STUDIES ON A THERMAL GASIFICATION REACTOR

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
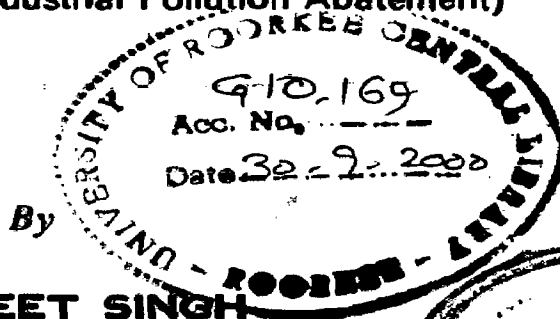*of*
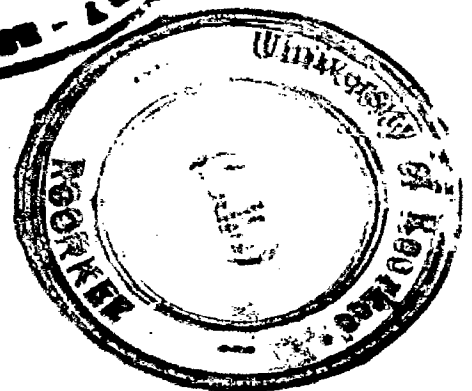
MASTER OF ENGINEERING

in

CHEMICAL ENGINEERING

(With Specialization in Industrial Pollution Abatement)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled 'STUDIES ON A THERMAL GASIFICATION REACTOR' in partial fulfillment of the requirement of the award of degree of MASTER OF ENGINEERING in CHEMICAL ENGINEERING with specialisation in INDUSTRIAL POLLUTION ABATEMENT of the University of Roorkee, Roorkee is authentic record of my own work carried out during the period from July 1999 to March 2000 under the guidance of Dr.I.M.Mishra, Professor, Department of Chemical Engineering, University of Roorkee, Roorkee.

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other University.
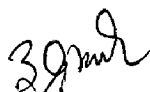
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CERTIFICATE

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

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INDERJEET SINGH

ABSTRACT

Fast depletion of petroleum and its related products is leading to shortage of fossil fuels and their high prices in the market. So the adoption of new and renewable energy sources is being encouraged. Biomass is a form of renewable energy and is preferable to fossil energy on account of its excellent storage properties, availability and competing cost with all other forms of renewable energies like, wind, solar, tidal, ocean thermal etc. The attractiveness of biomass as a fuel for power generation stemss from its many similarities to fossil fuel.

Biomass such as bagasse, rice husk, wood and cotton stalk are now available as agricultural wastes. Therefore it is necessary to study the gasification characteristics of such biomass in a downdraft thermal gasification reactor. Present study reports experimental investigation carried out with three biomass materials namely, wood, briquettes (press mud) and blend (mixture of wood and rice husk)

A downdraft gasifier of capacity 5 kg/hr has been designed and operated. A blower supplied air and its rate was measured by a venturimeter. The temperatures at strategic point were measured by k-type thermocouples. Gas flow was measured by another venturimeter. The gas was scrubbed using a jet scrubber and the clean and cool gas was snap-sampled under steady state operating conditions of the gasifier for various air flow rates. The gas samples were analyzed by using a gas chromatograph. Heating values of the gas were calculated using heating values of the individual components of the gas.

Experimental results indicated that optimum gasification rate is achieved at a certain value of airflow rate. Reactor temperature also depends on airflow rate. With increasing airflow rate beyond a certain value the heating value decreases.

Operational experience indicated that high ash low bulk density and small sized biomass materials are not suitable as a feedstock for a venturi type downdraft gasifier.

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INTRODUCTION

The ever increasing energy demands and the fast depleting limited stock of fossil fuels have necessitated the exploration of alternative resources i.e. solar, wind, biomass, ocean etc. Almost 43% of the energy used by the third world is derived from biomass with over 2 billion people nearly totally reliant on biomass fuels for their energy needs. In India, the energy supplied, from non-conventional energy is about 55% of the total energy requirement.

About 3.0×10^{21}GJ of solar energy is stored in 2×10^{11} tonnes of organic matter produced annually by photosynthesis. Yet only 14% of the worlds total energy comes from biomass. In developed countries only 1% of the total energy demand is met from biomass.

1.1 BIOMASS

The term biomass generally refers to renewable organic matter generated by plants through photosynthesis in which the solar energy aids in the transformation of carbon dioxide and moisture into carbohydrates and oxygen. Materials having combustible organic matter are also referred to as biomass. Coal is the end product of a sequence of biological and geological processes undergone by biomass itself but is not considered as biomass on a "renewable basis". Biomass are oxygenated hydrocarbons containing C, H, and O. Biomass generally has high moisture and volatile matter

constituents. Residues from agricultural and agro-industries, having high carbonaceous content are also referred to as biomass.

1.2 AVAILABILITY AND CHARACTERISTICS

India is a large country with a total land area of 328.8 million hectares, with an estimated human population of 911 millions, and a livestock population of about 450 millions living in about 587000 villages (singh,1996). The estimated quantity of agricultural, and agro-industrial residues is about 320 million tonnes with the cattle dung availability being about 240 million tonnes per year. About 20% of the total land area are under forest cover, which produces 4 million tonnes of sawdust (singh,1996).

Biomass characteristics, which depend upon such constituent as lignin, hemicellulose, cellulose, mineral matter and ash, vary from species to species. The compositions of typical biomass species are given below in Table 1.1(Grover, 1996).

TABLE 1.1 CHARACTERISTICS OF IMPORTANT FUEL WOODS

Species	Cellulose (%)	Hemicellulose(%)	Lignin(%)	Ash(%)
Soft wood	41	24	27.8	0.4
Hard wood	39	35	19.5	0.3
Rice straw	30.2	24.5	11.9	16.1
Bagasse	33.6	29	18.5	2.3

1.3 CLASSIFICATION OF BIOMASS

Biomass is generally classified as woody and non-woody (powdery) on the basis of its bulk density. For woody biomass, bulk density is more than 250-300kg/m^3, whereas for non-woody biomass, bulk density is less than 250-300kg/m^3. Woody biomass is

essentially the solid stalk of the main trunk and branches in trees/plants. It is a structural element in the living material. It is dense and has little ash. Even agricultural residues, which may consist of whole plants or branches of plants, can be woody, like cotton stalk and mulberry stalk. Weeds like juliflora prosopis, lantana camera, usually found in tropical climates can also be treated as woody biomass. Examples of powdery biomass are- bagasse, Rice husk, Rice straw, Coir pith, Peanut Shells, Groundnut shells, Sawdust etc.

The classification of biomass as woody and non-woody is important, and it is also useful to recognize that the composition of any biomass is nearly the same. Table 1.2 depicts the elemental composition of typical biomass materials.

TABLE1.2 COMPOSITION OF BIOMASS $CH_nO_mN_p$ [*Mukunda et al. 1997*]

Biomass	n	m	p
Rice husk	1.78	0.56	0.007
Saw dust	1.65	0.69	Nil
Paper	1.60	0.65	0.005
Rice straw	1.56	0.50	0.008
Rice wood	1.33	0.60	0.002

Biomass is found to be composed of volatiles, fixed carbon and ash. Based on 'Ash content' the various biomass species can be classified as follows.

Low ash biomass   (Ash content 1-4%)

Medium ash biomass   (Ash content 4-8%)

High ash biomass   (Ash content >8%)

This classification, together with description like powdery, stalk like etc is given in Table 1.3[*Grover,1996*].

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Table-1.4[*Grover, 1996*] Gives the proximate analysis and Table-1.5[*Grover, 1996*] provides the comparative assessment of fuel.

TABLE 1.3 CLASSIFICATION OF BIOMASS BASED ON ASH CONTENT

POWDERY MATERIAL

S.No	Low ash	Ash %	Medium ash	%	High ash	Ash %
1.	Eucalyptus saw dust	0.4	Nil		Industrial bamboo dust	9.9
2.	Saw dust	1.3	Nil		Jute dust	19.9

COARSE/GRANULAR MATERIAL

S.No	Low ash	Ash %	Medium ash	Ash %	High ash	Ash %
1.	Bagasse	1.8	Bagasse pith	8.0	Tea waste	19.8
2.	Coconut shell	1.9	Cotton shells	4.6	Rice husk	22.4
3.	Groundnut shell	3.6	Sugarcane leaf	7.7	Sunflower	10.1

STALK LIKE MATERIAL

S.No	Low ash	Ash %	Medium ash	Ash%	High ash	Ash %
1.	Corn cab	1.2	Congress grass	4.2	Ground paddy straw	15.5
2.	Jute stick	1.2	Dry potato waste	5.8	Rice straw	20.4
3.	Mulburry stick	2.1	Sunflower branch	7.7	Jowar stalk	10.1

TABLE 1.4 PROXIMATE ANALYSIS AND CARBON-HYDROGEN CONTENT OF SOME BIOMASS MATERIAL.

S.No	Biomass	Volatiles	Fixed Carbon	Ash	Carbon	Hydrogen
1.	Bagasse	75.10	16.87	8.03	45.71	5.89
2.	Coconut coir	70.30	26.77	2.93	47.17	6.54
3.	Jute stick	75.33	19.00	5.67	54.77	8.20
4.	Rice husk	60.64	19.90	19.90	40.10	6.03

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TABLE 1.5 COMPARATIVE CONSTITUENTS OF FUELS

Component	Biomass	Wood	Coal
Fixed carbon(%)	10-20	15-20	60-80
Volatile matter(%)	60-85	70-80	20-30
Ash content(%)	1-20	1-3	5-40

1.4 FEED STOCKS

1.4.1 WOOD

Wood is a predominant fuel in developing countries, and is easily available as firewood for many applications. It competes well with fossil fuels, because it is renewable, and is a cheap source of energy on account of its energy storage capacity. Wood is a composite of cellulose, lignin and hemicellulose (43, 35 and 22%, respectively). A typical analysis of dry wood yields carbon—52%, hydrogen-6.3%, oxygen-40.5% and nitrogen-0.4%(Reddy. 1994). The proximate analysis of wood gives the following components; volatile matter-80%, fixed carbon-19.4% and ash-0.6%. The calorific value of wood depends on the percentage of carbon and hydrogen. The calorific value of fuel wood lies in between 17.5-22.7MJ/kg. The bulk density of wood lies between 200-220kg/m^3. In the present study Popolar wood is used for the gasification, since it is a fast growing energy plantation and is easily available in this part of northern India.

1.4.2 RICE HUSK

Rice is a major agricultural crop of our country. The rice husk is the outer cover of the rice grain and is in the form of the hull. It is also called rice hull or paddy husk/hull

and also sometimes referred to as whole rice husk, in contrast to ground husk which is its finer form. It accounts for 14-35% of the weight of the paddy harvested, depending on the paddy variety and on average, it represents 20% of the paddy produced, on weight basis. The average lower heating value of the rice husk is about 13-16 MJ/Kg. It may be noted that the lower heating value is about one third of furnace oil, one half that of good quality coal and comparable with that of sawdust, lignite and peat. The rice husk is renewable in nature and is less polluting due to its low sulphur and low heavy metals content. There are many rice mills located in this part of Western Uttar Pradesh and rice husk is abundantly available.

1.4.3 PRESS MUD

The western plains of Uttar Pradesh are country's major producers of sugar cane. Many sugar mills are located in this area. Press mud is a non-sucrose solid waste in sugar cane industry. It is a byproduct of sulphitation process and amounts to about 4% of the cane crushed. It contains valuable nutrients like phosphorous, nitrogen, and potassium besides containing combustibles, fibers, and waxes. Total combustible substances on dry basis is about 75%, indicating a possibility of using it as a fuel (Elkader & Yassin, 1989). Press mud is briquetted with bagasse in proportion of 1:12. The advantage of admixing press mud with bagasse is that the melting point of ash produced by the mixture is about 1300^0C as compared to 970^0C for pure bagasse ash. The calorific value of briquetted press mud on dry basis is about 3.5MJ. The analysis of press cake obtained by sulphitation process is given in Table1.6.

TABLE 1.6 ANALYSIS OF PRESS CAKE (PRESS MUD)

Component	Percentage (Dry basis)
Sugar	2-5
Fibre	10-20
Crude wax	5-10
Crude protien	5-14
Total Ash	20 to 30%
a) CaO	2 to 6
b) SiO_2	3 to 5
c) P_2O_5	2 to 4
d) K_2O	2 to 5
e) Micro-nutients	2 to 5

1.5   OBJECTIVES OF PRESENT STUDY

The aims and objective of present study are as follows.

(i)   Study of the Operational features of a downdraft gasifier with three biomass material like Poplar wood chips, briquettes of press mud and a blend of wood and rice husk.

(ii)   Study the effect of airflow rate on gasification rate.

(iii)   Identification of various zones of the gasifier based on temperature profile along the gasifier.

Air drying, flue gas drying, hot conveyer system, rotary drum hot gas system and solar drying.

2.1.2 BRIQUETTING

Low bulk density of powdery biomass adds to its transportation cost. Biomass can be densified by compressing it. This is done either by briquetting or pelletization. The compression ratio in the former is 5:1 and in later is 3:1.

Briquetting is a well-known technique. This is brought about by the compression bailing i.e. by squeezing out moisture and breaking down the elasticity of the biomass and bark. If the elasticity is not sufficiently removed, the compressed biomass will tend to regain its predensified volume. Densification is also brought about by compression under a die at high temperature and pressure. The phenolic compounds in biomass aid in densification by acting as natural glue under conditions of high temperature and pressure. Sometimes waxes are used to bind the wood.

Briquettes made from paddy husk or saw dust have proved to be very cheap and useful as a fuel for the industry. Briquettes are also prepared from bagasse, press mud and other agricultural residues.

2.2 CHEMICAL CONVERSION PROCESS

Biomass energy can be utilized by the following two chemical conversion processes.

1) Biochemical conversion process

2) Thermochemical conversion process

2.2.1 BIOCHEMICAL CONVERSION PROCESS

Biochemical Conversion is the process by which biomass is converted to gas (CO_2/CH_4), waste (compost or fertilizer) and water (H_2O or C_2H_5OH) by the action of microorganisms. The biochemical processes are as follows.

1. Aerobic Fermentation which produces compost, carbon dioxide and water;

2. Anaerobic Fermentation which produces fertilizer and gas (CH_4/CO_2) ; and

3. Alcoholic Fermentation which produces ethanol (C_2H_5OH), carbon dioxide and waste.

2.2.2 THERMOCHEMICAL BIOMASS CONVERSION PROCESSES

The energy in biomass may be realized either by direct use as in combustion or by upgrading into a more valuable and usable fuel such as fuel gas, or higher value products. At present, agricultural and forestry residue type biomass is either grossly under-utilized or inefficiently utilized or wasted by "in situ" burning in the fields as a method of their disposal. The constraints of having high moisture content and relatively low bulk density of the powdery biomass (i.e. agro-forestry residues) inhibit their economical transportation over long distances, necessitating their utilization near the source of production. Development of technologies to utilize this major source in a more effective and efficient way and their management is essential to meet the energy demand of domestic as well as industrial sectors, especially in the developing countries.

Fuel derived from biomass may be classified in a number of ways, but basically they fall into three main categories; solid, liquid and gaseous fuels. There are four main thermochemical methods of converting biomass: namely, combustion, pyrolysis,

gasification and liquefaction. Each gives a different range of product and employs different equipment configurations operating in different modes. Direct combustion of biomass in which heat is the basic product may give higher efficiency as compared to carbonised fuel such as char due to loss of volatiles. But the gases thus generated are highly contaminated and cause pollution problems. The present trend is to follow the route of pyrolysis and gasification of biomass.

2.2.2.1   PYROLYSIS OF SOLID BIOMASS

Pyrolysis means thermal decomposition of organic matter in vacuum or in an inert atmosphere. Depending upon the operating parameters such as temperature, rate of heating, retention time and physico-chemical nature of biomass, different types and yields of solid, liquid and gaseous products can be obtained. Since biomass is a mixture of three main components namely cellulose, hemicellulose and lignin, its pyrolysis proceeds through a series of complex reactions resulting in gases, liquids and char. The yield of these products is greatly dependent on operating conditions as mentioned below. The various operating conditions, pyrolysis processes and product are given in Table2.1[Grover, 1996]

TABLE 2.1 PYROLYSIS TECHNOLOGY VARIANTS

Type	Residence Time	Heating Rate	Max Temp.(^{O}C)	Major Product
Very Slow (carbonisation)	Hr-day	Very low	400	Charcoal
Slow	5-30 min	Low	600	Liquid, charcoal & gas
Fast	0.5-5 sec	Fairly high	650	Bio-oil (liquid)
Flash	< 1 sec	High	<650	Bio-oil (gases)
Ultra	< 0.5 sec	Very high	1000	Gases
Vacuum	< 2-30 sec	Medium	400	Bio-oil
Hydro-pyro	< 10 sec	High	<500	Bio-oil, chemical

2.2.2.1 GASIFICATION PROCESS

Thermochemical gasification is defined as the conversion of biomass material into gaseous energy carrier (producer gas) by means of partial oxidation at elevated temperatures. Gasification of biomass has certain advantages over direct combustion. Small scale generation of electricity can be realised without the necessity of a steam cycle, and can be achieved by combustion of the producer gas in a reciprocating engine coupled to a generator. Existing boilers, kilns or furnaces can also use producer gas as a fuel. Moreover, the producer gas can be cleaned prior to combustion. The disadvantages are that the gasification system has to be designed specifically to suit the thermochemical characteristics of biomass, and the technology is more complicated than that of direct combustion. A comparison between direct combustion and gasification is shown in TABLE-2.2.

