Regn No: ______________________

Name : ______________________
(To be written by the candidate)

18th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS – September, 2017

PAPER – 4:Energy Performance Assessment for Equipment and Utility Systems

Date:24.09.2017 **Timings: 14:00-16:00 HRS** **Duration: 2 HRS** **Max. Marks: 100**

General instructions:

- *Please check that this question paper contains **7** printed pages*
- *Please check that this question paper contains **16** questions*
- *The question paper is divided into three sections*
- *All questions in all three sections are compulsory*
- *All parts of a question should be answered at one place*

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

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

S-1	In a parallel flow heat exchanger the hot fluid inlet temperature is 150 °C . The cold fluid inlet and outlet temperatures are 50 °C and 70 °C. Calculate the effectiveness.
Ans	Effectiveness, $S = (t_o - t_i) / (T_i - t_i)$ **= 20/100 =0.2**
S-2	A pure resistive load in an alternating current (AC) circuit draws only active power – True or False
Ans	True (active power)
S-3	Integrated Part Load Value (IPLV) in a vapour compression refrigeration refers to average of ____with partial loads
Ans	kW/TR
S-4	If slip of an induction motor increases, the shaft speed decreases – True or False
Ans	True

S-5	In a reciprocating air compressor, if the speed is reduced to 80%, the power will reduce by about 50% -True or False
Ans	False
S-6	The advantage of evaporative cooling is that it is possible to obtain water temperatures below the wet bulb economically. True or false
Ans	False
S-7	A fluid coupling changes the speed of the driven equipment without changing the speed of the motor. True or false
Ans	True
S-8	In a step down transformer for a given load the current in the primary will be less than the current in the secondary. True or false
Ans	True
S-9	A rise in conductivity of boiler feed water indicates a rise in ____ level of feed water.
Ans	TDS
S-10	For two pumps to be operated in parallel their ______heads should be the same
Ans	Shut off (or 'closed discharge valve' heads)

…………. End of Section - I ………….

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

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

L-1	A shell-and-tube heat exchanger with 2-shell passes and 8-tube passes is used to heat ethyl alcohol (c_p = 2670 J/kg·^oC) in the tubes from 25^{o}C to 70^{o}C at a rate of 2.1 kg/s. The heating is to be done by water (c_p = 4190 J/kg·^{o}C) that enters the shell side at 95^{o}C and leaves at 45^{o}C. The LMTD correction factor for this heat exchanger is 0.82 If the overall heat transfer coefficient is 930 W/m^2·^{o}C, determine the flow rate of water in kg/s and surface area of the heat exchanger in m^2.

Ans

Heat duty

Cold fluid = Q_{cold} = 2.1 x 2670 x (70-25)

= 252315 Watts

= 252.315 kW ……………….1 mark

Hot fluid (water) Q_{hot} = m_w x 4190 x (95 -45)

= m_w x 209500 kJ/s

= (209500 m_w) Watts

= (209.5 m_w) kW ……………….1 mark

Q_{cold} = Q_{hot}

252.315 kW = (209.5 m_w) kW

m_w = 1.204 kg/s

LMTD = (95-70) –(45-25) / {ln (95-70)/ (45-25)}

= 22.42 ^oC

Corrected LMTD = 0.82 x 22.42

= 18.38 ^oC ……………….2 marks

Q = UA LMTD

A = 252315 / (930 x 18.38)

= 14.76m^2 ……………….1 mark

L-2

In a Process Industry the L.P and H.P boilers have the same efficiency of 83%. The operating parameters and data are given below:

Boiler	L.P. (Low Pressure)	H.P. (High Pressure)
Efficiency on G.C.V.	83%	83%
Fuel	Furnace Oil	Furnace Oil
G.C.V.	10,000 kcal/kg.	10,000 kcal/kg.
Steam enthalpy	666 kcal/kg.	737 kcal/kg.
Feed water temperature	85^oC	95^oC

The cost of steam from L.P boiler is Rs. 3000 per tonne. Find out the cost of steam from H.P boiler.

