STEAM GENERATION AND DISTRIBUTION NETWORK ANALYSIS, INCLUDING COGENERATION SYSTEM AT STAR PAPER MILLS LTD., SAHARANPUR

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

PULP & PAPER ENGINEERING

By

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CANDIDATE'S DECLARATION

I hereby declare that, the work which is being presented in this dissertation entitled "**STEAM GENERATION AND DISTRIBUTION NETWORK ANALYSIS, INCLUDING COGENERATION SYSTEM AT M/S STAR PAPER MILLS LTD., SAHARANPUR**" in partial fulfillment of the requirement for the award of degree of "**Master of Engineering**' in '**PULP AND PAPER**' is an authentic record of my own work carried out for a period of about six months from August 1995 to January 1996 under the supervision of **Dr. M.C. Bansal,** Professor, Institute of Paper Technology (University of Roorkee), Saharanpur.

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

Date.- 24/01/1996

Place - SAHARANPUR

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

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Date - 24/01/1996

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ABSTRACT

It is found that the Paper industry is the third highest consumer of electrical power & water after Steel and Petrochemical industries. With foreseeable future of energy crisis & incremental fuel cost in 20th Century, it has become important that the mill should generate its own power at the lowest possible cost simultaneously fulfilling all the process steam demand. So it leads to do energy audit of the present mill and proposed for an efficient cogeneration cycle which will increase the mill energy conversion efficiency from 50% to Indian standard practice of 58%. Here in this dissertation an effort has been made to analyze the performance of steam generator, steam distribution and cogeneration cycle technically as well as more economically.

Chapter two evaluates the efficiencies of different steam generators. It is seen that the thermal efficiency of C/F boilers is 64%. It is only due to variation in coal grade with low C.V of 4500 Kcal/kg and absence of air preheater, otherwise the efficiency could have reached above 70%. The recovery boiler also gives nearly 65-70% of thermal efficiency with chemical recovery efficiency of 70% which are quite low and efforts should be made to increase the chemical recovery efficiency at least to 85% by retrofitting to increase its economic viability and environmental compatibility.

Chapter three notes the per day steam consumption chart & hence draws the steam balance diagram for the total cycle of the mill. It checks the sizing of pipe lines & finds 776 Tons of 80 PSI steam and 876 tons of 40 PSI steam lost due to condensation in steam pipe lines & radiation. Mill data indicated that about 10 Tons of steam per day is lost through different systems and media faults. The annual steam loss cost, if there is a leak in the steam pipe lines, has also been calculated.

Chapter four analyzes the feasibility of a cogeneration system. It is observed that, the present cogeneration system with a bottoming cycle can never lead the mill energy conversion efficiency more than 50% & cogeneration cycle efficiency utilization factor not more than 70-75%. The mill total heat demand ratio is to power demand found to be 7.6:1 which lags the effective cogeneration system heat to power ratio value of 5:1. The power cost is found to be Rs.2.90/- per unit at the load of 3.8 MW. So it is advised to maintain the turbine load in between 3.2-3.9 MW out of a 5 MW capacity BHEL turbine.

Chapter five proposes for an Atmospheric Fluidised Bed Combustion boiler cogeneration cycle which can generate 12.483 MW of power fulfilling all the process steam needs of future mill of 200 TPD capacity. This topping cycle will lead to mill energy conversion of nearly 55% and return on investment is about 20% over the ROI of 10% on the present system. The heat to power ratio can be improved to 6:1 & expected pay back period found to be 5-6 yrs. The power cost is Rs.1.13/kwH leading to a saving of approx in 11.3 Crores over the present system of power generation per annum.

Chapter six concludes the dissertation.

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NOMENCLATURE

HCV = Higher calorific value of coal in kJ/Kg.

W = Total weight of pipe including flanges, fillings, kgs.

m_o = Time taken for warming of pipe

Q = Rate of condensation, Kg/sec.

T = Steam temperature, ^0C

t = Temperature of atmospheric air, ^0C.

h_{fg} = Specific enthalpy of evaporations of steam at the working pressure, kJ/Kg.

B = Radiation energy in watts/m run of pipe.

A/H = Air heater

B/L = Black liquor

BLS = Black liquor solids

SPM = Star Paper Mills Ltd.

$(\eta_0)_c$ = Conventional cycle efficiency

EUF = Energy utilization factor

Q_u = Prcess heat utilization, KJ

F = Fuel energy input, KJ

η_a = Artificial thermal efficiency, %

PRS = Pressure reducing station

W_T = Total work output of turbine, kW

Q_i' = Fuel input to the cycle kJ/kg

Q' = Heat input in equivalent terms of power kW

W_T' = Total work output of turbine in equivalent terms of heat per Kg of steam, KJ/kg of steam

m_e = Equivalent evaporation of C/F boiler kJ/kg of coal

h_{sup} = Enthalpy of superheat steam temp i.e. KJ/kg.

h_{fi} = Enthalpy of feed water to boiler, kJ/kg.

CHAPTER-1

INTRODUCTION

Power house is the mother unit to give existence of a paper mill. To run a mill steam is the first and foremost need to fulfill its Power and Process heat needs. So at first we should introduce with steam & its qualities. The main properties with steam are as follows-

- A. It has very high heat content and it gives up its heat when condensed.
- B. It can be used for power production with a corresponding pressure drop in turbine as well as for process heat.
- C. It can be readily distributed and easily controlled.

The steam used for process heat follows the two following principles.

- A. Boiling point of water decreases with reduced pressure.
- B. The latent heat of steam increases with reduced pressure.

Similarly the steam used for power production follows the two basic principles.

- A. Use the highest practicable initial pressure and temperature to the turbine.
- B. Use lowest practicable exhaust or, back pressure from the turbine.

Another universal rule followed by steam is

- Never permit steam to expand from one pressure to a lower pressure without getting some useful work or, heat from the expansion.

The energy management committe in the mill plans for a new project on short term return basis to improve the system efficiency and carries out energy audit of the mill to achive the desired objectives. An integrated approach is called for taking into considerations, the total energy system unit. Tremendous economic and environmental sense led us towards a cogeneration system i.e. simultaneously generation of power and process heat.

In a cogeneration system 80% of energy from the fuel can be utilized with half of fuel consumption in boiler than in a conventional system using steam for process heat and power production separately. In a paper mill, of the total paper manufacturing cost, energy constitutes around 25-30%, second only behind the raw material cost. As per the data of 1992 it is estimated that the annual energy bill of the paper industry is around Rs. 900 Crores and that the cogenration potential for thermal energy is about 15% and that for electrical energy is 8%. This comes to Rs. 225 crores in terms of possible annual savings. In India, energy consumption is 2.4 tonnes of oil equivalent per ton of paper as against the world average of 1.17 tonnes of oil. The large integrated paper mill specific energy consumption of steam and power varies from 10.2 to 17.4 tonnes and from 1305 to 1949 KWH per ton of paper which is very high than the normal international practice.

This leads to adopt a new Atmospheric Fluidised bed combustion (AFBC) cogeneration cycle with mill heat to power ratio of 5:1, mill energy conversion efficiency 55% against swedish standard of 70% and to put attention on non conventional energy sources like rice husk, baggase.

All the analysis done in this thesis system may not be correct fully due to some assumptions made during the calculations and data collected have not been checked for their exactness.

The government's rules over cogeneration enforce us to give a second thought on cogeneration system. These are as following (1)

- Promoter's contribution to be 11% and balance of 91% should be collected from public issues.
- Not more than 40% of total out lay through Indian Financial Institutions, promoters to arrange balance 40% from sources other then public financial institutions.

- Foreign equity upto 100%.
- Exemption from CEA concurrences for schemes upto Rs. 25 crores.
- Two part tariff based on prescribed operational norms optional plant load factor as also on the notified rates of depreciation.
- Licenses for 30 year in the first instance and subsequent renewals of 20 years.
- Rate of return of 5% above RBI rate.
- Capitalization of interest during construction at actual cost.

CHAPTER-2

STEAM GENERATION

2.1 Steam Generation at SPM:

Presently steam is generated by four boilers to fulfill all the steam requirement. There are two coal fired boilers and two recovery boilers (fuel is Black Liquor) out of which only one is in operation.

Type	Rated Capacity	[illegible] Capacity of Generation
Coal Fired Boiler No.9	35 TPH	20-25
Coal Fired Boiler No.10	35 TPH	20-25
Cifond Recovery Boiler	15 TPH	20-25
JMW Recovery Boiler	35 TPH	09-12

For detailed information of steam generation presently Table No. 2 is to be referred. Presently the mill generates about 1740 Tons of steam per day.

2.2. Steam Generation in Coal Fired Boilers:

One particular ultimate analysis of a depot coal gives the following results

C = 47

H = 3%

O = 8%

S = 1%

Ash = 30%

HCV = 4700 kcal/kg

LCV = 4500 kcal/kg

AIR: Fuel = 6.35:1

Combustion efficiency $= \frac{6.35}{9.79} \times 100$

= 65% (very low)

Theoretically analysis of stack gas gives the following results

CO_2 = 16.47%

H_2O = 3.44%

SO_2 = 0.001.%

N_2 = 72.00%

The boiler no. 9, sankey diagram of energy balance shows the following results-

Energy Input	= 19646	(100%)
Heat Carried By Dry Flue Gas	= 3006.36	(15.30%)
Heat Lost By Moisture	= 1016.53	(5,17%)
Incombustible Loss	= 422.71	(2.15%)
Blow Down Heat Loss	= 589.36	(3.01%)
Unaccounted Heat Loss (including loss with ash)	= 2626.6	(13.37%)

Here all the heat units are taken in KJS.

Heat Utilized For Steam Generation = 11983.95 (60.91%)

These are theoretically obtained values. So the boiler thermal efficiency found is to be 61%. But as data of SPM the boiler thermal efficiency is be 64%.

As due to some problems with the air preheater it has almost been cut off. So the efficiency obtained is 64%. If the problem of A/H can be solved the boiler thermal efficiency upto 67% can be obtained.

2.3 *Steam Generation in JMW Boiler:*

For detailed information of steam generation in JMW Appendix-II and Fig.1 are to be referred. The Black Liquor solid analysis shows that

C = 42.6%

H = 3.6%

S = 3.6%

O = 31.7%

Na = 18.3%

The smelt analysis shows the following results

Na_2S =28.5% as Na_2O

Na_2CO_3 =70% as Na_2O

Na_2SO_4 =1.5% as Na_2O

The material balance (MB) for the above boiler on the basis of 100Kg of BLS shows the following conclusions.

INPUTS		OUTPUTS	
BLS	= 100 Kg.	Flue Gas	= 753.83 kg
Water	= 66.66 Kgs.	(including water)	
Salt Cake	= 4.62 Kgs.	Smelt	= 43.41 kg.
Air Supplied	= 624.24 Kgs.	Inner Oxide	= 0.2 Kg
Balance	= .13 Kgs.		

The sankey diagram of EB of JMW is found to as given below:

INPUTS

Sensible heat in air	= 15667.25 kJ. (1.24%)
Heat available from BLS	= 1254000 KJ (98.76%)
Total heat input	= 126957.3 KJ (100%)

Heat of reduction	=	6972.24 (5.49%)
Heat of evaporation of water in B/L	=	149409.72 (11.76%)
Heat required for water formation due to presence of H	=	72632.05 (5.72%)
Sensible heat in flue gas	=	34661.10 (2.72%)
Heat of fusion smelt	=	6141 (0.48%)
S.H. Loss in smelt	=	37346.40 (2.94%)
S.H. in salt cake	=	79.69 (0.0061%)

So heat available for steam generation = 925787.5 KJ. (72.1%)

So thermal efficiency of this boiler is 72%. But as per the mill analysis due to radiation losses and other losses. The boiler thermal efficiency is found between 65-70%.

2.4 Axillary Tips for Efficiency Improvements of Steam Generators:

For efficiency improvements of steam generators following points should be considered.

Load Management-

Distribute highest load to most efficient boiler at first. This reduces total fuel consumption.

Tuning of Boilers-

Operate the boiler with lowest practicable excess air thus reducing stack gas temperature and improving the boiler efficiency. This is possible by proper control and fine adjustments of burning equipments.

Size of Coal-

Small sized, uniformly grinded fuel size (≥ 10 mm, ≤ 50 mm) proved to best distribution of air and optimum performance. Lumps and fines results uneven distribution of air hence reduction in efficiency.

Digester Control-

Proper control over digester and adoption of a new technology will avoid steam demand fluctaions and boiler efficiency can be improved.

CHAPTER-3

STEAM DISTRIBUTION NETWORK

3.1 Steam Distribution Analysis of Star Paper Mill:

For steam distribution in SPM, steam balance diagram no 1 and Table no. 2 are to be referred. During travel of steam in pipe lines some amount of steam gets condensed due to improper sizing of pipe or due to friction loss i.e. pressure drop in the pipe line.

3.2 Calculation for 40 PSI Steam Condensation Loss (8):

Basis of calculation = 100 meter run of Pipe

Nominal pipe size = 300 mm (12")

Approximate Weight of 1 m Pipe = 40 Kg. (standard)

Total no of flanges and joints = 20

Time taken for warming of pipe = m_0 = 60 min.

Total weight of pipe including flanges and fittings in kgs,

$$W = 40x100 + 40x20 = 4800 \text{ Kg.}$$

Q = Rate of condensation in Kg/Sec. (to be found)

T (from Table of Ref.8) = steam temperature = 144.7°C

t = temperature of atmosphere air = 30°C

0.49 = specific heat capacity of steel in KJ/Kg°C

h_{fg} = specific enthalpy of evaporation of steam at the working pressure in KJ/kg.

$= 2131$ KJ/kg (from Table)

$$Q = \frac{W \times (T-t) \times 0.49}{h_{fg} \times m \times 60}$$

$$= \frac{4800\ (144.7-30) \times 0.49}{2131 \times 60 \times 60}$$

$= 0.035$ Kg/s (0.126T/hr)

The rate of condensation is multiplied by a factor 3 and divided by total no of traps to find the steam trap capacity.

Calculation of Radiation Loss for 40 PSI Steam Pipe -

To find the rate of condensation due to heat loss in radition, the steam temperature at the working pressure from steam table and the air temperature is subtracted from this. That is obtained as 114^{0}C. From Table E, watts/meter run of piping of the size used at the temperature difference of 114^{0}C is obtained as, B = 2000 W/M; specific enthalpy of evaporation of steam of working pressure is obtained as, C = 2131 KJ/Kg.

So, rate of condensation in Kg/s $= \frac{\text{Bxlength of pipe in meters}}{1000\text{xC}}$

$$= \frac{2000 \times 100}{1000 \times 2131}$$

$= 0.093$ Kg/ sec. (0.33T/hr)

Lagging of pipe reduces the value of condensation to 1/4th i.e. 0.023 Kg/s or 0.082T/hr.

3.3 Calculation for 80 Psi Steam Condensation Loss (8):

Basis of calculation = 100 meter run of pipte

Nominal Pipe size = 250 mm (10")

Approximate Wt of 1 m. of pipe = 32 Kg.

Total no flanges = 20

Time required for warming up = 50 mins

Total weight of pipe including flanges and fittings in Kgs

= 32x100 + 32x26 = 3840 Kg.

$T = 159.6^0C$

$t = 30^0C$

$h_{fg} = 2084$ KJ/Kg

$$Q = \frac{3840x(159.6-30)x0.49}{2084x50x60}$$

= 0.039 Kg/Sec (0.140 T/hr)

Calculation of Radiation Loss For 80 Psi Steam Pipe -

B = 1300 W/meter

$\therefore$ Rate of condensation $= \frac{1300 \ x100}{1000x2084}$

= 0.062 Kg/Sec.

But after insulation the rate of condensation is obtained as 0.062/4 = 0.015 Kg/S (0.05 T/hr), assuming that the heat loss with insulation is only 25% of the heat loss calculated without lagging (8).

So total condensation loss of 80 PSI steam in the pipe line

= (0.140 + 0.054) T/hr

= 0.194 T/hr

Annual condensation loss of 80 PSI steam

= 0.194 x 24 x 365

= 1699.44 Tons

Total condensation loss of 40 PSI steam in the pipe line

= (0.126 + 0.093) T/hr

= 0.219 T/hr

Annual condensation loss of 40 PSI steam

= 0.219 x24 x365

= 1918.44 Tons

If we consider 4000 running hours of steam run in the pipe line then 776 Tons of 80 PSI steam and 876 Tons of 40 PSI steam is lost due to condensation.

So annual loss due to condensation and radiation ins the 100 m run of steam pipe line with fittings-

= Rs. (776x114 + 876x150)

= Rs. 1,31,400/-

From the above data it is found that annual steam loss due to condensation is very high. So the pipe sizing should be checked. Instead of using vertical pipes it is advised to use horizontal pipe to avoid this loss.

The incorrect sizing of steam pipe may lead steam starvation at the point of use for which steam traps are blamed unnecessarily if the pipes sizes are too small. If the pipes are oversized it will cause more installation cost and more radiation loss. The superheat steam velocity should not exceed 20-25 m/sec for the steam pipe lines.

For condensate return pipe line sizing, following points need to be checked-

- all pipe lines should have a slope, preferably in the direction of the flow if the slope in water pipe is graded so that the slope per meter is equal to or, greater than the heat lost in friction per meter, then the water will flow freely without needing pressure to push it along i.e, without causing back pressure.
- If, however, the pipe line is horizontal, the back pressure set up to cause flow will be equal to loss of head in friction per meter multiplied by length of the pipe.

- If the water/condensate has to rise up, then a pressure must be available to push the water up and this pressure (which is back pressure on the trap) will equal the head of lift plus the frictional head x the length of pipe. It is always preferable to use horizontal pipes.

