

**25TH NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS - SEPTEMBER 2025**

PAPER - 4: ENERGY PERFORMANCE ASSESSMENT FOR EQUIPMENT AND UTILITY SYSTEMS
Date : 28.09.2025 Timings: 14:00-16:00 HRS Duration: 2 HRS Max. Marks: 100

General instructions:

- o Please check that this question paper contains 6 printed pages*
- o Please check that this question paper contains 16 questions*
- o The question paper is divided into three sections*
- o All questions in all three sections are compulsory*
- o All parts of a question should be answered in one place*
- o Time management guidance: Section - I & II: 10 Minutes each, Section - III: 100 Minutes*

Section - I: BRIEF QUESTIONS

Marks: 10 x 1 = 10

- (i) Answer all **Ten** questions
- (ii) Each question carries **One** mark

1.	Lower the TTD (Terminal Temperature Difference) and DCA (Drain Cooler Approach) for feedwater heaters, the higher will be the efficiency of the cycle.	True
2.	If wet steam is generated, the high Evaporation ratio indicates high efficiency of boiler.	False
3.	The only reason for installing condensate recovery systems is to reduce makeup water.	False
4.	The heat rate of a thermal power plant can be improved by decreasing the condenser cooling water temperature.	True
5.	In a cement rotary kiln, the highest heat loss occurs through clinker discharge.	False
6.	Evaporation ratio is based on actual performance data (steam output and fuel input) and does not depend on whether efficiency is expressed on GCV or NCV basis.	True
7.	Isentropic efficiency of a back-pressure turbine will be more if extraction temperature is higher than steam temperature at back-pressure condition.	False
8.	Profitability Index (PI) will be greater than 1 for projects with positive NPV, but its value varies with cash flow patterns and is not always higher for all positive NPV projects.	True
9.	In an integrated iron & steel plant, all the rolling mills consumes more energy compared to energy consumed for iron making.	False
10.	In indirect method of boiler efficiency calculations, blowdown losses are also considered.	False

