	[illegible]	1099.85	[illegible]	10.0	46.2	7681.9	52.7
12	[illegible]	[illegible]	1092.58	[illegible]	10.0	46.2	7627.4	56.9
13	[illegible]	[illegible]	1085.56	[illegible]	10.0	46.2	7573.0	60.9
14	[illegible]	[illegible]	1078.80	[illegible]	10.0	46.2	7518.9	64.8
15	[illegible]	[illegible]	1072.30	[illegible]	10.0	46.2	7464.9	68.5
16	[illegible]	[illegible]	1066.06	[illegible]	10.0	46.2	7411.1	71.9
17	[illegible]	[illegible]	1060.09	[illegible]	10.0	46.2	7357.6	75.2
18	[illegible]	[illegible]	1054.39	[illegible]	10.0	46.2	7304.2	78.4
19	[illegible]	[illegible]	1048.96	[illegible]	10.0	46.2	7251.0	81.3
20	[illegible]	[illegible]	1043.81	[illegible]	10.0	46.2	7197.9	84.1
21	[illegible]	[illegible]	1038.94	[illegible]	10.0	46.2	7145.1	86.7
22	[illegible]	[illegible]	1034.35	[illegible]	10.0	46.2	7092.5	89.1
23	[illegible]	[illegible]	1030.06	[illegible]	10.0	46.2	7040.1	91.4
24	[illegible]	[illegible]	1026.06	[illegible]	10.0	46.2	6987.8	93.4
25	[illegible]	[illegible]	1022.36	[illegible]	10.0	46.2	6935.8	95.3
26	[illegible]	[illegible]	1018.96	[illegible]	10.0	46.2	6883.9	97.1
27	[illegible]	[illegible]	1015.87	[illegible]	10.0	46.2	6832.2	98.6
28	[illegible]	[illegible]	1013.09	[illegible]	10.0	46.2	6780.7	100.0
29	[illegible]	[illegible]	1010.62	[illegible]	10.0	46.2	6729.4	101.1
30	[illegible]	[illegible]	1008.47	[illegible]	10.0	46.2	6678.3	102.2
31	[illegible]	[illegible]	1006.64	[illegible]	10.0	46.2	6627.4	103.2
32	[illegible]	[illegible]	1005.13	[illegible]	10.0	46.2	6576.7	103.9
33	[illegible]	[illegible]	1003.94	[illegible]	10.0	46.2	6526.2	104.5
34	[illegible]	[illegible]	1003.08	[illegible]	10.0	46.2	6475.9	104.9
35	1.500	715.12	907.92	300.00	10.5	49.2	6376.0	105.3

HEIGHT OF THE COOLING ZONE=1.750M

TABLE P.9 (B1)

TITLE:SIMULATION OF LIME SHAFT KILN
STITLE:PREHEATING-CUM-DEVOLATILIZATION ZONE

INPUT DATA FOR SET NO. 9 (B)

(TGO = 798 K)