3.4 Steam Leak Survey For SPM:

The steam leak through a hole in lb/hr calculated using the following formulas

$W = 51.43 \times \overline{PxAXF_s}$

where p = line pressure, PSI

A = orifice area, in^2

W = Discharge rate in lb/hr

F_s = Correction factor

$$= \frac{1}{1+0.00065\ T_s}$$

T_s = superheated temperature in ^0F.

The steam leack through different leak holes of different diameter, if any, are given in Table-1.

TABLE-1

Sl.No.	Dia of Leak in mm	ANNUAL STEAM LOSS					
		3.5kg/cm²		5.1kg/cm²		19kg/cm²	
		Tons/Yr	Rs/Yr	Tons/Yr	Rs/Yr	Tons/Yr	Rs/Yr
1.	1.5	29.09	3316	37.27	55905	116.36	53060
2.	3.0	116.36	13265	142.72	21408	465.36	272204
3.	4.5	232.72	26530	312.72	46908	922.76	420778
4.	6.0	465.44	53060	566.31	84946	1820.26	830038

Cost of Steam

3.5 kg/cm^2 = 114 Rs./Ton

5.1 kg/cm^2 = 150 Rs./Ton

19 kg/cm^2 = 456 Rs./Ton

TABLE-2

STEAM CONSUMPTION CHART OF THE MILL

A. 40 PSI STEAM CONSUMPTION	Normal Steam Consumption in Tons/Dsy	Actual Steam Consumption in Tons/Day
1. S.P. PULPER	05	09
2. BLEACH PLANT	45	47
3. CL_2 VAPOURISER	12	12
4. DEARATOR (C/F)	30	29
5. CAUSTICIZER	59	60
6. S/R DEARATOR & MISC.	30	30
7. DEARATOR CIFOUD	29	30
8. AH (JMW + CIFOUD)	40	40
9. AH - C/F BLRS	21	-
10. B/L HEATERS	35	36
11. FINISHER EFFECT	59	53
12. EVAPORATORS	239	246
13. P.M.1	125	103
14. P.M.2	121	132
15. P.M.4	-	-
TOTAL	= 850	827
B. 80 PSI STEAM CONSUMPTION		
16. AH (JMW + CIFOUD	30	20
17. AH - C/F BLRS	-	10
18. P.M.2	82	56
19. P.M.3	97	87
20. P.M.4	65	68
TOTAL	= 274	241

C. 260/200 PSI STEAM CONSUMPTION	Normal Steam Consumption in Tons/Day	Actual Steam Consumption in Tons/Day
21. NDH : BLOWS/REF [13/1]	284	350
22. EJECTORS	2	18
23. AH (CIFOOD) - 200 PSI	20	30
D. CONDENSATE	207	275
E. MISC (SYSTEM LOSSES)	16	10
TOTAL	=1653	1701
5000 KW TURBINE 260 PSI STEAM CONSUMPTION	1331	
STEAM FROM : JMW & CIFOOD	704	676
STEAM FROM COAL F.BLRS	942	1032
TOTAL	=1653	1708

TABLE-3

PAPER PRODUCTION CHART

M/c No.	Average M/c Production Tons/Day	Average finished Paper Production Tons/Day
PM - 1	38	35
PM - 2	64	59.5
PM - 3	36	34.0
PM - 4	24	21.5
TOTAL	162	150

TABLE-3 A

LOAD CHART

Sl.No.	Steam Demand by Turbine in Tons/Hr	Load on Turbine in MW
1.	55.3	3.65
2.	47.6	4.0
3.	53.9	4.35
4.	54.6	3.9

TABLE-4

POWER CONSUMPTION CHART FOR P.M/Cs

M/c No.	Power Consumption in KWH per Ton of Finished Paper
PM - 1	370.96
PM - 2	349.82
PM - 3	496.89
PM - 4	691.69

CHAPTER-4

COGENERATION

4.1 Feasibility of a Cogeneration System:

Cogeneration is defined as the simultaneous production of power (either electrical or mechanical) and useful heat (e.g., process steam) with the reject heat of one process thus becoming an energy input to subsequent process so that same fuel is used twice. The cogeneration cycle or combined (heat and power) cycle used for industrial heating or district heating purpose. The advantages of a cogeneration system are as follows

- flexibility and easier adjustment of supply to demand ratio.
- ability to generate power at lower cost then possible by state electricity board (SEB)
- reduce vulnerability due to shortages in grid power.
- technically and commercially viable project with short and predictable pay-back period.

The feasibility of cogeneration system depends upon heat to power demand of the plant. This is around 5:1 for an efficient cogeneration system which is much higher than breakeven value of 2.5:1. The overall industrial cogeneration system efficiency could be over 80% as against less then 40% in conventional utility thermal power plants.

The wide variation in self generation as a percentage of total power consumed in an integrated paper mill due to different modes of cogeneration system. Those modes are as follows -

A cogeneration cycle can have either back Pressure steam turbine (simple or with controlled extraction) or, a condensing cum extraction. A back pressure turbine is one in which the total quality of steam let into the turbine at high pressure is exhausted at low pressure at outlet steam at inbetween process level can be either bled off or, extracted in case of back pressure turbine with extraction pressure. Fig. 2 and 3)

An extraction condensing type turbine is one in which more amount of steam is let into turbine at high pressure and the required amount of steam for process extracted at desired pressure and balance steam in condensed in the surface condenser (Fig.4). The (T,S) and (h,s) Fig. no. 11 and 12 can be referred for this type of turbine.

But drawback of back pressure extraction type cogeneration system is that production of electrical power is limited and governed solely by the quantity of process steam requirement. The power generated is not sufficient to meet the full electrical load. The power generated meet only the demand of PM/Cs and evaporators and the rest power in purchased from SEB.

In extraction condensing type of turbine condenser is maintained at atmospheric pressure hence less amount of steam (20%) condensed of total inlet steam. Here after use of steam in process rest of steam is fed to condenser to produce extra power hence the total entrical load can be met. The electrical power output here is 20% more that back pressure type of cogeneration cycle. But the installation cost of this system is too high.

Frequently some LP steam is vented out due to fluctuations in LP steam demand for example breaks in PM/Cs reduces the LP steam consumption with reduction in power consumption. The vented steam could be as high as 50 Tons/day.

For different cogeneration system TIMMERMAN's diagram show the energy balance diagram. Fig. 7.2 (F) for extraction condensing type turbine concludes that for combustion efficiency of 90%, 38% of energy input produces power and 10% in used as process heat and 40% of energy gets condensed.

In a topping cycle total steam energy is fed to turbine to produce power and process heat but, in a bottoming cycle, after fulfilling demand of steam for proceses heat the rest amount is fed into turbine for same purpose.

Annual cogeneration cost can be calculated by the following information.

Annual cogeneration cost = cost of steam production only

+ cost of power generation only

+ cost of combined production.

For an extraction-condensing type TG set with combustion efficiency of boiler 90%. The following standard data are observed (Reference -9)

F_{CG} = Fuel input = 1

$(W)_{CG}$ = work output = 0.38

$(Q_u)_{CG}$ = heat utilisation = 0.10

FESR (fuel energy saving ratio) = 0.057

IHR (Incremental heat rate) $= \dfrac{1}{\text{artifical } \eta_a} = 2.3$

EUF (Efficiency utilization factor) = 0.48

where, Energy utilization factor $= \dfrac{\text{Total process utilisaiton}}{\text{Total energy input}}$

$$\text{Artificial efficiency} = \eta_a = \frac{W}{F - \dfrac{Q_u}{(\eta_B)_n}}$$

$$\text{Fuel saved} = \Delta F = \frac{Q_u}{(\eta_B)_n} + \frac{W}{(\eta_0)_{cG}} - F$$

$$\text{Fuel energy saving rati o} = \text{FESR} = \frac{\Delta F}{\dfrac{Q_u}{(\eta_B)_H} + \dfrac{W}{(\eta_0)_c}}$$

$$= 1 - \frac{(\eta_0)_c / (\eta_0)_{cG}}{1+\lambda_{cG}(\eta_0)_c/(\eta_B)_H}$$

where, $\lambda_{CG} = (Q_u/W)_{CG}$ = useful heat to work output

Savings in energy = P (10000 Btu/KWH)

where P = Total kWhr of energy required/annum.

4.2 Cogeneration System Analysis for SPM:

In SPM Double Extraction Condensing type BHEL turbine of 5 MW capacity is used. (Fig.10) Out of two extractions 1st stage HP extraction is uncontrolled one and 2nd stage extraction is controlled one. In uncontrolled extraction the steam flow rate depends upon the turbine load. For detailed information of present system steam balance diagram no 1 is to be referred. For detail calculations Appendix III can be referred.

Theoretical work output is found to be 4.19 MW. But assuming generator efficiency as 96%, the output obtained as 4.05 MW. But the average work output or power generation from the turbine in 3.80 MW.

Mill heat demand to total power requirement ratio obtained as

$$\frac{91263 \text{ KW}}{12749 \text{ KW}} = 7.3:1$$

But the average heat to power ratio $= \frac{91263}{11967} = 7.6:1$

But for an efficient cogeneration system it should come about 5:1

The energy utilization factor (EUF) of the turbine come about 75% assuming process utilization efficiency as 90% whereas it should come above 80%.

The energy utilization factor (EUF) for the total mill is obtained about 50-56%. The energy conversion efficiency of the total mill can be observed from the sankey digram (Fig. 12.A) as of energy balance for the whole mill as 50%. But for Indian standard mill value comes as 58% and for Swedish mill it is obtained upto 70%.

The cogeneration cycle steam consumption rate or, specific consumption of steam is found to be 13.85 kg/KWH. But as per the standard it should come around 10-11 kg/KWHr for a 150 TPD mill. If a bigger size or, high capacity turbine can be used the incremental rate of steam consumption can be reduced.

The specific heat consumption or heat rate for the cogeneration system is 3.57 MJ/KWH. But it should be below the range of 2.5 MJ/KWH.

The Heat demand: Power generation obtained as 11.82:1 for a load of 4095 MW. But the average ratio is found as 15.62:1.

Total power required per Ton of finished paper production is found as 1582.85 KWH/Ton of paper. But as for an efficient operation it should be below 1250 KWHr/Ton. Total steam use in tons/ton of finished paper production in the cogeneration cycle is obtained as 11.50 Tons/Ton of paper, which is also on relatively lower side.

For ideal running of a turbo generator set 1.2T/hr of steam should be condensed. So variable running cost/unit of power at the minimum condensate and full extraction in obtained as Rs. 1.36. The 1/4th of steam demand is meant without any fuel cost i.e. obtained from recovery boiler. So the final variable running cost/unit of power at the minimum condensate and fuel extraction in obtained as Rs. 1/- for the total load of 3949.80KW

where,

Total 1st extraction power = 279.015 KW

Total 2nd extraction power = 2242.350 KW

Total 3rd extraction power = 1428.44 KW

So it is economical for the system to maintain the load below 3.90 MW so that power can be generated at the running cost of 90 paisa. Cost of power per unit brought from the UPSEB Rs. 2.90. As the fixed cost/unit of power of present system is Rs. 2/- so it is advisable to maintain the load below 3.90 MW and power obtained below Rs. 2.90/unit.

At the condition of maximum condensate (15T/hr) and full extraction final running cost of power is obtained as Rs. 1.20/unit for the total load of 4613.69 MW

energy saved KJ/hr

= P (10550 KJ/KWH - 4958 KJ/KWH)

where, P = KWH/yr

4958 Net incremental heat rate KJ/KWH

= 90100x1000 (10550-4958) = 3.5×10^{12} KJ/yr. or, 3.5×10^{9} MJ/yr.

TABLE -5

DAILY POWER CONSUMPTION CHART OF THE MILL

DEPARTMENT	AVERAGE Power KWH	TOTAL KWH CONSUMED UPSEB	TURBINE	DISEL	TOTAL
VECO CHIPPER	1488	800	-	-	800
NORMAN CHIPPER	5064	5910	-	-	5910
DIG HOUSE/WASHING	21024	17500	-	3000	20500
OLD SCREENING	1440	1400	-	-	1400
OLD BLEACHING	1224	-	-	-	-
NEW BLEACHING	16772	157200	-	2000	17200
NEW SCREENING	7272	6400	-	600	7000
S.P.P.I	13728	130000	-	-	13000
P.M.I	121481	11000	-	-	11000
S.P.P.II	10800	9000	-	-	9000
P.M.II	26608	-	2000	-	2000
S.P.P.III	7392	8000	8000	-	8000
P.M.III	16996	13500	2500	-	16000
P.S.P.P.IV	4296	4000	-	-	4000
AUX FIBER PROCESSING	1380	-	-	-	-
CUTTER PM-2 & 3	300	300	-	-	300
D.M.I REW & CUTTER	500	500	-	-	500
P.M.II (DO)	500	-	500	-	500
P.M.III (DO)	500	500	-	-	500
P.M.IV REW & CUTTER	500	500	-	-	500
GEN.OFFICE	500	500	-	-	500
PUMP HOUSE	9144	2100	7000		9110
TURBINE HOUSE	2880	-	3200	-	3200
SODA RECOVERY	22872	-	23000	-	23000
WORKSHOP	600	600	-	-	600
COLONY	4888	-	7400	-	7400
LAB	500	500	-	-	500
EFF. TREATMENT	7500	6000	-	-	6000
MILL LIGHT	2200	-	3000	-	3000
TOTAL	226500	128800	90100	5600	224500

Sankey Diagram Analysis of the Total Mill

Total energy input = (91263 + 5859 + 2800) KWH

= 99982 KWh

By product energy (from BLS) = $(20+9) \times \frac{1000}{3000} \times 3093$ KWH.

Total input energy = $\frac{4.44 \times 4500 \times 4.18 \times 2 \times 1000}{3000}$

= 46398 KWH

For other information Appendicies are to be referred.

Net energy conversion of SPM

$= \frac{50630.2}{99922}$

= 50.66%

But the normal Indian industry standard of energy conversion is 58% against the Swedish mill standard of 70% (refer diagram no 12(a))

The condenser loss of 7% should not be confused with 13% of steam loss into the condenser. (Reference-12)

KWH

CHAPTER-5

PROPOSAL AND FUTURE WORK

Here two new cogeneration systems have been proposed for the future mill of 200 TPD capacity. where steam pressure is increased upto 40Kg/cm^2 over the present system of 19Kg/cm^2, Steam production rate is increased to 100T/hr over the old value of 72T/hr. The first proposal cogeneration system is a topping cycle with FBC boiler and ENMASS recovery Boiler. The 2nd proposal cogeneration system is also a topping cycle with 2 no of Heat Exchanger (HX) in which water cycle is closed one.

PROPOSAL-1

It is proposed to use an ENMASS Recovery type boiler of 800T/day rated capacity and FBC boiler of 1600T/day rated capacity at the drum pressure of 40 Kg/cm^2 in each case to meet the power and steam demand of 200 TPD future mill. For detail information Fig. 15 and Appendix IV are to be

Basis of chossing FBC boiler of 800 T/day steam generation capacity boiler is shown below.

Total finished paper-production	= 200T/day
Plant loading	= 10%
Moisture content of paper	= 5%
So total pulp required	= $(200 \times 10 \cdot) \times \frac{5}{100} \frac{}{10}$ Tons/day
	= 170 Tons/day
Pulp yield	= 50%
so pulp converted in to B/L	= 85 Tons/day
Total steam fed into digester	= 325 Tons/day

So total B/L produced/day : (325+85)

= 410 T/day

B/L concentration into the furnace = 60%

So total BLS = $400 \times \frac{60}{100} = 240$ T/day

Atmosphere FBC technique gives the following advantages over conventional C/F boiler (Refer Fig. 13,14 and Table 6) -ability to use compliance and non-compliance (e.g. high sulphur, etc.) coal as well as other low grade fuels e.g. baggase, wood scraps, residual oil, peat etc.

- effective direct capture of SO_2 from the combustion of coal.
- Significantly lower NO_x emission
- Improvement in boiler thermal efficiency upto 75-80%
- Leads to efficient cogeneration system

Atmospceric Fluidised bed combustion occurs at normal atmospheric pressure in the temperature range of 600 to 650°C with excess air value of 15-25%. The bed crushed of a mixture of consheed limestone, dolomite, oriental material and large ash particles, which is 'fludised' by an stream of air or, combustion gases rising from the supporting grid beneath the bed. Steam is produced in the tube bundlers or, water walls located in fludised region conventional steam turbines convert this steam to electrical energy.

Time, temperature and turbulance are maintained at an optimum level with fludisation. This technology finally ensures higher thermal efficiency resulting lower fuel bill.

In this topping cycle Ist stage extraction steam is fed to digester house instead of feeding directly from the boiler through PRS.

Boiler thermal efficiency = 75% (assumed)

So to find amount of fuel used in this FBC boiler

$$\frac{75}{100} = \frac{18.5 \text{ Kg/sec } (3269-436)}{m_f \times 4500 \times 4.18}$$

So, m_f = 13.37 T/hr

The coal cost in obtained as Rs. 106 per KJ of energy.

It is found that power generated per hr in 12.483 MW for a 200TPD mill at the cost Rs. 1.13 per unit of power.

Total average power cost for the future plant

$$= 1.13 \times 299612.37 + 2.90\ (336000 - 299612.37) \times \frac{7000}{24}$$

$$= (338561.9 + 105524.13)\ 7000/24$$

$$= (444086.03)\ 7000/24$$

$$= \text{Rs. } 1.29 \times 10^8/\text{annum}$$

Total average power cost needed for the present mill

$$= 2.90 \times 12000 \times 7000$$

$$= 2.43 \times 10^8/\text{annum}$$

So that net profit by new system over the old cogeneration system on power

$$= (2.43 - 1.29)\ 10^8$$

$$= 1.13 \times 10^8$$

= Rs.11.3 Crores/annum

The mill heat to power ratio is also improved to 6:1 and mill total energy conversion improved to 55% over the present system of 50% and achieved the Indian standard value.