..... End of Section - I

Section - II: SHORT NUMERICAL QUESTIONS**Marks: 2 x 5 = 10**

(i) Answer all the **Two** questions
(ii) Each question carries **Five** marks

L-1	<p>During the assessment year 2024-25, one of the thermal power plants reported a gross heat rate of 2300 kCal/kWh and an auxiliary power consumption of 8%, while the baseline net heat rate was 2600 kCal/kWh.</p> <p>If the baseline generation is 5000 MU and considering that 1 kg of oil equivalent = 10,000 kCal and 1 e-Certificate = 1 ton of oil equivalent (TOE), calculate the reduction in net heat rate compared to the baseline and determine the expected number of e-Certificates.</p>																		
L-1 Ans	<p>Assessment Year Net Heat Rate = $2300 / (100-8) / 100$ $= 2500 \text{ kCal/kWh}$</p> <p>Reduction in net heat rate = Baseline - Assessment year Net Heat Rate $= 2600 - 2500$ $= 100 \text{ kCal/kWh}$</p> <p>Expected E-certs = $5000 \times 10^6 \times 100 / 10000 \times 1000$ $= 50,000 \text{ e-Certificates}$</p>																		
L-2	<p>In a petrochemical industry, both the Low-Pressure (LP) boiler and the High-Pressure (HP) boiler operate with the same evaporation ratio of 14, using the same fuel oil. The operating details are provided below:</p> <table border="1" data-bbox="367 1034 1229 1236"> <thead> <tr> <th>Particulars</th> <th>LP Boiler</th> <th>HP Boiler</th> </tr> </thead> <tbody> <tr> <td>Pressure</td> <td>10 kg/cm²a</td> <td>32 kg/cm²a</td> </tr> <tr> <td>Temperature</td> <td>Saturated steam</td> <td>400 °C</td> </tr> <tr> <td>Enthalpy of steam</td> <td>665 kcal/kg</td> <td>732 kcal/kg</td> </tr> <tr> <td>Temperature of feed water</td> <td>80 °C</td> <td>105 °C</td> </tr> <tr> <td>Evaporation Ratio</td> <td>14</td> <td>14</td> </tr> </tbody> </table> <p>If the efficiency of the LP boiler is 80%, calculate the efficiency of the HP boiler.</p>	Particulars	LP Boiler	HP Boiler	Pressure	10 kg/cm ² a	32 kg/cm ² a	Temperature	Saturated steam	400 °C	Enthalpy of steam	665 kcal/kg	732 kcal/kg	Temperature of feed water	80 °C	105 °C	Evaporation Ratio	14	14
Particulars	LP Boiler	HP Boiler																	
Pressure	10 kg/cm ² a	32 kg/cm ² a																	
Temperature	Saturated steam	400 °C																	
Enthalpy of steam	665 kcal/kg	732 kcal/kg																	
Temperature of feed water	80 °C	105 °C																	
Evaporation Ratio	14	14																	
L-2 Ans	<p>Effyⁿ = ER. (hg - hf) / GCV</p> <p>Effy_{LP}ⁿ¹ = 0.8 = 14 x (665 - 80) / GCV</p> <p>Effy_{HP}ⁿ² = 14 x (732 - 105) / GCV</p> <p>Effy_{HP}ⁿ² / Effy_{LP}ⁿ¹ = (732 - 105)0.8 / (665 - 80) = 0.8574 = 85.74%</p> <p>Or</p> <p>Effy_{LP}ⁿ¹ = 0.8 = 14 x (665 - 80) / GCV</p> <p>GCV = 14 x (665 - 80) / 0.8 = 10237.5 kcal/kg</p> <p>Effy_{HP}ⁿ² = 14 x (732 - 105) / GCV</p> <p>= 14 x (732 - 105) / 10237.5 = 0.8574 = 85.74%</p>																		

..... End of Section - II

Section - III: LONG NUMERICAL QUESTIONS

Marks: 4 x 20 = 80

(i) Answer all the **Four** questions
(ii) Each question carries **Twenty** marks

N-1	<p>A boiler is fired with 200 kg/hr of a hydrogen-enriched hydrocarbon fuel ($C_nH_m-H_2$) at atmospheric pressure and a temperature of 20 °C. The flue gas, leaving the boiler at atmospheric pressure and 300 °C, has the following dry composition by weight:</p> <ul style="list-style-type: none"> • $CO_2 = 12\%$ • $O_2 = 3\%$ • $N_2 = 85\%$ <p>Based on this information, determine:</p> <ol style="list-style-type: none"> a) The main constituents of the fuel (carbon and hydrogen) 12 Marks b) The percentage composition of each constituent in the fuel 4 Marks c) The total mass flow rate (kg/hr) of the dry flue gas. 4 Marks
	<p>N-1 Assumptions (per 100 kg dry flue gas): Nitrogen -85 kg/hr, Oxygen – 3 kg/hr, CO_2 – 12 kg/hr</p> <p>Sol Take air O_2 mass fraction = 0.23 and N_2 mass fraction = 0.77.</p> <p>Carbon in the fuel (from CO_2): $CO_2 \rightarrow C$:</p> $m_C = 12 \text{ kg } CO_2 \times \frac{12}{44} = \frac{144}{44} = \frac{36}{11} \text{ kg}$ <p>$m_C = 36/11 = 3.2727 \text{ kg/h of carbon/ per 100 kg/hr of flue gas}$</p> <p>Actual air supplied: $\text{Air mass} = \frac{N_2}{N_2 \text{ mass fraction in air}} = \frac{85}{0.77} = 110.39 \text{ kg/hr of air / 100 kg/hr of flue gas}$</p> <p>$O_2$ supplied with that air: $O_2^{\text{supplied}} = 0.23 \times 110.39 = 25.39 \text{ kg/hr / 100 kg/hr of flue gas}$</p> <p>$O_2$ consumed (used in combustion) = supplied – residual in flue gas $O_2^{\text{consumed}} = 25.39 - 3 = 22.39 \text{ kg/hr / 100 kg/hr of flue gas}$</p> <p>$O_2$ used to oxidize carbon (to form CO_2): Stoichiometry: $C + O_2 \rightarrow CO_2 \rightarrow \text{mass factor} = \frac{32}{12} = \frac{8}{3}$.</p> $O_2 \text{ for } C = \frac{8}{3} \times m_C = \frac{8}{3} \times \frac{36}{11} = \frac{288}{33} = 8.73 \text{ kg/hr/100kg/hr of flue gas}$ <p>O_2 available for hydrogen: $O_2 \text{ for } H = O_2^{\text{consumed}} - O_2 \text{ for } C$ $= 22.39 - 8.73 = 13.66 \text{ kg/hr/100kg/hr of flue gas}$</p> <p>Each kg H requires 8 kg O_2 to form H_2O, so H mass: $m_H = \frac{13.66}{8} = 1.70779 \text{ kg/hr}$</p> <p>Fuel mass & composition (per 100 kg dry flue gas): Total fuel mass (C + H): $m_{\text{fuel}} = m_C + m_H = 3.2727 + 1.70779 = 4.9805 \text{ kg/hr}$</p> <p>Mass fractions: $\%C = \frac{3.2727}{4.9805} \times 100 = 65.732663\% (\approx 65.73\%)$ $\%H = \frac{1.7077}{4.9805} \times 100 = 34.267337\% (\approx 34.27\%)$</p> <p>If fuel flow = 200 kg/h: Carbon: $m_C(200) = 200 \times 0.6573 = 131.465326 \text{ kg/h}$ $= 131.46 \text{ kg/hr}$</p> <p>Hydrogen: $m_H(200) = 200 \times 0.3426 = 68.534674 \text{ kg/h}$</p>

