Paper 4 Code: Green

20th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS - September, 2019

PAPER – 4: ENERGY PERFORMANCE ASSESSMENT FOR EQUIPMENT AND UTILITY SYSTEMS

Section - I: BRIEF QUESTIONS **Marks: 10 x 1 = 10**

(i) Answer all **Ten** questions

(ii) Each question carries ONE mark

1.	Two pumps can be operated in parallel provided their closed valve heads are not the same.	**False**
2.	Installing a VFD and operating a screw compressor at 50 Hz will increase the power consumption.	**True**
3.	Building energy performance index (kWh/yr/m^2) will not include captive power used in the building.	**False**
4.	The COP and EER (w/w) in a refrigeration system will be numerically different.	**False**
5.	The gross heat rate of the power plant does not include auxiliary consumption.	**False**
6.	The unit of Specific humidity is kg moisture / kg dry air.	**True**
7.	In a water Lithium bromide refrigeration system, the concentration of the lithium bromide is increased, in the evaporator.	**False**
8.	For the same no of poles and kW rating, the rpm of an energy efficient motor is higher that of a standard motor.	**True**
9.	The atmospheric pressure of 1 kg/cm^2 (a) is 76 mm of mercury column.	**False**
10	The capacity of diesel generator designed for sea level condition decreases at high altitude.	**True**

…………. End of Section – I ………….

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

(120) Answer all the **Two** questions

(ii) Each question carries FIVE marks

L1	A highly viscous oil which requires rapid initial heating, with a flow rate of 22 tonnes/hr, has to be heated in a shell and tube heat exchanger, from 55 ^{O}C to 155 ^{O}C, using saturated steam at 175 ^{O}C. The specific heat of oil is 0.5 kcal/kg ^{O}C. Only latent heat of steam at 485 kcal/kg is used for heating. 1. What type of heat exchanger is recommended? **(1 Mark)** 2. Draw a schematic of fluid flows with directions and temperatures. **(2 Marks)** **3.** Find the LMTD for this application and also the steam requirement. **(2 Marks)**

Ans :

1. Parallel flow Heat Exchanger

   The appropriate choice is parallel flow heat exchanger, mainly to cater for providing rapid initial heating of the viscous fluid.

2. Schematic Diagram

Schematic of Parallel flow Heat Exchanger

3. **LMTD and Steam Requirement:**

ΔT_1 at feed end = 175 – 55
= 120 °C

ΔT_2 at discharge end = 175 – 155
= 20 °C

$$\text{LMTD (parallel)} = \frac{\Delta T_1 - \Delta T_2}{L_n\, \Delta T_1 / \Delta T_2}$$

$$\text{LMTD (parallel)} = \frac{120 - 20}{L_n\, 120 / 20} = \mathbf{55.81\ ^oC}$$

Steam requirement = (22000 x 0.5 x (155 – 55)) / 485
= **2268.04 kg/hr**

L2

A food processing industry has been importing 3 tonnes/hr of steam, at 8 kg/cm^2(g), with an enthalpy of 661 kcal/kg, at a price of Rs 3,300 per tonne, from a neighboring industry. The steam metering is done at the point of delivery. However, the seller is demanding for higher price, as the steam has to be transported over a distance of 1 km, through a 100 mm (internal diameter) pipe line, from the boiler house.

- The thickness of the pipe is 4 mm and it is insulated with 50 mm of insulation.
- The measured outside surface temperature of insulation is 45 °C, whereas the ambient temperature is 30 °C.

Estimate the following:

1. Heat loss in piping distribution in 'kg equivalent of steam /tonne of steam'. **(2.5 Marks)**
2. Final price of steam per tonne after accounting for distribution losses. **(2.5 Marks)**

Ans :

Outer dia. Of insulated pipe = (100+4+4+50+50)
= 208 mm
= 0.208 m

Surface area of the 1 km pipe = πDL
= 3.14 x 0.208 x 1000
= 653.12 m^2

Surface heat loss per unit area = [10+ (Ts – Ta)/20] x (Ts–Ta) kcal/m^2.hr

Total heat loss = [10+ (45–30)/20] x (45–30) x 653.12
= 1,05,315.6 kcal/hr

	Equivalent steam loss (for surface heat loss in the piping distribution), occurring while transporting 3 tonnes/hr of steam = (1,05,315.6) / (661) **= 159.327 kg steam/hr** Equivalent steam loss in **kg of steam per tonne of steam** = (159.327 / 3) **= 53.109 kg/tonne steam** Additional price to compensate for heat losses per tonne of steam = (53.109 x (3300/1000)) **= Rs 175.26/ tonne steam** **Final price of steam** = (Rs.3300+ Rs.175.26)/ tonne **= Rs. 3475.26/ tonne steam**