So the expected pay back period for new cogeneration system

$$= \frac{\text{Total Investment}}{\text{Net profit in the cogeneration cycle/yr}}$$

$$= \frac{70 \text{ crores}}{11.3 \text{ crores/yr.}}$$

= 6.1 yrs.

With this steam turbine topping cogeneration plant a control system should be adopted which is shown in Fig. 8. The tie-line power flow control is the on line interface between the utility power system and the cogeneration plant. The tie-line controller adjusts turbine governor speed control to change generator output. If necessary in the event of tie-line interruption, it can perform process electrical load shedding to balance available generation with load and avoid system collapse. This system mantains power control to meet process steam needs at the industries priority basis and continuously safe operation.

Unit Power Cost Calculation of Future Cogeneration Plant -

Basis- A.	Total investiment cost	= 70 croers
	Cost of recovery boiler	= Rs. 10 Croers
	Cost of FBC boiler	= Rs. 20 Croers
	Cost of turbine	= Rs. 20 Croers
	Cost of digester	= Rs. 5 Croers
	Cost of stand by boiler	= Rs. 10 Croers
	Miscellaneous/ Auxilliaries	= Rs. 5 Croers
	Yield	= 50%

Plant loading = 10%, Moisture = 5% (paper)

B. 100% capital cost is assumed to be borrowed at an interest of 16% on load per year. The operation and maintenance charges for the project is 3% per Yr. Hence the total yearly fixed interest is taken as 19%.

C. Depreciation is not considered as real term in cash outflow.

D. The fuel is considered for the above coal is having G.C.V. 4500 KCal/Kg at the cost of Rs. 2000/- per ton.

E. The state Government power tariff Rs. 2.90 per KWH unit.

Unit Power Cost Calculation-

(Considering the interest on investment and running cost for 7000 hrs of running/annum.)

A. Total investment cost : 70

B. Yearly interest 19% on investment: 13.3

C. Cost of two boilers and accessories to meet the steam requirement if not going for congenetation :30

D. Yearly interest on boilers : 5.7

E. Fixed cost chargeable to power (B-D) : 7.6

F. Fuel cost for cogenration plant (31.7x7000x2000) : 18.71

G. Fuel cost for FBC boiler : 16.9

H. Fuel cost chargeable to power (F-G) : 1.81

I. Additional Manpower/Maintenance Cost in case of going for cogenartion plant: 0.24

J. Net operating cost of cogenration plant (F+H+I): 9.65

K. Total power Generation per annum (KW in cores) :8.738

L. Cost of Generation of one KW unit (J/k): Rs. 1.13

(All the cost values are taken in croers)

PROPOSAL-2

It is proposed to use a closed water circulation for the total cycle of the mill. In this system steam generated from the atmospheric fludised bed boiler and a new recovery boiler for a steam pressure of 40 Kg/cm^2 each at a steam temperature of 425^{0}C. Refer fig. 15 for this type of cogeneration cycle. These are 2 HX for meeting the process steam demand at required pressure. It is roughly calculated that,this type of system can generate upto 15 MW of power meeting all the process steam demand of the future 200 TPD capacity mill. For this system HX design is very important criteria.

Here Ist stage extraction steam is passed through HX1 as per the process steam demand of 5.1kg/cm^2 and 8kg/cm^2 process steam after PRS is passed to digester house. After fulfilling the 2nd stage extraction demand of HX the rest of the steam is again taken back to boiler and after reheating upto 300^{0}C, it is passed through LP turbine.

This system will reduce deminerlisation cost by 18% and make up water consumption of 16%. The plant can be converted to a total energy unit with mill heat to power ratio of 5:1 and fuel consumption is reduced to its half value of over the present system. The expected pay back period is very short.

FUTURE WORK -

Future work can be proceeded to design the system that is the optimum value of steam flow rate into the HP turbine and extraction points steam flow rates and accordingly can be ordered for the back pressure turbines. (MIXED INTEGER LINIEAR PROGRAMMING)

CHAPTER-6

CONCLUSION AND RECOMMENDATION

CONCLUSION

From all the analysis done in this dissertation following points are concluded.

- The Mill energy conversion is 50% and cogeneration cycle efficiency utilization factor is below 70% for SPM.
- These values are much below than the Indian standard value of 58% and 80% respectively. These lower side of values of the above factors are only due to the presence of old equipments and adoption of a bottoming cycle for the cogeneration system.
- The mill heat to power ratio is not less than 7.6:1 which should be 5:1 for an efficient cogeneration system.
- The boiler efficiency is found to be between 65-70% which is much below than new technology of AFBC cogeneration system with boiler thermal efficiency of 80-85%. The excess air consumption is too high i.e. 50% which causes high convection and radtiation losses. The lower boiler efficiency is due to steam demand fluctuation (12.5-20) T/hr by the Pulp Mill.
- The incremental specific heat consumption rate and steam consumption rate is too high due to improper utilization of process heat and a low capacity TG set.
- The condensation and radiation loss in a steam pipe line is approxmately about 776 Tons for 80 PSI and 876 Tons for 40 PSI per annum, which may be caused a very high profit degradation. So the pipe lines are to be checked.

- The steam venting is about is 25 Tons/day due to variation in steam demand.
- The power generation cost is Rs. 2.90 per unit at the turbine load of 3-9 MW against the turbine capacity of 5MW which is equivalent to the cost of power brought from UPSEB so that the profit obtained is very less.
- The R.O.I. (return on investment) for the present system is 10% which is very low due to high specifice steam consumption rate and high specific heat consumption rate and a low capacity T.G. set.
- Only 30% of power demand is fulfilled by the mill C.P.P. (captive power plant) of the total power demand of the mill.

RECOMMENDATIONS

It is recommended that, the mill should go for new system of cogeneration to meet the energy crises (power shortage) of 20th century on small pay back period basis.

- An AFBC cogeneration cycle can be used with steam generation pressure of $40kg/cm^2$ and 425^0C temperature which will result boiler thermal efficiency of 75-80% and improve mill total energy conversion to 55% at least. The return on investment of this system is expected 20%. 12.5 MW Power can be generated at the cost of Rs. 1.13 per unit giving a benefit of 11.3 crores per annum and the pay back period of the new system is expected to be 5-6 years for the future mill of 200 TPD capacity.
- It is to be tried to make the mill a full energy unit and make the cogeneration cycle a topping unit. So that the high pressure steam can be totally used in the turbine for power generation of 15 MW which is discussed in proposal-2.

- Secondly it is purposed to use an AFBC cogeneration system with 2 nos of shell and tube counter current HX. The main technology lies behind this is to close the water cycle of the mill which will result reduction in DM plant processing cost of 18% to its present value and make up water consumption reduction to 16%.
- Finally it is to be tried make the cogeneration cycle computer simulated to the steam demand to load on the turbine and control the fluctuation of steam demand in the Pulp Mill operation.

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APPENDIX-I. (A)

1. COAL ANALYSIS

The ultimate analysis of coal gives the following percentages of each constituent. As the coal grades varies from depot to depot, the boiler efficiency is also varied, so here we take a certain coal.

C = 47%

H = 3.0%

O = 8%

S = 1%

Ash = 30%

$$\text{HCV of coal} = \frac{4.18}{100}\left[8080\ C + 34500\left(H - \frac{0}{8}\right) + 2220\ s\right] \text{kg/kg}$$

(Ref.Dulong's Formulae)

$$= \frac{4.18}{100}\left[\begin{matrix}8080\\ x47\end{matrix} + 34500\left(4 - \frac{8}{8}\right) + 2220x1\right]$$

$$= \frac{4.18}{100}\left[379760 + 103500 + 2200\right]$$

= 20209 kJ/kg

(4834.48 Kcal/kg)

$$\text{LCV of coal} = \left(HCV - \frac{9H}{100} \times 588.76 \times 4.18\right)$$

$$= 20209 - \frac{9x4}{100} \times 588.76 \times 4.18$$

= 20209 - 885.96 (Taking moisture value = 4%)

= 19323 KJ/kg (4622.53 Kcal/kg)

But due to high scarcity of coal availability there are many grades of coal used in the boiler.So for average calculation G.C.V. of coal in taken as 19646 KJ/kg and L.C.V. in taken as 18810 KJ/kg.

2. AIR REQUIREMENT CALCULATIONS

Minimum quantity of air supplied/kg of fuel i.e, theoretical air

$= 11.6\ c + 34.8 \left(H - \frac{0}{8}\right) + 4.35 \times S\ 4.18$

$= 11.6 \times 0.47 + 34.8 \left(0.04 - \frac{0.08}{0.08}\right) + 4.35 \times 0.01$

$= 5.45 + 1.044 + 0.0435$

$= 6.35$ Kg/kg of fuel

$\therefore$ Air : fuel = 6.35:1

Excess air supply = 50%

So, actual air supplied to the boiler

$= 6.53 \times 1.5$ Kg/kg of fuel

$= 9.79$ Kg/kg of fuel

(3) FLUE GAS ANALYSIS

Basic combustion equations are

$C + O_2 = CO_2$

$H_2 + \frac{1}{2} O_2 = H_2O$

$S + O_2 = SO_2$

$C + \frac{1}{2} O_2 = CO_2$

Orsat's Apparatus analysis provides the flue gas analysis results before excess air feeding as

CO_2 = 11%

CO = 1%

O_2 = 6%

N_2 = 82%

So percentage of carbon converted to CO_2

$$= \frac{CO_2}{CO + CO_2} \times 100$$

$$= \frac{11}{21 + 11} \times 100$$

= 85%

So % of C converted to CO

= 100 - % conversion of C → CO_2

= (100-85)%

= 15%

$12\,C + 32\,O_2 \rightarrow 44CO_2$

$C + 2.66\,O_2 \rightarrow 3.36\,CO_2$

So 0.47 kg will require 2.66 x 0.47 = 1.25 Kg of O_2 to produce 0.7x3.66 = 1.72Kg of CO_2.

$H_2 + 1/2\,O_2 \rightarrow H_2O$

1 Kg H_2 requires 8 Kg O_2 to produce 9 Kg of water vappour.

0.04 Kg. H_2 requires 0.04x8 = 0.32 Kg of O_2 to form 9x0.04

0.36 Kg of H_2O.

$S + O_2 \rightarrow SO_2$

$32S + 32O_2 \rightarrow 64SO_2$

$1S + 1O_2 \rightarrow 2SO_2$

$\therefore$ 0.01 Kg of *S* requires 0.01 Kg of O_2 to produce 0.02 Kg of SO_2

O_2 in excess air = 0.23x0.5x6.53

= 0.75 Kg.

N_2 in excess air = 0.77x1.5x6.53

= 7.59 Kg.

So the final flue gas analysis shows the following results

Compound	Amount in Kg	% by Wt
CO_2	1.72	16.47
H_2O	0.36	3.44
SO_2	0.02	0.0001
N_2	7.59	72%

So total weight of wet fuel gas = 10.44 Kg

Total weight of dry flue gas neglecting SO_2, moisture = 10.06 Kg.

APPENDIX-I (B)

PERFORMANCE EVALUATION OF C/F BOILER

Boiler NO-9

Boiler Type - Coal fired boiler (Babcock Wilcox Co.)

DATA COLLECTED-

Coal feeding rate	= 4.44 T/hr
Steam formation	= 20-25T/hr
Feed water flow rate	= 15-25 T/hr
Air percentage	= 62

Pressure-

Steam from superheater outlet	= 18.36-19.00 Kg/cm^2
Feed water before economizer	= 24 Kg/cm^2
Feed water after economizer	= 23 Kg/cm^2

Temperature-

Boiler thouse	= 25^{0}C
Feed water after economizer	= 130 -135^{0}C (105^{0}C)
Superheat steam	= 340 -360^{0}C
Fuel gas after superheater	= 590 - 606^{0}C
Fuel gas before economizer	= 300^{0}C
Fuel gas after economizer	= 190^{0}C

Draught (mm of water)-

Forced draft fan discharge	= 42 -50
Combustion chamber	= 2 - 3
After superheater	= 15 - 16
Economizer inlet	= 50
ESP inlet	= 150
ESP outlet	= 156

HEAT BALANCE SHEET-

Basis = 1 Kg of coal

Heat Input = C.V. of coal

= 19646 KJ/kg

Heat Output-

1. Heat carried away by dry flue gas

= 10.06 x 1.086 (300-25)

= 3006.63 KJ/kg.

2. Heat lost by moisture

$$= 0.36 \left[h + C_p \left(T_{sup} - T_s\right) - hf\right]$$

$$= 0.36 \left[2561.6 + 2.09 \left(320 - 32.9\right) - 25\right]$$

$$= 0.36 \left[2561.6 + 287.1 - 25\right]$$

$$= 0.36 \left[2823.7\right]$$

= 1016.53 KJ/kg

3. Heat used to generated steam

$$= \frac{m_s}{m_f} \left(h_{sup} - h_{f1}\right)$$

$$= \frac{20000}{4440} \left(3100 - 436.9\right)$$

$= 11983.95$ KJ/kg

4. For 10% blow down of boiler 3% heat is lost

So blow down heat loss $= 19646 \times \frac{3}{100}$

$= 589.38$ KJ/kg

5. Incombustible losses as 'C' in converted in to CO instead of getting converted into CO_2

Loss $= 0.47 \times \frac{15}{100} \times 5996$

$= 422.71$ KJ/kg

Combustion efficiency $= \frac{\text{HHV - stack loss}}{\text{HHV}}$

$= 85\%$ (Theoretical value)

6. Unaccounted heat loss (including ash loss)

$= 19646 - (3006.63 + 1016.53 + 11983.95 + 589.38 + 422.71)$

$= 19646 - 17018.45 = 2627.55$ KJ/kg

Boiler thermal efficiency calculation-

$$\eta_{th} = \frac{M_s\ (h_{sup} - h_{f1})}{CV}$$

$$= \frac{2000\ (3100-436.8}{18810}$$

$= 63.71\%$

$\approx 64\%$

Equivalent evaporation $= M_e = \frac{M_s\ (h_{sup} - h_{f1})}{2259.9}$ Kg/kg of coal

$$= \frac{4.5\ (3100-436.8)}{2259.9} \text{ Kg/kg of coal}$$

$= 5.30$ Kg/kg of coal.

APPENDIX-II

PERFORMANCE EVALUATION OF RECOVERY BOILER

Boiler type = JMW Recovery Boiler (90 Ton capacity)

DATA COLLECTED :

B/L temp to the system	= 105^{0}C
Concentration of Black liquor to the system (i.e. after cyclone evaporator)	= 60%
Average salt cake make up	= 6 Tons/day
Amount of B/L fired (13 mm nozzle)	= 9m^3/hr (9T/hr)
Average % of reduction	= 96%
Excess air Supplied	= 15%
Water fed to economizer	= 18 T/hr
Temperature of atmospheric air	= 42^{0}C
Relative humidity of air	= 70%
Temperature of air before air-Preheater	= 42^{0}C
Temperature of air after air-Preheater	= 130^{0}C
Flue gas temperature after economizer	= 160^{0}C
Temperature of steam generation	= 310^{0}C
Pressure at which B/L fired	= 1.2kg/cm^2
Pressure of steam generation	= 19kg/cm^2
Temperature of smelt	= 750^{0}C

DATA FOR REFERENCE :

Calorific value of B/L	= 3000 kcal/kg of BLS
	= 12540 kj/kg of BLS
Specific heat of air	= 1 kj/kg^{0}C
Specific heat of salt cake	= 0.96 kj/kg^{0}C
Specific heat of Smelt	= 1.34 kj/kg^{0}C
Heat of fusion of smelt	= 1.34

BLS ELEMENTAL ANALYSIS

C	=	42.6%
H	=	3.6%
S	=	3.6%
O	=	31.7%
Na	=	18.3%

SMELT ANALYSIS

Na_2S	=	28.5% as Na_2O
Na_2CO_3	=	70% as Na_2O
Na_2SO_4	=	1.5% as Na_2O

MATERIAL BALANCE

1. Basis for doing MB = 100 kg of BLS
2. Salt Cake make up (Na_2SO_4) = 6t/day

   = 250 kgs/hr

   Amount of BLS fired = 9 x 0.6 T/hr

Salt Cake amount for 100 kg of BLS $= \frac{250 \times 100}{9000 \times 0.6}$

= 4.62 kgs/100 kg BLS

3. Moisture in air = 0.038kgs/ of air

4. Total NA IN FURNACE

Na from BLS	= 18.3 kg
Na from Salt Cake	= 1.87 kg
Total	= 20.17 kgs

5. Weight of smelted chemicals in Furnace

Compound	Chemicals in kgs	% Na	Na in kgs
Na_2S	9.75	28.5	5.75
Na_2SO_4	0.96	1.5	0.36
Na_2Co_3	32.53	70.0	14.14
Inner Oxide	0.20		
Total =	43.41 kgs		

6. Sulphur Content in Smelted Chemicals

Compound	Chemicals in kgs	Sulphur in kgs
Na_2S	9.75	3.95
Na_2SO_4	0.93	0.21
	Total =	4.20 kg

7. Sulphur in stack gas :-

Sulphur from BLS = 3.60 kg

Sulphur from Salt Cake = 1.30 kg

Total = 4.90 kg

Sulphur in Smelt = 4.20 kg

Total Sulphur as SO_2 in flue gas = 4.90 - 4.20

= 0.70 kgs

SO_2 in stack gas $= 0.7 \times \frac{62}{32} = 1.4$ kgs

8. Smelt Weight Leaving furnace (99%) and 1% is lost in stack.

Smelt Weight = 0.99 x 43.21 (Ref.item 5)

= 42.71 kg

9. CO_2 from BLS

C to Unit (from elemental analysis) = 42.6 kg

C to Na_2CO_3 = $32.53 \times \frac{22}{106}$ (Ref. item -5)

= 3.69 kgs

C in CO_2 (by difference) = 42.6 - 3.69

= 38.91 kgs

∴ CO_2 in gas = $38.91 \times \frac{44}{12}$

= 142.7 kgs

10. Water formed from Hydrogen in BLS :-

Hydrogen to unit = 3.6kgs

(Ref. elemental analysis)

H_2O formed = $3.6 \times \frac{18}{2}$

= 32.4 kgs

11. So gaseous Products of combustion -

CO_2 (item 9)	=	142.7 kgs
SO_2 (item 7)	=	1.4 kgs
H_2O (item 10)	=	32.4 kgs
Total	=	176.5 kgs

12. Theoretical O_2 required for Combustion :-

Combustion Products	Wt. in Kgs.	Amount of O_2 in Compound in kgs
CO_2	142.7	103.80
SO_2	1.4	0.70
H_2O	32.4	28.80
Na_2SO_4	0.93	0.42
Na_2CO_3	32.53	14.73
	Total =	148.45 kgs

O_2 input to unit i.e. Present in BLS and Salt Cake make up :-

O_2 in solids (ref element of analysis) = 3170 kgs

O_2 in salt cake (ref Smelt analysis) = 2.007 kgs

$$\left[4.62 \times \frac{64}{142.7} = 2.07 \right]$$

So theoretical O_2 required forthe Combustion

= 148.42 - (31.7 + 2.07)

= 114.65 kgs

∴ Theoretical air required for Combustion

$$= \frac{114.65 \times 1.00}{0.232} \text{ kgs}$$

(Where 0.232 = kgs of O_2/kg of air)

= 494.18 kgs

Excess air supplied = 15%

∴ Wt. of dry air $= \frac{1.15 \times 114.65 \times 1.0}{0.232}$

= 602.40 kgs

13. Moisture in air = 0.038 kgs of Water Vapour/kg of air

∴ Wt. of moisture in air	= 0.038 x 602.40
Wt. of N_2 in air	= 22.89 kgs.
	= 0.768 x 602.40
	= 462.04 kgs.
Weight of O_2 in air	= 0.232 x 602.40
	= 139.75 kgs.