TABLE 2.2 COMPARISON BETWEEN DIRECT COMBUSTION AND GASIFICATION

Parameter	Direct Combustion	Gasification
Air/Fuel control (Instantaneous)	Inadequate (Fuel size, shape, shape, moisture variation)	Good char reduction process permits auto control.
Power control (Instantaneous)	Inadequate	Good
Emission control (NO_x, SO_x, Dioxisms)	Possible	Superior
Installed cost/kW	————	High on retrofit ; comparable otherwise
Electricity	Economical only at large power levels (~ a few MWs)	Economical evens at smaller power levels.
Pulverised Fuel	Deposition of metal vapours, oxides, etc on inaccessibility parts of boiler.	Allows for cooling gas indirectly, eliminating the condensation inaccessibility areas and burning gas to rigorous standards.

The gasification is a process in which solid fuel is converted to a gaseous fuel (producer gas) by a series of thermochemical reactions as the gasifier is considered to be having different zones in which fundamentally different chemical and thermal reaction take place.

Drying zone

The drying zone is generally at the top of the gasifier, above the pyrolysis zone. Here the temperature is not enough to cause chemical breakdown, but any moisture in the fuel is driven of in the form of water vapour.

Pyrolysis zone

Pyrolysis zone is above the combustion and reduction zone. No air is admitted to it, but it draws heat from the hotter regions that are adjacent. Once the temperature reaches about 400^0C a self-sustaining exothermic reaction takes place in which the natural structure of the biomass or other organic material being used as feedstock breaks down. Water vapour, methanol, acetic acid, and considerable quantity of heavy hydrocarbon tars are evolved. In the case of wood, 50% or more of the original mass may be given off as tars and volatiles.

$$C + heat \rightarrow CH_4 + condensable\ hydrocarbons + char$$

The solid material remaining after pyrolysis is carbon, in the form of charcoal. This passes down through gasifier, and is consumed in the combustion and reduction zones. If the gas is to be used in an internal combustion engine, it is essential that it be free from tar. The volume of tar produced when biomass is used as the fuel is so large that it would be virtually impossible for any gas cleaning system to eliminate it from the gas stream after it had left the gasifier, which result in considerable loss in energy.

Combustion Zone

Combustion zone is generally situated near the base of the gasifier. Also referred to as oxidation or hearth zone, is where air is fed into the gasifier, allowing combustion of the fuel to take place as in ordinary stove or furnace. The basic chemical reaction taking place in the combustion zone is the combination of oxygen in the air with carbon from the fuel to produce carbon dioxide an incombustible gas. This is an exothermic reaction, and the temperature in the combustion zone consequently rises until the rate of heat loss balances the rate of heat gain from combustion. Normally a combustion zone reaches a temperature of between 900-1300^{0}C, but in some gasifier such as cross draft type it can rise as high as 2000^{0}C. If any hydrogen is present in the combustion zone, it also reacts with oxygen. Again an endothermic reaction takes place and water vapour is formed as the product.

Combustion reaction $C + O_2 \rightarrow CO_2 + heat$ -74.9KJ/mol
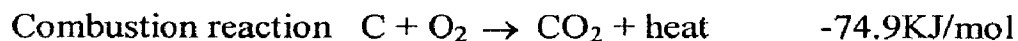
Reduction Zone

From the combustion zone, the hot gases are next drawn into the reduction zone. This is always adjacent to the combustion zone, but depending on the configuration of the gasifier it may be above, below or beside it. No air is admitted here, hence there is no free oxygen, and different reactions take place. These are referred to as reducing reactions, and they play essential role in gasification as they convert some of the incombustible gases emerging from the combustion zone into combustible products. The principle reaction in the reduction zone is 'Boudouard' reaction and carbon monoxide produced is the major combustible component in the final mixture of gases drawn from the gasifier.

This is an endothermic process and temperature in excess of 900^0C are required for it to take place.

Boudouard reaction $C + CO2 + heat \rightarrow 2CO$ $+ 172.6 \, kJ/mol$
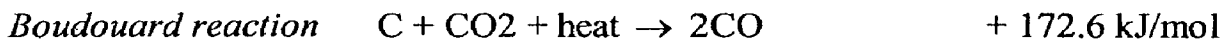
Another important reduction reaction is that between water vapour and carbon. This is an endothermic reaction and again, takes place only at temperatures above 900^0C. Water is dissociated, yielding carbon monoxide and hydrogen as the products. It is usually called the 'water gas' reaction, and since both of its products are combustible it also increases the calorific value of the final gas.

Water gas reaction $C + H_2O \rightarrow CO + H_2$ $-131.4 KJ/mol$

In the course these endothermic reaction, heat is absorbed from the gas stream. The temperature of the reduction zone progressively drops, as the gas is drawn further from the combustion zone. As it drops, a different set of reactions take over, one of which is the reaction of water vapour with carbon to produce hydrogen and carbon dioxide. This predominates between $500-600^0C$.

$$C + H_2O \rightarrow CO_2 + H_2$$
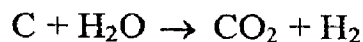
If excess water is present in the reduction zone, the so-called 'water shift reaction' can also take place. In this, carbon monoxide reacts with water to produce carbon dioxide and hydrogen. This is exothermic and generally regarded as the unfavorable reaction since it reduces the calorific value of the final gas. Excess moisture in the fuel is therefore to be avoided.

Water shift reaction $CO + H_2O \rightarrow CO_2 + H_2$ $-41.2 KJ/mol$
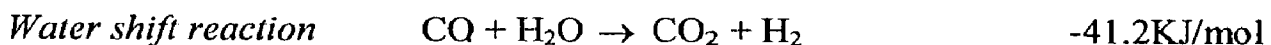
Most of the hydrogen that is produced in the reduction zone remains free. However a portion of it combine with carbon to form a small amount of methane.

Hydrogasification Reaction C + 2H$_2$ → CH$_4$ + heat   -74.9KJ/mol
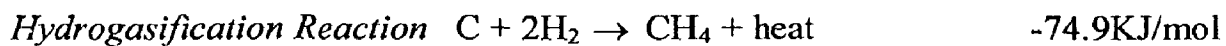
The gas produce through this process has relatively low thermal value, generally only 10-15% that of natural gas. A typical composition of gas obtained from wood gasification on volumetric basis is as follows

CO	18-22%
H$_2$	13-19%
Methane	1-5%
Heavier hydrocarbon	0.2-0.4%
CO$_2$	9-12%
N$_2$	45-55%
Water Vapour	4%

2.2.2.3 DIRECT COMBUSTION OF SOLID BIOMASS

Complete combustion requires three T'^{s} meaning sufficiently high temperature, strong turbulence of air-gas mixture, and long residence time of mixture in the fire chamber. Turbulence and long residence bring each pyrolysis-gas molecule close to oxygen and provide chances for combustion. Fuel molecules as such doesn't react, they have to break up (dissociate) on impact when they collide at high speed of intense molecular motion, which actually is characteristic of high temperature. Wood or woody biomass burns to carbon dioxide (CO$_2$) and water vapour.

$$C_{42}H_{60}O_{28} + 43O_2 \longrightarrow 42CO_2 + 30H_2O$$

Direct combustion of solid biomass is used for electricity generation, generation of heat and steam also.

2.3   GASIFIER CLASSIFICATION

Depending upon the position of air inlet and gas withdrawal, with reference to fuel bed movement, four broad types of the gasifier have been designed and operated to date, these are.

1.   Updraft gasifier
2.   Downdraft gasifier
3.   Crossdraft gasifier, and
4.   Fluidized bed gasifier.

2.3.1 UPDRAFT GASIFIER

In the updraft gasifier, air is introduced below the grate to provide the oxygen for partial combustion of carbon immediately above the grate. The hot gaseous combustion products proceed upward through a reduction zone of incandescent charcoal, where heat is consumed to gasify carbon and produce hydrogen and carbon monoxide. Then the gases transfer heat to raw fuel, first pyrolysing it then drying it. The gas exits above the upper Zone or at side port near the top of the gas producer. The exiting gas has a very low solid particulate content. The schematic diagram of updraft gasifier is shown in Fig2.1.The advantage of updraft gasifier is that they can use a wide variety of high moisture fuels. The disadvantages are that the tar vapour are almost impossible to remove and highly corrosive, and must be burned. Thus, updraft biomass gasifier is used primarily for retrofitting boilers.

2.3.2 DOWNDRAFT GASIFIER

In the Downdraft gasifier, air enters through radial tuyeres near the top of the firebox. The partial combustion takes place in the zone in front of tuyere openings. The

BIOMASS
FEED

→ GAS

Drying zone
R_2O (moisture) → H_2O (steam)

Pyrolysis zone
C + heat→CH_4+ condensable
hydrocarbon + char

Reduction zone
$2CO → CO_2 + C$
$C + 2H_2O ⇌ CO_2 + 2H_2 (+)78.7 KJ/mol$
$C + H_2O ⇌ CO + H_2 (-)131.4 KJ/mol$
$C + CO_2 ⇌ 2CO$

Combustion Zone
$C + O → CO_2 (+)97.65 KJ/mol$

AIR →

ash

Fig. 2.1 Updraft Gasifier

BIOMASS FEED

Drying zone
R_2O (moisture) → H_2O (steam)

Pyrolysis zone
C + heat → CH_4 + condensable hydrocarbon + char

Drying Zone

Pyrolysis Zone

Combustion Zone
C + O → CO_2 (+)97.65KJ/mol

throat

AIR →   ← AIR

Reduction Zone
C + $2H_2O$ ⇌ CO_2 + $2H_2$(+)78.71
C + H_2O ⇌ CO + H_2(-)131.4KJ/mol
C + CO_2 ⇌ 2CO(-)172.6KJ/mol
CO + H_2O ⇌ CO_2 + H_2 (+)41.21 KJ/mol

grate

GAS 2CO → CO_2 + C

ash

Fig. 2.2 Downdraft Gasifier

heat generated pyrolysis the fuel immediately above and hot gases proceed downward through grate. The throat (constriction) forces the raw gases to pass through a high temperature zone so that most of the tars can be cracked into gaseous hydrocarbons, thus producing a relatively clean gas. The downdraft gasifier is shown in Fig-2.2.

The down draft gasifier, also called the co-current moving bed gasifier, is most commonly used for engine application because of its ability to produce relatively clean gas. However, the presence of throat poses problems of fuel movement. Of late, the so-called throatless gasifier has been developed for fine biomass.

Another advantage of down draft gasification is that the initial reaction air or oxygen with biomass produces lower temperatures than reaction of air/oxygen with charcoal, due to the endothermic pyrolysis reactions. Thus, the downdraft gasifier does not require steam or other cooling at the grate and produces the heat for pyrolysis by burning the tars in situ.

The disadvantage in downdraft gasifier is gas leaves the charcoal bed at a temperature of 700 to 800°C where the char/gas reaction becomes slow. To achieve the highest efficiencies, it is necessary to recover the sensible heat, which represents about 10% of the energy in the gas by using heat exchangers. The fuel for downdraft gasifier must be more uniform in size and lower in moisture content than fuels for updraft gasifier.

2.3.3 CROSSDRAFT GASIFIER

In the Crossdraft gasifier, air is taken in through a horizontal nozzle and, is taken out through a vertical on opposite side. The burning zone is formed next to the nozzle and reduction zone adjacent to the burning zone. This type of gasifier is suitable for charcoal

BIOMASS FEED

Drying Zone

Drying zone
R_2O (moisture) → H_2O (steam)

Pyrolysis Zone

C + heat → CH_4 + Condensable + char
hydrocarbon

Reduction Zone

$C + 2H_2O \rightleftharpoons CO_2 + 2H_2$ (+)78.7KJ/mol
$C + H_2O \rightleftharpoons CO + H_2$ (-)131.4KJ/mol
$C + CO_2 \rightleftharpoons 2CO$ (+)172.6KJ/mol

AIR →

GAS →

Combustion Zone

$C + O_2 \rightarrow CO_2$ (+)97.65KJ/mol

grate

Ash
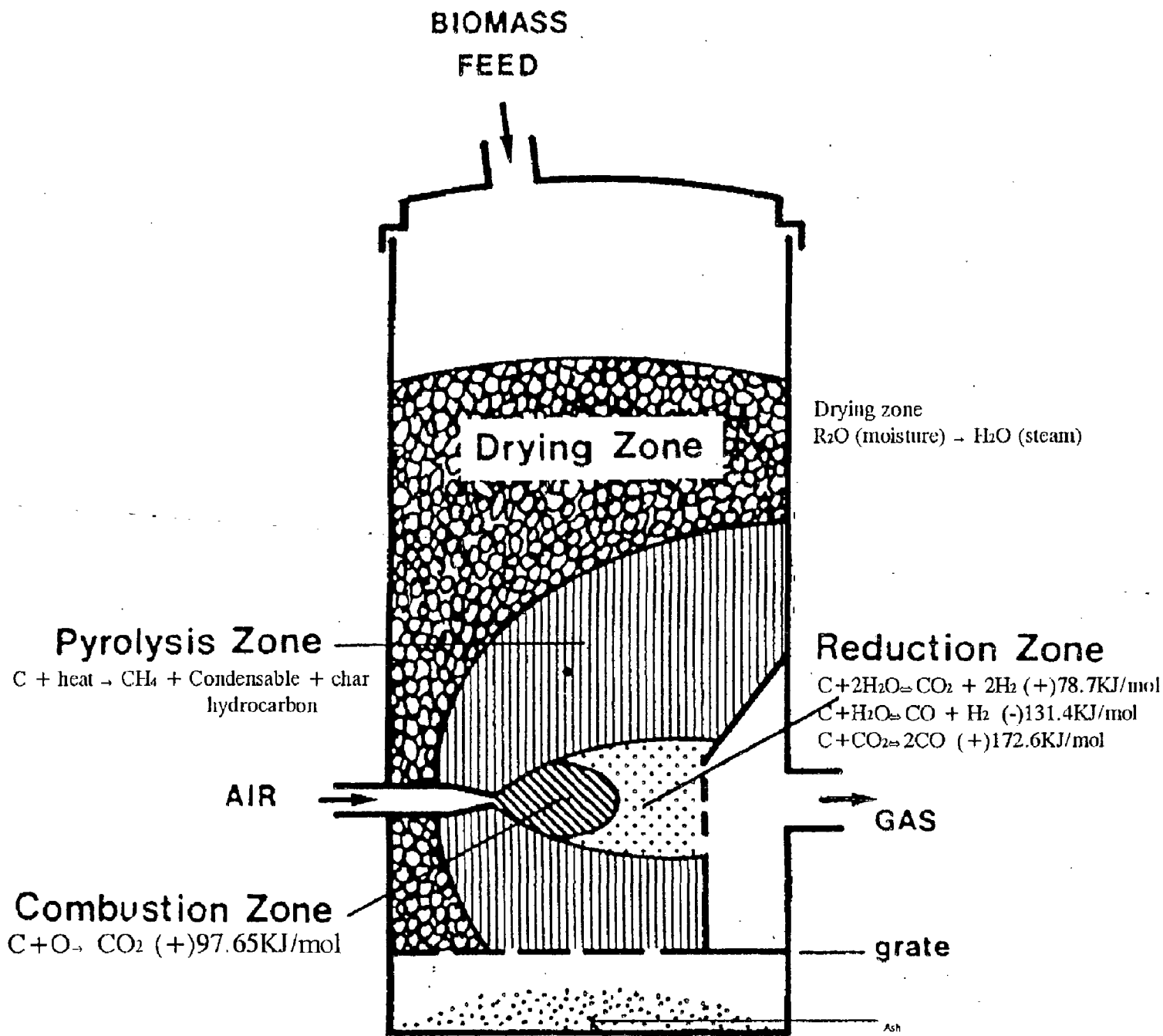
Fig. 2.3 Crossdraft Gasifier

fuel. Crossdraft gasifier is shown in Fig-2.3. Considering the merits and demerits of this type of gasifier, we find that it may be put in between updraft and downdraft types. In the case of Crossdraft, a gas containing less tar and small size char particles is produced due to oxidation zone temperatures.

2.3.4 FLUIDIZED BED GASIFIER

Fluidized bed gasifier is essentially a hot bed of solid particles kept constantly under agitation by the gasifying agent, steam or inert gas. The fluidising gas is distributed through nozzles at the bottom. The gas has the same high temperature maintained in the bed and contains small quantities of tar and large quantities of ash particles; the schematic diagram is shown in Fig 2.4.