Ans

$$\% \text{ Boiler Efficiency} = \frac{\text{(TPH of Stm) x 1000 x (Enth of Stm – Enth of FW)}}{\text{(Mass of Fuel x GCV Fuel)}} \text{ x 100}$$

$$\text{Evaporation ratio of LP Boiler; ER LP} = \frac{0.83 \text{ X } 10000}{(666 – 85)} = 14.29$$

……………….1.5 marks

Evaporation ratio of HP Boiler; ER HP $= \frac{0.83 \text{ X } 10000}{(737 - 95)} = 12.93$

……………….1.5 marks

ER HP is less than ER LP ;

Thus, the specific fuel consumption (kg fuel / kg steam) is more in the case of the HP boiler than in the case of the LP boiler.

Therefore, the cost of steam from HP boiler is higher than the cost of steam from LP boiler.

HP Steam Cost $= \frac{14.29\text{x } 3000}{12.93} =$ Rs.3315.5 per tonne

……………….2 marks

Or

1 T of FO – 14.29 T of LP steam

Cost of LP steam – Rs.3000/T

$\therefore$cost of 1 T of FO= Rs.3000 x 14.29 = Rs.42870/-

……………….1 mark

1 T of FO – 12.93 T of HP steam

$\therefore$cost of 1T of HP steam = Rs.42870/12.93 = Rs.3315.5/T

……………….1 mark

…………. End of Section - II …………

Section - III: LONG NUMERICAL QUESTIONS Marks: 4 x 20 = 80

(i) Answer all **Four** questions

(ii) Each question carries **Twenty** marks

N-1 The monthly energy consumption for 30 days operation in a 25 TPD (Tonne Per Day) ice plant producing block ice is 36,950 kWh. The ice plant produces 15 Tonnes of block ice daily by freezing 16.5 m^3 of water at 30^{o}C. The higher water consumption is due to loss of ice while removing the block ice from ice cans for customer delivery. The following data have been given:

Temperature of ice block = (-) 8^{o}C

Latent heat of freezing of ice = 80 kcal/kg.

Specific heat of water = 1 kcal/kg ^{o}C

Specific heat of ice = 0.5 kcal/kg ^{o}C

Energy consumption in the ice plant chiller compressor = 85% of the total energy consumption

Efficiency of compressor motor = 88%

Estimate

a) Energy consumption per tonne of ice 'output',
b) Total daily cooling load in kcals for freezing water into ice blocks
c) Refrigeration load on the chiller in TR (Tonne refrigeration) and
d) E.E.R. of ice plant chiller compressor.

The Management intends to pre-cool the inlet water from 30°C to 12°C using a separate water chiller drawing 0.8 kW/TR.

e) Find out the reduction in energy consumption per tonne of ice block output
f) % reduction in the condenser heat load of the plant chiller due to the use of pre-cooled water.

Assume absolute auxiliary energy consumption of the plant remains same and only consider water chiller compressor energy consumption for estimating the savings.

Ans

a) Monthly energy consumption = 36950 kWh
Daily energy consumption = 36950 / 30 = 1231.67 kWh

∴ **Energy consumption per tonne of ice delivered** = 1231.67/15
= 82.11 kWh/tone

……………….3 marks

b)

Quantity of water input for the production 16.5 m^3 = 16500 kg.
(sp.wt of water = 1000 Kg./m^3)

Total cooling load per day

$Q = Q_1 + Q_2 + Q_3$

Q_1 = Heat removed from lowering temperature from inlet 30°C to 0°C in kcals
Q_2 = Latent heat removed in freezing water to ice at 0°C in kcals
Q_3 = Heat removed for sub-cooling of ice from 0°C to -8°C in kcals

$$Q = (16,500 \times 1 \times (30-0)) + (16,500 \times 80) + \{16,500 \times 0.5 \times [0 - (-8)]\}$$
$$= 4,95,000 + 13,20,000 + 66,000$$

Total Daily Cooling Load = 18,81,000 kcals ……………….3 marks

c)

Refrigeration load on the Chiller $= \dfrac{18,81,000}{24 \times 3024} =$ **25.92 TR**

……………….3 marks

d)