14 Water in liquor to unit :-

Weight of H_2O to the furnace	$= 100 \times \frac{40}{60}$
	= 66.66 kgs.

15 Weight of dry the gas leaving :-

CO_2 (item 9)	= 142.7 kgs
SO_2 (item 7)	= 1.4 kgs
N_2 (item 13)	= 462.64kgs
O_2 (item 9)	= 139.75 - 114.65
	= 25.14 kgs
∴ Total Wt. of dry flue gas	= 142.7 + 1.4 + 462 - 64 + 25.14
	= 631.88 kgs

Here all the Water entering into the furnace in taken out with the flue gas. Water plays an important roll with Energy Balance so it is taken in account in Material balance calculation otherwise it has no role in MB.

FINAL MATERIAL BALANCE

INPUT in Kgs	OUTPUT in Kgs
BLS = 100	FLUE GAS + WATER = 631.88 + 121.95 = 753.83
SALT CAKE = 4.62	INNER OXIDE = 0.2
AIR SUPPLY = 626.29	SMELT = 43.41

Total Input = 797.57 Kgs

Total Output = 797.44 Kgs

Balance = 0.13 Kgs

ENERGY BALANCE :-

BASIS = 100 kg of BLS

Tref = 105^0C

HEAT INPUTS :-

1. *Sensible heat in air :-*

Air supplied = 602.40 kgs

Moisture Contents of air at 42^0C & 70% RH

= 0.038 kg of water Vap/ kg of dryar

(Refer Molier chart)

∴ Total Moisture entering to the furnance

= 602.40 x 0.038

= 23.89 kgs

∴ Total Weight of air entering = 625.29 kgs

∴ Sensible heat in air = $M(p.(\Delta t)$

= 626.29 x 1 (130 - 105)

= 15667.25 kJ

2. *Heat available from BLS :-*

Heat available from BLS = 12540 x 100

= 1254000 kJ.

∴ Total heat input to furnace or recovery boiler

= 15567.25 + 1254000

= 1269657.3 kJ.

HEAT OUTPUTS :-

1. *Heat required for reduction of Salt Cake :*

Heat of red^n = 3000 BTU/kg

= 30000 x 0.5560 x 4.18 kJ/kg.

= 6975.24 kJ/kg

Percentage of reduction = 96

∴ Total heat required for reduction

= 4.62 x 6972.24 x 0.96

= 30923.27 kJ.

2. *Heat required for the evaporation of water in B/L-*

B/L Conc at firing to furnace = 60%

100 kg of BLS is compared with 66.66 kg of water from the steam table

Latent heat evaporation of water at 105^{0}C

= 2241.73 kJ/kg

∴ Total heat required for evaporation of Water

= 2241.73 x 66.66

= 149409.72 kJ

3. *Heat required for evaporation of water heat is formed due to presence of Hydrogen in Water :-*

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

1 kg H_2 produces 9 kg of Water.

Total amount of water formed from 100 kg of BLS

= 9 x 3.6

= 32.4 kgs.

∴ Heat required for evaporation = 32.4 x 2241.73

= 72632.05 kJ.

4. *Sensible heat lost with the flue gas :-*

Flue gas analysis :-

CO_2	= 142.7 kgs	
SO_2	= 1.4 kgs	
N_2	= 462.64 kgs	
O_2	= 17.6 kgs	(Refer MB item 15)
TOtal	= 631.88 kgs	

Total Wt. of water vapour in flue gas

H_2O from B/L	= 66.66	
H_2O from Hydrogen	= 32.4	(Refer MB item 13,14)
H_2O in air	= 22.89	
Total	= 121.95 kgs	

∴ Total Wt. of flue gas with moistur = 631.88 + 121.95

= 753.83 kgs

∴ SH lost in flue gas after leaving the cenomizer

= 753.83 x 0.836 (160-105)

= 34661.10 kJ

5. Heat of fusion of Smelt = 142.12 kJ/kg

Total Wt. of Smelt = 43.21 kgs

∴ Heat output by fusion of smelt = 43.21 x 142.12

= 6414 kJ.

6. *Sensible heat loss in Smelt :-*

Sensible heat in Smelt = *43.21 x 1.34 (750 - 105)*

= 37346.40 kj

7. *Rediation & Unaccounted Losses :-*

Assuming 1% of total heat lost of total input = 1269657.3 x $\frac{1}{100}$

= 12696.57 kj

8. *Sensible heat in Salt Cake :-*

Sensible heat in Salt Cake = 4.62 x 0.96 x 75

= 79.69 kj

9. ∴ Total heat loss = 30923.27 + 149409.72 + 72632.05 + 34661.10

+ 6141 + 37346.40 + 12696.57 + 79.69

= 343889.8 kj

So heat available for steam generation = Total heat Input - Total losses

= 1269657.3 - 343889.8

= 925767.5 kj

Pressure of steam generation = 19 kg/cm^2

∴ Absolute Pressure of steam generation = 20.02 kg/cm^2

Temperature of Saturated at steam at the above Pressure = 211.41^{0}C

But, temperature of superheated steam = 310^{0}C

∴ Degree of superheat = 98.5^{0}C

Enthalpy of Superheated steam at 20.02 kg/cm^2 = 2795.16 kj/kg

∴ Total heat content of Superheated steam = 2795.16 + 2.29 x 98.5

= 3020.72 kj

Tempeture of feed water = 95^{0}C

So heat content of feed water = 398 kj/kg

So heat available for steam generation = 3020.72 - 398

= 2622.72 kj/kg

So amount of steam generation per 100 Kg of BLS

$= \frac{925767.5}{2622.72}$

= 352.97 Kg/100 Kg of BLS

Total Solids fired in T/hr

= 9x0.6

= 5.4 T/hr

∴ Amount of steam generated in T/he

$= \frac{352.97}{100} \times 5400$ Kg/hr

= 19060.38 Kg/hr

= 19.06 T/hr

Thermal efficiency of recovery boiler $= \frac{\text{Heat utilised}}{\text{Heat Input}} \times 100$

$= \frac{925767.5}{1269657.3}$

= 72.91%

≈ 73%

But the recovery boiler average reduction of 93% and 140 Tons of BLS feeding gives the average thermal efficiency of 65-70% and chemical recovery efficiency of about 85% (including the total Pupl Mill recovery)

COAL AND STEAM COST CALCULATIONS:

ECL Coal = Rs. 1750/Ton

CCL Coal = Rs. 1475/Ton

AV Coal Cost $= 1758 \times \frac{75}{100} + 1475 \times \frac{25}{100}$

= Rs. 7680/Ton

Average steam productin $= 5.2 \times \frac{75}{100} + 4.0 \times \frac{25}{100}$

= 5 Tons/ Ton of cost

∴ steam cost $= \frac{1680}{5}$ = Rs. 336/Ton of steam

But present coal cost = Rs. 2000/Per Ton of coal

So steam cost $= \frac{2000}{4.5}$ = ₹444/Per Ton

APPENDIX-III

COGENERATION SYSTEM PERFORMANCE EVALUATION

FOR PRESENT SYSTEM -

Collected Data

Turbine Type- BHEL Double Extraction Condensing Type (5 MW)

Speed = 6200 rpm

Load = 3.2-4.7 MW

Flow Rates

Live Steam Flow - 56.37 T/hr (15.66 Kg/sec)

Uncontrolled Extraction (Ist Extraction) - 10.04 T/hr (2.7 Kg/sec)

Controlled Extraction (2nd Extraction)- 34.45 T/hr (9.56 kg/sec)

Flow to Condenser (Exhaust Hood)- 12.24 T/hr (3.4 Kg/sec)

Temperatures

Live Steam temperature - 330^{0}C

Ist extraction Steam temperature - 275^{0}C

2nd Extraction Steam temperature - 200^{0}C

Exhaust Hood Steam temperature - 50^{0}C

Absolute Pressures and Enthalpies

Lives Steam Pressure - 19 Kg/cm^2 (3093.2 KJ/kg)

Ist Extraction Steam - 10 Kg/cm^2 (2997 KJ/kg)

2nd Extraction Steam - 4.1 Kg/cm^2 (2859 KJ/kg)

Exhaust Hood Steam - 1.4 Kg/cm^2 (2592 KJ/kg)

i.e .1 Kg/cm^2

Temperature of Ist Stage Extracted Steam After Desuperheating

- 100 -175°C

- 165°C

Temperature of 2nd Stage Extracted Steam After Desuperheating

- 150 -160°C

- 155°C

Circulating Water Inlet Temp. in Condenser - 31°C

Circulating Water Ounlet Temp. in Condenser- 37°C

Ejector Condensate Inlet Temp. - 47°C

Ejector Condensate Outlet Temp. - 68°C

Bearing Oil Pressure - 1.2 Kg/cm²

Governing Oil Pressure - 10 Kg/cm²

EVALUATION

Total Work Output from the turbine, W_T = 15.66(3093-2997)

+ 12.96(2997-2859)

+ 3.4(2859-2592)

= 1503.36 + 1788.48 + 907.8

= 4199.64

= 4.19 MW

Bu average generation of this day = 90100 kWhr

(24 running hours of the turbine) = $\frac{90100}{24}$

= 3.80 MW

Actual generation of this day = 4.19x0.90 = 4.095 MW

High Pressure Heat Output = Q_1(Assing gen eff. 97%)

(Ist Extraction) = 2.7(2780) (Assuming generator efficiency of 90%)

= 75.06 KW

Low Pressure Heat Output = Q_2 = 9.56(2770)

= 26481 kW

So total heat to process = Q_H

= 7506+26481

= 35987 kW

= 35.987 MW

Total Heat Input to all 4 Boilers = Q^1

$$= [4.44 \times 4500 + 4.4 \times 4500 + 9 \times 300 + 4 \times 3000] \times \frac{4.18 \times 1000}{3000}$$

= 91263 kW

Purchased Energy in Terms of Power = 12880 KWhr

$$= \frac{128800}{22} \text{ kW}$$

= 5854.54 kW

= 5.8 MW

Power from Disel Generator Set = 5600 KWhr

$$= \frac{5600}{2} \text{ kW}$$

= 2800 KW

= 2.8 MW

So total power demand = (4095 + 2800 + 5854.5)kW

= 12749.5 kW

= 12.749 MW

Energy Utilisation factor of the turbine

$$= \frac{W_T + Q_H}{Q_{Turine}}$$

$$= \frac{4095 + 35987}{15.66 \times 3093}$$

$$= \frac{40082}{48436.38}$$

= 0.8275

So the turbine EUF is found to be <82.75%.

Assuming process eff. as 90%

$$EUF = \frac{4095 + 3598}{15.66 x 3093} x 09$$

$$= 75\%$$

Fraction of energy (Q') utilised in form of process heat ($Q_H + 2_D$) and work (W_T) in the total cycle

$$= \frac{W_T + Q_H + Q_D}{Q_1'}$$

where, Q_D = Process heat to digester

= 12.5 T/hr (3093 KJ/kg)

= 3.4 Kg/sec (3093 Kg/kg)

= 10733 KW

$$= \frac{4095 + 35987 + 10733}{91263}$$

$$= \frac{50815}{91263}$$

$$= 0.556$$

Assuming process efficiency 90% above fraction comes as

$$= \frac{4095 + (35987 + 10733)\ 0.9}{91263}$$

$$= 0.5056$$

So efficiency utilisation of the mill comes around 55.46%. But the efficiency of the total cycle will be reduced to around 50.56%

So total work output of turbine in terms of heat per Kg of steam

$$= W_{T^1} = \left\{(3093\text{-}2997) + \frac{12.96}{15.66}(2997\text{-}2859) + \frac{3.4}{15.66}(2859\text{-}2592)\right\} \text{KJ/kg}$$

$$= (96 + 105.93 + 57.96) \text{ KJ/kg}$$

$$= 259.89 \text{ KJ/kg of steam}$$

So the cogeneration cycle steam consumption rate i.e

$$\text{specific steam consumption} = \frac{3600}{259.89}$$

$$= 13.85 \text{ kg/kwhr.}$$

Total process heat in kj/kg of steam

$$Q_H' = \left\{\frac{2.7}{12.26} X\ 2997 + \frac{9.56}{12.26} X\ 2859\right\}$$

$$= (624.37+2229.36) \text{ KJ/KG}$$

$$= 2853.73 \text{ kj/kg}$$

So specific heat consumption

$$\text{rate of the cogeneration cycle} = \frac{3600 \ X\ Q_{TURBING}}{W_T{}' + Q_H{}'}$$

$$= \frac{3600 \ X\ 3093}{259.89 + 2853.73} \text{ KJ/Kwhr.}$$

$$= \frac{11134800}{3113.62}$$

$$= 3576.15 \text{ kJ/kwhr.}$$

$$= 3.576 \text{ MJ/kwhr.}$$

HEAT : POWER for the turbine

$$= \frac{15\text{-}66 \ X\ 3093}{4095}$$

$$= \frac{4843638}{4095}$$

$$= 11.82{:}1$$

$$\text{Average heat demad: Power generation} = \frac{15.56 \ X\ 3093}{3080}$$

$$= 15.62 :1$$

Total steam used in tons/Tons of finished paper production

(In the cogeneration cycle)

$$= \frac{70.80 \text{ T/hr}}{147 \text{ T/day}}$$

$$= \frac{70.80 \ X\ 24}{147}$$

$$= 11.50 \text{ Tons/ Ton of paper.}$$

Total power required/ ton of finished paper production

$$= \frac{4095X24+5854X22+280X2}{147}$$

$$= \frac{232679}{147}$$

= 1582.85 kWh/Ton of paper

Total puchased power/ Ton of finshed paper $= \frac{5854.5 \times 22}{147}$

= 876.18 kwhr/ton

Total disel power/ ton of finished paper production $= \frac{2800X.2}{147}$

= 38.09 kwhr/ton.

COST ANALYSIS OF POWER FOR PRESENT SYSTEM

Total 80 psi consumption $= \frac{(3093-2997)}{3594.8} X\ 1000$

= 26.70 kW/ton

∴ Total Ist extraction Power consumption

= 26.70 X 251

= 6701..7 kW

Ist extraction power cost $= \frac{(3093-2997)\ X\ 336\ X\ 1000}{4.18x0.65x26.70x10^6}$

(Assuming boiler efficiency as 65 %)

= Rs. 0.44 per unit (Avg.coal)

= Rs. 0.62 per unit (Truck coal)

Total 40 psi consumption $= \frac{(3093-2859)\ X\ 1000}{3594.8}$

= 65.9 kw/ton

∴ Total 2nd extraction power consumption

= 65.09 X 827

= 53829.43 kw

2nd extraction power cost $= \frac{(3093-2859)X336X1000}{4.18x0.65x65.09x10^6}$

= Rs. 0.51 per unit (Avg. coal)

= Rs. 0.72/unit (Truck coal)

Total condensation power = $\frac{(3093-2592) \times 1000}{3594.8}$

= 139.36 kW/ton

∴ Condensation power = 139.36 X 275

= 38326.4 kW

Condensation power cost = $\frac{(3093-2592) \times 1000 \times 336}{4.18 \times 139.36 \times 10^6}$

= Rs. 2.88 /- per unit (Avg.coal)

= Rs. 4.08 /- per unit (Truck coal)

But for ideal running of a turbogenerator set 1.2T/hr of steam should be condensed.

So to find variable cost/ Unit of power at the condition of minimum condensate & full extraction.

Ist Extaction = 10.45 X 26.70 = 279.015 kw

2nd Extaction = 34.45 X 65.09 = 2242.350 kw

condensation = (11.45 -1.2) X 139.36 = 1428.44

Total = 3949.80 kw.