………. 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

N1	Pressurized hot water circulation system is employed for heating in a process industry. Hot water at 140 °C is supplied to a process, through a steel piping of 100 mm internal diameter and equivalent length of 2000 meters by an oil-fired hot water boiler of 6,00,000 kcal/hr output capacity. After each weekend holiday, at the beginning of the first shift during startup, while raising the water temperature from 50 °C to 140 °C, the entire piping system carrying water also gets heated from 50 °C to 140 °C. 1. Find out the start-up heating time if the boiler operates at 90% capacity, during this period. **(12 Marks)** 2. Also, find out the % reduction in start-up heating load and fuel savings, with each start up, if the initial temperature at the start up is increased to 65 °C due to improved housekeeping and insulation. **(8 Marks)** **Make use of the following data and information:** Efficiency of the hot water boiler = 80% GCV of fuel oil = 10,000 kcal/kg Specific heat of water = 1 kcal/kg °C Density of water = 1000 kg/m^3 Specific heat of steel = 0.12 kcal/kg °C Density of steel = 8000 kg./m^3 Outer diameter of the pipe = 108 mm *Ignore the heat loss from the surface of the insulated pipe during start up, in the calculations.*
	Ans : **1. To Find Start-up Heating Time:** Outer diameter of pipe = 108 mm **= 0.108 m** Inner diameter = 100 mm **= 0.1 m** Equivalent length of pipe network = 2 km **= 2000 m** Hold up volume of water = $\pi/4 \times (0.1)^2 \times 2000$ **= 15.7 m^3** Mass of water = (15.7 X 1000) **= 15,700 Kg** Volume of steel pipe = $\pi/4 \times [(0.108)^2 - (0.1)^2] \times 2000$ **= 2.612 m^3** Mass of steel pipe = 2.612 X 8000 **= 20,896 Kg** Startup heating load = Heat required to heat water and steel from 50 °C to 140 °C

= (Mass x Specific heat x Temperature difference)
= [15700 x 1 x (140 – 50)] + [20896 x 0.12 x (140 – 50)]
= [14,13,000 + 2,25,677]
= 16,38,677 kcals

Time taken for start-up heating = 16,38,677 / (600000 x 0.90)
= **3.035 hrs**

2.

Temperature differential for heating in the existing case = 140 – 50
= 90^oC

Temp. differential when Initial temp is increased to 65^oC = 140 – 65
= 75^oC

% reduction in start-up heating load = ((90 – 75) x 100)/ (90)
= **16.67%**

Savings in fuel due for each start up = (0.1111 X 1638677) / (10000 X 0.8)
= **34.14 kg per start up**

(or)

Startup heating Load = *Heat required to heat water and steel from 65^oC to 140^oC*
= (mass x Specific heat x temp. difference)
= *[15700 x 1 x (140 – 65)] + [20896 x 0.12 x (140 – 65)]*
= *[11,77,500 + 1,88,064]*
= *13,65,564 kcal*

% reduction in start-up heating load = *((**16,38,677** – 13,65,564) x 100)/ (**16,38,677**)*
= ***16.67%***

Savings in fuel due for each start up = *(**16,38,677** – 14,56,602) / (10000 X 0.8)*
= ***34.14 kg per start up***

N2

The management of a process industry is planning to switch over from the existing 300 TR directly-gas-fired double effect absorption water chiller to a 300 TR centrifugal water chiller, as a cost saving measure.

The double effect absorption chiller is rejecting its heat in to a cooling tower. The proposed centrifugal chiller will be rejecting its heat to the same cooling tower.

The management is also planning to connect the heat load of a water-cooled process heat exchanger to the same cooling tower. The cooling water entering the heat exchanger will cool the hot oil from 110 ^oC to 50 ^oC. The hot oil flow rate in the heat exchanger is 18,000 kg/hr.

Make use of the following data:

C.O.P. of double effect absorption chiller	=	1.2
Electrical energy input to centrifugal chiller motor	=	0.8 kW/TR
GCV of Natural Gas	=	9450 kcal/m^3
Cost of Gas	=	Rs.27/m^3
Efficiency of gas firing	=	80%
Electrical energy cost	=	Rs.8.5 / kWh
Specific heat of oil to be cooled by water	=	0.5 kcal/kg ^oC
Motor efficiency	=	87.5 %
Annual operating hours	=	7200 hrs.