	= 68.54 kg /hr
	c) The total Mass Flow rate of Dry Flue gas in kg/hr:
	Carbon (C) = 131.46 kg/h Hydrogen (H) = 68.54 kg/h
	Mass of dry flue gas = Mass of wet flue gas – Mass of H ₂ O = 200 + Actual Air – 9* 68.54 = Actual Air – 416.86
	Actual Air = Ta + Ea
	Ta = (2.67 x 131.46 + 8 x 68.54) / 23% = 3910 kg/hr
	Ea = E% x Ta
	E% = O ₂ % / (21% - O ₂ %)
	O ₂ % = 3/32 / (12/44 + 3/32 + 85/28) = 2.75%
	E% = 2.75% / (21% - 2.75%) = 15.07%
	Ea = 15.07% x 3910 kg/hr = 589.24 kg/hr
	Therefore, Actual Air = Ta + Ea = 3910 kg/hr + 589.24 kg /hr = 4499.24 kg/hr
	Mass of Dry flue gas = 4499.24 – 416.86 = 4082.38 kg/hr

N-2 i) A small Topping Cycle Gas Turbine cogeneration plant has the following operating parameters. Estimate the power generation in kW and the steam supplied from the HRSG in TPH. The Energy Auditor has suggested that the HRSG exit flue gas temperature can be maintained at 95 °C by recovering more heat from the HRSG. If the HRSG exit flue gas temperature is maintained at 95 °C, estimate the additional steam generation and also the EUF with improved steam generation. The operating parameters are given below:

12 Marks

Parameter	Value
Natural Gas Fuel Firing Rate	1500 Sm ³ /hr
Lower Heating Value (LHV)	9600 kcal/Sm ³
Exhaust Gas Flow Rate	16.35 kg/s
Exhaust Gas Temperature	525 °C
Mean Specific Heat of Gas (Cp)	0.265 kcal/kg·°C
Specific Power Generation	3.044 kWh/Sm ³
HRSG Inlet Temperature	520 °C
HRSG Exit Temperature	135 °C
Steam Pressure	10 kg/cm ²
Saturated Steam Temperature	179 °C
Steam Enthalpy	663 kcal/kg
Feedwater Temperature	105 °C
HRSG Efficiency	79%

ii) A coal-fired boiler operates with the following parameters.