Although it has a somewhat higher throughput per unit of reactor volume than the moving bed, its main disadvantage is high outlet temperature, entrainment of charcoal fines and requires a complex control system because of low biomass holdup in the bed. These systems are, however most appropriate for biomass whose particle size ranges from 0.1to 1cm.

2.4   PROPERTIES OF BIOMASS RELEVANT TO GASIFICATION

The most important physico chemical characteristics of any Biomass species is:

(1)   Bulk density.

(2)   Proximate analysis – moisture, fixed carbon volatile matter and ash

(3)   Heating value.

(4)   Ultimate Analysis- C, H, O & N content.

GAS   ASH

BIOMASS

DRYING
+
PYROLYSIS
+
OXIDATION
+
REDUCTION

AIR
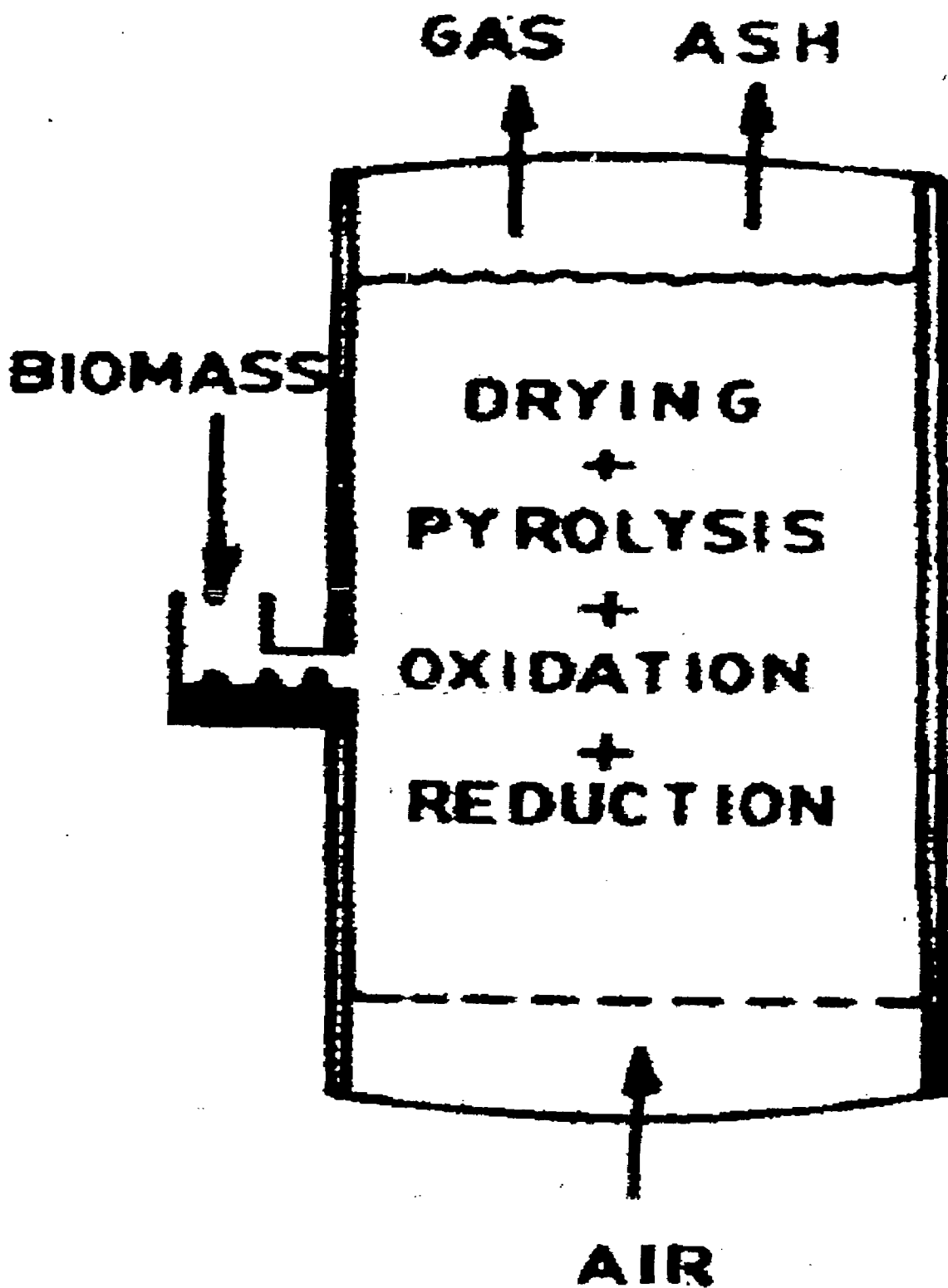
Fig. 2.4 Fluidised Bed Gasifier

Procedure for characterisation

Standard procedures recommended for the determination of properties are coal and coke (IS: codes) are used for the characterisation of the biomass as separate codes are not available yet. These codes largely meet the demands for characterisation of biomass materials.

2.4.1 BULK DENSITY

The bulk density depends upon the moisture content, shape and size of the biomass. As the property normally varies depending upon the fuel preparation method employed, this should be determined in situ for specific applications. Bulk densities of some biomass species taken from literature are presented in Table 2.4[*Iyer et al, 1997*].

TABLE 2.4 BULK DENSITY

S.No	Biomass	Bulk density (Kg/m^3)
1.	Bagasse pith	74
2.	Jute dust	74
3.	Rice husk	235
4.	Sugarcane leaf	167

2.4.2 PROXIMATE ANALYSIS

Proximate analysis, as the name suggests, gives the proxy information of biomass constituents. The proximate analysis of air dried sample is reported as follows: An air dried sample is one, which is exposed to the atmosphere of a laboratory to bring it in equilibrium with humidity conditions of the laboratory so that sample doesn't gain or loose weight during analysis.

Moisture: Water expelled in its various forms when tested under specified condition.

Volatile matter (VM): Total loss in weight minus the moisture in sample when sample is heated under specified conditions

Ash: Inorganic residues left over when sample (coal/biomass) is incinerated in air to constant weight under specified conditions.

Fixed carbon (FC): Obtained by subtracting from 100, the sum of the percentage by weight of moisture, VM and ash.

Tests for proximate analysis

IS: 1350(part I) is used for the proximate analysis of biomass. The general procedure for the analysis is described below as per IS code.

Moisture: The moisture in the coal /sample is determined by drying the known weight of the sample at $108^0C \pm 2^0C$.

Volatile Matter: The method for determination of volatile matter consist of heating a weighed quantity of air dried sample at a temperature of $900^0C \pm 10^0C$ for a period of seven minutes. Oxidation has to be avoided as far as possible. VM is the loss in weight less by that due to moisture.

Ash: In this determination sample is heated in air up to 500^0C for 30 min and maintained at this temperature until the sample weight become constant.

Fixed Carbon: Fixed carbon is determined by deducting the moisture, VM and ash (as wt%) from 100.

Proximate analysis of some biomass samples on dry basis is given below in Table 2.5.

TABLE 2.4 PROXIMATE ANALYSIS

Component	Biomass*	Wood	Coal
Fixed carbon(%)	10-20	15-20	60-80
Volatile matter(%)	60-85	70-80	20-30
Ash content(%)	1-20	1-3	5-40

* Agro and forest residues except wood

2.4.3 Heating value

IS: 1350(part II) relates to the determination of the heating value of the solid fuel sample. The higher heating value (HHV) of the sample is determined in a standard calorimeter. A bomb calorimeter is employed to measure the calorific value. The general principle of calorimeter is the transference of the total heat of the combustion of a known weight of fuel to a known weight of water; from rise of temperature of the latter the calorific value is deduced. The heating value is represented by

Lower Cal Value (MJ/kg) = $(18.0-20f_w)(1-f_{ash})$　　　(for $f_w < 50\%$)

Where f_w = moisture fraction in dry wood

f_{ash} = ash fraction in dry wood.

2.4.4 Ultimate analysis

The ultimate analysis of solid fuel sample(biomass) gives the constituent elements, namely, carbon, hydrogen and nitrogen. The percentage of carbon given in the ultimate analysis should not confused with FC, the latter being always lower than the

former. The oxygen content of the sample is obtained by finding the difference of 100 and the sum of other constituent Elements. IS: 1350 gives the test methods for ultimate analysis of coal and is employed for biomass sample also.

For the ultimate analysis, the coal sample is burnt in a current of oxygen. As a result, the hydrogen, carbon get oxidized to water and carbon dioxide. Water and carbon dioxide are absorbed in suitable solvent and constituents are determined gravimetrically. Sulphur products are retained by lead chromate. The nitrogen in the biomass is determined by the Kjeldahl method. The hydrogen determined by the above procedure includes the hydrogen Content of organic matter of volatile matter and the hydrogen of the moisture Present in the biomass. The ultimate analysis of the some biomass material is given from literature in Table-2.5

TABLE 2.5 ULTIMATE ANALYSIS OF SOME BIOMASS

Biomass	C	H	N	S	O	Ash
Wood	53.5	5.9	0.1	Nil	40.3	0.2
Rice hull	38.5	5.7	0.5	Nil	39.8	15.5
Saw dust	47.2	6.5	Nil	Nil	45.4	1.0

LITERATURE REVIEW

Gasification is a thermochemical conversion process in which biomass reacts in oxygen deficient air atmosphere to produce a gaseous mixture of carbon monoxide and hydrogen as main combustible gases along with carbon dioxide and nitrogen. Producer gas is a low thermal value gas (4.5-5.5 MJ/Nm^3), when air is used as gasifying agent and can be used as supplementary fuel in internal combustion engines and as a fuel in furnace for thermal applications. The gasification process is carried out in a reactor called the gasifier, in which biomass is converted into gaseous fuel by partial oxidation at elevated temperature (600^0C-1200^0C).

Downdraft gasifier has been studied since 1939. However in the present study, the literature on downdraft gasifier has been reviewed since 1979. Sharma (1988) had made a comprehensive review of literature on downdraft gasification.

William and Goss (1979) used a laboratory-scale downdraft gasifier to study the gasification properties of certain biomass fuels. The grate was the most critical part of the gasifier. Two designs were tested: a rotating eccentric grate and a perforated steel basket. The latter was designed for use with granular fuels such as mulled walnut shells. Batch test was performed with different biomass fuels and at varying fuel consumption rates. Biomass fuel consumption rate was determined by mounting the gasifier on a platform scale and weighing it before and after a run. The composition of the generated gas and the mass and heat balances were determined. Results were that yield varied from 75.5% in the case of walnut shells to 46% for rice hulls. The gas produce from the walnut shells

was having high heating value as compared to mulled shell. Special grate was required for the gasification of mulled shell.

Hos, *et al.* **(1980)** has discussed the performance of a co-current moving bed reactor for gasification of solid wastes. They found the performance of a co-current moving bed reactor depends upon the reactor geometry, the characteristics of solid waste and the gasifying agent used. Wood chips containing 11to 46 wt% of moisture could be gasified. The lower heating value of the fuel gas produced was 2.5-5.08 MJ/Nm^3. The main problem in gasifying the solid waste was removal of cinders out of the reactor. Wood waste could be gasified without problems.

Baudeouin *et al.* **(1984)** undertook a testing programme in France on sugarcane bagasse gasification and found that the thermal efficiency (LHV of dry gas /LHV of 10% moisture bagasse) of these gasifier ranged from 0.4 to 0.66 with gases characterized by very different composition and LHVs: 3.285 to 5.689 MJ/Nm^3

Sharma and Prasad (1986) designed, fabricated and operated a 20Kg/hr batch type downdraft gasifier running on wood chips and evaluated its performance. The gas composition obtained was found as H_2 14-20%; CO 17-24%; CH_4 1-2%; C_2H_6 0.1%; CO_2 8-12%; O_2 2.5-5.0%; N_2 48-52%. The calorific value of gas was about 1.2MJ/m^3. The ratio of CO and H_2 is almost 3:2. The efficiency of the gasifier was calculated as 73.7% and some work was proposed on catalytic gasification of biomass and upgradation of producer gas to methanol/methane

The air gasification of wood chips and wood pellets was investigated (in a 0.6ID) downdraft gasifier by **Walawender.***et.al.***(1987)** to assess the influence of various parameters on its performance. They found the type of bed support had little affect on the

gasifier performance. The char yield from pellets was higher than that from chips as a consequence of the larger characteristic dimension for pellets. Increasing the extent of bed agitation increased the char yield and decreased both the air-to-feed ratio and the cold gas efficiency.

Sharma, S.K. (1998) and Sharma, Prasad and Mishra (1989) conducted an experimental study on a downdraft gasifier of 5 kg/hr capacity. The gasifier had a venturi section with eight air nozzles. The system also had a jet scrubber to cool and scrub the gas. Experiments were conducted for three different biomass materials namely shishum, deodar and corncobs representing hard wood, softwood and agricultural residues respectively. Gas quality and gas flow rates were determined at air flow rates in the range of 1.4 to 6.65 Nm^3/hr. the moisture content was varied in the range 5 to 30% by sprinkling water. Results indicated that the gas production rate was function of the air flow rate and was independent of moisture content and the type of the biomass.

Rajvanshi & Joshi (1989) used leucaena leucocephala as a fuel in a topless wood gasifier in their study. During this study the composition of gas obtained (by volume %) was CO 5-14, H_2 16-26, CO_2 4-12,and O_2 4-11. The temperature in the combustion /reduction zone was in the range of 800-1050^{0}C. The gas average calorific value was reported in the range 3.55-4.6MJ/Nm^3.From the study it was found that topless hybrid gasifier was very easy to operate.

Gao Xian sheng (1989) conducted studies on gasifier and has discussed that temperature in the combustion layer should range from 700-900^{0}C. It should not exceed 1000^{0}C for biomass fuels. If the temperature is lower than the required value the CO_2 is not fully reduced to CO, even if CO_2 is in contact with carbon in the fuel for long time.

When the temperature rises above the required value, the ash melts and forms slag, creating bridging in the reduction zone and clogging the gas stream channel. In order to use producer gas for I.C. engines, the gas produced must contain more than 15% hydrogen by volume. To achieve this, the ratio between the heat generated in the oxidation zone (Q1) and heat absorbed in the reduction zone (Q2) must be maintained at a certain value, $dQ1/dQ2=2.8$. It is also emphasized that modern downdraft gasifier should be used which has a conversion efficiency of 75%.

Chern *et al.* **(1989)** developed an empirical stichiometeric equation of wood chip gasification in a commercial-scale moving bed downdraft gasifier. The equation is based on an analysis of experimental overall and elemental material balance data obtained with the gasifier. A thermodynamic analysis of the gasifier has also been performed, based on the resultant empirical stoichiometric equation. The first law and second law thermodynamic efficiencies of the gasifier have been evaluated for four different operating modes at three different output temperatures. The resultant empirical stoichiometry is in agreement with the means of the experimental data within standard deviation. The highest efficiencies have been obtained when all the products are considered useable; they are 90% and 62%, respectively. The lowest first law and second law efficiencies have been obtained when cool dry gas is considered as the only useable product; they are 72% and 53%, respectively. They also noticed that the available energy dissipation due to various irreversibility of the gasification process was 31%. This dissipation was not recoverable and did not reflect the nature of process.

Kishore (1992) has discussed the potential, problems and research needed in thermal gasification of biomass. The factors affecting the gas composition in a real

gasifier were temperature distribution in the fuel bed, average gas residence time, and the residence time distribution. These were in turn dependent on the mode of air entry, dimension of the gasifier, and heat loss to the surroundings. Modeling of the various processes occurring in the gasifier required not only knowledge of kinetics but also an understanding of the heat and mass transfer processes occurring in the various zones of the gasifier.

Mahajan and Mishra (1992) have discussed pertinent development in the field of energy from paddy husk and stress on R&D initiative and techno-economics for resolving barriers impeding the speedy realization of this untapped energy potential. They stressed on the use of modern design for husk gasifier. Modern design is a cylindrical gasifier with an open top but no narrow throat or air intake nozzles with air entry through top of gasifier from system engine. Ash falls through slowly rotating grate and is removed by ash auger. The gas exits from bottom of the gasifier.

Mukunda et al. (1993) have studied the technology and economics of a new class of open- top gasifier for use with diesel engines in dual mode. Studies indicated that open-top design achieved diesel replacement value greater than 80% and is less dependent on the feedstock quality, moisture content and density. The amount of diesel saved per system was more than 70%.

Reddy (1994) has presented an overview on biomass energy for India. The study on biomass energy reports the most of the population is dependent on the local energy resources i.e. biomass. Also the rate of population growth, rising prices of commercial energy carriers suggests that biomass energy consumption will increase. So he stressed

the need to identify such problems, the possibilities for solution and the formation of policies is required.

Chakravarty *et al.* **(1994)** studied the behaviour of a downdraft rice husk gasifier of diameter 200 mm and height 940 mm. The gasification rate was varied in the range $1.8\text{-}4.3 \times 10^{-2}$ kg/m^{2}s. The air velocity was varied in the range 0.032-0.099 m/s. the producer gas obtained from the gasifier has calorific value in the range 3.24-4.382 MJ/m^3. A set of theoretical kinetic equation on the assumptions of nonequilibrium conditions has been developed and solved numerically. The simulated temperature profile and outlet gas compositions have been compared with those obtained from experimental runs. The model developed from mechanistic approach is found to explain the behaviour of the system appreciably within the range of variables studied.