***Find out the following* -:**

a) The yearly monetary savings in operating centrifugal chiller in place of the double effect absorption chiller. **(8 Marks)**
b) C.O.P. of the centrifugal chiller. **(2 Marks)**
c) Whether the capacity of the cooling tower is sufficient to take the additional heat load of the process heat exchanger, in addition to that of centrifugal chiller. **(10 Marks)**

Ans :

C.O.P. of double effect chiller	=	1.2

	1TR (Ton refrigeration)	=	3024 kcal/hr
	Heat input to double effect chiller (Generator)	=	(3024/1.2) kcal/hr
		=	**2520 kcal/hr**
	Overall heat input considering gas firing efficiency	=	(2520 kcal/hr / 0.80 Effy of gas firing)
		=	**3150 kcal/hr**
	Operating cost of double effect chiller	=	((3150 x 27) / 9450)
		=	**Rs.9 /TR**
	Electrical input power in centrifugal chiller	=	0.8 KW/TR
	Operating cost of centrifugal chiller	=	(0.8 X 8.5)
		=	**Rs.6.8 / TR**
	Saving in cost	=	Rs.9.0 – Rs.6.8
		=	**Rs.2.2 / TR**
	Yearly monitory saving	=	(2.2 x 300 x 7200)
		=	Rs.47,52,000/-
		=	**Rs.47.52 Lakhs**
	Heat rejection load from double effect chiller for 1 TR	=	(Chilling load at evaporator + Heat input to generator)
		=	(3024 kcal/hr + 2520 kcal/hr)
		=	**5544 kcal/hr**
	C.O.P. of centrifugal chiller (1 TR)	=	(3024) / (0.8 x 0.875 x 860)
		=	**5.02**
	Heat rejection load for 300 TR double effect chiller	=	(5544 X 300)
		=	**16,63,200 kcal/hr**
	Capacity of the cooling tower should be	=	16,63,200 kcal/hr.
	Heat rejection load to cooling tower in the case of of 300 TR Elec'l Centrifugal chiller power for 1 TR = (Electrical Input x Motor eff.)		
		=	(0.8 kW/TR X 0.875)
		=	**0.7 kW / TR**
	In case of centrifugal chiller, heat rejection / TR	=	((3024) + (0.7 x 860))
		=	**3626 kcal/TR**
	Heat rejection load of 300 TR centrifugal chiller	=	(3626 x 300)
		=	**10,87,800 kcal/hr**
	Heat load on the cooling tower due to		
	process heat exchanger oil cooling	=	18,000 X 0.5 X (110 – 50)
		=	**5,40,000 kcal/hr**
	Total heat rejection load on the cooling tower	=	10,87,800 + 5,40,000
		=	**16,27,800 kcal/hr**
	Cooling tower capacity is adequate to take the heat load of process heat exchanger in addition to heat rejection load of the centrifugal chiller		
N3	The operating details and particulars of a natural gas-fired, smoke tube boiler, are given below :		

Steam flow	=	8 tonnes/hr steam
Steam Pressure	=	10 kg/cm^{2}g.
Feed water temperature	=	80 ^{o}C.
% O_2 in dry flue gas	=	4%
Exit flue gas temperature	=	215 ^{o}C.
G.C.V. of natural gas	=	13,500 kcal/kg
Density of natural gas	=	0.7 kg/m^3
Cost of natural gas	=	Rs 27/m^3
Enthalpy of steam at 10.0 Kg./.cm^2.(g)	=	666 kcal/kg.
Inlet feed water temperature	=	80 ^{o}C
Loss due to Hydrogen	=	9.92%
Radiation losses in the N.G. boiler	=	1.52%
Specific heat of flue gases	=	0.29 kcal/kg ^{o}C
Ambient temperature	=	30 ^{o}C
Density of air	=	1.125 kg/m^3
Daily hours of operation	=	24 hours
Yearly operation	=	320 days

Composition of natural gas (per kg)

Carbon = 0.74 kg /kg Hydrogen = 0.22 kg /kg
Nitrogen = 0.03 kg /kg Oxygen = 0.01 kg /kg
Ignore Sulphur & Moisture

Find out the following

a. Steam to fuel ratio, in the existing case, in kg/kg **(8 Marks)**
b. Total combustion air required in m^3/min **(4 Marks)**
c. % improvement in the steam to fuel ratio, when the feed water temperature is raised to 95°C due to improved condensate recovery **(2 Marks)**
d. Savings in gas consumption in m^3/hr **(4 Marks)**
e. Yearly monetary savings **(2 Marks)**