8 Marks

Parameter	Value
Hours of Operation	24 hours
Feed Water Temperature	145 °C
Steam Enthalpy	805 kcal/kg
GCV of Coal	4200 kcal/kg
Evaporation Ratio	5.7
Steam Flow Rate	265 TPH

	<p>Calculate the Boiler Efficiency and Coal Consumption per hour. If the boiler efficiency is improved by 2% relative to the existing efficiency, then estimate the coal savings per day.</p>
N-2 Ans	<p>a)</p> <p>Power Generation</p> $\text{Power} = \text{Fuel rate} \times \text{Specific power generation}$ $= 1500 \times 3.044 = 4566 \text{ kW}$ <p>Steam Generation at Baseline (Exit 135 °C)</p> $\text{Heat recovered} = 4,744,101 \text{ kcal/hr}$ <p>Steam generated = 8502 kg/hr = 8.50 TPH</p> <p>Steam Generation at Improved Condition (Exit 95 °C)</p> $\text{Heat recovered} = 5,236,995 \text{ kcal/hr}$ <p>Steam generated = 9385 kg/hr = 9.39 TPH</p> <p>Additional steam = 9385 - 8502 = 883 kg/hr = 0.88 TPH</p> <p>Energy Utilization Factor (EUF)</p> <p>Fuel input = 16,744 kW</p> <p>Useful output = Power (4566) + Steam thermal (6086) = 10,652 kW</p> <p>EUF = 10,652 / 16,744 = 63.60 %</p> <p>b)</p> <p>Heat Output</p> <p>Net enthalpy gain = 805 - 145 = 660 kcal/kg</p> $Q_{\text{out}} = 265,000 \times 660 = 174,900,000 \text{ kcal/hr}$ <p>Coal Consumption (from ER)</p> $\text{Coal/hr} = 265,000 \div 5.7 = 46,491.22807 \text{ kg/hr} = 46.49 \text{ TPH}$ <p>Heat Input</p> $Q_{\text{in}} = 46,491.22807 \times 4200 = 195,263,157.9 \text{ kcal/hr}$ <p>Boiler Efficiency</p> $\eta = Q_{\text{out}} \div Q_{\text{in}} \times 100 = (174,900,000 \div 195,263,157.9) \times 100 = 89.57\%$ <p>Improved Efficiency (relative 2%)</p> $\eta_{\text{new}} = 89.57 \times 1.02 = 91.36\%$ <p>New Coal Consumption</p> $\text{Coal}_{\text{new}} = Q_{\text{out}} \div (\eta_{\text{new}} \times \text{GCV})$ $\text{Coal}_{\text{new}} = 174,900,000 \div (0.9136 \times 4200) = 45,584.085 \text{ kg/hr} = 45.58 \text{ TPH}$ <p>Coal Savings</p> $\Delta \text{Coal/hr} = 46,491.228 - 45,584.085 = 907.143 \text{ kg/hr}$ <p>Daily Saving = 907.143 × 24 = 21,771.43 kg/day ≈ 21.77 TPD</p>
N-3	<p>A pharmaceutical manufacturing plant operates a central chilled water system that serves both cleanroom AHUs and a process cooling water loop for tablet coating machines. The process cooling water passes through a counterflow heat exchanger, entering at 20 °C and leaving at 14 °C with a flow rate of 166 m³/h. On the other side, the chilled water enters at 7 °C and leaves at 12 °C, with a flow rate of 200 m³/h. The heat exchanger has an overall heat transfer coefficient of 2.8 kW/m² °C.</p> <p>The chilled and condenser cooling water loops are each served by centrifugal pumps with operating efficiencies of 78 % and 80 %, respectively and with a head of 18 m. The cooling tower is fitted with an induced-draft axial fan delivering 28 m³/s of air at 42.83 mmWC total pressure, with a fan efficiency of 62 %. All pumps and the fan are driven by directly coupled three-phase induction motors with an efficiency of 92 %.</p> <p>The plant's HVAC system operates for 300 days annually, running 18 hours per day, to handle an average cooling load of 850 kW with an ISEER value of 4.5.</p> <p>Calculate the following:</p>