So average cost of power/ Unit = $\frac{279.015 \times 0.44 + 2242.35 \times 0.51 + 1428.48 \times 2.88}{3949.80}$

= $\frac{122.76 + 1143.59 + 4113.90}{3949.80}$

= Rs. 1.36 per unit (final cost Rs. 1/-)

Total Cost of Power/Unit for the

truck coal = $\frac{279.015 \times 0.62 + 2242.35 \times 0.72 + 1428.44 \times 4.08}{3949.80}$

= $\frac{172.98 + 1614.49 + 5828.03}{3949.80}$

= $\frac{7615.51}{3949.80}$

= Rs. 1.90/Per Unit of Power (Final Cost = Rs.1.42/-)

For getting maximum condensate & full extraction i.e. 15 T/hr condensate (max) can be removed.

So generating Power from condensation = 139.5 x (15 - 1.2)

= 1925.1 KW.

So there average cost of Power/Unit

$$= \frac{279.015 \times 0.44 + 2247.35 \times 1.51 + 1925.1 \times 2.88 + 1.2 \times 139.36 \times 2.88}{4613.697}$$

$$= \frac{122.76 + 1143.59 + 5544.28 + 481.62}{4613.697}$$

= Rs. 1.60/- Per Unit (Av coal)

(F.C. = Rs. 1.20)

= Rs. 2.10/- Per Unit (Truck coal)

(F.C. = Rs. 1.57)

For calculation of cost of Power the following factors considered.

The total steam fed to turbine, 1/4th of that steam amount is given by the recovery boilers at very low cost. Hence steam cost from the recovery boilers are neglected.

APPENDIX - IV

PROPOSED SYSTEM EVALUATION:

Steam generation from FBC = 40 kg/cm^2, 425^{0}C, 1600 T/day rated.

Steam generation from ENMASS Boiler = 40 kg/cm^2, 425^{0}C,800 T/day rated

TURBINE INLET :

ABS Pressure = 40 kg/cm^2 (3269 kj/kg)

Temperature = 425^{0}C

Flow Rate = 2400 Tons/day

1st EXTRACTION (TO DIGESTER & AH ALSO)

ABS Pressure = 12 kg/cm^2 (2993 kj/kg)

Temperature = 275^{0}C

Flow Rate = 961 Tons/day (325 T/day to digester)

2nd EXTRACTION

ABS Pressure = 4.1 kg/cm^2 (2859 kj/kg)

Temperature = 200^{0}C

Flow Rate = 1144 Tons/day

TO CONDENSER

ABS Pressure = .1 kg/cm^2 (2592 kj/kg)

Temperature = 50^{0}C

Flow Rate = 295 Tons/day

1st EXTRACTION POWER

1st Extraction Power $= \frac{3269 - 2993}{3294.8} \times 1000$KW/Ton

= 76.77 kW/Ton

∴ Total 1st extraction Power = 76.77 x 961

= 73775.97 kW

2nd EXTRACTION POWER

2nd Extraction Power $= \frac{3269 - 2859}{3594.8} \times 1000$ kW/Ton

$= 114.05$ kW/Ton

So total 2nd extraction Power $= 114.05 \times 1144$

$= 130473.2$ kW

CONDENSATING POWER

Condensation Power $= \frac{(3269 - 2592)}{3594.8} \times 1000$

$= 186.38$ kW/Ton

$\therefore$ Total Condensation Power $= 186.38 (290 - 35)$

$= 95363.00$ kW

So Total Power generated in the cogeneration system

$= (73775 - 97 + 130473.2 + 95363.11)$ kW/day

$= 299612.37$ kW/day

$= 12483$ kW/hr

Expected Power demand of the mill = 14 MW

So the system is considered as nearly a full energy unit.

RUNNING COST ESTIMATION FOR UNIT OF POWER GENERATION

Landed Coal Cost = Rs. 2000/Tm

Cal Value of Coal = 4500 Kcal/kg

Cost/Kj $= \frac{2.0 \times 10^6}{4500 \times 4.18}$

$=$ Rs. 106/ per kj

So cost of Power at 1st extraction

$= \frac{(3269 - 2993) \times 1000 \times 106}{.75 \times 76.77 \times 106}$

$= R_S$ 50 Paisa/Unit of power

Cost of Power at 2nd extraction

$$= \frac{(3269 - 2859) \times 1000 \times 106}{.75 \times 114.05 \times 106}$$

= 50 Paisa/Unit

Cost of Condensation Power

$$= \frac{(3269 - 436) \times 1000 \times 106}{.75 \times 186.30 \times 10^6}$$

= Rs. 2.10/ Unit

So average Cost of Power at the above condition

$$= \frac{0.51 \times 3073.94 + 0.50 \times 5934.88 + 210 \times 3447.13}{12483}$$

$$= \frac{1567.73 + 2967.44 + 7238.97}{12483}$$

= Rs. 0.94/Unit

It is taken that 70% of total steam demand cost is met by the runnings cost of coal fired boiler and some amount of running cost of recovery boiler.

So the final cost of Power/Unit

$$= 0.94 \times \frac{70}{100}$$

= Rs. 0.658

= 66 Paisa

Table 6 *Steam inlet parameters most frequently noted in back-pressure heat and power plants* (Ref 9)

Steam boilers			Steam turbines	
Pressure		Temperature	Pressure	Temperature
Rated	At superheater outlet		At turbine inlet	
MPa	MPa	°C	MPa	°C
1·8 1·8	1·6 1·6	300 350	1·5 1·5	280 330
2·6 2·6	2·4 2·4	400 425	2·3 2·3	385 410
4·2 4·2	3·7 3·7	425 450	3·4 3·4	410 435
7·9 7·9	6·9 6·9	480 500	6·4 6·4	465 485
11·0 11·0	9·7 9·7	510 540	8·8 8·8	500 535
16·0 16·0	13·6 13·6	540 570	12·5 12·5	535 565

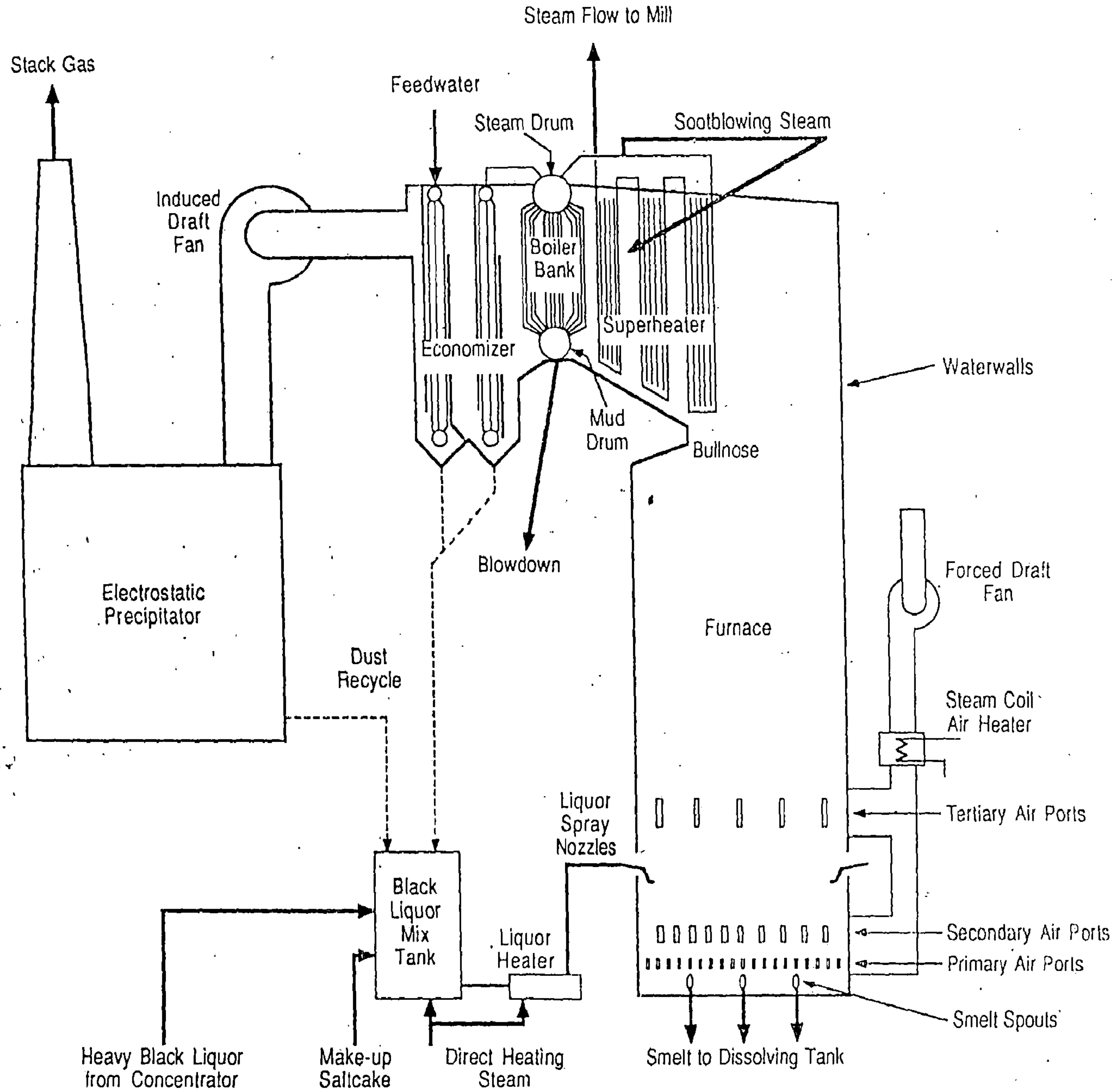


Fig. A. Schematic diagram of a kraft recovery boiler.

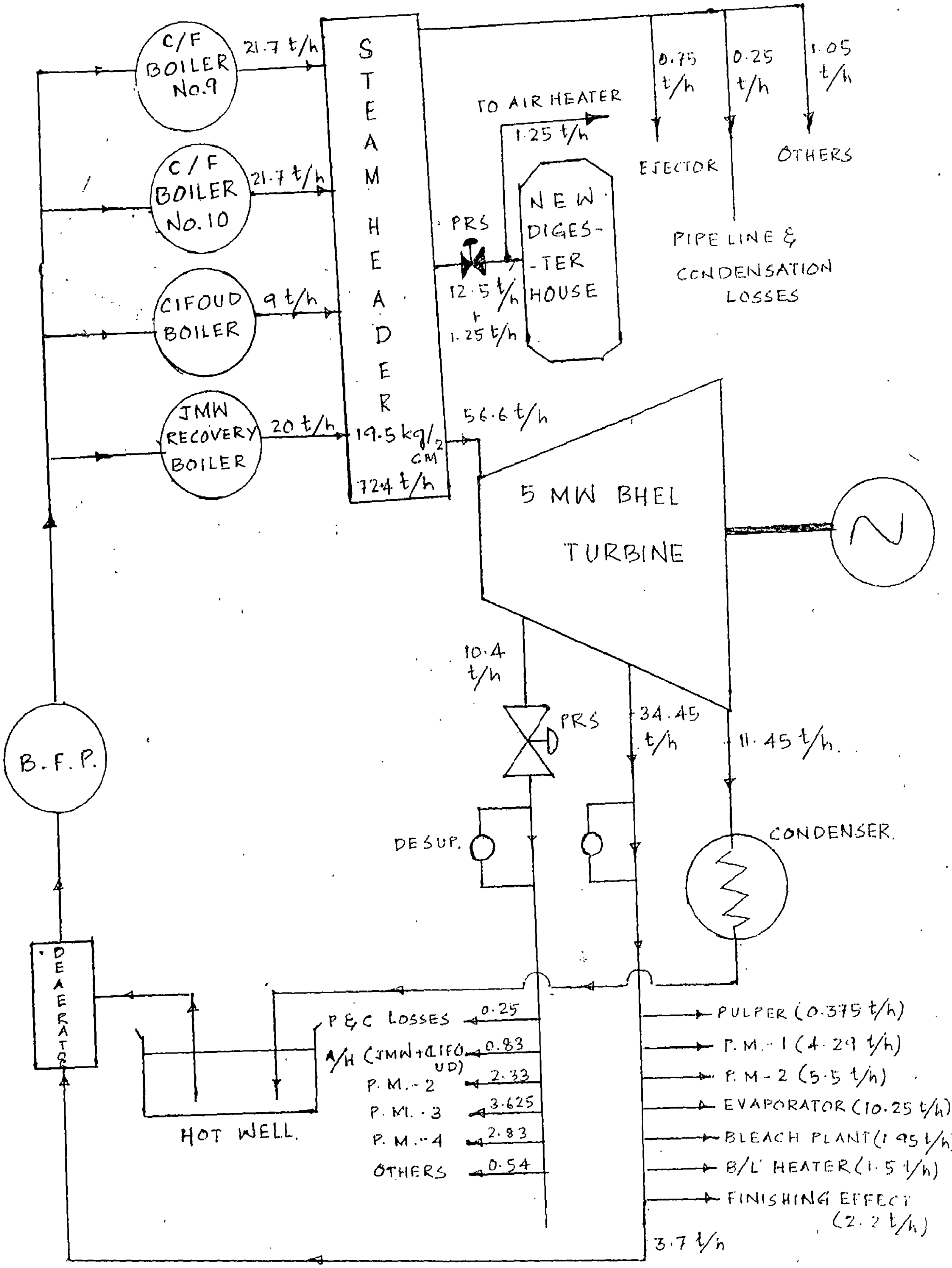
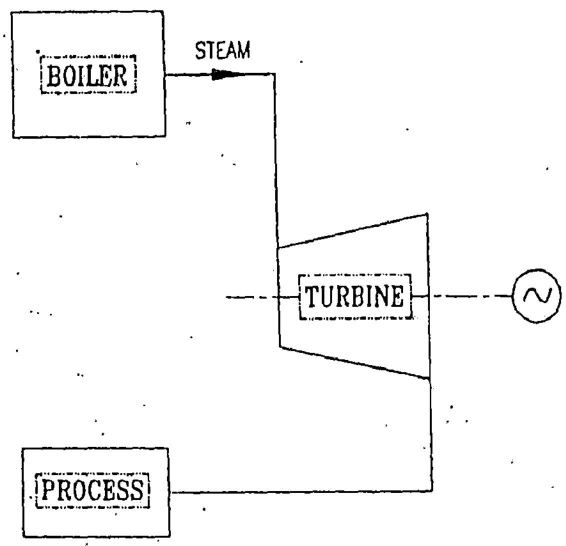


FIG. 1 STEAM BALANCE DIAGRAM OF SPM

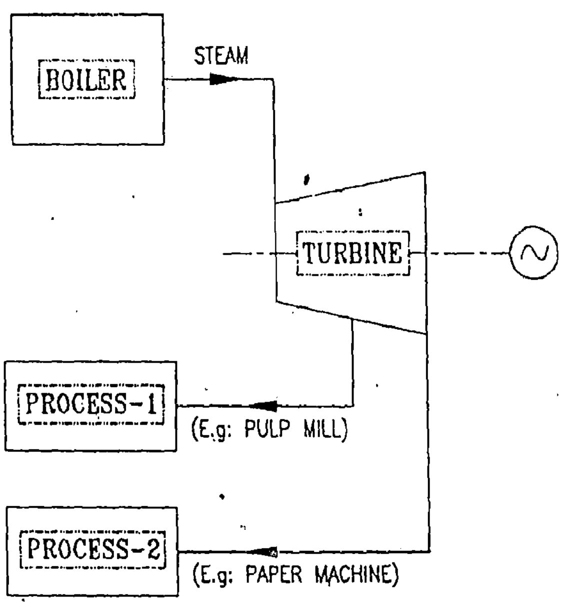
FIGURE - 1



APPLICATION

PAPER MILLS THAT DO NOT HAVE PULPING SECTION.

FIGURE - 2



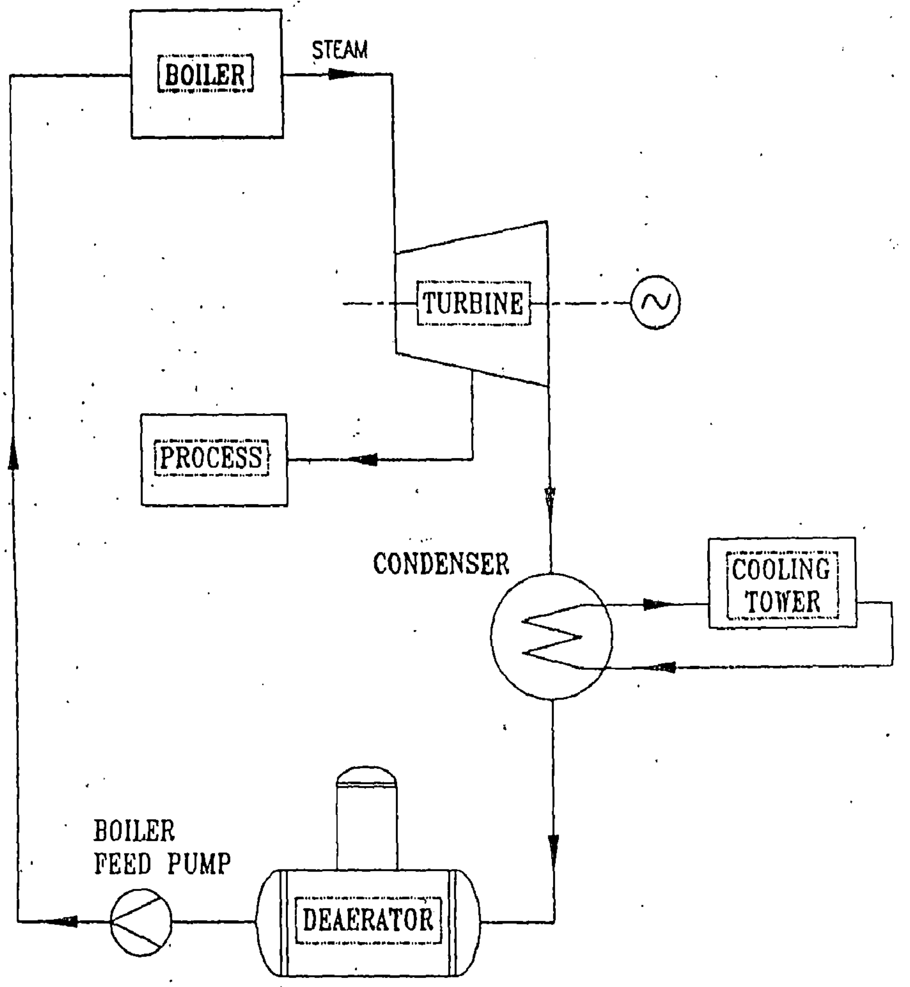
APPLICATION

PAPER MILLS THAT HAVE BOTH DIGESTORS & PAPER MACHINES.