Ans :

Theoretical air required = 11.6 C + [34.8 (H_2 – O_2/8)] + 4.35 S] kg air / kg gas
= 11.6 x 0.74 + [34.8 (0.22 – 0.01/8)]
= 16.2 kg air / kg gas

Excess Air, % = (% O_2) / (21 – % O_2) x 100
= (4) / (21 – 4) x 100
= 23.5%

Actual Air Supplied (AAS) = (1+0.235) x 16.2
= 20.0 kg air / kg gas

Mass of dry flue gas (m_{dfg}) = (Mass of combustion gases due to presence C,N,S) + (Mass of N_2 in the fuel) + (Mass of N_2 in air supplied) + (Mass of excess O_2 in flue gas)

= (0.74*44/12) + 0.03 + (20*0.77) + (20–16.2) x 0.23

= **19.02 kg** (dfg)/ kg gas

L1 = % heat loss due to dry flue gases

$$= \frac{M_{dfg} \times C_p \times (T_q - T_a)}{\text{G.C.V. of fuel}} \times 100$$

$$= \frac{\mathbf{19.02} \times 0.29 \times (215 - 30)}{13500} \times 100$$

= **7.56%**

L2 = **9.92%** (Given)

Radiation losses L3 = **1.52%** (Given)

∴ Efficiency of natural gas boiler on G.C.V. = 100 – [7.56 + 9.92 + 1.52]

= 81%

Steam to fuel ratio = (0.81 x 13500) / (666 – 80)
= 18.7

Amount of gas required for steam load of 8000 kg/hr = (8000 / 18.7)
= 427.81 kg/hr

Total Combustion air required = 427.81 x 20
= 8556.2 *kg/hr*
= 8556.2 /(1.125x60) m^3/min
= **126.76 m^3/min**

Steam to fuel ratio with feed water temp of 95°C = (0.81 x 13500) / (666 – 95)

	=	**19.15 kg/kg**
% Improvement in steam to fuel ratio	=	((19.15 -18.7) x 100) / (18.7)
	=	**2.41 %**
Gas consumption with feed water temp at 95^{O}C	=	8000 / 19.15
	=	417.75 kg/hr
Gas savings due to increase in feed water temp	=	427.81 – 417.75
	=	**10.06 kg/hr**
	=	10.06/ 0.7
	=	**14.4 m^3/hr**
Yearly monetary savings	=	14.4 x 24 x 320 x 27
	=	Rs.29,85,984
	=	**Rs. 29.86 lakhs**

N4 **Answer any ONE of the following**

A

In a particular biomass power plant, 33.6 TPH of steam at 63 kg/cm^{2}g, 450 ^{O}C is expanding to 0.1 kg/cm^2(a), and temperature of 45 ^{O}C. The boiler and the turbine are designed for superheat temperature of 475 ^{0}C.

The following data has been given.

Enthalpy of steam at turbine inlet with 450 ^{O}C	=	787.9 kcal/kg
Actual enthalpy at turbine outlet at 0.1kg/cm^2(a)	=	564.78 kcal/kg
Combined efficiency of gearbox and generator	=	92%
Enthalpy of steam at turbine inlet with temp of 475 ^{O}C	=	802.4 kcal/kg
Enthalpy at turbine outlet under isentropic condition (with 475 ^{O}C at inlet, exhaust pressure, 0.1 kg/cm^2(a)	=	511.77 kcal/kg
Isentropic efficiency of the turbine with turbine inlet at 475 ^{0}C	=	79%
Biomass Boiler Efficiency	=	72%
Calorific value of biomass fuel	=	3450 kcal/kg
Cost of biomass fuel	=	Rs 3.5 /kg
Electricity price for power sold	=	Rs 7/ kWh
Yearly hours of operation	=	8000 hrs.
Auxiliary consumption	=	Remains Same

Calculate the following: **(Each 4 Marks)**

a) Power generated in kW with turbine inlet temperature of 450 ^{O}C.
b) Steam rate in kg/kWh with improved turbine inlet temperature of 475 ^{O}C.
c) Additional power generated in kW with improved turbine inlet temperature of 475 ^{O}C, assuming steam flow rate remains the same.
d) Increase in fuel consumption kg/hr with improved turbine inlet temperature of 475 ^{O}C, assuming steam flow rate remains the same.
e) Yearly benefit by operating the turbine at inlet temperature of 475 ^{O}C.

A – Ans

Ans:

a) Power generated in kW with turbine inlet temperature of 450 ^{O}

Turbine power output with inlet temp 450^{O}C = m ($h_1 - h_2$)/ (860) x Comb eff (η_{gg}).