LP Heater 1	92.5	-0.23	93.07	64.2	47.2	13.7	63.6	12.6	2.88	4.8
LP Heater 2	140	0.49	111.23	70.4	-	-	105	11.5	2.95	4.95
LP Heater 3	209	1.97	132.9	110	-	-	130	10.4	2.95	4.95
HP Heater 5	416	17.4	207.33	171	170	202	210	199	0	5
HP Heater 6	335	43	254.94	212	-	-	255	197	0.1	5

Neglect temperature loss in the feedwater line between heaters and calculate the following:

a. Calculate the Turbine Heat Rate and the Unit Heat Rate. 8 Marks
 b. Determine the loss or gain in the Turbine Heat Rate due to deviations of the TTD (Terminal Temperature Difference) and DCA (Drain Cooler Approach) of the LP/HP Heater systems from their design values. 12 Marks

Consider the following criteria:

- For every 0.56°C increase or decrease in TTD from the design value, the Heat Rate will increase or decrease by 0.014%.
- For every 0.56°C increase or decrease in DCA from the design value, the Heat Rate will increase or decrease by 0.005%.

N-4 (A) Ans **Turbine Heat Rate:**

$$\text{Turbine: HR: } \{(1561000 \times (806.47-246)) + (1413000 \times (844.27 - 730.714))\} / (501700) \\ = 2063.72 \text{ kCal/kWh}$$

Unit Heat Rate:

$$= 2063.72 / 88\% \\ = 2345.131 \text{ kCal/kWh}$$

From the Above data, the following heater data can be inferred

Heater Ref.	Feed water Inlet Temp °C	Feed water Inlet Temp °C	Steam Inlet temp °C	Inlet steam Saturation Temp °C	Drain temp °C
LP Heater -1	47.2	63.6	92.5	93.07	64.2
LP Heater-2	63.6	105	140	111.23	70.4
LP Heater -3	105	130	209	132.9	110
HP heater-5	170	210	416	207.33	171
HP Heater -6	210	255	335	254.94	212

So

TTD (Terminal Temperature Difference) = Inlet Steam Saturation Temp °C – Feed Outlet Temp °C

DCA (Drain Cooler Approach) = Drain temperature °C – Feed Water Inlet Temperature °C

Heater Ref.	TTD °C (Design)	DCA °C (Design)	TTD °C (Calculated)	DCA °C (Calculated)
LP Heater -1	2.88	4.8	29.47	17
LP Heater-2	2.95	4.95	6.23	6.8
LP Heater -3	2.95	4.95	2.9	5
HP heater-5	0	5	-2.67	1
HP Heater -6	0.1	5	-0.06	2

Difference Between design values and Operating values of TTD and DCA of Heaters.

Heater Ref.	$TTD_{Operating} - TTD_{Design}$	$DCA_{Operating} - DCA_{Design}$
LP Heater -1	26.59	12.2
LP Heater-2	3.28	1.85
LP Heater -3	-0.05	0.05
HP heater-5	-2.67	-4
HP Heater -6	-0.16	-3
Total Difference	26.66	7.1

Change in Heat rate because of deviation in TTD =

(Net Change in TTD for All heaters X 0.014%/0.56°C)

Since given, for every 0.56°C change in TTD HR will increase by 0.014%

So Increase in HR because of TTD deviation= 26.66°C X 0.014 / 0.56 = 0.67475 %

Change in Heat rate because of deviation in DCA =

(Net Change in DCA for All heaters X 0.005%/0.56°C)