Bhattacharaya *et al.* **(1994)** have discussed that tar is the most undesirable contaminant of producer gas. Production of tar free gas from uncarbonized biomass seems to be rather elusive, and removing tar from the gas remains a daunting task requiring bulky, expansive equipment and considerable effort. A new multi-stage reactor design has been developed in order to separate the flaming pyrolysis zone from the reduction zone. Tars vapors generated in the first zone are burned or cracked to simple molecule by high temperature in the second zone. The tested two –stage reactor produced a better gas with higher value i.e. 4.15MJ/m with respect to single stage heating value of 3.72MJ/m^3 and this led to higher conversion efficiency. Remarkably tar of the gas was about 40 times less than for a single-stage reactor operating under similar condition.

With the aim of developing a small-scale power plant **Khabibulaev** *et al.* **(1995)** did work on cotton stem gasification apparatus. During its operation different biomass

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materials were used for the production of fuel gas. Effect of various parameters on gas composition was also studied. It was found that the gas compositions vary with variation in temperature.

The development of gasifier running on sugarcane leaf has been reported by **Jorapur et al. (1995).** A 15 kV. A diesel generator set was operated for 200 h using this gasifier. The gas flow rate and calorific value were 3-4 Nm^3 kWh^{-1} and 3.5-5.0 MJ Nm^{-3}, respectively. The cold gas efficiency was 35-60% over the entire range of loads tested (3.5-11.3 kW). The diesel saving was nearly independent of the load and was 70-93% at a pressure drop of 40 cm water gauge; it reduced to 50-70% at pressure drop >50 cm. About 15-28% by weight of the fuel was converted into char with calorific value of ~19 MJ kg^{-1}. This char, when mixed with a suitable binder and briquetted, formed an excellent fuel for wood stoves. An economic analysis using for such gasifier shows that such gasifier are most suited for direct heat applications than shaft power application at present level of technology.

Channiwala and Parikh (1996) has earlier done studies on flow properties and flowability of biomass. In the present work, they study the effect of nozzle parameters, namely, air entry velocity, nozzle height above the choke plate, and nozzle orientation through simulated cold flow studies; while a more in-depth study has been made on the effect of nozzle orientation on the performance of gasification process through trials on experimental research gasifier unit. The conclusion of the study were as follows:

1) Air entry velocity and the point of entry with reference to the choke plates, influences the flowability. For woody biomass material, air entry velocity in the range of 6 to 8 m/s and nozzle height in the range of 50-100 mm above the

choke plate, i.e., 0.4 to 0.8 times the choke plate diameter, improves the flowability.

2) Provision of tangential velocity component to the air entry velocity vector is beneficial from the point of view tar minimization. In Experimental Research Gasifier Unit, an orientation of 45^0 to 60^0 resulted minimum tar formation without affecting the performance.

Based on the studies conducted at SESA, Punjab Agricultural University Ludhiana **Bhatnagar** *et al.* **(1996)** have reported that crop residues having high ash content such as paddy husk and ground nut shell can not be gasified in the Imbert type gasifier. Throatless downdraft gasifier in the capacity range of 5 and 10 kW with rice husk as feed biomass has been designed and operated at SESA. Typical values of producer gas composition (vol. %) were $H_2=12.2$, $CO=19.8$, $CO_2=12.4$, $CH_4=3$ and $N_2=53.5$. Lower heating value of the gas was found to be $4.4MJ/Nm^3$. Temperatures were also recorded for various points in the system. Development of standard procedure and equipment for testing are also recommended for further R&D in the field of rice husk gasification. It is also concluded that large size husk-fired gasifier and pyrolyser system having capacities above 100 kW are not available in the country and the fluidized bed gasifier needs special attention.

Jorapur *et al.* **(1997)** have developed a commercial scale gasification system for the gasification of low density biomass, for thermal applications. The gasifier can handle fuels such as sugarcane leaves and bagasse, bajra stalk, sweet sorghum stalks etc. the system has been tested for >700 h under laboratory conditions at 288-1080 MJ/h output levels. The HHV of gas was 3.56-4.82 MJ/m^3. The system also produces char, ~24wt%

of the original fuel. It can be briquetted to form an excellent fuel for wood stoves or can be used as a soil conditioner. A furnace was operated on this gasification system and the product quality was found to be good on this system.

EXPERIMENTAL SETUP

The objective of this work is to study the thermal gasification of biomass in a downdraft gasifier with special emphasis on

1)   Gas Composition.

2)   Temperature Profile in the gasifier.

3)   Flow behavior of different biomass materials in a downdraft gasifier.

4)   Recognition of problems for practical implementation.

The schematic diagram of experimental set up is shown in fig-4.1. It essentially consists of a downdraft gasifier, a gas cooling unit, flaring system and two venturimeters for the measurement of airflow rate and gas flow rate. The details of the experimental set up are discussed below.

4.1.1   DOWNDRAFT GASIFIER

The gasifier is designed for gasifying 5Kg/hr of biomass. The sectional view of gasifier is shown in fig –4.2. It mainly consists of a biomass container and a hearth. The biomass container was fabricated from 3mm mild steel sheets. The holding capacity of the gasifier is 25 to 30 Kg of biomass depending upon the type of biomass; particle feed size and moisture content. It has a lid for periodical refilling of the container with biomass. The lid is kept air tight to prevent any leakage of the gas from the top. A ¼ H.P
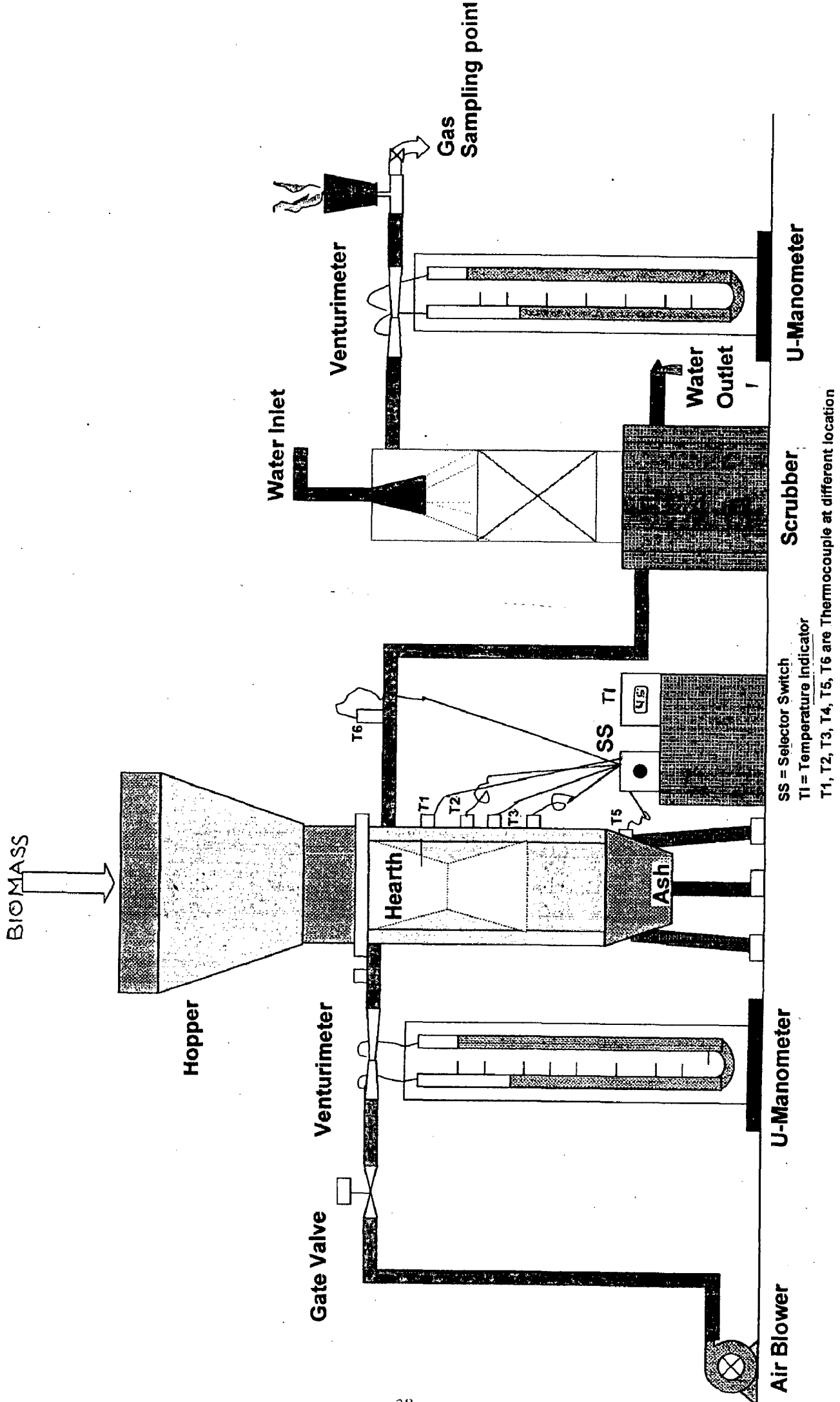
Fig. 4.1 Schematic Diagram Of Experimental Set Up

BIOMASS

Hopper

Gate Valve

Venturimeter

U-Manometer

Air Blower

Hearth

Ash

T1 T2 T3 T4 T5 T6

SS   TI

SS = Selector Switch
TI = Temperature Indicator
T1, T2, T3, T4, T5, T6 are Thermocouple at different location

Water Inlet

Venturimeter

Gas Sampling point

U-Manometer

Scrubber

Water Outlet

38

ø 560

320

210

ø 460

120

20

80

60

ø 300

200

ø 100

100

80

THICKNESS OF THE
PLATE = 6 mm

1500

50

20

150

ø 220
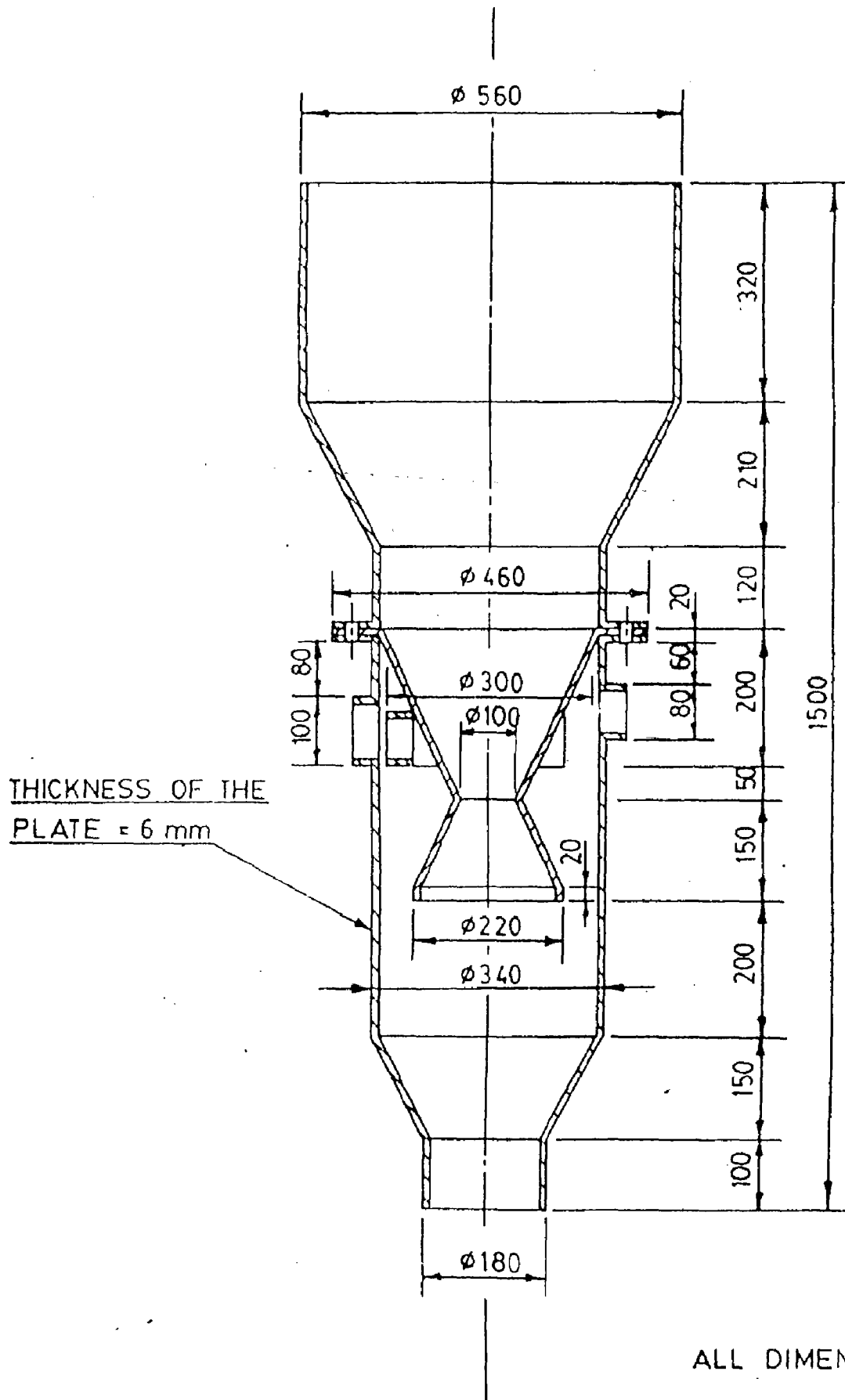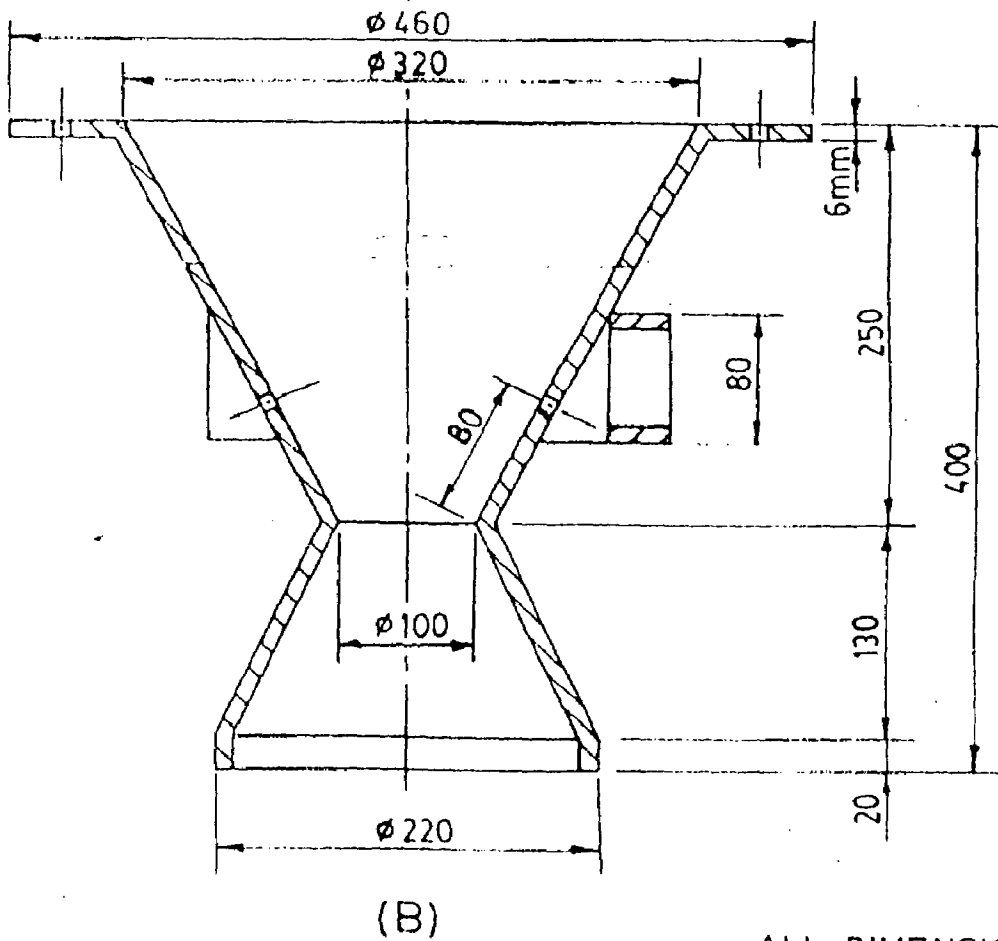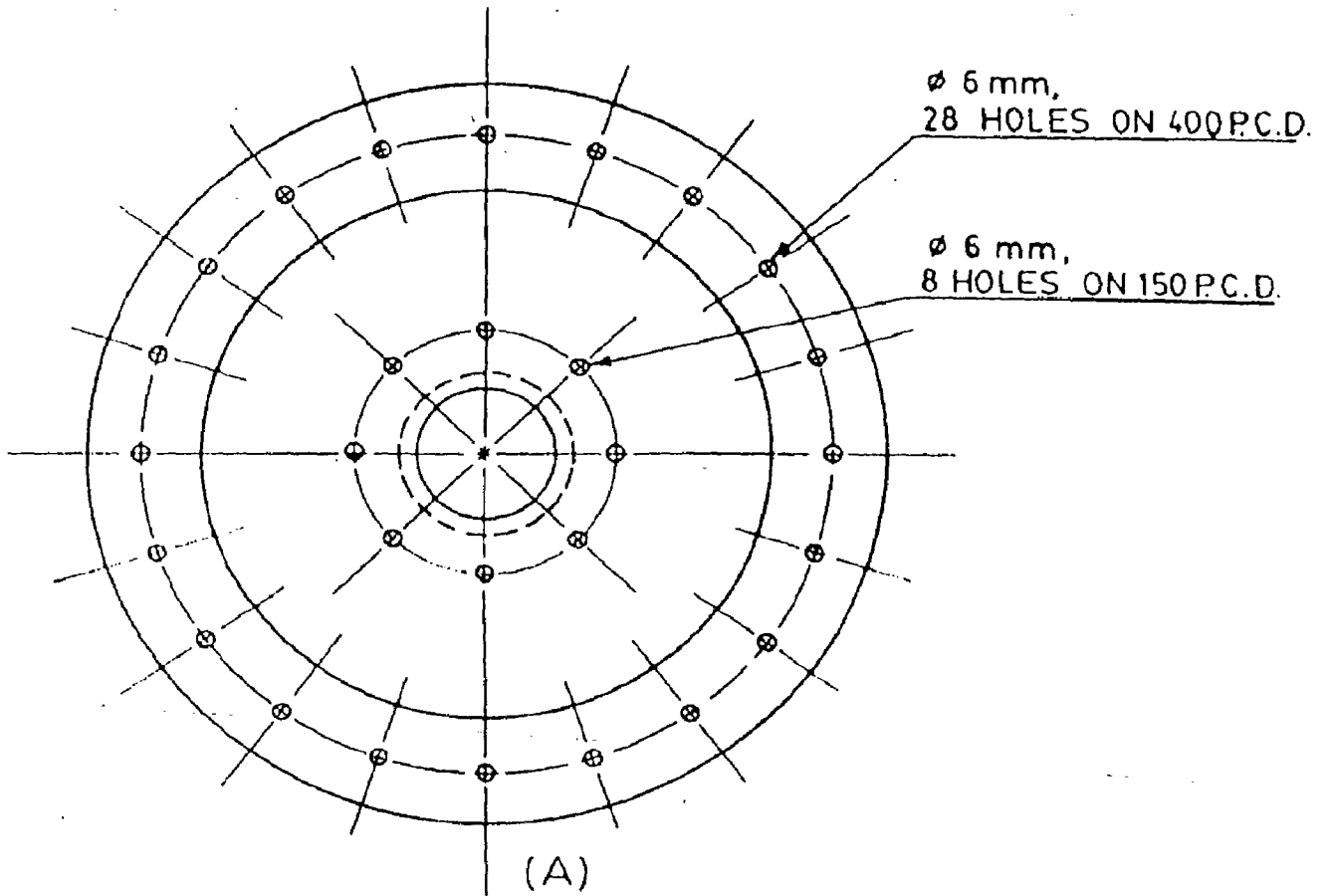
ø 340