Where;
m = 33,600 kg/hr;
h_1 = 787.9 kcal/kg;
h_2 = 564.78 kcal/kg

Power output	=	(33600 (787.9 - 564.78) x (0.92))/ (860)
	=	8019.86
	=	**say 8020 kW**

b) Steam rate in kg/kWh with improved turbine inlet temperature of 475 ^{o}C

Steam rate with improved turbine inlet temperature of 475^{O}C = 860 / [($h_1 - h_{2s}$) x η_s x η_{gg}]
where

η_s = isentropic turbine efficiency	=	79% = 0.79
η_{gg} = combined gear box and generator efficiency	=	92% = 0.92

Steam rate at inlet of 475 ^{O}C = 860 / [(802.4- 511.77) x 0.79 x 0.92)]

	= 4.071 kg/kWh **(Or)** **Steam rate with improved turbine inlet temperature of 475^{O}C**: Turbine isentropic efficiency, 79% = (Actual enthalpy drop / Isentropic enthalpy drop) x 100 0.79 = (802.4 – H_2) / (802.4 – 511.77) Actual enthalpy at the turbine exhaust, H_2 = 572.8 kcal/kg Power generated in kW with turbine inlet temperature of 475 ^{O}C = (33600 x (802.4 – 572.8) x (0.92))/ (860) = 8252.8 = **say 8253 kW** Steam rate with improved turbine inlet temperature of 475^{O}C = 33600/8253 = 4.071 kg/kWh **c) Additional power generated in kW with improved turbine inlet temperature of 475 ^{O}C, assuming steam flow rate remains the same** Power output with inlet temp of 475^{O}C = 33600 /4.071 = 8253.5 kW **= Say 8254 kW** Additional power generated = 8254 – 8020 = **234 kW** Additional revenue through power sold = 234 x 7 **= Rs.1638/hr** **d) Increase in fuel consumption kg/hr with improved turbine inlet temperature of 475 ^{O}C, assuming steam flow rate remains the same** Increase in fuel consumption = 33600 (802.4 – 787.9)/(0.72 x 3450) = **196.135 kg/hr** **e) Yearly benefit by operating the turbine at inlet temperature of 475 ^{O}C** Increase in fuel cost = 196.135 x 3.5 = Rs 686.47/hr Yearly benefit, net increase in revenue = (1638 – 686.47) x 8000 = Rs. 76,12,240 /- (or) **= Rs 76.12 lakhs**
	OR
B	A Multispecialty hospital has conducted energy audit of all their utilities. In the existing system, an electrical chiller is operated and the operating cost is Rs. 11.25 / TR. Steam from the boiler, is used for hot water generation by indirect heating. Latent heat of steam is 500 kcal/kg and steam cost is Rs 2.85 / kg. **Other data's for existing system:** Electrical Load of the Hospital : 625 kW Cost of Grid Electricity : Rs 9.25 / kWh The audit has proposed to install trigeneration system with a gas engine of 700 kW. The gas engine is operating at 28 % efficiency. Chilled water will be produced through a single effect Vapour Absorption Chiller Machine (VAM) in the trigeneration system, using the entire heat rejected to the jacket cooling water. Hot water requirement will be met using heat recovered from the engine exhaust. **The data pertaining to tri-generation system is given below:**

Cost of Gas = Rs 45/ sm^3
GCV of Gas = 9000 kcal/sm^3
Heat Rejected by the engine to the Jacket cooling water = 29% of the engine heat input
COP of VAM = 1.65
Heat utilized from engine exhaust for hot water generation for hospital purpose = 20% of total engine exhaust heat
Temperature of inlet water for hot water system = 30^o C
Temperature of outlet water from hot water system = 60^o C

Calculate the following:

1. Hourly Gas Consumption in sm^3/hr **(2 Marks)**
2. TR delivered by VAM **(6 Marks)**
3. Quantity of hot water generated from exhaust heat for hospital purpose in kg/hr **(4 Marks)**
4. Annual cost savings in Rs. lakhs/yr on account of Trigeneration system, for 8000 hours of operation. **(8 Marks)**

Ans:

1. **Hourly Gas Consumption**

Power Generation = 625 kW

Gas Engine Efficiency = 28 %

Heat rate = 860 / 0.28

= 3071.43 kcal/ kWh

Hourly Gas Consumption = (625 x 3071.43) / 9000

= 213.29 sm^3/hr

2. TR delivered by VAM

Input heat = 213.29 sm^3/hr x 9000 kcal/sm^3

= 1919610 kcal/hr

Heat used for power generation = 1919610 x 0.28

= 537491 kcal/hour

Balance heat available after power generation = 1919610 - 537491

= 1382119 kcal/hr

Heat Utilized for VAM through jacket cooling water = 1919610 kcal/hr x 0.29

= 556687 kcal/hr

COP of VAM = 1.65

COP,1.65 = *(TR X 3024 kcal/hr) / (Input Heat, 556695 kcal/hr)*

TR delivered by VAM = (1.65 x 556687) / 3024

= 303.8 TR

3. Quantity of hot water generated from exhaust heat for hospital purpose in kg/hr

Heat available for hot water generation = 1919610 x ((100 – 29 – 28) /100)

= 825432 kcal/hr

(Or) Engine Exhaust Heat

= Heat Input – Heat output for power – Heat for VAM thro' jacket cooling water

= 1919610 – 537491 – 556687 = 825432 kcal/hr

20 % of the heat in the exhaust is used for hot water generation from 30°C to 60 °C for hospital purpose = 825432 x 0.20 kcal/hr

= 165086.4 kcal/hr

Equivalent Qty of hot water generated from 30°C to 60 °C for hospital purpose = 165086.4 kcal/hr / (60 -30)

= 5503 kg/hr

4. Annual cost savings due to Tri-generation for 7500 hours of operation.

Cost of Existing System:

Cost of grid power per hour = (625 kW x 9.25 Rs./kWh)

= Rs. 5781.25 / hr

Cost of chiller operation per hour = (303.8 TR x 11.25 Rs/TR)

= Rs. 3417.75 / hr

Cost of hot water generation from boiler = [(5503 kg/hr x 1 x (60-30)) / (500 kcal/kg stm)]

= 330.18 kg steam/hr x 2.85 Rs./kg steam

= Rs 941 / hr

Total Operating cost of existing system = Rs (5781.25 + 3417.75 + 941) /hr

= Rs 10140 /hr

Cost of operation with tri-generation = Gas consumption x Cost of gas

= 213.29 sm^3/hr x Rs.45 / sm^3

= Rs. 9598.1 /hr

Hourly savings = (Existing Cost / hr – Trigeneration Cost / hr)

= Rs.10140 / hr - Rs. 9598.1 /hr

= Rs 541.9 / hr

Annual savings for 8000 hrs operation = Rs 541.9 / hr x 8000 hrs / yr

= Rs.43,35,200/yr

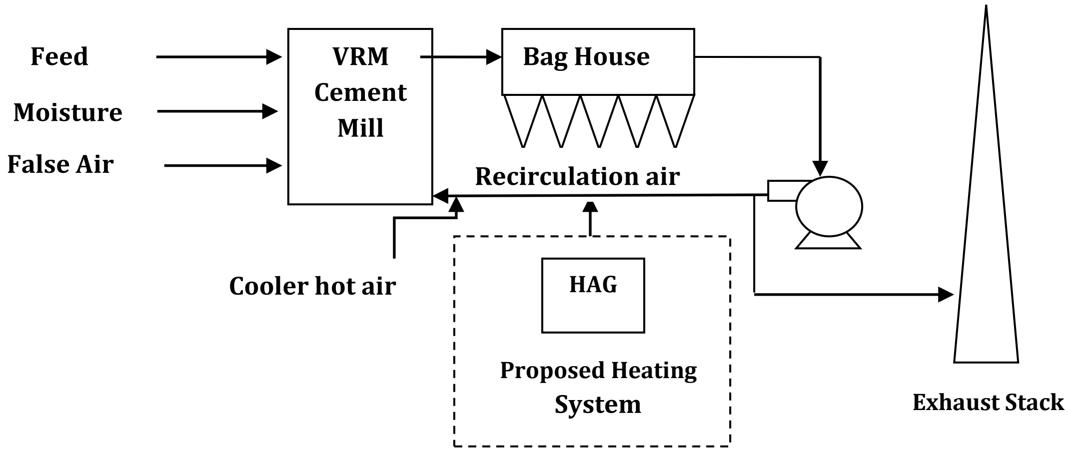
= Rs 43.35 lakhs /yr

C

An integrated cement plant is having vertical roller mill (VRM) of 200 TPH capacity for cement grinding, drawing hot air (Temperature: 380 °C and Sp.heat Cp : 0.246 kcal/kg °C) from clinker cooler exhaust. The operational data while grinding PPC, is as under :