Since given, for every 0.56°C change in TTD HR will increase by 0.005%

So Increase in HR because of DCA deviation

$$7.1 \times 0.005 / 0.56 = 0.064 \%$$

Total % Increase in Turbine HR because of deviation in operation of TTD and DCA of Heaters from Design Values

$$= 0.7381 \%$$

$$= 0.7381 \times 2063.72 = 15.23 \text{ kCal/kWh}$$

Or

N-4 (B) A DRI-route steel plant operates a DRI unit and a Steel Melting Shop (SMS). The plant also has a coal-based captive power plant (CPP). Any shortfall in electrical energy is met by imported grid power. On average, the plant imports 1,20,000 kWh/day and the operational parameters are given below:

Description	Parameter	Value
DRI Unit	Rated capacity	500 TPD
	Capacity utilization	70%
	Specific coal consumption	1.25 t coal / t sponge iron
	Specific power consumption	95 kWh / t sponge iron
SMS	Coal GCV	5000 kcal/kg
	Yield	87%
CPP	Specific power consumption	830 kWh / t liquid steel
	Gross efficiency	27%
	Auxiliary power consumption	8% of gross generation
Grid	Coal GCV	5000 kcal/kg
	Grid electricity heat rate	2700 kCal/ kWh

Calculate the following:

- The daily production of sponge iron and liquid steel in TPD. (2 marks)
- DRI coal consumption in TPD and its thermal input in Million kcal/day. (2marks)
- Total daily electrical energy demand of DRI and SMS in kWh/day. (3 marks)
- The CPP gross generation in kWh/day, CPP heat rate in kCal/kWh, CPP thermal input in Million kcal/day and the CPP coal consumption in TPD. (6 marks)
- The overall specific energy consumption (SEC) in Million kcal per tonne of liquid steel. (4 marks)
- Compare your SEC with a benchmark of 6.5 Million kcal/t of liquid steel, and comment briefly on performance. (3 marks)

N-4 (B) 1) Daily Production

$$\text{Sponge iron} = 500 \times 70\% = 350 \text{ TPD}$$

$$\text{Liquid steel} = 350 \times 0.87 = 304.5 \text{ TPD}$$

2) DRI Coal & Heat Input

$$\text{Coal} = 1.25 \times 350 = 437.5 \text{ TPD}$$

$$\text{Thermal input} = 437.5 \times 5,000 \times 1000 = 2,187.5 \text{ Million kcal/day}$$

3) Electrical Demand

$$\text{DRI} = 95 \times 350 = 33,250 \text{ kWh/day}$$

$$\text{SMS} = 830 \times 304.5 = 252,735 \text{ kWh/day}$$

$$\text{Total} = 285,985 \text{ kWh/day}$$

4) CPP Generation & Coal

$$\text{CPP net} = 285,985 - 120,000 = 165,985 \text{ kWh/day}$$

$$\text{CPP gross} = 165,985 / 0.92 = 180,418.5 \text{ kWh/day}$$

$$\text{Heat rate} = 860 / 0.27 = 3,185.2 \text{ kcal/kWh}$$

$$\text{Thermal input} = 180,418.5 \times 3,185.2 = 574.67 \text{ Million kcal/day}$$

$$\text{CPP coal} = 574.67 \times 10^6 / 5000 = 114.93 \text{ TPD}$$

5) Overall SEC

$$\text{Total heat input} = \text{Thermal input to DRI} + \text{Thermal input to CPP} + \text{Thermal Input of Import}$$

$$\text{Imported electricity thermal eq.} = 120,000 \times 2700 = 324.0 \text{ Million kcal/day}$$

$$\text{Total heat input} = 2,187.5 + 574.67 + 324.0 = 3,086.17 \text{ Million kcal/day}$$

$$\text{SEC} = 3,086.17 / 304.5 = 10.14 \text{ Million kcal/t}$$

6) Benchmark Comparison & Comment

Benchmark = 6.5 Million kcal/t;
 Actual = 10.14 Million kcal/t (~56% higher)
 Comments:
 Need reduction in DRI coal use,
 improved SMS SPC,
 better CPP efficiency,
 adoption of WHR, and auxiliary load reduction.