FIGURE - 4

APPLICATION

PAPER MILLS THAT ARE SELF-SUFFICIENT IN POWER.



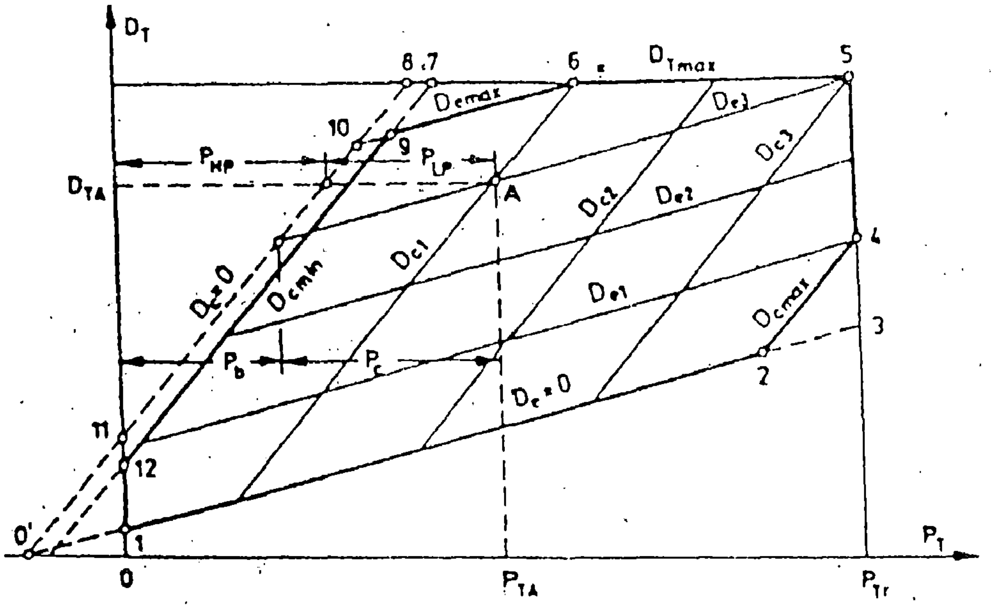


Fig. 5 *General characteristics of an extraction-condensing turbogenerator set of the steam-power type*

1–2 operating line which is solely condensing where $D_e = 0$;
2–4 line of maximum capacity of low-pressure part $D_{c\ max}$;
4–5 line of rated power output P_{Tr};
5–6 line of maximum capacity of high-pressure part $D_{T\ max}$;
6–9 line of maximum extraction capacity $D_{e\ max}$;
9–12 line of minimum capacity of low-pressure part $D_{c\ min}$;
12–1 line of idling $P_T = 0$. (REF - 9)

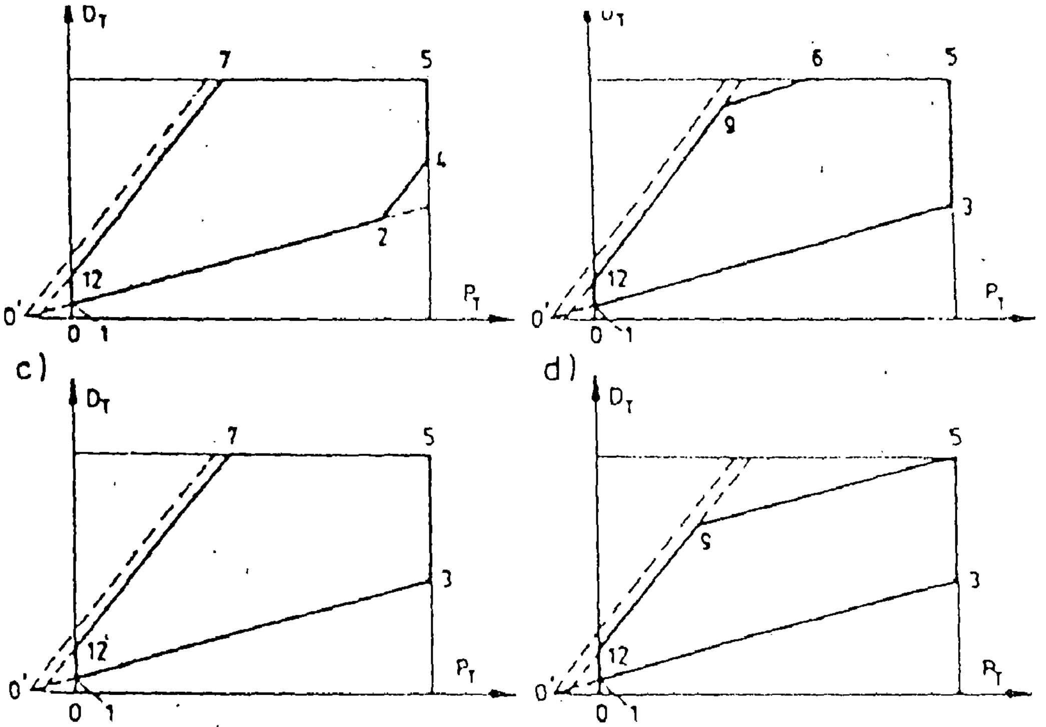


Fig. 6 Specific cases of characteristics of an extraction-condensing turbogenerator set: (a) without limitation $D_{e\ max}$; (b) without limitation $D_{c\ max}$; (c) without limitations $D_{e\ max}$, $D_{c\ max}$; (d) with steam flow $D_{T\ max}$ restricted to point P_T.

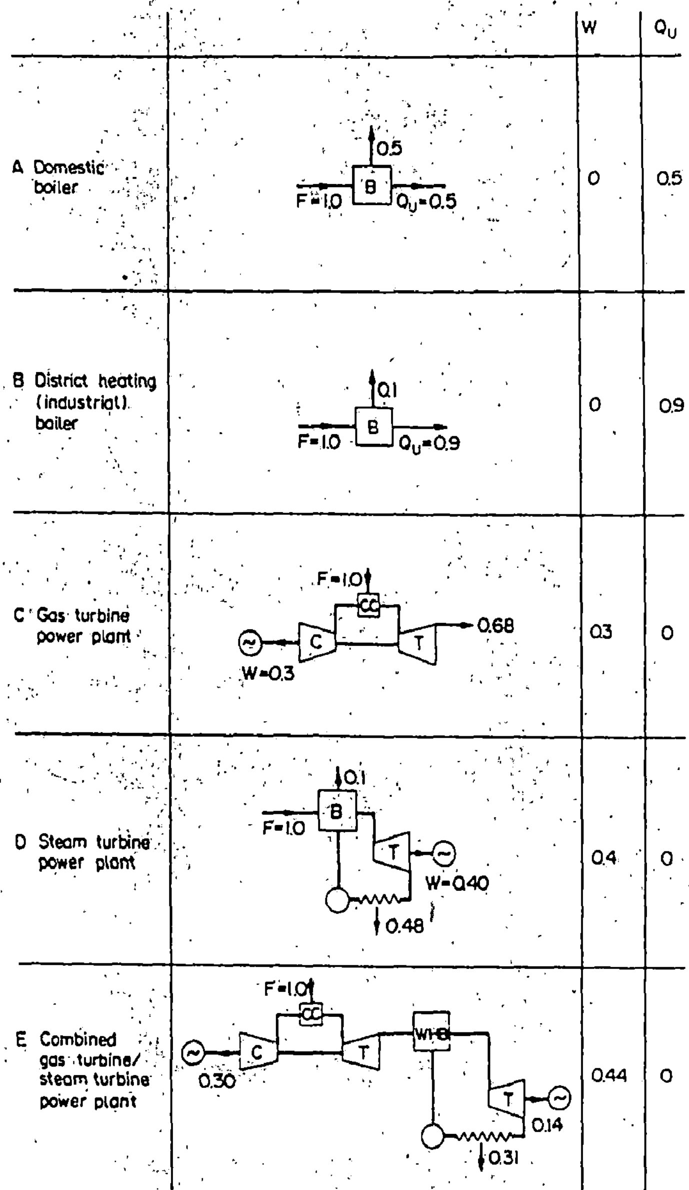


FIG. 7.1 Systems for separate generation of electricity (W) or heat (Q_U) showing energy flows (after Timmermans[1]).

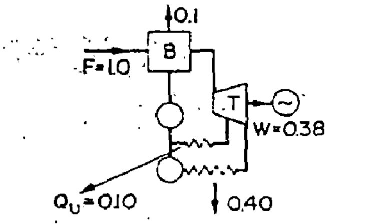
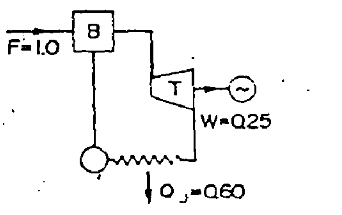
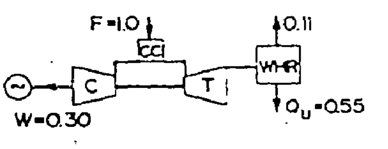
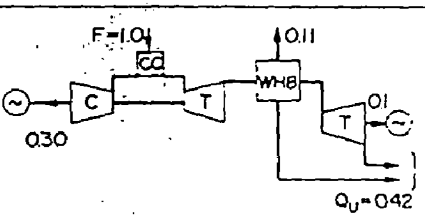
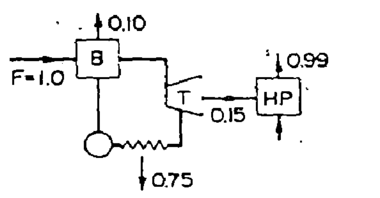
		W	Q_U
F. Extraction condensing plant		0.38	0.10
G Back pressure plant		0.25	0.60
H Gas turbine with waste heat recuperator (WHR)		0.30	0.55
J Combined cycle (gas turbine/back pressure steam turbine)		0.4	0.42
K Heat pump driven by back pressure steam turbine (heat only scheme)		0	1.74

FIG. 7.2 (*cont.*) Systems for combined heat and power showing energy flows (after Timmermans[1] and Kolbusz[2]).

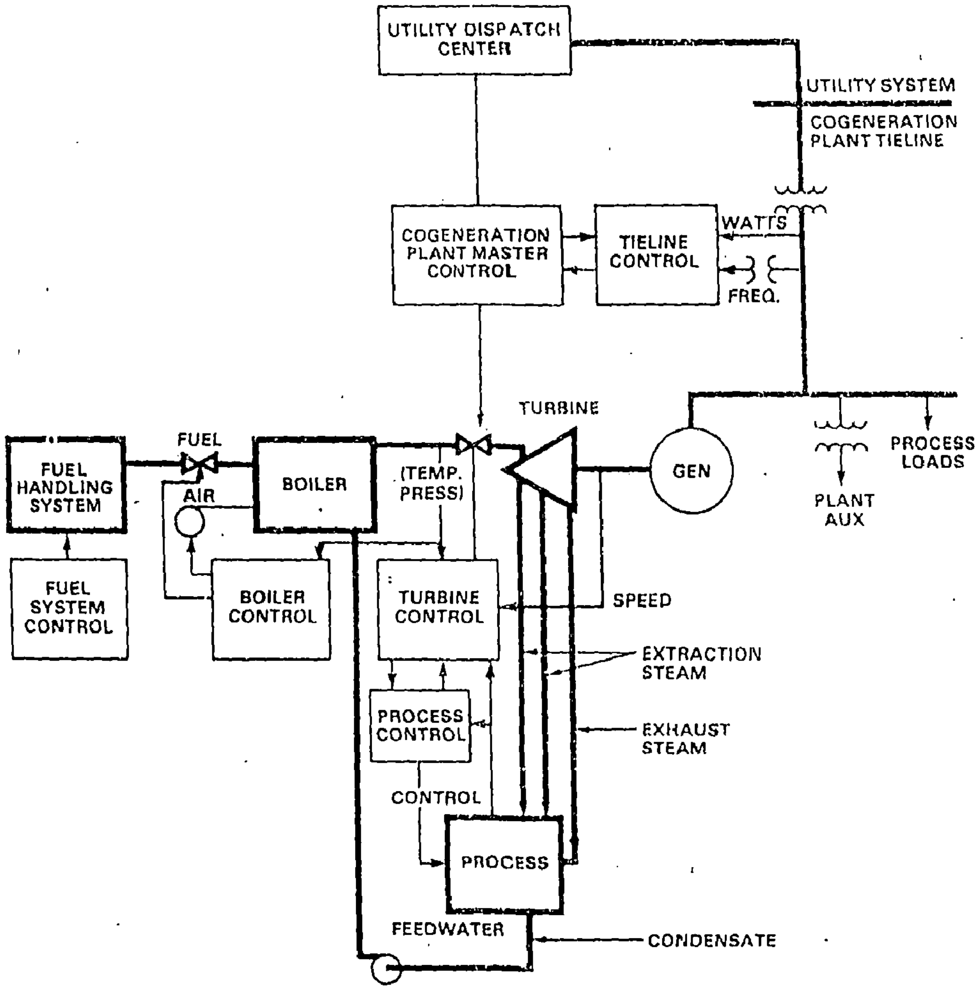
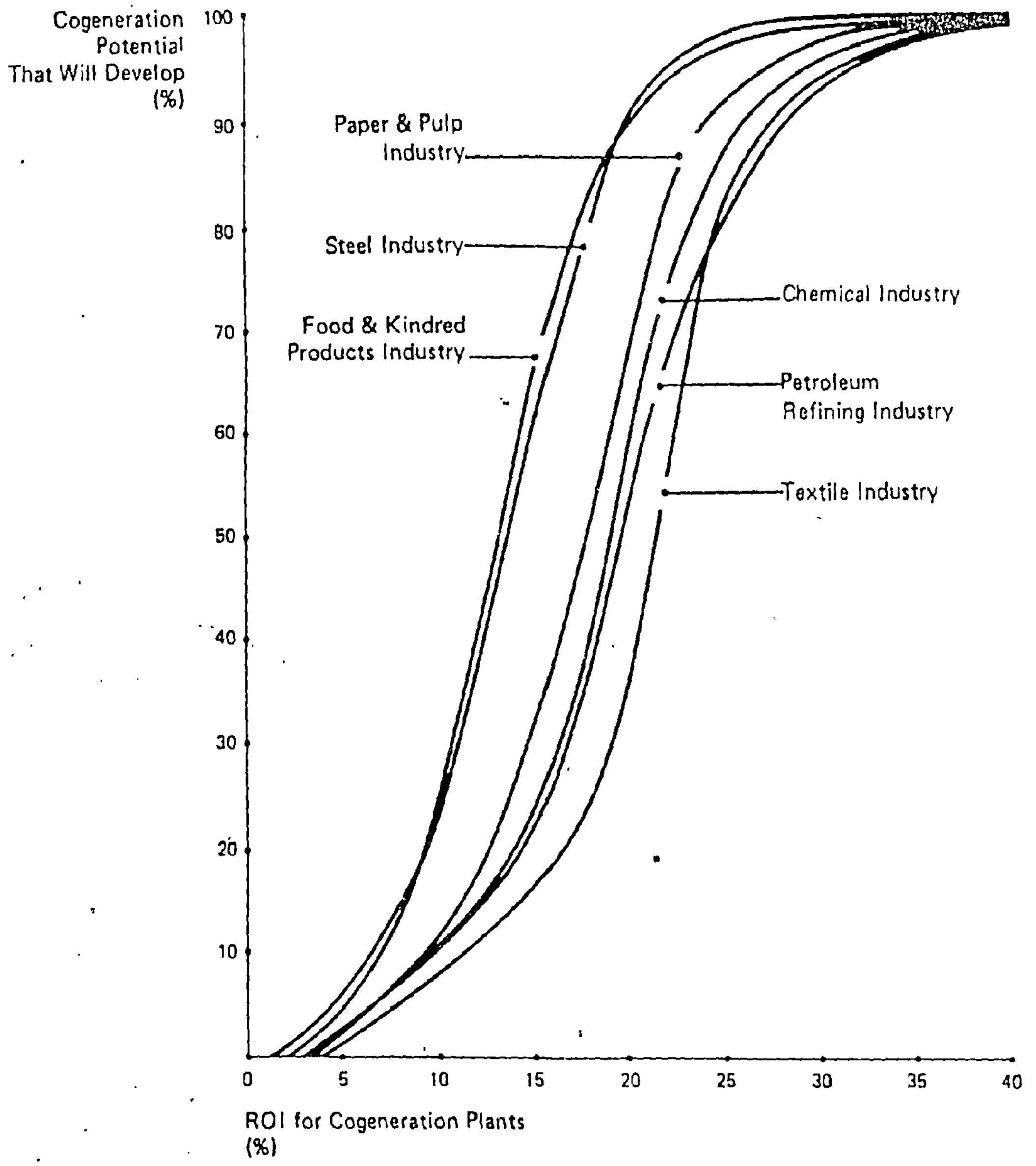


FIGURE 8
Steam turbine topping cogeneration plant control system. (Modified from GE .)