200

150

100

ø 180

ALL DIMENSIONS ARE IN M.M.

FIG.4.2.SECTIONAL VIEW OF GASIFIER.

induction motor with eccentric weight of 0.5Kg with its shaft was mounted at the top of the fuel container. Its vibration facilitates the easy downward movement of the biomass.

4.1.2 HEARTH

The hearth of the gasifier is shown in the fig-4.3. It consisted of venturi structure with an upper convergent section having an apex angle of 53^0 and 250mm height. The top of the convergent section has a diameter of 320mm. The convergent section was joined at the throat by a lower divergent section having an apex angle of 50^0 and 130mm height. The bottom exit of the divergent section was of 200mm diameter and was having a 20mm long cylindrical portion at the bottom. The throat diameter was 100mm. To ensure proper supply of air for oxidation, eight air nozzles of 8mm diameter each were provided around the convergent section at a height of 80mm from the throat. The lower divergent section was fitted with 10mm mild steel grate to support the charged biomass. The hearth was made from 6mm stainless steel plate.

The air inlet was devised so that it opened only in the ring shaped chamber. The air was blown in; with the help of a 0.22KW wolf make air blower. The hearth and air container was flanged together with champion fireply gasket in between for a leak proof joint. The gas outlet was on the opposite side of air inlet so that gas gets cooled while travelling from downward to upward direction. The ash and fine char were collected at the bottom of gasifier. The complete gasifier was mounted on a mild steel angle iron frame.

ø 6 mm,
28 HOLES ON 400 P.C.D.

ø 6 mm,
8 HOLES ON 150 P.C.D.

(A)

ø 460
ø 320
6mm
250
80
80
400
ø 100
130
ø 220
20

(B)

ALL DIMENSIONS ARE IN M.M

FIG.4.3.(A) TOP VIEW (B) SECTION OF HEARTH.

4.1.3 TEMPERATURE MEASUREMENT

For temperature measurement across the gasifier, thermocouples were prepared from a 22-gauge chromel and alumel wires. The beads were prepared by spot welding. The thermocouple wires were inserted in twin hole refractory pieces of 5mm diameter and 50 mm in length to avoid the formation of secondary junction. The refractory pieces along with the thermocouple wire were sheathed in stainless steel tubing of internal diameter of 8mm. The thermocouple beads were carefully brazed with tube wall.

4.1.4 GAS COOLING AND CLEANING SYSTEM

The gas leaves the gasifier at about 350-500^0 C and contains finely entrained tar/ash. To facilitate the gas flow measurement, the gas is to be cooled to ambient temperature by swirling in a jet scrubber. The gas entrained water droplet are to be separated in mild steel rectangular chamber of 400*200*200 mm size. The hot water is drained through a U bend to provide necessary water sealing in the chamber. The gas is taken from the top to eliminate entrainment. To eliminate entrainment stainless steel wire mesh is fitted as shown in fig-4.4.

4.1.5 GAS MEASURING SYSTEM

Two venturimeters were fabricated for air and gas flow measurements. These designed as per I.S.4477 and made from solid brass rods. Both the venturimeters have wall thickness of about 6mm. Two pressure measuring tapping of 3 mm copper tubing were provided in each venturimeter, one tapping at the middle of throat and other at the
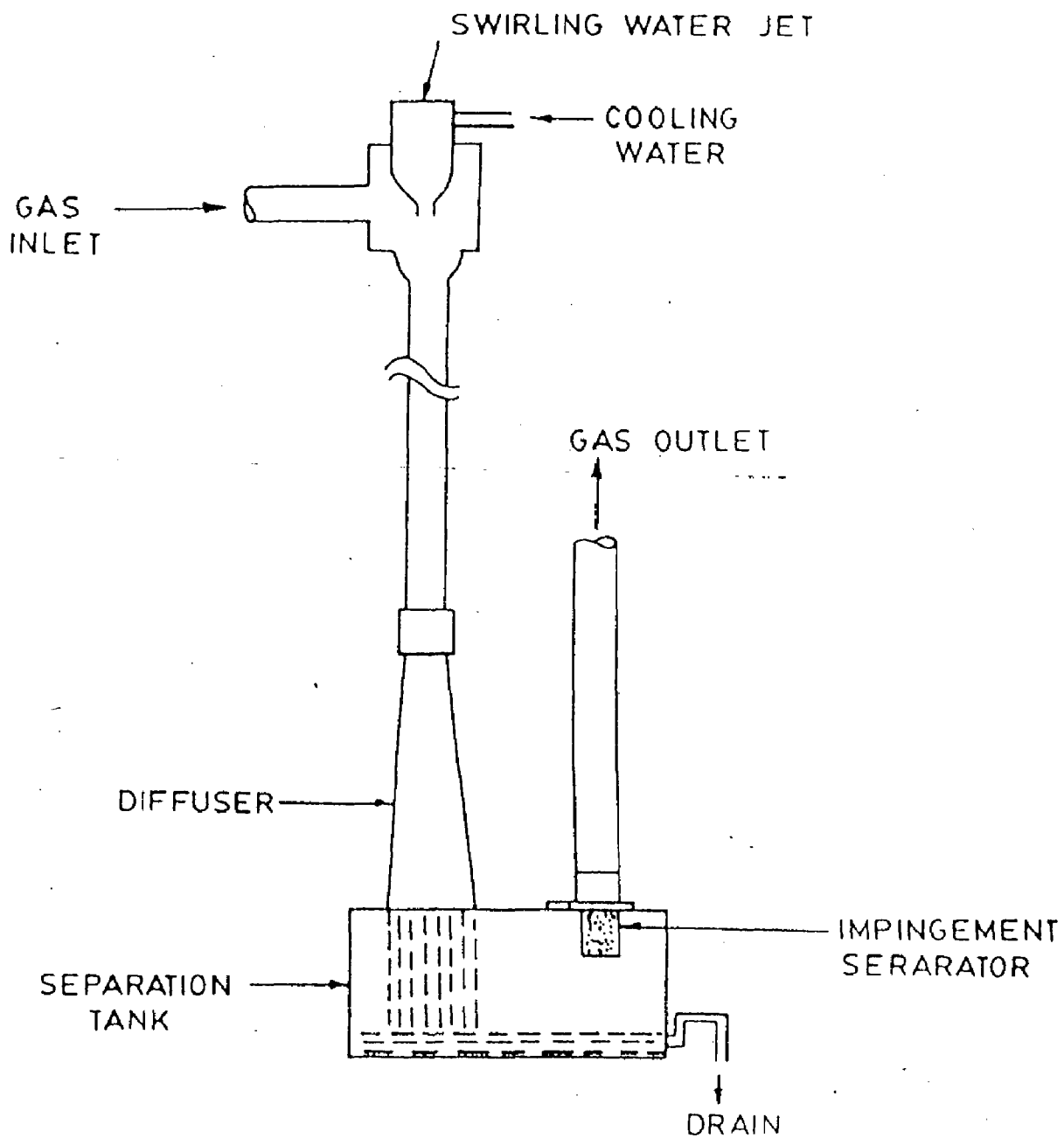
FIG. 4.4. SCHEMATIC DIAGRAM OF GAS COOLING SYSTEM.

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joint of the entrance tube and convergent section. The dimension of the connecting entrance tube and the convergent, divergent and throat section of the two venturimeters are given below.

Air side venturimeter:

Entrance Tube: Length = 23mm, diameter = 25mm

Convergent section: Length = 31mm, Apex angle = 21^0

Throat section: Length = 13mm, diameter = 13mm

Divergent section: Length = 66mm, Apex angle = 11^0

Gas side venturimeter:

Entrance Tube: Length = 25mm, diameter = 28mm

Convergent section: Length = 33mm, Apex angle = 22^0

Throat section: Length = 16mm, diameter = 16mm

Divergent section: Length = 69mm, Apex angle = 10^0
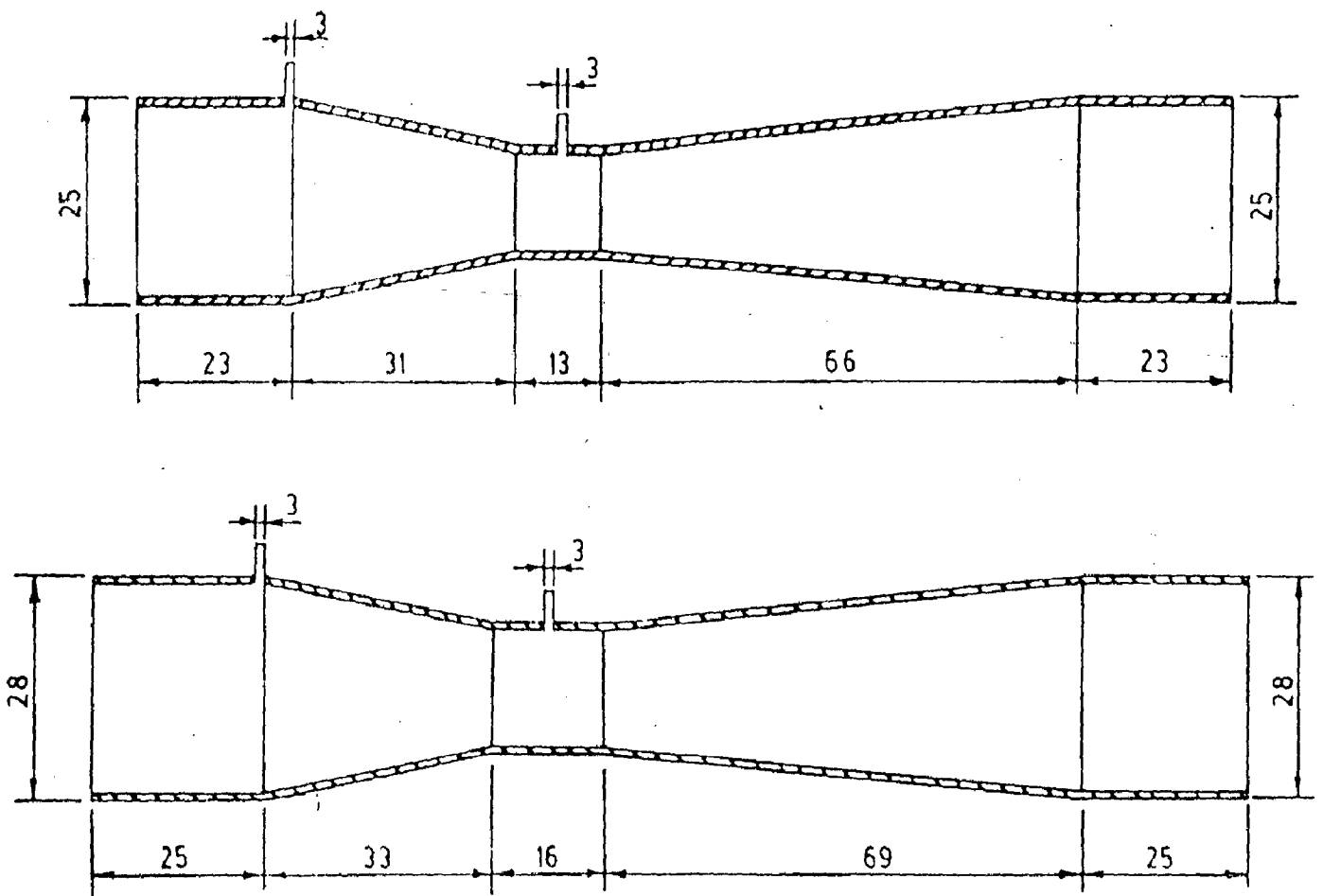
The sectional view is shown in fig-4.5.

4.1.6 GAS FLARING SYSTEM

The cooled gas after volumetric measurement was flared in the atmosphere. The flaring system was manually operated.

4.1.7 FEED STOCKS

Three different types of feed stocks were used in gasifier during the present study. These are as follows.

1. Wood chips of 2cm*5cm*2cm size in the first run set.

ALL DIMENSIONS ARE IN mm.

FIG. 4.5, SECTIONAL VIEW OF THE VENTURIMETER.

(a) AIR SIDE.   (b) GAS SIDE.

1. Briquettes of press mud in second run set.

2. Mixture of wood chips (70%) and rice husk (30%) in the third run set.

4.2 EXPERIMENTAL PROCEDURE

4.2.1 START UP OF THE GASIFIER

The gasifier was first checked for the air leakage by blocking the gas outlet in the air through gasifier with the help of soap solution. The gasifier was filled with charcoal, upto the air injection nozzles and subsequently by the biomass. The kerosene soaked cotton was put in the ignition port and ignited by the matchbox. The water was injected in the gas cooling and cleaning system, which created draft to induce the flame in the gasifier. Now the air blower was started with precaution, the ignition port closed. The smoke in gas outlet indicated the starting of the gasifier.

4.2.2 GASIFICATION MEASUREMENT

The airflow rate was set to desired level with help of inlet gate valve. The air flow rates and gas flow rates were measured from calibrated venturimeters. The temperatures were measured with help of digital temperature indicator connected through a selector switch to individual thermocouples. The vibrations were introduced in the gasifier by turning on the ¼ H.P. motor mounted on the container. The temperature was achieved in the gasifier. The steady state value of temperatures, air and gas flow rates was than recorded.

4.2.3 GAS SAMPLING

After the steady state values of temperature in the gasifier were reached, the gas samples were collected for off-gas analysis of gas composition. The snap gas samples were collected in gas collecting tubes by water displacement method. Before collecting gas, flushing of the tubes were done to remove traces of air.

4.2.4 GAS CHROMATOGRAPH

Chromatography is a process of separation achieved by means of partition between a stationary phase and a moving phase. Although chromatography is essentially a separating procedure, it can also be used to isolate or confirm component present in complex mixtures.