Ice plant chiller consumption per day	=	0.85 X 1231.67
		1046.92 kWh

Ice plant auxiliary consumption per day	=	1231.67 – 1046.92
		184.75 kWh
Power consumption of the chiller	=	1046.92 / 24
		43.62 KW
∴Input KW/TR Ice Plant chiller	=	43.62 / 25.92
		1.683
Motor Efficiency	=	88%
∴Input power to the ice plant compressor	=	0.88 X 1.683
		1.48 kW / TR
∴E.E.R. ice plant chiller		(3024)kcal/hr/(1.48X860) kcal/hr
		2.376
		……………….4 marks
e) reduction in energy consumption per tonne of ice delivered		
Condenser heat rejection load in the existing case Q1	=	$Q_E + Q_C$
		(25.92 X 3024) + (25.92 X 1.48 X 860)
		111373.1 kcals/hr
Refrigeration load for pre-cooling from 30°C to 12°C in a separate water chiller		16500 X 1 X (30 – 12)/ 24 X 3024 4.09 TR
Energy consumption in water chiller	=	0.8 X 4.09 X 24 = 78.53 kWh
∴Reduced ice plant chiller load	=	25.92 – 4.09 = 21.83 TR
Energy consumption for the plant chiller	=	21.83 X 1.683 X 24 = 881.76 kWh
∴Total energy consumption per day by resorting to pre-cooling of inlet water in a separate water chiller is		Energy consumption in ice plant chiller+ Auxiliaries in ice plant (no change) + Energy consumption in water chiller for pre-cooling
	=	881.76 + 189.75 + 78.53
		1150 kWh/day
∴Reduction in energy consumption **Kwh/tone** for ice delivered	=	(1231.67 – 1150) /15
		5.44
		……………….4 marks
f)		
Heat rejection load in the ice plant condenser	=	(21.83 X 3024) + (21.83 X 1.48 X 860)
		93799.14 kcal/hr
∴% reduction in ice plant condenser heat load	=	(1,11,373.1 –93799.14)x100 /(1,11,373.1)
		15.78 %

……………….3 mark

N-2

In a Petrochemical Industry a gas turbine cogeneration system comprising of 20 MW gas turbine generator along with a waste heat boiler (WHB) of 70 Tonne per hour capacity at 10 kg/cm^2 (g) are operated to meet the power and steam requirements. The existing operating data is given below:

Power supplied by the Cogenerator = 16000 KW
Power drawn from the grid = 1500 KW
Grid power cost = Rs 5 /kwh
Steam at 10 Kgf/cm^2 g supplied by WHB (without supplementary fuel firing) = 48 Tonne/hr
Efficiency of gas turbine on G.C.V. = 28%
Efficiency of generaror = 95%
G.C.V. of fuel (Natural Gas) = 13000 Kcal/Kg
Density of natural gas = 0.7 Kg./m^3
Cost of natural gas = Rs.25/m^3
Temperature of gas turbine exhaust gas entering WHB = 515^{o}C
Specific heat of exhaust gas 0.3 Kcal/Kg^{o}C
Ambient temperature = 30^{o}C
Air to natural gas ratio for gas turbine combustion = 60:1
Enthalpy of steam at 10 Kgf/sq.cm.g = 665 Kcal/Kg
Enthalpy of feed water = 105 Kcal/Kg

a) Find out the heat rate of the gas turbine generator and

b) Estimate the efficiency of the waste heat boiler.

The plant personnel claim and believe that by resorting to supplementary fuel firing to increase steam generation in the WHB. is likely to improve its efficiency by 1.5 % points.

c) Determine if it is economical to generate additional steam requirement of 10 Tonne per hour by supplementary fuel firing in WHB. as against in a separate natural gas fired smoke tube boiler of 80% efficiency on G.C.V.

The plant operations are steady and continuous with 8600 yearly hours of operation.

Ans

a)

Efficiency of gas turbine generator = 28%

∴ **Heat Rate** = 860 / 0.28

= **3071.43 kcal/kWh**

……………….4 marks

b)

Gas Rate = 3071.43 / 13000

= 0.236 kg.Natural gas/kWh

………… …….2 marks

Power generated by Gas turbine = 16000 kW

Steam supplied by WHB = 48000 kg./hr

∴ power to Steam ratio = 3 kW / kg. steam

Air to fuel ratio of gas turbine combustion= 60 : 1

∴Exhaust gas per Kg. of natural gas fired = 60 + 1 = 61 kg. per kg of natural gas

Efficiency of waste heat boiler = $\frac{48000 (665 – 105)}{16000 \times 0.236 \times 61 \times 0.3 \times 515}$ =**75.5%**
(without supplementary fuel firing)

……………….4 marks

c)

Efficiency of WHB with supplementary firing (as per claim) = 75.5 + 1.5
= 77%

Additional gas consumption for meeting 10 Tonne/hr steam through supplementary firing in WHB =

$$= \frac{10000 (665 – 105)}{0.77 \times 13000} = 559.44 \text{ kg./hr.}$$

Gas consumption in separate gas fired boiler with 85% on GCV = $\frac{10000 (665 – 105)}{0.85 \times 13000}$

= 506.79 kg/hr

……………….5 marks

Operating separate gas fired boiler is economical.