RESULTS OF ANALYSIS

I	Z(M)	XF	TG(I)	TF(I)	TS(I)	TW(K)	HFS	HFG	HSG	ASPZ	AFPZ	QFS	QFG	QSG	DELMTL
1	0.000	0.00000	798.00	300.00	300.00	318.00	4.93	25.19	15.17	40.11	12.50	0.0	0.0	0.0	0.0
3	0.100	0.00000	512.36	300.00	300.00	320.56	7.26	25.22	15.19	40.11	12.50	237.0	-143.5	-206.6	140.5
5	0.200	0.00000	419.63	300.00	300.96	321.12	9.17	25.22	15.18	40.11	12.50	295.4	-143.1	-199.6	302.5
7	0.300	0.00000	448.37	300.00	301.51	321.41	11.07	25.21	15.16	40.11	12.50	327.9	-138.0	-193.1	466.0
9	0.400	0.00000	465.88	300.00	302.00	321.91	12.99	25.20	15.15	40.11	12.50	338.9	-134.9	-187.0	632.4
11	0.500	0.00000	479.64	300.00	302.46	322.26	14.94	25.18	15.13	40.11	12.50	355.5	-134.6	-181.3	798.5
13	0.600	0.00000	490.15	300.00	302.90	322.65	17.92	25.21	15.15	40.11	12.50	605.3	-122.7	-175.4	952.9
15	0.700	0.00000	497.97	300.00	303.32	323.01	20.56	25.24	15.17	40.11	12.50	727.8	-110.9	-169.9	1123.9
17	0.800	0.00000	502.45	300.00	303.73	323.36	23.07	25.26	15.19	40.11	12.50	764.9	-112.2	-162.2	1298.9
19	0.900	0.00000	505.30	300.00	304.13	323.69	25.59	25.29	15.20	40.11	12.50	763.2	-109.1	-155.8	1475.4
21	1.000	0.00000	507.51	300.00	304.52	324.02	28.16	25.31	15.22	40.11	12.50	746.6	-108.8	-148.8	1656.9
23	1.100	0.00000	509.34	300.00	304.91	324.34	30.82	25.33	15.24	40.11	12.50	725.6	-114.1	-144.1	1839.4
25	1.200	0.00000	511.02	300.00	305.30	324.65	33.55	25.35	15.25	40.11	12.50	704.0	-117.7	-139.7	2025.1
27	1.300	0.00000	512.71	300.00	305.71	324.96	36.36	25.36	15.27	40.11	12.50	682.6	-119.7	-135.6	2215.2
29	1.400	0.00000	514.52	300.00	306.13	325.27	39.34	25.39	15.27	40.11	12.50	593.9	-96.0	-128.7	2408.9
31	1.500	0.00000	516.55	300.00	306.58	325.59	42.55	25.39	15.27	40.11	12.50	425.5	-95.7	-121.2	2597.3
33	1.600	0.00000	518.91	300.00	307.06	325.94	46.04	25.40	15.27	40.11	12.50	357.5	-94.0	-118.0	2795.8
35	1.700	0.00000	521.80	300.00	307.60	326.32	49.90	25.40	15.27	40.11	12.50	327.6	-92.1	-114.9	3199.1
37	1.800	0.00000	525.37	300.00	308.22	326.76	54.27	25.40	15.26	40.11	12.50	312.6	-89.3	-111.6	3399.1
39	1.900	0.00000	529.82	300.00	308.94	327.27	59.29	25.39	15.26	40.11	12.50	301.7	-88.3	-108.3	3603.7