The mixture under investigation is injected either directly or by using a bypass chamber into a stream of a carrier gas at the head of column of separating medium. This medium can be either a solid absorbent such as charcoal or a liquid dispersed on an inert solid such as glycerol on firebrick. The sample mixture is swept by the carrier gas on to the column where the various components are separated from each other. Some components may be swept through the column without being retarded, some may completely absorbed by it, whilst other s will undergo partition between the separating medium and the carrier gas and be separated from other compounds present during the progress along the chromatographic column. This process of chromatographic separation is a complex one and although the theory is know well developed, all or almost all of the separations used in practice were first developed and exploited empirically.

In the carrier gas stream leaving the column are firstly any sample component not retarded and then in term the components fractionated during passage through the

column. The presence of these sample components in the stream of carrier gas is indicated by the detector, from which a response is obtained corresponding to changes of a suitable property of the carrier gas, for example of thermal conductivity. This response is usually converted to an electrical signal for the ease of recording. Therefore essential parts of any chromatograph are carrier gas stream, a sample inlet mechanism, a chromatographic column and a detector. In order to obtained reproducible results a thermostat is also necessary.

In the present study HP5890 Gas chromatograph was used to analyze the sampled gas. A molecular sieve-5A and porapak-Q was used as a column packing with argon as carrier gas with a flow rate of 30ml/min. Thermal conductivity detector was used to identify the component gases. The conditions were: oven temperature 40^0C, injector temperature 100^0C and detector temperature 100^0C. The gases of interest were H_2, O_2, N_2, CO, and CH_4. The chromatograph was initially conditioned sufficiently to expel the residual gases. The chromatograph was calibrated using a standard calibration mixtures (1100vpm CH_4, 1004vpm H_2, 5000vpm CO, 5200vpm CO_2 in N_2). After this a sample quantity of 50 µl was drawn in gas tight injection syringe (Hamilton make) and injected into column port. Chromatographic peaks were obtained for isothermal operation of GC. The peaks were identified with prior known retention times of given calibration mixtures. The areas of the various peaks were readily available from the built in integrator of the GC. From this data the various component gases were evaluated volumetrically.

4.2.5 CALCULATION OF HIGH HEATING VALUE OF GAS

The high heating value of the producer gas was calculated from the volumetric composition of the producer gas and heating value of individual gas constituent from the following formula (*Mukunda et al. 1997)*

High Heating Value = $H_{H2} * f_{H2} + H_{CO} * f_{CO} + H_{CH4} * f_{CH4}$

Where H = Heating value of the given component

H_{CO} = Heating value of Carbon monoxide.

H_{H2} = Heating value of Hydrogen.

H_{CH4} = Heating value of Methane.

f = Fraction of Components of Gas

RESULTS AND DISCUSSIONS

A closed top downdraft gasifier of 5kg/hr capacity was fabricated and operated using the following as feed stocks.

(i)   Poplar wood pieces (2cm x 5cm x 10cm).

(ii)   Briquetted press mud, and

(iii)   Blend of wood pieces and rice husk.

The proximate analyses of the feed stocks were carried out in the laboratory according to the standard method and have been presented. The ultimate analysis data has been adopted from the literature.

The feed stock type, and airflow rate were operational variables. Temperatures at strategic points and gas flow rate were experimentally measured parameters. Gas sampling and analysis were carried out for each run for various airflow rate values.

5.1   PROXIMATE ANALYSIS

The Proximate analysis as the name suggests, gives the proximate information of biomass constituents such as moisture, volatiles, fixed carbon and ash content. ASTM standards D3172-73 through D3173-75 modified procedure and IS: 1350 standard are recommended for the determinations of volatiles (sparking fuels), and fixed carbon in the solid fuels. The selection of this method is based upon the presence of large quantum of

volatiles in the biomass materials. The proximate analysis of three biomass materials as per IS:1350 is given in Table 5.1.

TABLE 5.1 PROXIMATE ANALYSIS OF BIOMASS MATERIAL

Component	Wood	Press Mud	Rice husk
Fixed carbon (%)	14.53	20	14.7
Volatile matter (%)	84.52	65.8	66.1
Ash content (%)	0.95	14.2	19.2

The above analysis indicates that wood and agricultural residue like rice husk have similar amounts of fixed carbon. However, wood has very high volatile matter, but very little ash. Rice husk has approximately 19% ash content. This indicates that the heating value of rice husk should be much lower than that for wood. Press mud has highest amount of fixed carbon with volatile matter similar to that for rice husk.

5.2   ULTIMATE ANALYSIS

The ultimate analysis of biomass material gives the constituent elements, namely carbon, hydrogen, nitrogen, and sulphur. ASTM, D3174-76 and IS:1350 give the test methods for the ultimate analysis. This analysis is performed by burning a sample in a current of oxygen. As a result, the hydrogen, carbon and sulphur get oxidized to water, carbon dioxide and sulphur dioxide respectively. Water and carbon dioxide are absorbed in a suitable solvent and the constituents are determined gravimetrically. Sulphur products are retained by lead chromate. The nitrogen in biomass is determined by the Kjeldahl method. Since there is no facility in the university for ultimate analysis we could

not perform these tests. However the ultimate analysis of some biomass material is taken from literature is given in Table-5.2

TABLE-5.2 ULTIMATE ANALYSIS OF BIOMASS MATERIAL

Biomass	C%	H%	N%	O%	Ash%
Wood	44.02	6.35	1.95	39.08	8.60
Bagasse	47.0	6.5	Nil	42.5	4.00
Rice husk	36.42	4.91	0.59	35.88	22.2

The determination by ultimate analysis in terms of C, H, O and N is important in the case of biomass materials. With the ultimate analysis and the analysis of gases, one can have overall material and energy balance during conversion process and the individual components can be tracked. These calculations are prerequisite in assessing the performance of any gasification /combustion system. Also, knowing the amount of combustible constituent, specially carbon and hydrogen, the equivalence ratio, normally defined as the ratio of air required for gasification to theoretical amount of stoichiometric air for complete combustion, can be determined. Ultimate analysis is also essential to design and to quantitatively measure the performance of gasifiers.

5.3 GASIFICATION PERFORMANCE ANALYSIS

5.3.1 Effect of Airflow on temperature profile in the gasifier

Gasification air was supplied by a blower and its rate was measured with a calibrated venturimeter and U-tube manometer. The temperature was measured inside the gasifier along the central axis using a K-type thermocouples connected to a digital

temperature indicator through a selector switch. Readings were taken after the gasifier has attained the steady state as indicated by a stable reading on the indicator. Figure-5.3.1 to 5.3.3 depict the effect of airflow rate on the variation of temperature along the gasifier using different feedstock materials. Fig-5.3.1 gives variation of temperature with airflow when poplar pieces were as feedstock. It is observed that the temperature increases linearly up to a distance of 80cm from the top of the gasifier. Clearly this is a reduction zone. In a downdraft gasifier the reaction zone keeps moving upwards while the biomass moves downwards, hence the name moving bed gasifier. The reduction zone has the highest temperature in a gasifier operation. As seen in from the figure the temperature decreases with increase in distance from the top. Similar trend is observed during the gasification of other two feed stocks namely, Blend and briquettes. Fig.5.3.2 shows the temperature variation for briquettes and fig.5.3.3 shows the temperature variation for the blend of wood and rice husk. For briquettes, the temperature variation in the reduction zone shows a complex trend – sharp increase and followed by sharp decrease. For comparative assessment of reduction zone, the temperature attained in the gasifier is plotted against airflow rate for all the three feed stock materials. It is found that the highest temperature attained for different materials is not at the same airflow rate. This is expected as depending upon the chemical constitution of a particular material, airflow rate will be material specific. However, it is found that the airflow giving highest temperature remains in a narrow range. This is in line with the findings of Sharma et al. (1989).
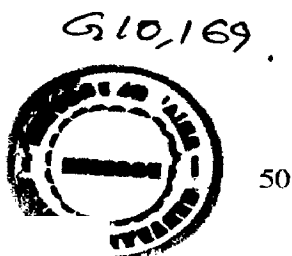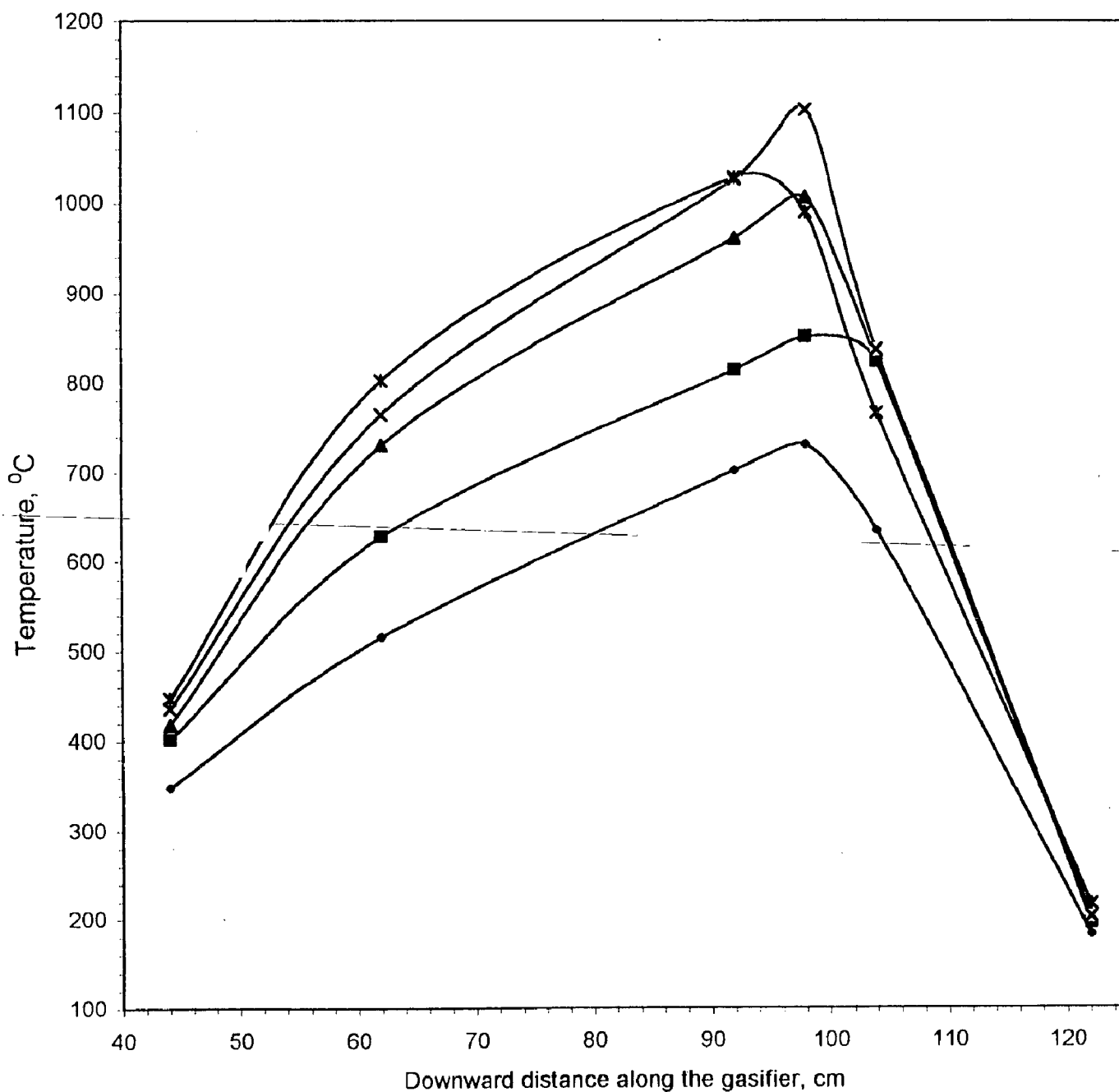
Fig.5.3.1 Effect of Airflow Rate (Nm³/hr) on the Temperature Profile for Wood

———◆——— Airflow rate=10.36367 Nm3/hr   ———■——— Airflow rate=13.37944 Nm3/hr   ———▲——— Airflow rate=15.83077 Nm3/hr

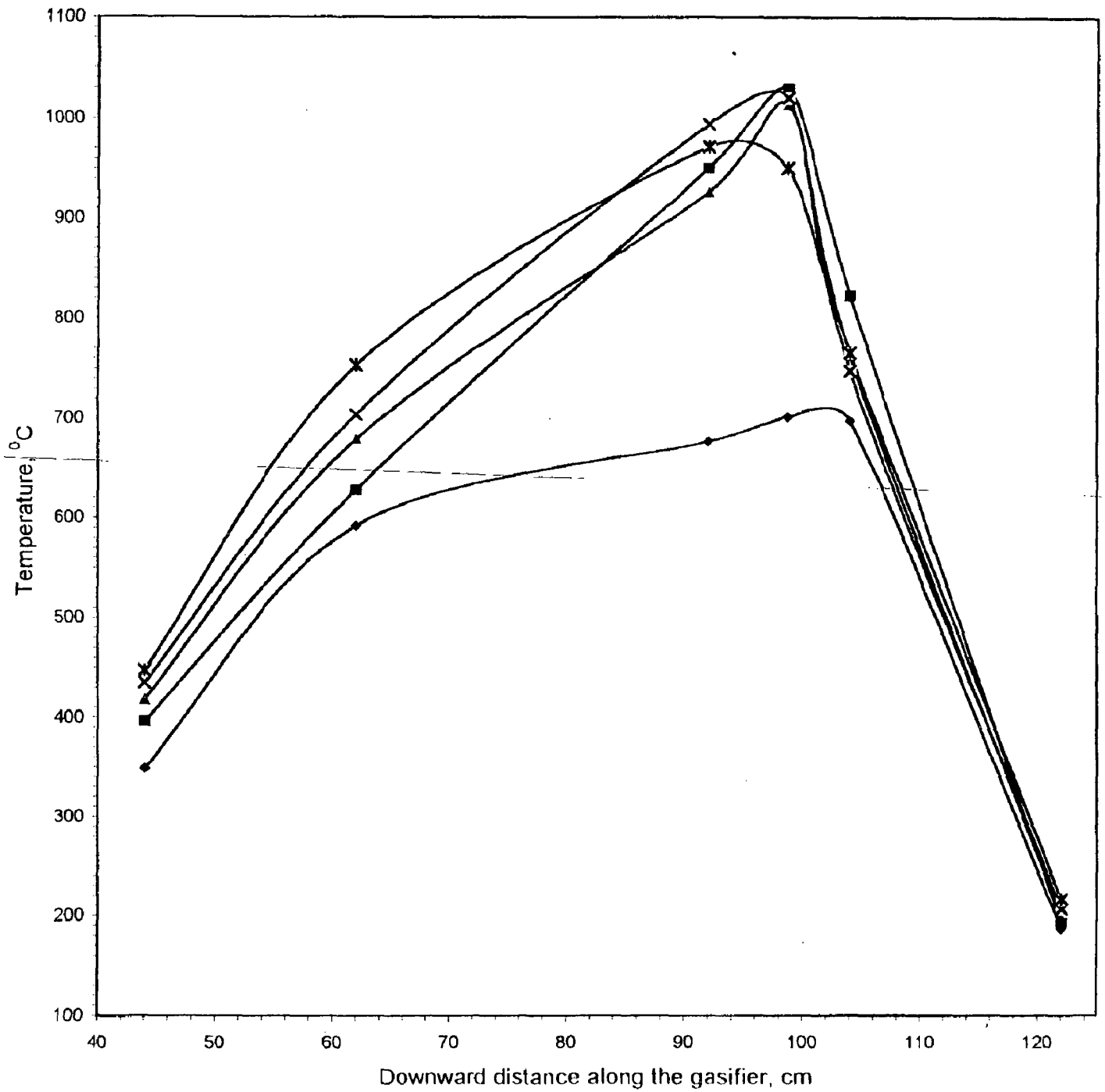———✕——— Airflow rate=17.95041 Nm3/hr   ———✳——— Airflow rate=20.72734 Nm3/hr

Fig.5.3.2 Effect of Airflow Rate (Nm³/hr) on the Temperature Profile for Briquettes

—◆—Airflow rate=10.36367 Nm3/hr   —■—Airflow rate=13.37944 Nm3/hr   —▲—Airflow rate=15.83077 Nm3/hr