Particulars	Unit	Value	Particulars	Unit	Value
VRM output (dry basis)	TPH	200	Mill exit temperature	°C	90
Average feed temperature	°C	52	Total gas mass flow rate of circuit at process fan inlet	kg/hr	487490
Avg. feed moisture	%	3	Stack exhaust gas mass flow rate	kg/hr	128124
Ambient temperature	°C	30	False air into the circuit (% of total fan flow)	%	15
VRM motor efficiency	%	95	Sp. heat (Cp) of material	kcal/kg °C	0.21
Mill water spray	TPH	3.5	Sp. heat of mill false air	kcal/kg °C	0.238
Coal NCV	kcal/kg	7000	Sp. heat of mill exit air	kcal/kg °C	0.239
Coal cost	Rs./MT	9000	VRM motor operating power	kW	4000
Latent heat of evaporation of water	kcal/kg	540			

A recent energy audit of the plant recommended to install Waste Heat Recovery System (WHRS) for power generation, that may be sold out at Rs. 5.0 per kWh and cement mill heat requirement can be fulfilled by installing a separate Hot Air Generator (HAG) with 90% thermal efficiency.



Schematic Diagram of Cement Mill (VRM) Circuit

Estimate the following:

a) Calculate the heat and mass balance of input and output components of the VRM (cement mill), considering radiation and convection heat loss to be negligible and also estimate the heat requirement (kcal/hr) of VRM. **(6 Marks)**
b) Determine the amount of hot air being drawn from the clinker cooler. **(4 Marks)**
c) The power generation potential in the cooler hot air, which is presently used for VRM (cement mill) heating, at 28% overall efficiency of WHRS. **(6 Marks)**
d) Hourly coal requirement in HAG. **(2 Marks)**
e) Hourly monetary saving of WHRS power generation using HAG, for cement mill heating. **(2 Marks)**

C-Ans

Water Balance:
Dry Feed = 200 TPH
Feed moisture = 3%
Wet Feed = 200 / (1 - 0.03) = 206.186 TPH
Moisture = (206.186 – 200) = 6.186 TPH
Total moisture (including water spray) = 6.186 + 3.5 = **9.686 TPH**
Air Balance:
False air = Total process fan mass flow rate x 15/100 = 487490 x 0.15 = **73123 kg/hr**

Recirculation air = Total mass flow rate at Process fan Inlet – Mass flow rate of exhaust from stack
Recirculation air = 487490 – 128124 = **359366 kg/hr**

S.No.	**Description**	**Calculation**	**Value** (kcal/hr)
1.	Sensible heat in dry feed (H_{fi})	H_{fi} = m_{fi} x Cp x ΔT = 200x1000x0.21x(52-30)	924000
2.	Sensible heat input in feed moisture (H_{wi})	H_{wi} = m_{wi} x Cpx ΔTa = 6186 x 1 x (52-30)	136092
	Sensible heat input in mill water spray	= 3500x 1 x (30-30)	0 kcal/hr
3.	Sensible heat in false air (H_{fa})	H_{fa} = m_{fa} x Cp x ΔT =73123.5 x 0.238 x (30-30)	0 kcal/hr
4.	Sensible heat in hot air (H_{ha})	H_{ha}= m_{ha} x Cp x ΔT	H_{ha} is unknown
5.	Sensible heat in recirculation air (H_{rec})	H_{rec}= m_{rec} x Cp x ΔT = 359366 x 0.239 x (90-30)	5153308.4
6.	Heat input equivalent of electrical energy (H_{Elect})	H_{Elect}= P x 860 x motor eff. = 4000 x 860 x 0.95	3268000
	Total Heat Input	H_{fi} + H_{wi} +H_{fa}+H_{ha}+ H_{rec}+ H_{Elect}	H_{ha}+9481400.4
Output Heat Components:			
1.	Sensible heat in product (cement) (H_{Prod})	H_{prod}= mp x Cp x ΔT = 200000 x 0.21 x (90-52)	1596000