41	2.000	0.00911	535.37	300.00	309.80	327.87	65.14	25.39	15.25	40.11	12.50	300.0	-84.1	-104.8	3810.3
43	2.100	0.03174	542.27	300.27	310.85	328.61	71.92	25.39	15.25	40.11	12.50	293.8	-82.5	-101.3	4018.7
45	2.200	0.05716	550.79	301.51	312.15	329.55	79.75	25.39	15.24	40.11	12.50	286.1	-80.7	-97.6	4229.0
47	2.300	0.08524	561.23	303.89	313.79	330.76	88.74	25.39	15.24	40.11	12.50	279.3	-78.9	-93.9	4441.1
49	2.400	0.11576	573.94	307.53	315.87	332.32	99.02	25.39	15.24	40.11	12.50	272.3	-77.2	-90.4	4654.7
51	2.500	0.14826	589.31	312.61	318.53	334.32	110.74	25.39	15.24	40.11	12.50	265.3	-75.5	-86.9	4870.1
53	2.600	0.18251	607.79	319.34	322.00	336.89	124.07	25.39	15.23	40.11	12.50	258.5	-73.9	-83.5	5087.1
55	2.700	0.21827	629.93	328.04	326.57	340.22	139.21	25.39	15.23	40.11	12.50	252.0	-72.4	-80.3	5305.7
57	2.800	0.25537	656.42	339.09	332.62	344.58	156.39	25.39	15.23	40.11	12.50	245.7	-71.0	-77.3	5525.7
59	2.900	0.29370	688.07	352.98	340.64	350.36	175.91	25.39	15.22	40.11	12.50	239.3	-69.4	-74.5	5747.5
61	3.000	0.33324	725.92	370.31	351.32	357.99	198.16	25.39	15.22	40.11	12.50	233.2	-67.9	-71.8	5970.7
63	3.100	0.37401	771.08	391.87	365.66	368.04	223.66	25.39	15.21	40.11	12.50	227.2	-66.5	-69.3	6195.3
65	3.200	0.41611	824.77	418.67	385.06	381.21	253.09	25.39	15.21	40.11	12.50	221.3	-65.2	-66.8	6421.2
67	3.300	0.45971	888.46	452.12	411.14	400.78	287.33	25.39	15.21	40.11	12.50	215.5	-63.9	-64.5	6648.6
69	3.400	0.50507	963.59	493.13	446.78	427.91	327.51	25.39	15.21	40.11	12.50	209.9	-62.6	-62.4	6877.3
71	3.500	0.55260	1051.09	544.08	495.04	465.91	374.12	25.39	15.20	40.11	12.50	204.3	-61.4	-60.4	7107.5
73	3.600	0.60297	1152.97	607.35	559.64	519.04	428.52	25.39	15.20	40.11	12.50	198.8	-60.1	-58.5	7338.5
75	3.700	0.65719	1271.35	686.81	646.17	591.17	492.39	25.39	15.20	40.11	12.50	193.4	-59.0	-56.8	7571.0
77	3.800	0.71688	1408.32	787.98	761.60	687.29	568.74	25.39	15.20	40.11	12.50	188.0	-57.8	-55.3	7804.7
79	3.900	0.78448	1566.85	917.67	915.41	814.32	660.32	25.39	15.19	40.11	12.50	182.8	-56.6	-53.9	8039.7
80	3.950	0.82323	1658.30	1000.74	1017.64	907.47	767.60	24.65	15.67	40.11	12.50	177.6	-55.4	-52.6	8275.4