FIGURE 9: COGENERATION POTENTIAL THAT WILL DEVELOP UNDER NORMAL ROI HURDLE RATES* (10)



*Industry interview results showed that some companies do make energy conservation investments at low or negligible ROIs for policy, modernization, and other reasons.

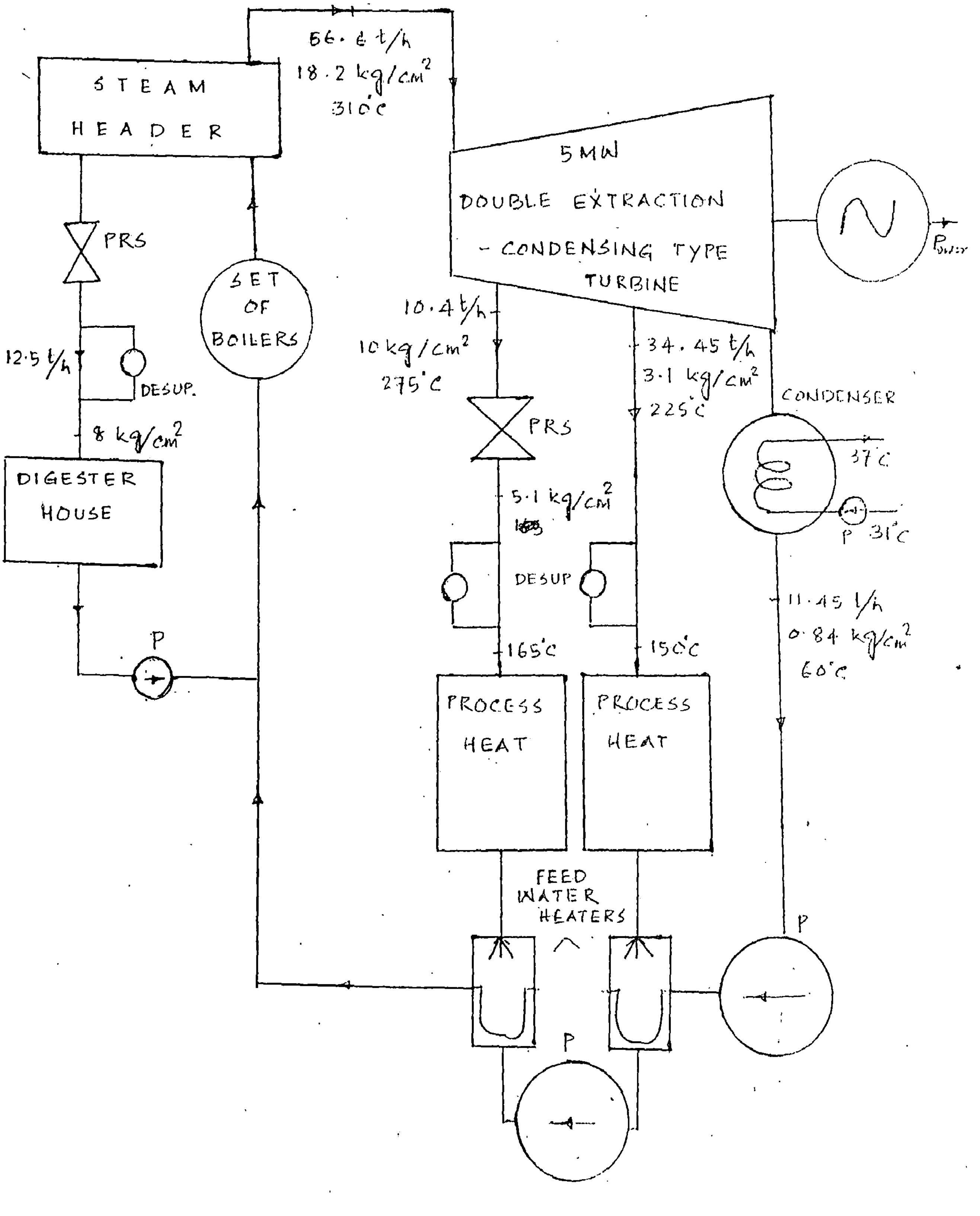


FIG. 10. BOTTOMING CYCLE CO-GENERATION SYSTEM OF SPM

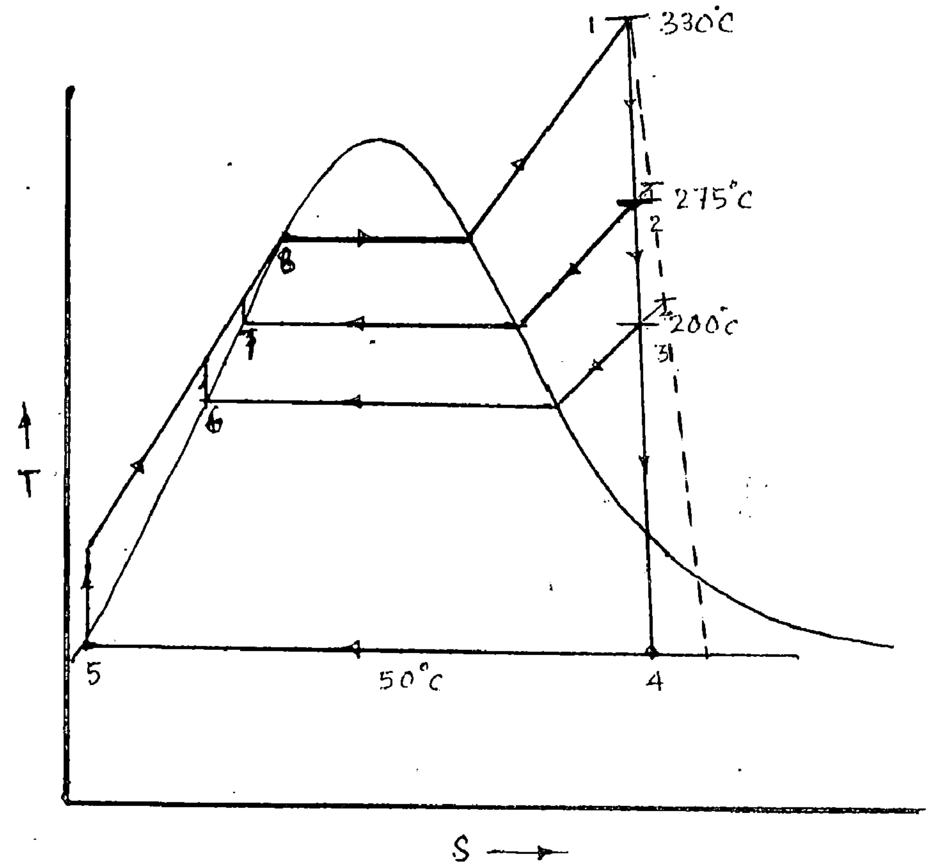


FIG 11 T-S DIAGRAM FOR THE PRESENT SYSTEM

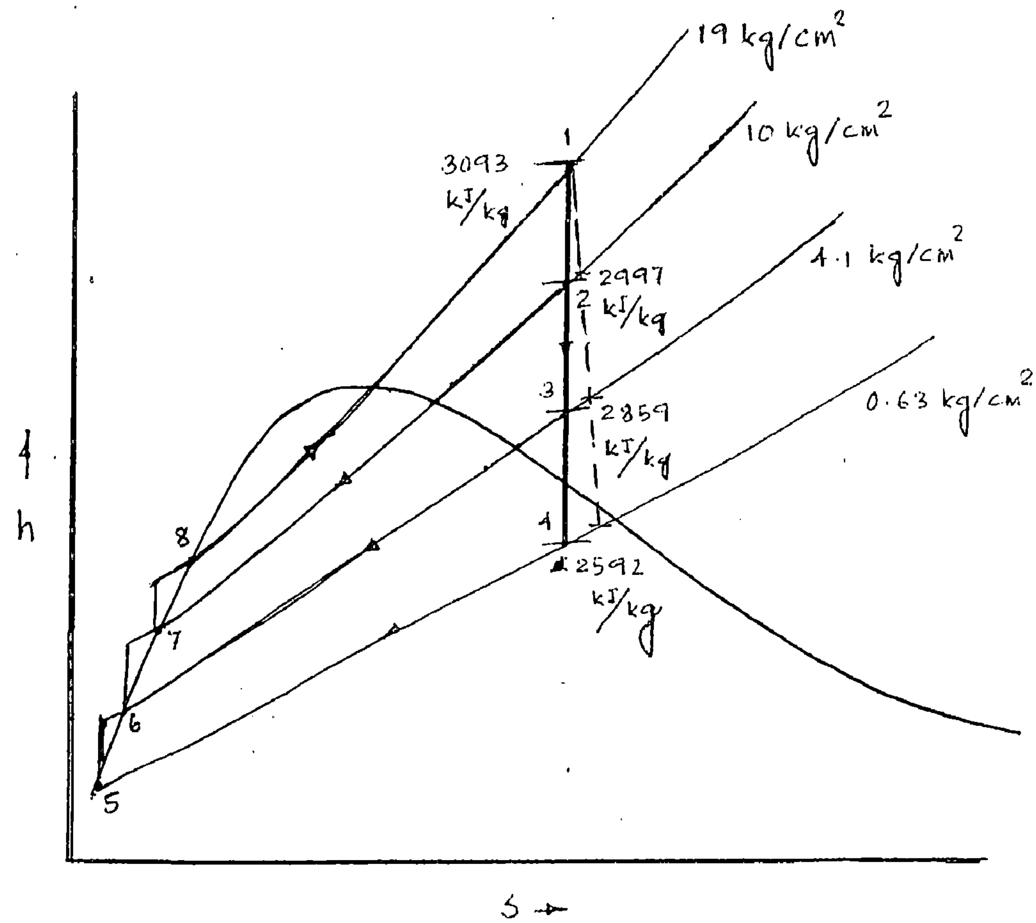


FIG.12 h-S DIAGRAM FOR THE PRESENT SYSTEM.

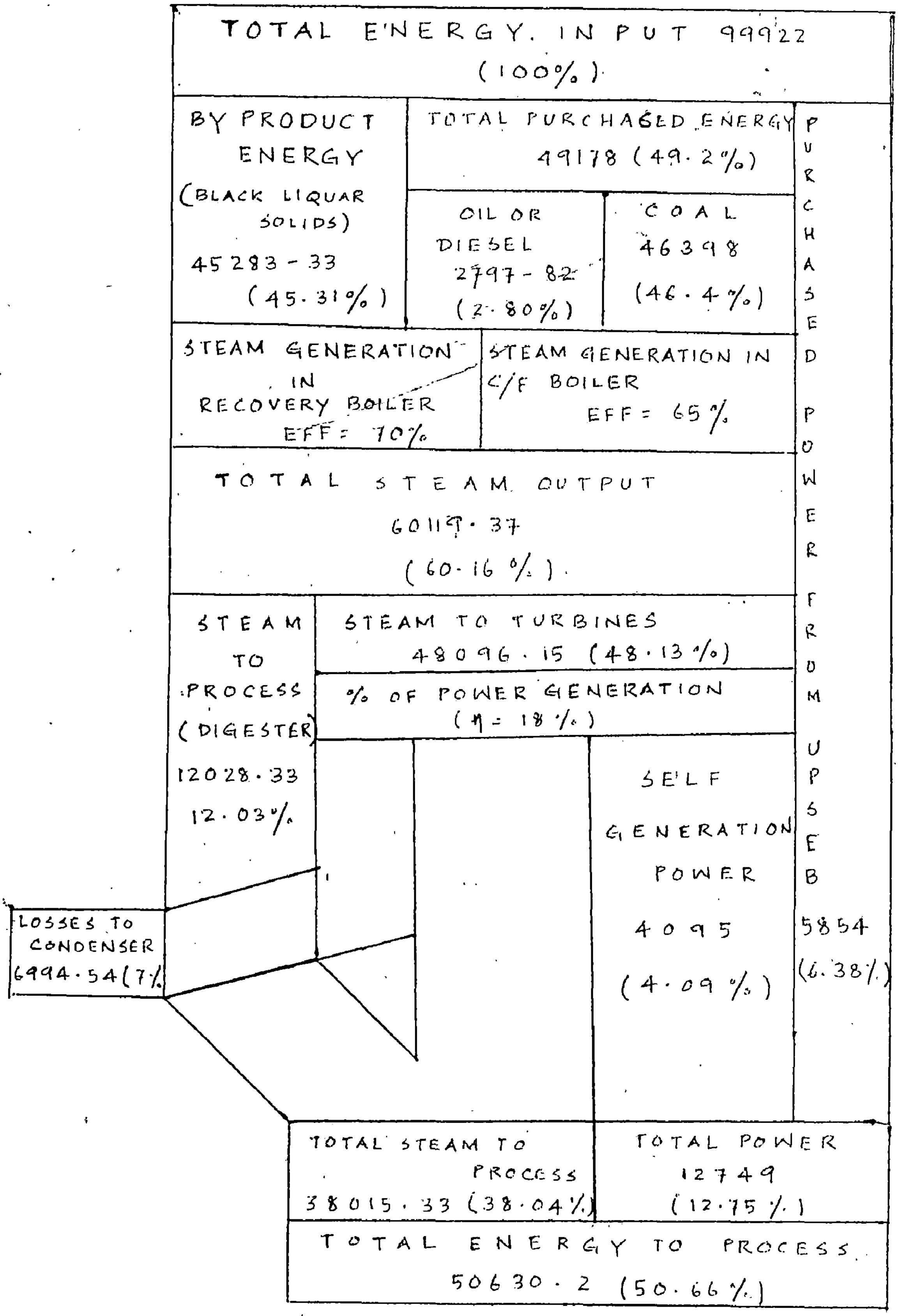
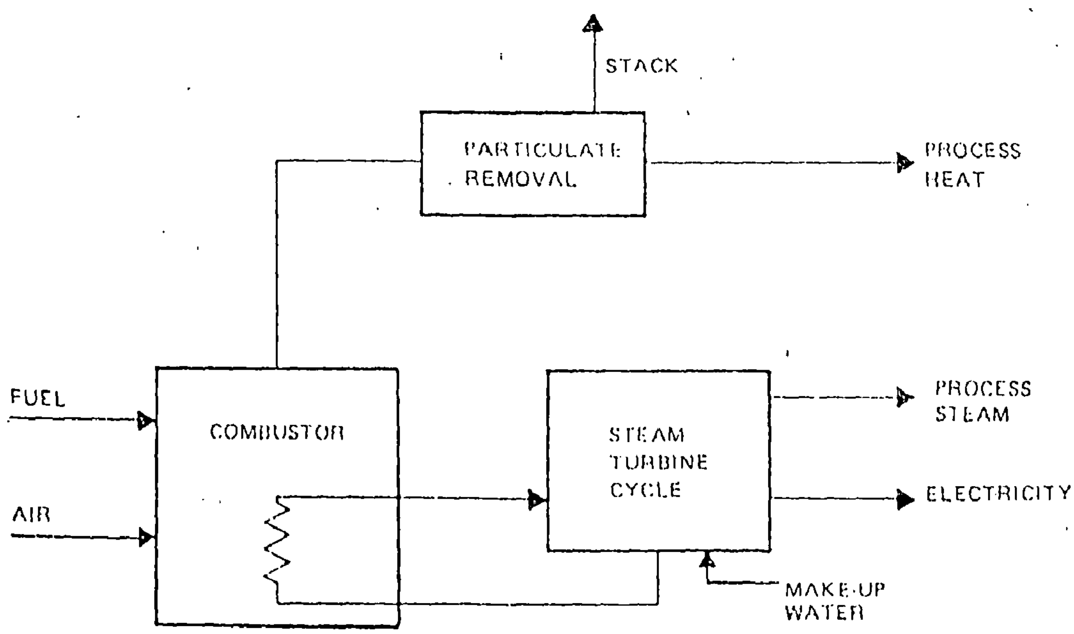


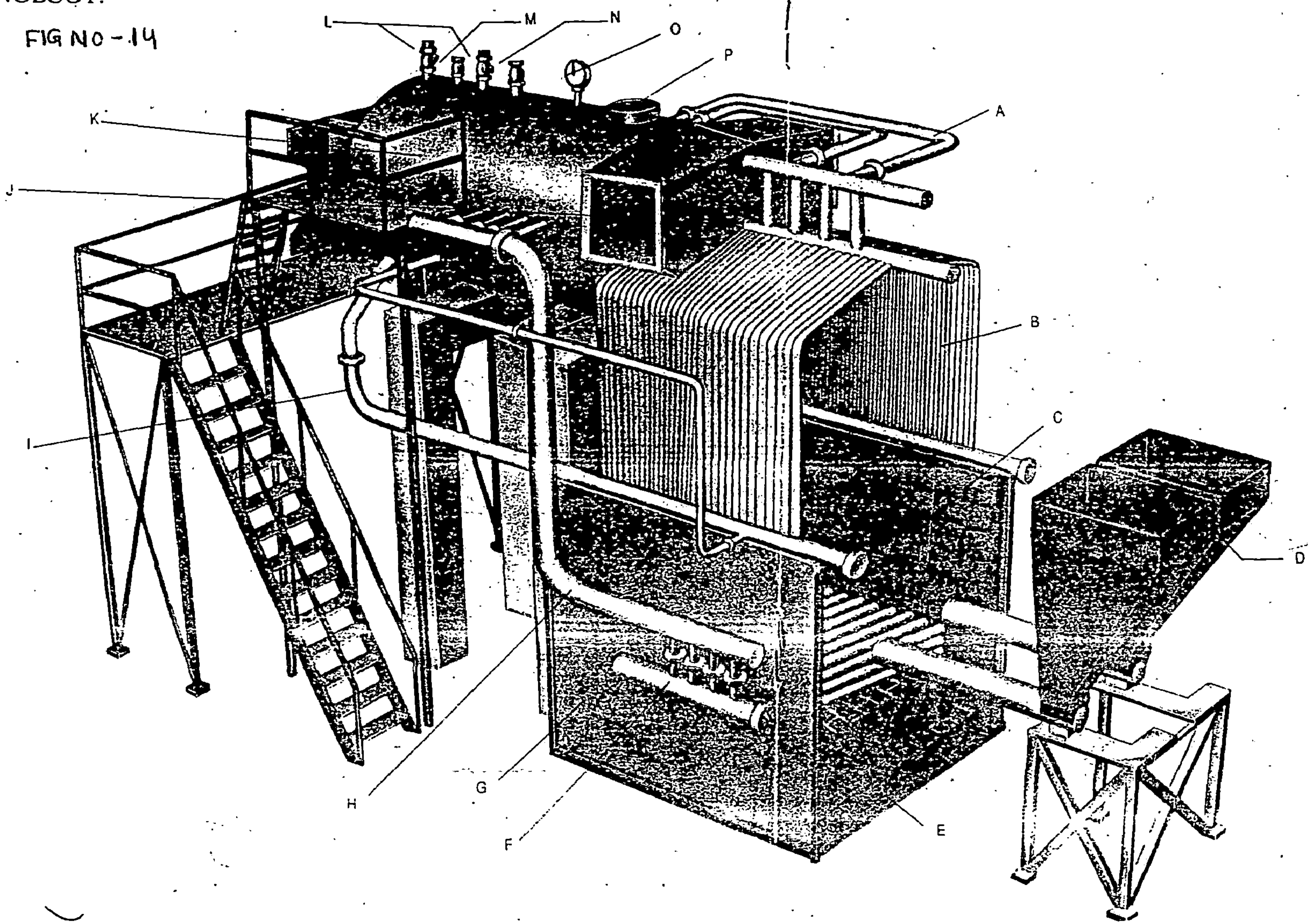
FIG. 12 (A) SANKEY DIAGRAM OF ENERGY CONVERSION OF S.P.M.