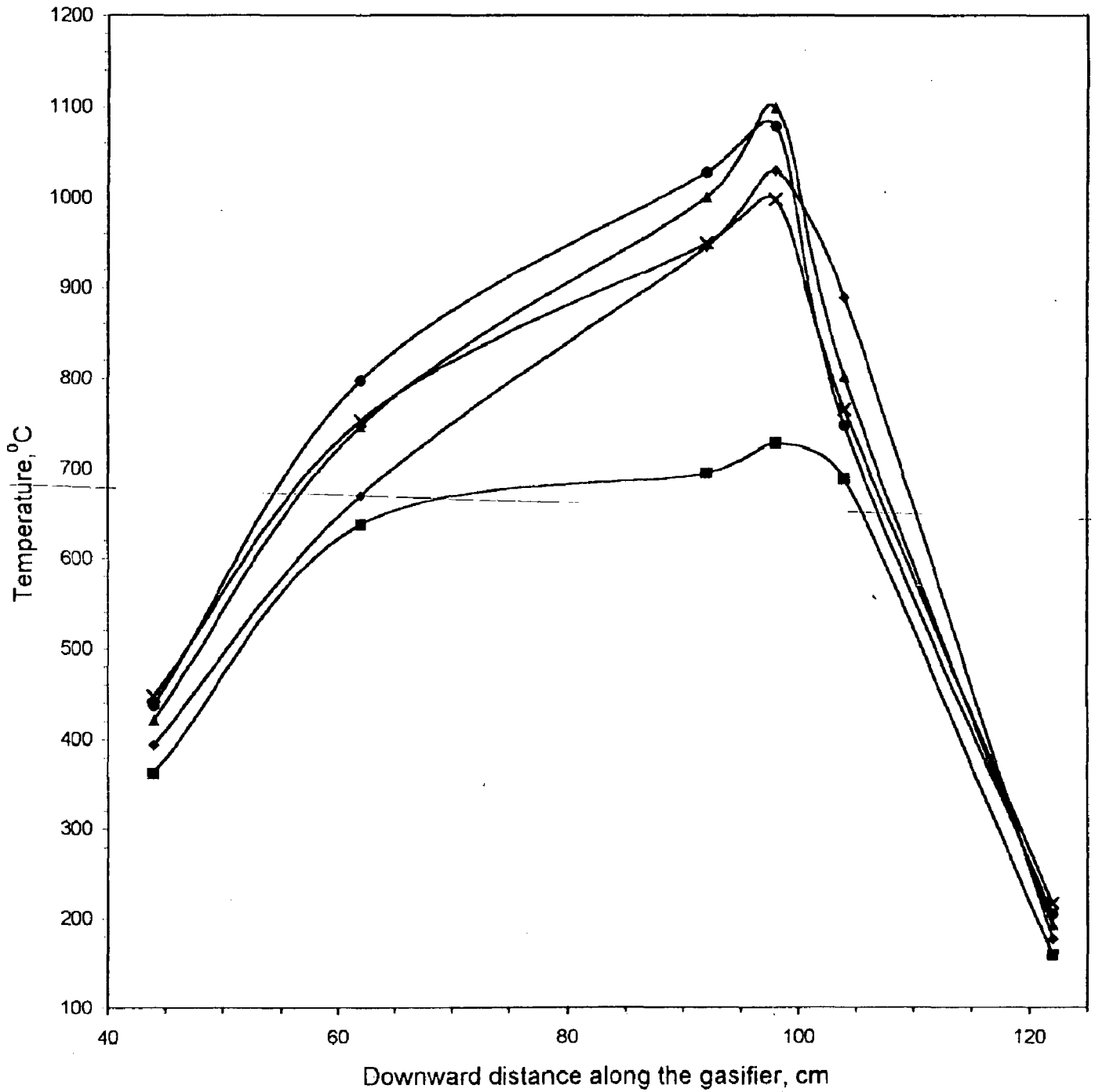—✕—Airflow rate=17.95041 Nm3/hr   —✶—Airflow rate=20.72734 Nm3/hr

Fig.5.3.3 Effect of Airflow Rate (Nm^3/hr) on the Temperature Profile for Blend [Wood(70%)+Rice Husk(30%)]

— ■ — Airflow rate=10.36367 Nm3/hr   — ♦ — Airflow rate=13.37944 Nm3/hr   — ▲ — Airflow rate=15.83077 Nm3/hr

— ● — Airflow rate=17.95041 Nm3/hr   — ✖ — Airflow rate=20.72734 Nm3/hr
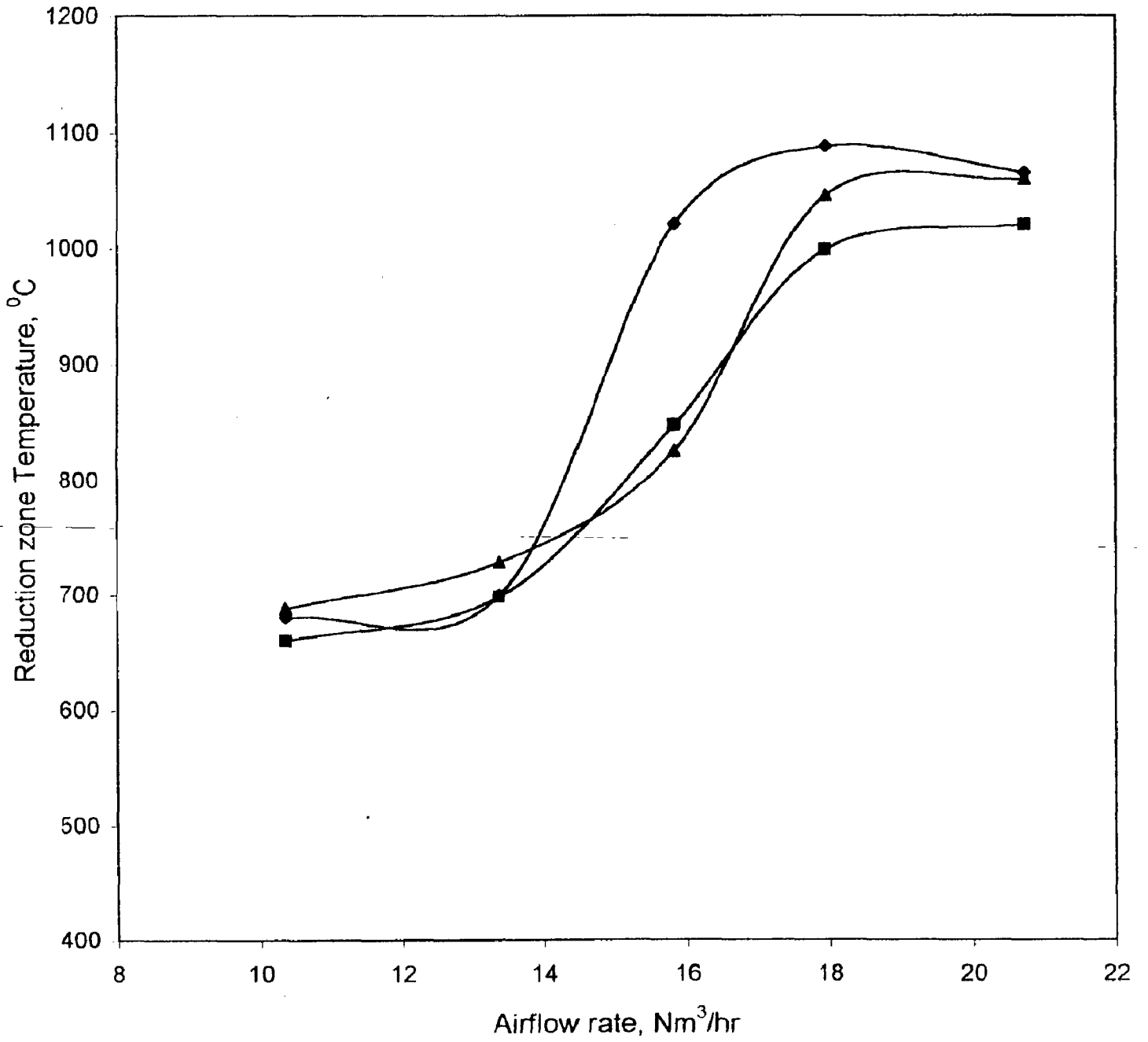
Fig.5.3.4 Variation of Reduction zone Temperature(^{0}C) with Airflow Rate (Nm^3/hr)

——◆——Wood   ——■——Briquettes   ——▲——Blend[Wood(70%)+Rice husk(30%)]

5.3.2 GAS COMPOSITION

Gas sampling as described previously was carried out and the samples were analyzed for their composition in a gas chromatograph. The results of the gas analysis are shown in figs-5.3.5-5.3.7. The gasifier outlet gas consisted obtained mainly consist of H_2, CO, N_2, CH_4 and CO_2. Fig-5.3.5 indicates that as airflow increases the component CO_2 increases and then decreases where as CO decreases and then remains almost constant. Hydrogen shows decrease and then increase with the increase in airflow rate. As expected nitrogen content goes on increasing with the airflow rate increase. Methane content is very low .For briquettes and the blend, CO_2 and CO compositions almost remain constant at different air flow rates, where as H_2 and CH_4 compositions show a decreasing trend (See Figs. 5.3.6 and 5.3.7). Fig.5.3.8 presents a comparative plot of flammable gas components composition at different flow rates for poplar, briquettes and blend. It is clear that as airflow rate increases, the flammable content decreases for the briquettes and the blend. For wood, the flammable contents increase first and thereafter decrease. Thus it can be concluded that for the briquettes and the blend, minimum flow rate of air is required for the highest flammable gas composition. This will eventually lead to reduction in cost as less air is to be supplied to the gasifier. For wood, however, the gasifier should be run at a flow rate between 13 to 16 Nm^3/hr. Nitrogen is a diluent and doesn't contribute to the heating value of the gas and is inevitable when air is used as a gasifying agent. Therefore, the gas heating value decreases with increase in airflow rate, although there is increase in gasifier temperature.

All the gas components are the products of devolatilization reactions, while the main components of heterogeneous gasification reactions are essentially CO (char .
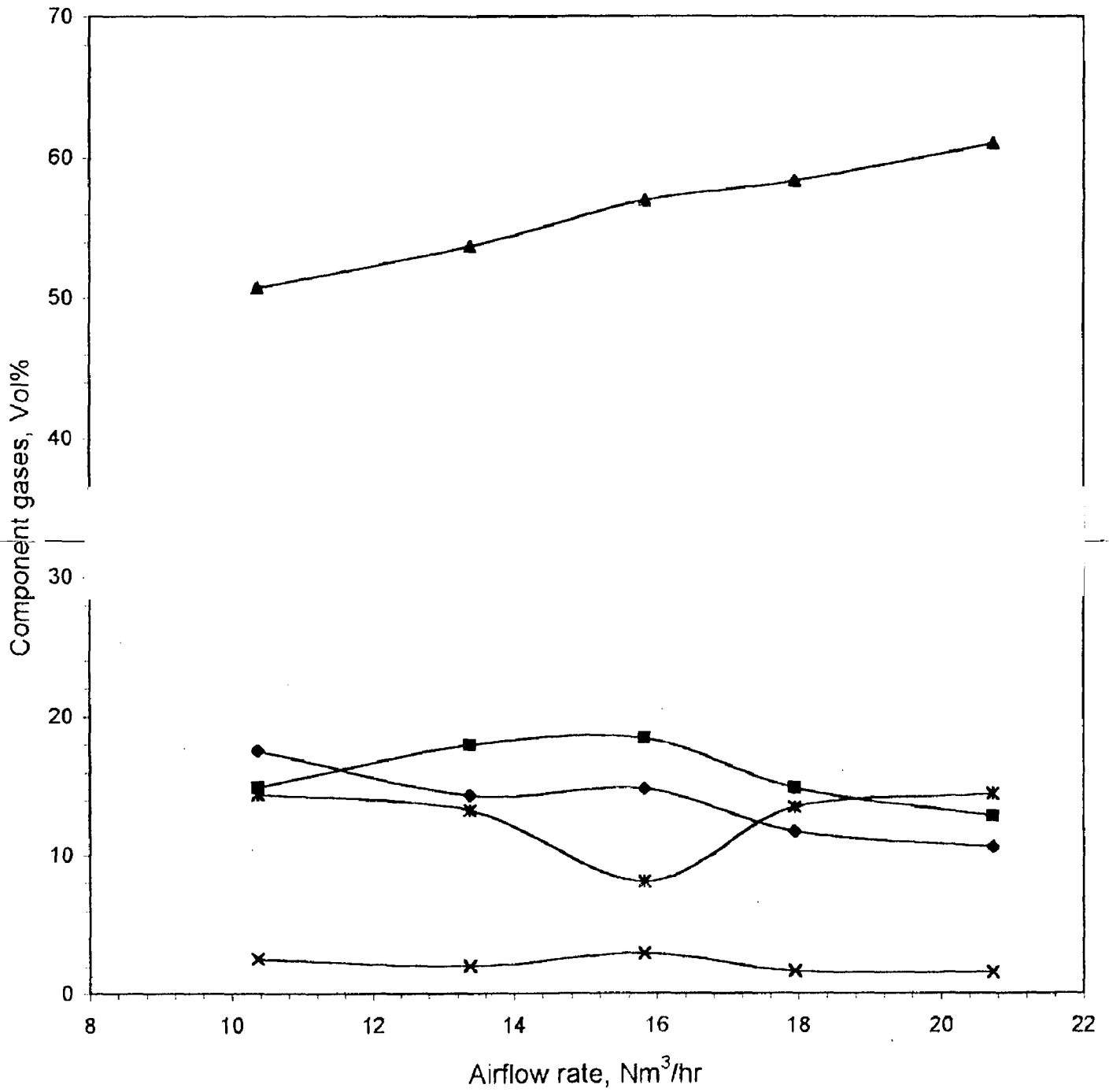
Fig.5.3.5 Variation of Component Gases with Airflow Rate (Nm^3/hr) for Wood

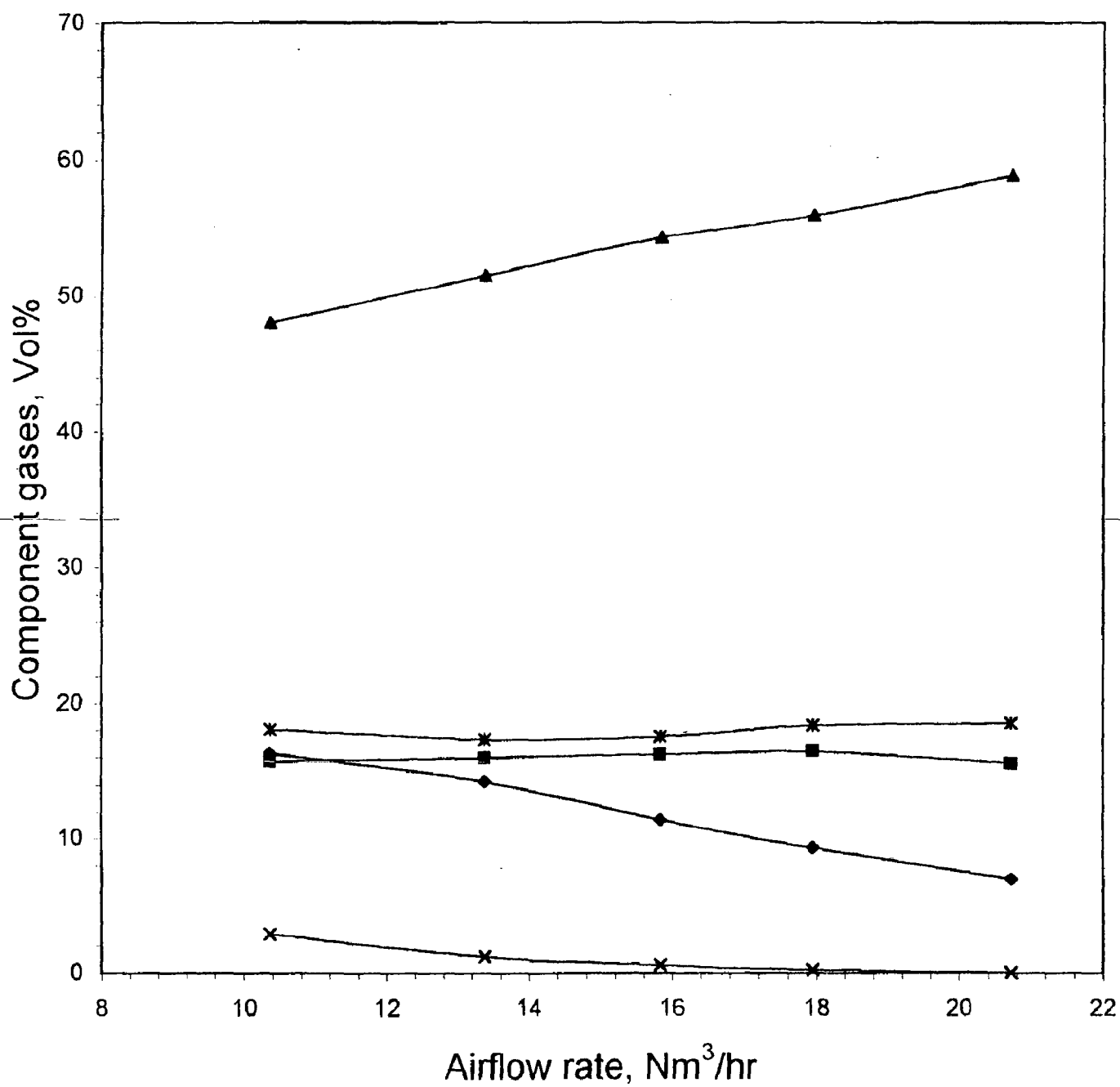— ♦ — Hydrogen   — ■ — Carbon monoxide   — ▲ — Nitrogen   — ✕ — Methane   — ✳ — Carbon dioxide