VM COMBUSTION STARTS AT XF = 0.1732 AND AT HEIGHT (FROM TOP) = 3.950 M

HEIGHT OF THE PREHEATING-CUM-DEVOLATILIZATION ZONE = 3.950 M

TABLE P.9 (S.2)

SIMULATION OF ... SHAFT KILN
ANALYSIS OF THE BURNING ZONE

INPUT DATA FOR SET NO. 9 (S)

(TGC = 795 K)

RESULTS OF ANALYSIS

I	Z(M)	XF	XS	TG(K)	TF(K)	TS(K)	TW(K)	RSHLHD	DELSHT	HFS	HFG	HSG	ASBZ	AFBZ	QFS	QFG	QSG	DELNTL	PCZ6	PCO2B
1	0.000	0.17323	0.00000	1113.3	950.7	967.6	329.5	0.00000	0.	107.4	24.0	18.6	40.1	12.5	165.	-555.	-0555.	0.	0.00000	24.2
2	0.035	0.18941	0.00000	1113.3	1168.4	971.4	329.5	0.00000	0.	142.9	24.0	18.5	40.1	12.5	1257.	42.	-0555.	113.	0.00000	24.2
3	0.105	0.21761	0.00000	1111.3	1164.0	1107.9	329.5	0.00000	0.	142.9	24.0	18.4	40.1	12.5	879.	17.	-0555.	113.	0.00000	24.2
4	0.175	0.24579	0.00000	1111.3	1106.1	1107.9	329.5	0.00000	0.	142.9	24.0	18.4	40.1	12.5	879.	-1.	-0555.	113.	0.00000	24.2
5	0.245	0.27397	0.00000	1110.9	1127.1	1107.6	329.5	0.00000	0.	183.3	24.0	18.4	40.1	12.5	919.	0.	-0555.	113.	0.00000	24.2
6	0.315	0.30215	0.00000	1110.9	1210.4	1103.3	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	919.	0.	-0555.	113.	0.00000	24.2
7	0.385	0.33033	0.00000	1110.1	1241.6	1107.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
8	0.455	0.35851	0.00000	1109.4	1251.8	1107.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
9	0.525	0.38669	0.00000	1109.4	1251.8	1173.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
10	0.595	0.41487	0.00000	1109.4	1251.8	1174.3	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
11	0.665	0.44305	0.00000	1107.7	1251.8	1174.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
12	0.735	0.47123	0.00000	1107.7	1251.8	1175.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
13	0.805	0.49941	0.00000	1106.3	1251.8	1176.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
14	0.875	0.52759	0.00000	1106.3	1251.8	1176.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
15	0.945	0.55577	0.00000	1106.3	1251.8	1177.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
16	1.015	0.58395	0.00000	1106.3	1251.8	1178.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
17	1.085	0.61213	0.00000	1106.3	1251.8	1178.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
18	1.155	0.64031	0.00000	1106.3	1251.8	1179.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
19	1.225	0.66849	0.00000	1106.3	1251.8	1180.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
20	1.295	0.69667	0.00000	1106.3	1251.8	1180.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
21	1.365	0.72485	0.00000	1106.3	1251.8	1181.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
22	1.435	0.75303	0.00000	1106.3	1251.8	1182.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
23	1.505	0.78121	0.00000	1106.3	1251.8	1182.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
24	1.575	0.80939	0.00000	1106.3	1251.8	1183.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
25	1.645	0.83757	0.00000	1106.3	1251.8	1184.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
26	1.715	0.86575	0.00000	1106.3	1251.8	1184.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
27	1.785	0.89393	0.00000	1106.3	1251.8	1185.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
28	1.855	0.92211	0.00000	1106.3	1251.8	1186.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
29	1.925	0.95029	0.00000	1106.3	1251.8	1186.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
30	1.995	0.97847	0.00000	1106.3	1251.8	1187.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
31	2.065	1.00000	0.00000	1106.3	1251.8	1188.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
32	2.135	1.00000	0.00000	1106.3	1251.8	1188.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
33	2.205	1.00000	0.00000	1106.3	1251.8	1189.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
34	2.275	1.00000	0.00000	1106.3	1251.8	1190.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
35	2.345	1.00000	0.00000	1106.3	1251.8	1190.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
36	2.415	1.00000	0.00000	1106.3	1251.8	1191.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
37	2.485	1.00000	0.00000	1106.3	1251.8	1192.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
38	2.555	1.00000	0.00000	1106.3	1251.8	1192.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
39	2.625	1.00000	0.00000	1106.3	1251.8	1193.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
40	2.695	1.00000	0.00000	1106.3	1251.8	1194.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
41	2.765	1.00000	0.00000	1106.3	1251.8	1194.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
42	2.835	1.00000	0.00000	1106.3	1251.8	1195.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
43	2.905	1.00000	0.00000	1106.3	1251.8	1196.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
44	2.975	1.00000	0.00000	1106.3	1251.8	1196.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
45	3.045	1.00000	0.00000	1106.3	1251.8	1197.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
46	3.115	1.00000	0.00000	1106.3	1251.8	1198.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
47	3.185	1.00000	0.00000	1106.3	1251.8	1198.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
48	3.255	1.00000	0.00000	1106.3	1251.8	1199.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
49	3.325	1.00000	0.00000	1106.3	1251.8	1200.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
50	3.395	1.00000	0.00000	1106.3	1251.8	1200.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
51	3.465	1.00000	0.00000	1106.3	1251.8	1201.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
52	3.535	1.00000	0.00000	1106.3	1251.8	1202.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
53	3.605	1.00000	0.00000	1106.3	1251.8	1202.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
54	3.675	1.00000	0.00000	1106.3	1251.8	1203.6	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
55	3.745	1.00000	0.00000	1106.3	1251.8	1204.2	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2
56	3.815	1.00000	0.00000	1106.3	1251.8	1204.9	329.5	0.00000	0.	214.8	24.0	18.4	40.1	12.5	879.	0.	-0555.	113.	0.00000	24.2

ASH FUSION STARTS AT xf = 0.6927 AT HEIGHT (FROM TOP OF BURNING ZONE) = 1.935 M

HEIGHT OF THE BURNING ZONE = 2.265 M

TABLE F.9 (B3)

SIMULATION OF LIME SHAFT KILN
ANALYSIS OF THE COOLING ZONE

INPUT DATA FOR SET NO. 9 (B)

(TG0 = 79? K)