2.	Sensible heat in mill exit gas (H_{EG})	H_{EG} = mg x Cp x ΔT = 487490x 0.239x (90-30)	6990606.6
3.	Heat of evaporation of moisture in feed (H_{Evep})	H_{Evp}= mw x [540+ΔT~~exit~~] = 6186 x [540+(90-52)]	3575508
	Heat of evaporation of Water (mill spray)	= 3500x1x[540+(90-30)]	2100000
Total Heat Output		= H_{prod} + H_{EG} + H_{Evp}	14262114.6
Heat supplied from clinker cooler air		(H_{ha}) = 14262114.6 – 9481400.4	4780714.2
VRM heat requirement		= H_{ha}+ 9481400.4 = 4780714.2 + 9481400.4	14262114.6
Amount of hot air drawn from cooler		m_{ha} = 4780714.2 /(0.246x (380-30))	55525 kg/hr
Power generation potential in cooler hot air		P = 4780714.2 x (0.28/860)	1556.5 kW
Hourly coal requirement in HAG		m_{coal} = 4780714.2 /(7000 x 0.9)	758.8 kg/hr
Revenue from WHR power (Rs. per hour)		R = 1556.5 x 5	Rs. 7782.5 per hour
Cost of coal consumption in HAG (Rs./hr)		= 758.8 x 9	Rs. 6829.2 per hour
Monetary Saving		S = 7782.5 – 6829.2	Rs. 953.3 per hour

OR

D

In a textile process house, a stenter is running at a speed of 75 meters/min where, the dried finished cloth is leaving at 6% moisture and 75 °C, whereas the wet cloth is entering at a temperature of 25 °C.

The hot air for drying in the stenter is heated by circulating thermic fluid, which in turn is heated in a dedicated furnace oil-fired thermic fluid heater, having an efficiency of 84%. The furnace oil consumption in the thermic fluid heater is 90 kg/hr.

The unit takes measures to reduce the inlet moisture. The inlet moisture is now found to be 55%, at the same temperature of 25 °C. The outlet conditions remain the same. The stenter operates 24 hours a day and 30 days a month. The other data is given below -:

Stenter dryer efficiency = 50%
G.C.V. of furnace oil = 10000 kcal/kg
Weight of 10 meters of dried cloth at the outlet = 1 kg

Find out :

a) Feed rate in kgs/hr **(12 Marks)**
b) Percentage reduction in stenter drying load with the change in inlet moisture. **(6 Marks)**
c) Furnace oil savings in Tonnes/month. **(2 Marks)**

D-Ans

Ans:

Feed rate in kgs/hr and percentage reduction in stenter drying load with the change in inlet moisture.

Moisture % at stenter inlet = % moisture (unknown)
Temperature at stenter inlet, T_{in} = 25 °C
Moisture % at stenter outlet = 6% moisture,
Temperature at stenter outlet, T_{out} = 75 °C
Stenter speed = 75 meters / min
Dried cloth output = (75 x 60 x (1/10))
= 450 kg/hr
Wt. of bone-dry cloth at outlet per hr (W) = 450 x (1 - 0.06)
= 423 kg/hr

Hence, Wt. of outlet moisture per kg. of bone dry cloth (m_o) = (450 x 0.06) / 423
= 0.0638 kg/kg bone dry cloth

Heat supplied by stenter for drying = (Fuel consumption x GCV x Heater eff x Dryer eff)
= (90 x 10,000) x 0.84 x 0.50

= 3,78,000 kcal/hr

Heat load on the dryer (Heat Consumed) = W x (m_i – m_o) x [(T_{out} – T_{in}) + 540] kcal/hr

= 423 x (m_i – 0.0638) x [(75 – 25) + 540]

Heat supplied by stenter for drying = Heat load on the dryer (Heat Consumed)

3,78,000 kcal/hr = 423 x (m_i – 0.0638) x [(75 – 25) + 540]

Inlet moisture per kg of bone dry cloth, m_i = 1.578 kg moisture / 1 kg bone dry cloth

Total weight of inlet cloth = (1 + 1.578)**]**

Inlet moisture %, wet cloth = $\frac{\text{(Inlet moisture per kg of bone dry cloth)}}{\text{(bone dry cloth + Inlet moisture per kg of bone dry cloth)}}$

= (1.578 x 100)/(1+ 1.578)

= 61.21 %

Reduction in moisture inlet, the moisture will be 55%

Hence, feed rate = 423 x (100/(100-55))

= 940 kg/hr

m_i = (940 x 0.55)/(423)

= 1.222 kg/ kg bone dry cloth

Stenter dryer load with 55% inlet moisture = 423 x (1.222 – 0.0638) x [(75–25)+540]

= 2,89051.974 kcal/hr

= say 2,89,052 kcal/ hr

Reduction in stenter drying load = 3,78,000 - 2,89,052

= 88,948 kcal/hr

% Reduction in stenter drying load = (88,948 x100) / (3,78,000)

= 23.53%

Furnace oil savings in Tonnes/month.

Monthly furnace oil savings = 0.2353 x 90 x 24 x 30

= 15247.44 kgs / month

= 15.25 tonnes/month

………. End of Section - III …………