Or

N-4 (C) A composite textile mill uses stenters for drying and heat-setting applications, currently the stenter system is running on a coal-fired boiler, and there is a proposal to modify the system to a biomass-fired thermic fluid heater. The relevant data is given below:

Parameter	Value
Cloth inlet temperature	32 °C
Cloth outlet temperature	78 °C
Cloth inlet moisture	65 %
Cloth outlet moisture	6 %
Stenter output	1250 kg/hr
Stenter Efficiency	48%
Latent heat of inlet steam to stenter at 10 bar	477 kcal/kg
Sensible heat of inlet steam to stenter at 10 bar	184 kcal/kg
Dryness fraction of inlet steam	0.95
Condensate temperature	87 °C
Boiler efficiency (coal-fired)	72 %
Distribution line losses – Boiler	5 %
Cost of coal	Rs. 7000/ton
GCV of Coal	4200 kCal/kg
Operating hours per annum	7200 hours
Thermic fluid heater efficiency	70 %
Distribution line losses – Thermic Fluid Heater	7 %
Biomass cost	Rs. 4000/ton
GCV of Biomass	3800 kCal/kg

Calculate the following:

- Steam and coal required for the current coal-fired boiler. 8 Marks
- If the system is converted to a biomass-fired thermic fluid heater, calculate the biomass required and its associated cost per hour. 8 Marks
- Estimate the difference in annual fuel cost savings. 4 Marks

N-4 (C) a) Steam and Coal Required for the Coal-Fired Boiler

Dry cloth mass:

$$m_{dry} = 1,250 \times (1 - 0.06) = 1,175 \text{ kg/h}$$

Wet inlet mass and moisture evaporated:

$$m_{inlet} = 1,175 / 0.35 = 3,357 \text{ kg/h}$$

$$\text{Moisture evaporated} = 3,357 - 1,250 = 2,107 \text{ kg/h}$$

Heat required to evaporate moisture:

$$\begin{aligned} Q_{evap} &= 2,107 \times [540 + (78-32)] \\ &= 2,107 \times 586 = 12,34,702 \text{ kcal/h} \end{aligned}$$

Heat input to stenter (48% efficiency):

$$Q_{stenter} = 12,34,702 / 0.48 = 25,72,296 \text{ kcal/h}$$

Steam required:

$$h_{steam} = 0.95 \times 477 + 184 = 637.15 \text{ kcal/kg}$$

$$\text{Also condensate leaves at } 87^\circ\text{C} = 87 \text{ kCal/kg}$$

$$\text{Required Steam} = 2,567,490 / (637.15-87) = 4675 \text{ kg/h}$$

Boiler output required (5% distribution loss):
 $Q_{boiler_out} = 25,72,296 / 0.95 = 27,07,680 \text{ kcal/h}$

Boiler heat input (72% efficiency):
 $Q_{boiler_in} = 27,07,680 / 0.72 = 37,60,666 \text{ kcal/h}$

Coal required:
 $\text{Coal} = 37,60,666 / 4,200 = 895.4 \text{ kg/h} = 0.895 \text{ t/h}$

Coal cost per hour:
 $\text{Cost} = 0.895 \times 7,000 = \text{Rs. } 6265 \text{ Rs/hr}$

b) Biomass Required & Cost per Hour – Thermic Fluid Heater (7% Loss)

Heater output required (7% distribution loss):
 $Q_{heater_out} = 25,72,296 / 0.93 = 2,765,909.677419355 \text{ kcal/h}$

TFH thermal input (70% efficiency):
 $Q_{TFH_in} = 2,765,909.677419355 / 0.70 = 3,951,299.539170507 \text{ kcal/h}$

Biomass required:
 $\text{Biomass} = 3,951,299.539170507 / 3,800 \approx 1,039.289352409603 \text{ kg/h} = 1.039 \text{ t/h}$