RESULTS OF ANALYSIS

I	Z(M)	TG(K)	TS(K)	TW(K)	HSG	ASCZ	GSG	DELHTL
1	0.000	607.70	1394.23	306.20	10.8	49.2	8512.9	0.0
3	0.100	600.97	1382.14	305.4?	10.8	49.2	8398.9	35.8
5	0.200	594.32	1359.25	305.4?	10.7	49.2	8285.8	70.9
7	0.300	587.72	1345.55	305.2?	10.7	49.2	8173.7	105.2
9	0.400	581.2?	1331.99	305.17	10.7	49.2	8062.5	138.7
11	0.500	574.??	1318.54	306.0?	10.7	49.2	7952.2	171.4
13	0.600	568.??	1297.6?	305.9?	10.7	49.2	7842.8	203.4
15	0.700	562.??	128?.??	305.8?	10.7	49.2	7734.4	234.7
17	0.800	556.17	1267.67	305.7?	10.7	49.2	7626.8	265.2
19	0.900	550.09	1251.50	305.62	10.7	49.2	7520.2	295.0
21	1.000	544.09	1235.85	305.51	10.7	49.2	7414.5	324.1
23	1.100	538.17	1220.42	305.40	10.7	49.2	7309.7	352.5
25	1.200	532.33	1205.11	305.29	10.7	49.2	7205.7	380.2
27	1.300	526.57	1189.96	305.19	10.7	49.2	7102.7	407.2
29	1.400	520.89	1174.99	305.09	10.7	49.2	7000.5	433.5
31	1.500	515.28	1160.11	304.98	10.7	49.2	6899.3	459.2
33	1.600	509.74	1145.42	304.88	10.7	49.2	6798.9	484.2
35	1.700	504.29	1130.8?	304.7?	10.7	49.2	6699.4	508.6
37	1.800	498.90	1116.4?	304.68	10.7	49.2	6600.8	532.3
39	1.900	493.60	1102.2?	304.5?	10.7	49.2	6503.1	555.4
41	2.000	488.36	1088.17	304.48	10.7	49.2	6406.3	577.9
43	2.100	483.20	1074.23	304.38	10.7	49.2	6310.5	599.7
45	2.200	478.11	1060.44	304.28	10.7	49.2	6215.2	621.0
47	2.300	473.09	1046.80	304.18	10.7	49.2	6121.0	641.7
49	2.400	468.15	1033.30	304.09	10.7	49.2	6027.7	661.8
51	2.500	463.27	1019.95	303.99	10.7	49.2	5935.3	681.2
53	2.600	458.47	1006.7?	303.90	10.7	49.2	5843.7	700.2
55	2.700	453.74	993.70	303.81	10.7	49.2	5753.0	718.5
57	2.800	449.07	980.79	303.71	10.7	49.2	5663.2	736.4
59	2.900	444.47	968.03	303.62	10.6	49.2	5574.2	753.6
61	3.000	439.94	955.41	303.53	10.6	49.2	5486.1	770.4
63	3.100	435.4?	942.9?	303.44	10.6	49.2	5398.9	786.6
65	3.200	431.09	930.6?	303.35	10.6	49.2	5312.5	802.2
67	3.300	426.78	918.42	303.26	10.6	49.2	5227.1	817.4
69	3.400	422.50	906.37	303.17	10.6	49.2	5142.5	832.1
71	3.500	418.30	894.46	303.09	10.6	49.2	5058.7	846.2
73	3.600	414.17	882.70	303.00	10.6	49.2	4975.9	859.9
75	3.700	410.10	871.09	302.92	10.6	49.2	4893.9	873.1
77	3.800	406.09	859.59	302.83	10.6	49.2	4812.7	885.8
79	3.900	402.15	848.23	302.75	10.6	49.2	4732.5	898.1
81	4.000	398.27	837.04	302.66	10.6	49.2	4653.1	909.9
85	4.200	390.69	815.05	302.50	10.6	49.2	4496.9	932.1
89	4.400	383.38	793.60	302.34	10.6	49.2	4344.1	952.6
93	4.600	376.26	772.69	302.18	10.6	49.2	4194.8	971.3
97	4.800	369.39	752.32	302.02	10.6	49.2	4048.9	988.5
101	5.000	362.75	732.49	301.86	10.6	49.2	3906.5	1004.0
105	5.200	356.35	713.17	301.71	10.6	49.2	3767.4	1013.0
109	5.400	350.13	694.39	301.56	10.5	49.2	3631.8	1030.6
113	5.600	344.15	676.11	301.41	10.5	49.2	3499.5	1041.7
117	5.800	338.37	658.35	301.26	10.5	49.2	3370.7	1051.4
121	6.000	332.79	641.0?	301.12	10.5	49.2	3245.1	1059.8
125	6.200	327.41	624.32	300.97	10.5	49.2	3122.9	1066.9
129	6.400	322.23	608.0?	300.82	10.5	49.2	3003.9	1072.8
133	6.600	317.24	592.26	300.66	10.5	49.2	2888.2	1077.5
137	6.800	312.43	576.94	300.51	10.5	49.2	2775.8	1081.1
141	7.000	307.80	562.09	300.37	10.5	49.2	2666.6	1083.5
145	7.200	303.34	547.71	300.21	10.5	49.2	2560.5	1084.9
149	7.400	299.06	533.78	300.01	10.5	49.2	2457.5	1085.3

HEIGHT OF THE COOLING ZONE=7.400M