FIGURE 2.13: ATMOSPHERIC FLUIDIZED BED COMBUSTION



COMBIPAC - CPF Series is a multi-fuel horizontal smoke tube, two pass, high efficiency, natural circulation, balanced draft, packaged boiler working on FLUIDISED BED TECHNOLOGY.

FIG NO - 14



A. Riser for Membrane Panel
B. Membrane Panel
C. Refractory Bricks
D. Hopper
E. Nozzles
F. Circular Header
G. Furnace Structure
H. Riser for Inbed Tubes
I. Downcomer for Membrane Panel
J. Exhaust Gas Outlet
K. Main Shell
L. Safety Valves
M. Main Steam Stop Valve
N. Air Vent
O. Pressure Indicator
P. Manhole

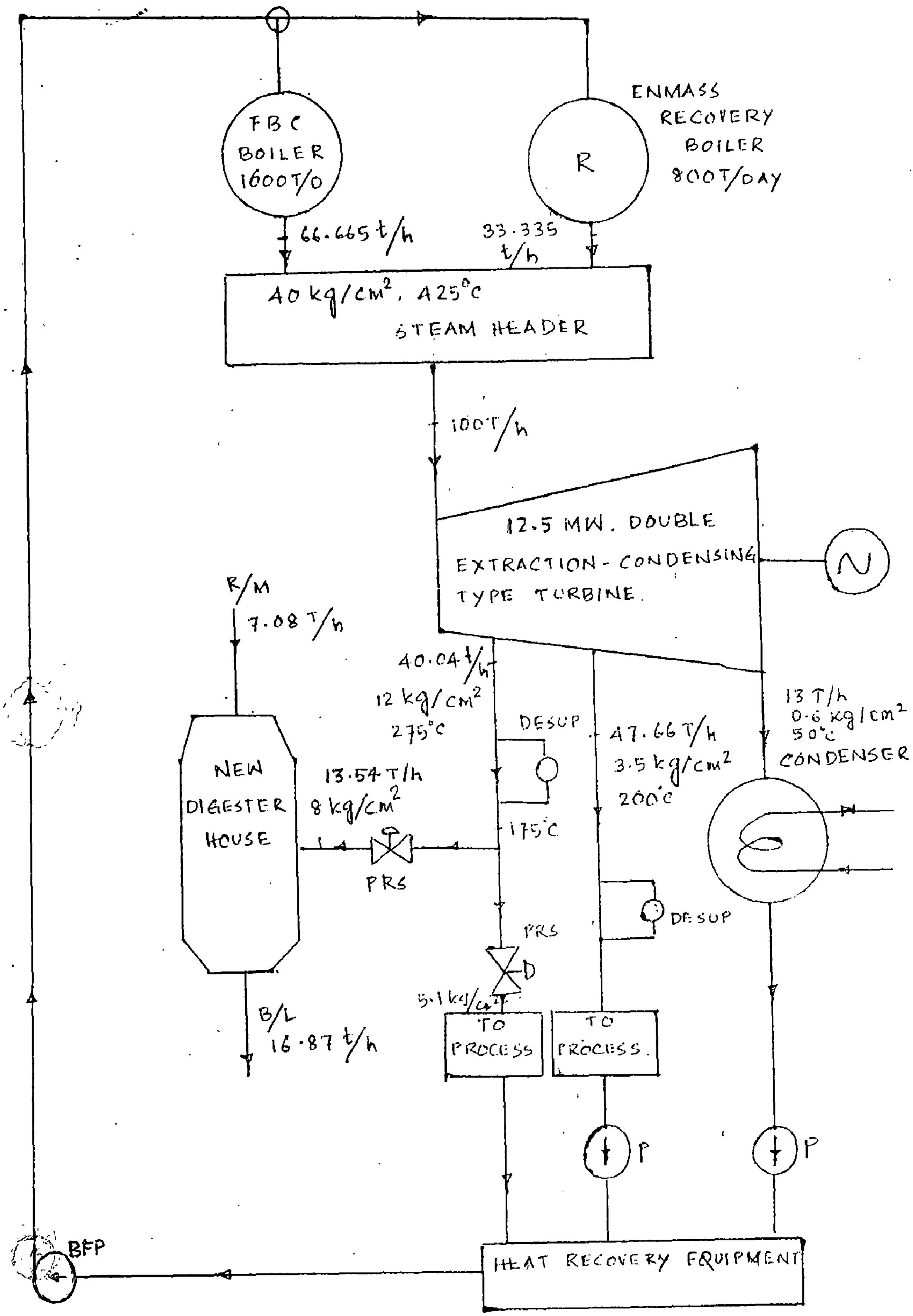


FIG. 15 TOPPING CYCLE DIAGRAM OF AFBC CO GENERATION SYSTEM FOR PROPOSAL - I

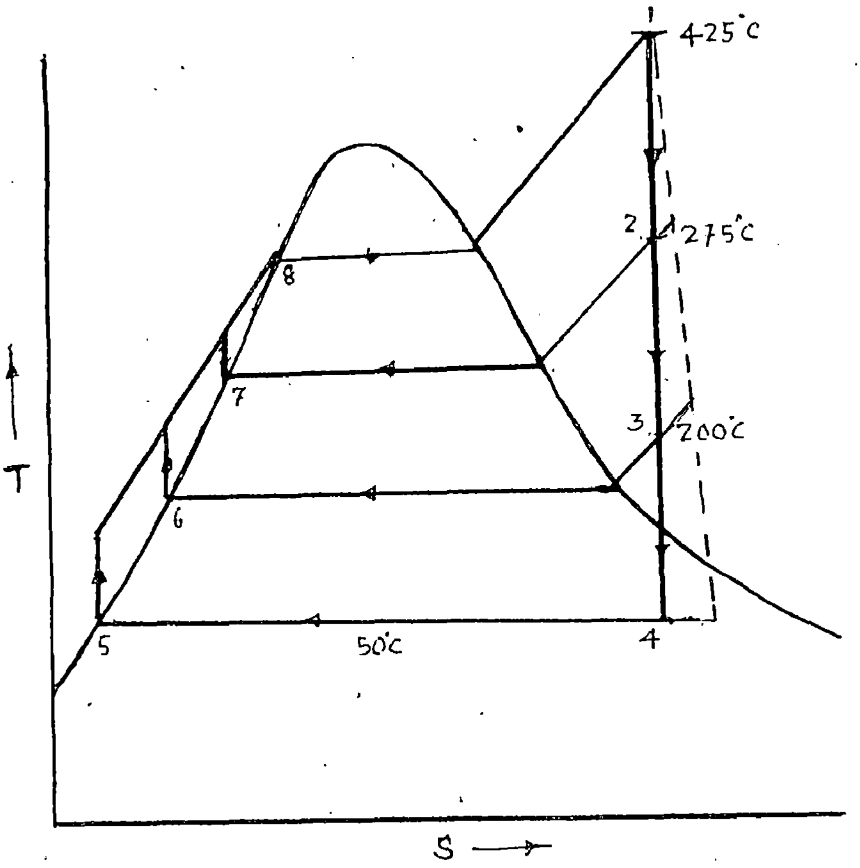


FIG. 15 (A) T-S DIAGRAM FOR PROPOSAL-1

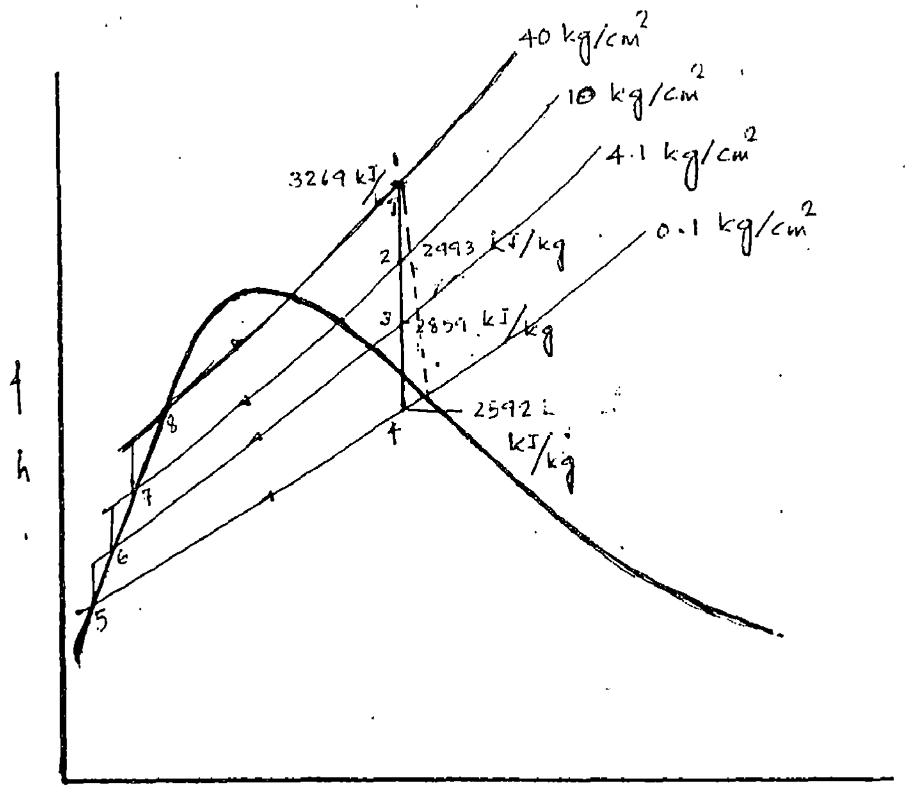


FIG. 15 (B) h-S DIAGRAM FOR PROPOSAL-1

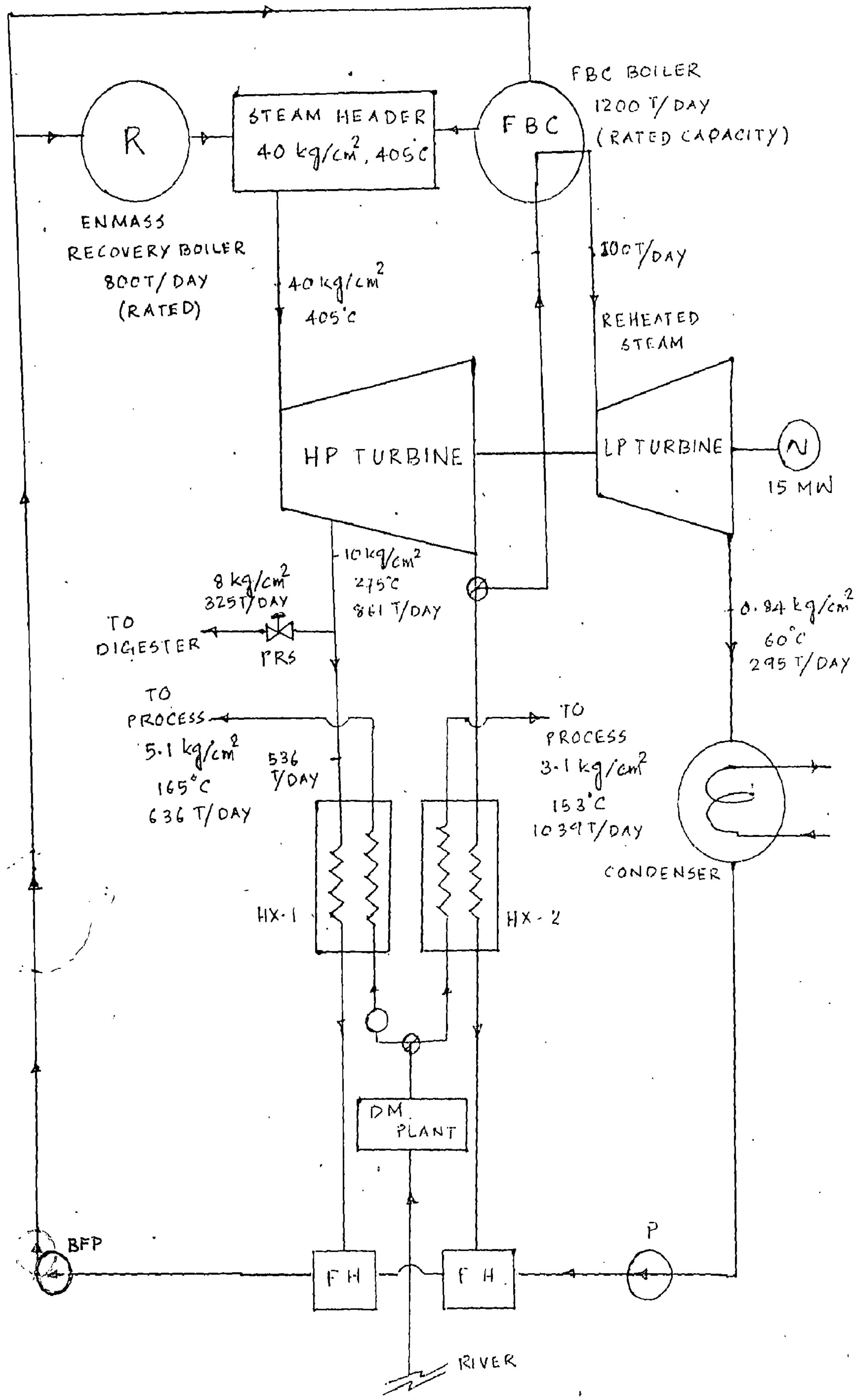


FIG. 16. CO-GENERATION SYSTEM FOR PROPOSAL-2

REFERENCES

1. Francis Wifriads Peter Martrin, *Fuel Technology Summerised Manual*, Pergaon Press Oxford, p. 50 - 100, (1986)

2. Goodla P.M., *Efficient Use of Steam*, West Buy House Pubucation, p- 123-200 (1980)

3. Verma Mahesh, *Power Plant Engineering*, Metropolitan Book Copn Ltd, p- 63- 130 (1987)

4. Ministry of Power, London. *Efficient Use of Fuel*, Her Majesty's Stationary Office, (2nd Edition), p-56-90

5. Verma V.K. & Elanchizhian P.K. *Optimizing Performance of Kraft Boiler*, JPPTA, vol 18, No.2, p- 63-67, (June 1981)

6. Hough Gerlad, *Chemical Recovery in Alkaling Pulping Process*, TAPPI Press, Atlanta, p 69- 123 (1965)

7. Kumar Ram, Bansal M.C. *HRD Consultancy Program on Chemical Recovery*, A.P.P.M. Rajamundry, India, 27th- 30th June 1994.

8. Northcroft L.G. & Barber W.M. *Steam Trapping & Air Venting*, Appendix 1-4,P-196-221 (1979)

9. Marecki J. *Combined Heat & Power Generating Systems*, Peter Pergrinus Ltd. on behalf of Institution of Electrical Engineering p-5,-10, 38-40,128-131 (1988)

10. David HU.S., *Cogeneration*, Reston Publishing co, Inc. a Poentice Hall co Reston virgzinia USA, P, 32, 343, 147.111-115, (1985)

11. Noyes Robert, *Cogeneration of Steam & Electric Power*, Noyes Data Corporation, USA, p. 3-1, 44, 109-113, 121, 244-247, 250, (1978)

12. Dept of Coal, Govt of India, *Coal, Pulp & Paper Industry Effcient Utilisation*, p-1,17-19, 26-27, 43-47, (1987)

13. Rao.M.V.G. *Aannual General Meeting & Seminar Report on Energy Management in Pulp& Paper Industry Including Cogeneration of Electrical Power*, p-1-3, (1992)

14. Horcon J.H., *Cogeneration of Combined Heat, Power Thermodynamics*, Pergaon Press, p-31- 45, (1987)

15. Nag P.K., *Engineering Thermodynamics*, Tata Mcgraw Mill Publication, N Delhi, India, p-322-328 (1989)

16. International Seminar on *"Energy Conservation in Pulp and Paper Indvstry"* March 18 & 19, IPPTA, (1985)

17. Kocurek, M.J. Alkaline Pulping, vol 5, TAPPI Press p 471-529, (1983)