Fig.5.3.6 Variation of Component Gases with Airflow Rate (Nm³/hr) for Briquettes

—◆—Hydrogen —■—Carbon monoxide —▲—Nitrogen —✳—Methane —✳—Carbon dioxide
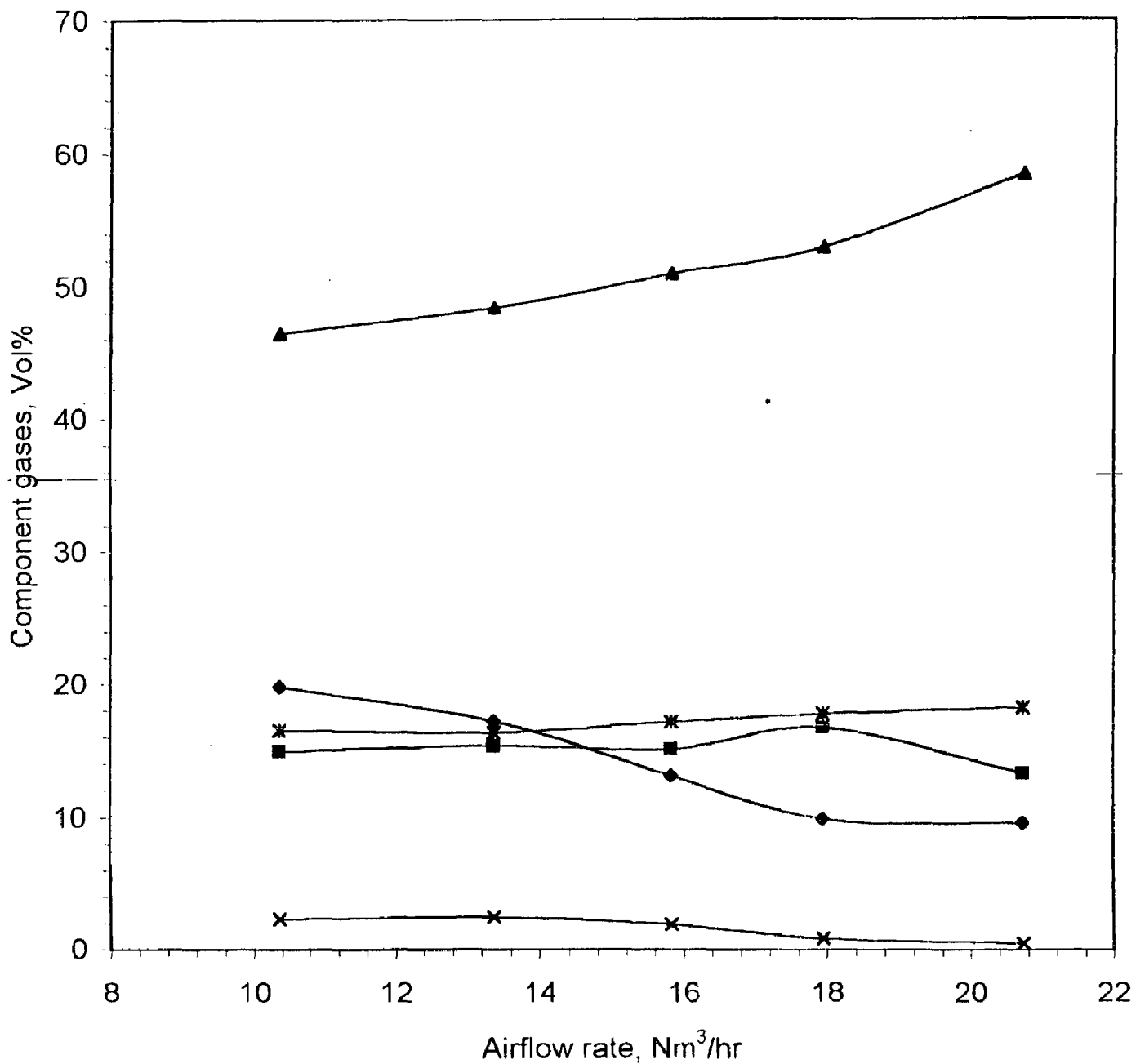
Fig.5.3.7 Variation of Component Gases with Airflow Rate (Nm³/hr) for Blend
[Wood (70%)+Rice Husk (30%)]

♦ Hydrogen   ■ Carbon monoxide   ▲ Nitrogen   ✕ Methane   ✳ Carbon dioxide
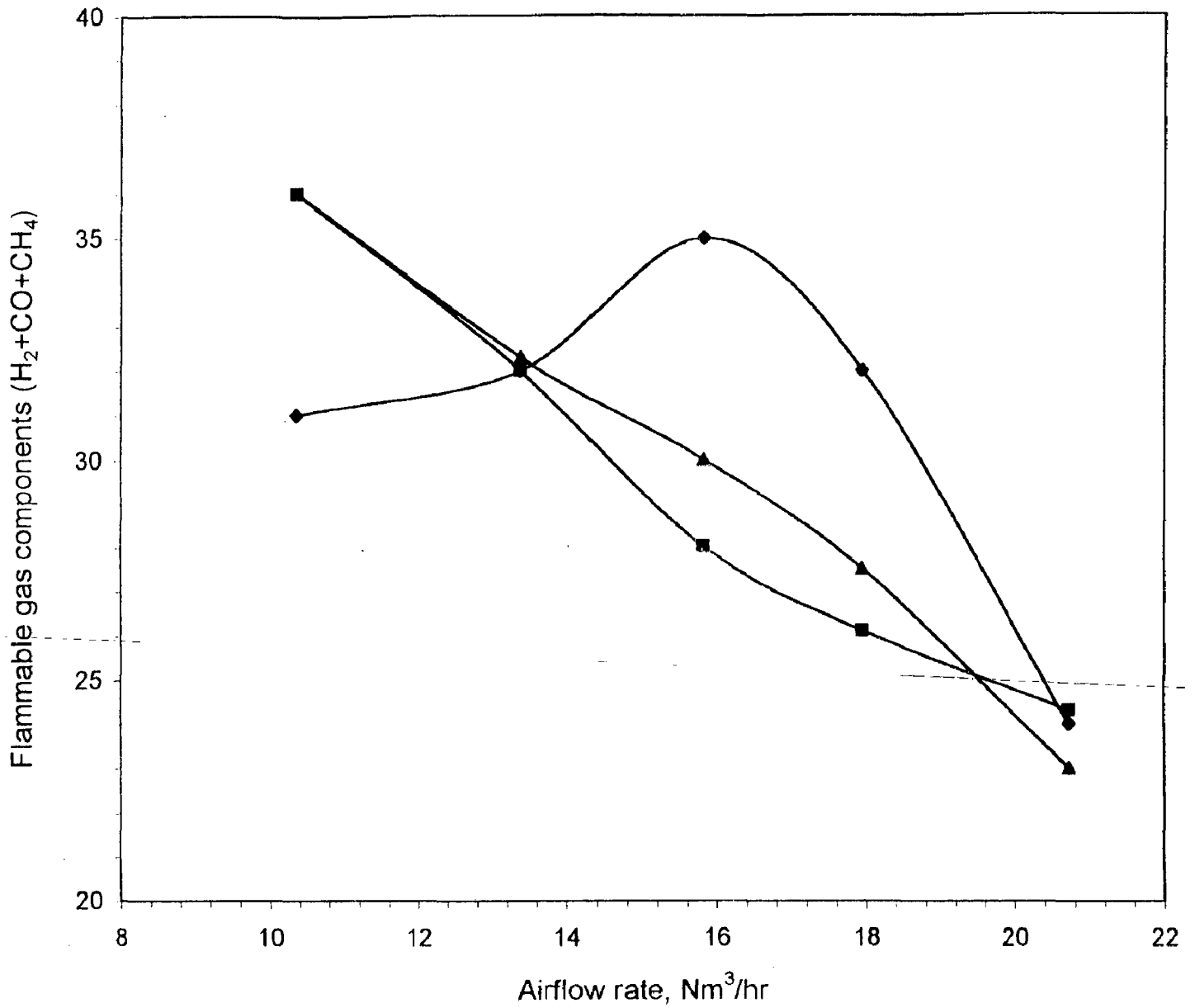
Fig.5.3.8 Variation of Flammable Gas Component with Airflow Rate (Nm^3/hr) for Briquettes, Wood, and Blend [Wood (70%)+Rice Husk (30%)]

——◆——Wood   ——■——Briquettes   ——▲——Blend[Wood(70%)+Ricehusk(30%)]

combustion) and CO_2 (char combustion and gasification). It is observed that the very first stage in gasification reaction is essentially due to combustion and devolatilization. With successive and progressive heating of the gasifier bed, the reaction zone gets enlarged and the formation of a char layer is obtained where the char gasification reaction takes place. Therefore, in the second stage CO_2 is consumed by the gasification reaction, with a corresponding increase in the concentration of CO and the heating value of the gas.

5.3.3 HEATING VALUE OF THE GAS

The high heating value of the producer gas was calculated from the composition of the producer gas and the heating value of individual gas constituent using the following formula:

High Heating Value = $H_{H2}*f_{H2} + H_{CO}*f_{CO} + H_{CH4}*f_{CH4}$

Where H = Heating value of the given component, and

$H_{CO} = 12.71$ MJ/Nm^3

$H_{H2} = 12.78$ MJ/Nm^3

$H_{CH4} = 39.76$ MJ/Nm^3

f= fraction of component in the producer gas.

f_{H2}=fraction of hydrogen.

f_{CO}= fraction of carbon monoxide.

f_{CH4}= fraction of methane

The heating value of the gas is thus calculated from the above formula. Calculated values for different biomass materials are plotted in Fig. 5.3.9 From this figure, it is found that the heating value of the gas for wood shows a slight increase and thereafter decrease

keeps on increasing with no corresponding increase in the flammable gas components. However, for briquettes and the blend, the heating value decreases with the increase in airflow rate. This is in line with the earlier observed from fig.5.3.8The maximum heating value for the gas is around 5.3 MJ/Nm^3. The range of heating value reported for producer gas by different investigators, ranges from 3.5 to 5.5 MJ/Nm^3. Thus the present results are on the higher side of the reported values.

It is observed from the figures that heating value of gas decreases as the flow rate of air increases. The optimum heating value of gas is obtained in the range 13 to 16 Nm^3/hr. Figure-5.3.9 , shows that as air flow rate increases the gas heating value increase as more CO is formed in second stage. Decreasing trend is observed when the reaction in gasifier approaches towards combustion. Similar trends were also observed in Figure-5.3.9.
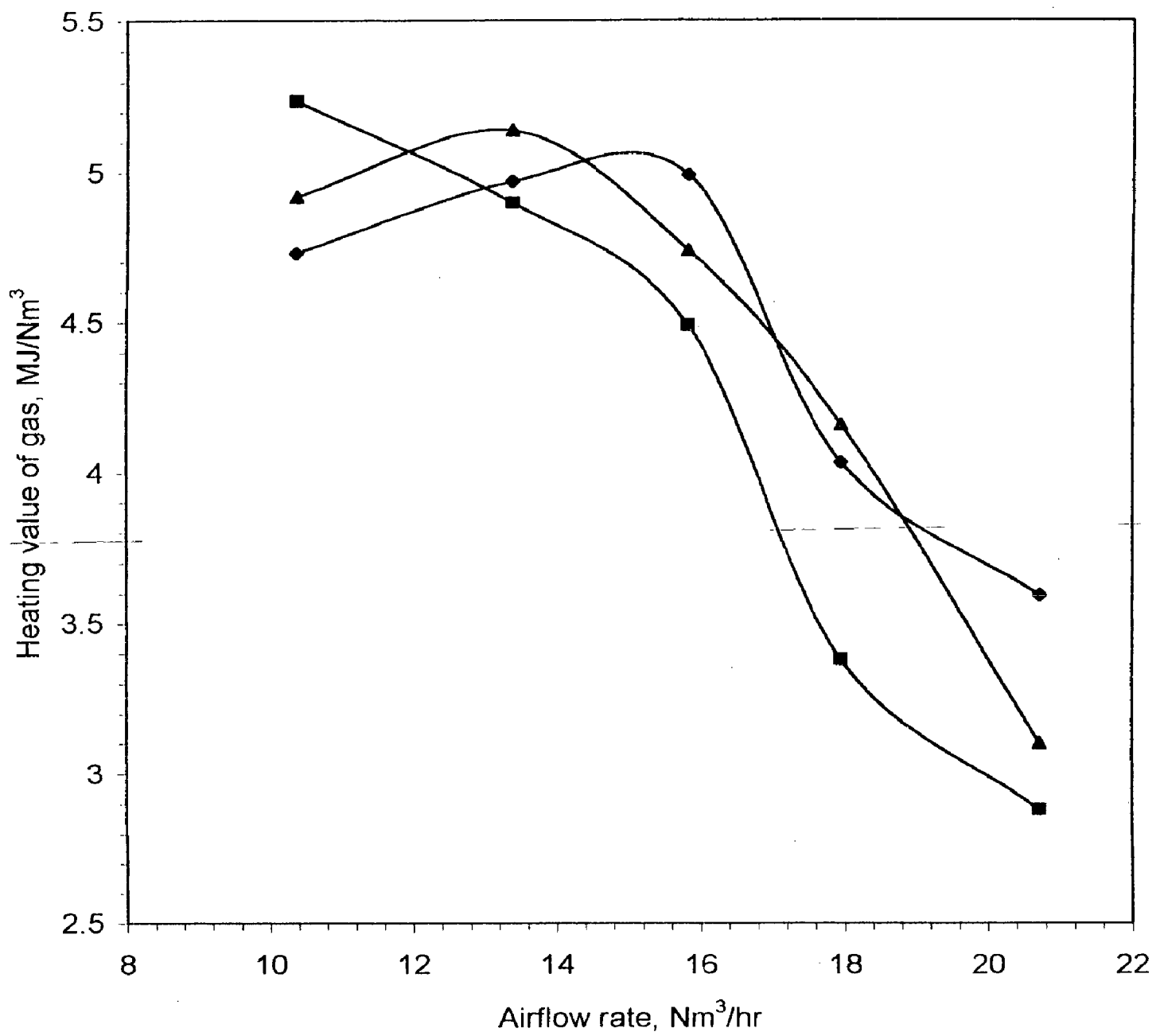
Fig.5.3.9 Variation of Heating Value of gas (MJ/nm^3) with Airflow Rate (Nm^3/hr)

——◆—— Wood ——■—— Briquettes ——▲—— Blend[Wood(70%)+Rice husk(30%)]

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

As a result of present experimental investigation the following conclusions have emerged out.

1. The thermal gasification of biomass with air requires an optimum flow rate of air. Beyond this flow rate the quality of gas goes down.

2. A blend of low ash (wood) and high ash (rice husk) biomass can be gasified with least operational problems

3. Briquetted biomass (press mud) in the present case is also suitable feedstock foi the downdraft gasifier but the size of briquettes should be less than hearth diameter.

4. High ash powdery biomass like rice husk is not a suitable feed stock for imbert type downdraft gasifier.

5. Reactor temperature is dependent on air supply rate rather than type of feed stock.

6. Suitable provision appears to be necessarily made for the removal of ash in downdraft gasifier operating on high ash content feed stock.

6.2 RECOMMENDATIONS

1. Since reactor temperature is strong function of air supply rate the gasifier should be operated with minimum possible airflow rate during the gasification of high

ash content biomass. This keeps the operational temperature below ash cintering/clinker formation temperature.

2. Making a blend of suitable feed stocks is a successful method of gasifying high ash content and otherwise difficult biomass.

3. It is advantageous to used densified biomass than to use loose biomass in case of powdery biomass.

6.3 OPERATIONAL EXPERIENCE

The gasifier was tested for its use for powdery biomass like rice husk.

1. Because of low bulk density, the rice husk was not free flowing (bunker flow problem). Even with motor mounted on the hopper to send vibrations, it was generally observed that, the rice husk flow was not uniform as indicated by the transients appearing in the flame on the burner. When the gasification operation was stopped, and the gasifier was dismantled, bridging and arching of the rice husk in the gasifier was observed. Due to this it was concluded that due to bridging and arching, rice husk is not suitable feed stock for closed top imbert type downdraft gasifier.

When bagasse was used as feed stock, it was found that the gasifier bottom has the problem of ash sintering and clinker formation. This was because of the high ash content of bagasse.

2. In view of the above problem, it was thought to use a blend (mixture) of wood and rice husk. Different percentages of rice husk in the blend were tried, and it was concluded that 30% of rice husk with 70% wood would be an ideal blend for the gasification.

3. It was observed that gasification of fine biomass (high ash content) was not possible in a downdraft gasifier of imbert type. The ash does not take part in the gasification process, but at high temperature in the reduction and combustion zone it melts to form a clinker. So open top downdraft gasifier should be used.

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