Biomass cost per hour:
 $\text{Cost} = 1.039 \times 4,000 = \text{Rs. } 4157 \text{ Rs/hr}$

c) Annual Fuel Cost Savings

Hourly Fuel Saving:
 $\text{Saving} = 6265 - 4157 = \text{Rs. } 2108 \text{ Rs/hr}$

Annual Saving (7,200 h/year):

$\text{Annual Saving} = 2108 \times 7,200 = \text{Rs. } 1,51,77,600 \approx \text{Rs. } 1.51 \text{ crore/year}$

Or

N-4 (D) A 10,000 TPD cement plant purchases power from the grid, operates an 18 MW Captive Power Plant (CPP) and also has a Waste Heat Recovery (WHR) system with a 9 MW turbine. Electricity is used for cement production and also supplied to the colony and other utilities. The plant also exports excess energy to the grid. The annual energy and production data are given below:

Parameter	Value
Annual operating hours	8,300 hrs
Energy imported	60,210,000 kWh
Energy exported	3,150,000 kWh
Energy supplied to colony & others	3,500,000 kWh
CPP average generation	18 MW
CPP heat rate	3100 kcal/kWh
WHR turbine average generation	9 MW
WHR turbine heat rate	3600 kcal/kWh
Indian coal consumption	96,000 MT (GCV 4500 kcal/kg)
Pet coke consumption	80,000 MT (GCV 7500 kcal/kg)
Imported coal consumption	198,000 MT (GCV 7200 kcal/kg)
Biomass consumption	10,000 MT (GCV 2850 kcal/kg)
Clinker produced	2,700,000 MT
Clinker-to-cement ratio	1.375

Calculate the following:

- Specific Electrical Energy Consumption (SEEC) in kWh/ton of cement. (8 Marks)
- Estimate the Specific Thermal Energy Consumption (STEC) in kcal/kg of clinker (7 Marks)
- If the CPP is operated using only Indian coal and Imported coal, calculate the coal blending ratio by weight required to achieve a blended coal GCV of 6000 kcal/kg. (5 Marks)

N-4 (D) Solution
Specific Electrical Energy Consumption (SEEC) – 8 Marks
 Energy Input

Sol	<p>CPP generation = $18 \times 8300 \times 1000 = 149,400,000$ kWh WHR generation = $9 \times 8300 \times 1000 = 74,700,000$ kWh Grid import = 60,210,000 kWh Total Input = 284,310,000 kWh Deductions Export to grid = 3,150,000 kWh Colony & others = 3,500,000 kWh Net for cement production = $284,310,000 - 3,150,000 - 3,500,000 = 277,660,000$ kWh Cement Production Clinker produced = 2,700,000 MT Cement produced = $2,700,000 \times 1.375 = 3,712,500$ MT SEEC SEEC = $277,660,000 \div 3,712,500 = 74.7$ kWh/ton cement Specific Thermal Energy Consumption (STEC) - 7 Marks Fuel Heat Input Indian coal = $96,000 \times 4500 = 432 \times 10^9$ kcal Pet coke = $80,000 \times 7500 = 600 \times 10^9$ kcal Imported coal = $198,000 \times 7200 = 1425.6 \times 10^9$ kcal Biomass = $10,000 \times 2850 = 28.5 \times 10^9$ kcal Total Heat Input = 2486.1×10^9 kcal Heat to Kiln As per PAT convention (no CPP deduction applied) Heat to kiln = 2486.1×10^9 kcal STEC Clinker produced = 2,700,000 MT = 2,700,000,000 kg STEC = $2486.1 \times 10^9 \div 2,700,000,000 = 920.04$ kcal/kg clinker Coal Blending Ratio Define ratio Let x = fraction of Indian coal, (1-x) = fraction of Imported coal Equation $6000 = 4500x + 7200(1-x)$ $6000 = 4500x + 7200 - 7200x$ $6000 = 7200 - 2700x$ $2700x = 1200$ $x = 0.444$ (44.4%) Ratio Indian coal = 44.4%, Imported coal = 55.6% Coal Blending Ratio = 44 : 56 </p>
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..... End of Section - III