∴**Saving in gas consumption by meeting additional steam through gas fired boiler** =

= 559.44 – 506.79
= 52.65 kg/hr
= 52.65 / 0.7
= 75.21 m^3/hr

$\therefore$ Yearly monetary savings= 75.21 X 25 X 8600
= Rs.1,61,70,150
= **Say Rs.16.17 million**

……………….5 marks

N 3 A Process Industry is operating a natural gas fired boiler of 10 tonnes/hr to cater to a steam load of 8 tonnes/hr at 10.5 kg/cm^2(g). The O_2 in the flue gas is 4 % and the exit flue gas temperature is 180^{o}C. Due to increased cost of natural gas the management has decided to revert to operating the furnace oil fired boiler having an efficiency of 82% on G.C.V. for meeting the above load.

In keeping with its sustainability policy the management proposes to offset the additional CO_2 emissions due to the use of furnace oil by sourcing a part of its total electrical energy consumption from green power (wind source).

The following is the additional data.

Composition of fuels (% by weight)

Constituents	**Natural gas**	**Furnace oil**
Carbon	73	84
Hydrogen	23	11
Nitrogen	3	0.5
Oxygen	1	0.5
Sulphur	-	4

G.C.V. of natural gas - 13000 kcal/kg
Enthalpy of steam at 10.5 kg/cm^2(g) - 665 kcal/kg.
Inlet feed water temperature - 90^{o}C
Heat loss due to Radiation and moisture in air - 1.2%
Specific heat of flue gases - 0.29 kcal/kg ^{o}C
Specific heat of super heated water vapour - 0.45 kcal/kg ^{o}C
G.C.V. of furnace oil - 10,000 kcal/kg
Ambient temperature -. 30^{o}C

Substitution of 1 kwh of green electrical energy in place of grid electricity reduces 0.80 kg. of CO_2
Determine the monthly amount of green electrical energy from wind, (for 700 hours operation) required to be purchased to maintain the existing level of CO_2 emissions.

Ans Theoretical air required = 11.6 C + [34.8 (H_2 – O_2/8)] + 4.35 S
= 11.6 x 0.73 + [34.8 (0.23 – 0.01/8)]
Kg.air/Kg.gas
= 16.43 kg. air / kg. gas

Excess Air % = % O_2 / (21 - % O_2) x100

= (4 / 21 – 4)

= 23.5 %

Actual Air Supplied (AAS) = (1 + 0.235) X 16.43

= 20.29 kg.air / kg.gas

………………..3 marks

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 nitrogen In air supplied + mass of excess O_2 in flue gas

= (0.73 X 44/12) + 0.03 + (20.29 X 0.77) + (20.29–16.43) X 0.23

= 19.217

= Say 19.22 kg. dry flue gas / kg. gas

………………..2 marks

(M_{air}*+*M_{fuel}*) ie (20.29+1) = 21.29 may also be considered.*

L1 = % heat loss due to dry flue gases

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

$$= \frac{19.22 \text{ X } 0.29 \text{ X } (180 - 30)}{13000} \text{ X } 100 = 6.43\%$$

………………..2 marks

L2 = Loss due to presence of hydrogen forming water vapour

$$= \frac{9 \text{ H } [584 + C_{ps} (T_q - T_a)]}{13000} \text{ X } 100 = 10.37\%$$

………………..2 marks

Heat loss due to Radiation and moisture in air = 1.2% ....Given

∴ Efficiency of natural gas boiler on G.C.V. = 100 – [6.43 + 10.37 + 1.2]

= 82%

Steam Load = 8 tonne/hr.

$$\text{Amount of Gas required} = \frac{8000 (665 - 90)}{0.82 \text{ X } 13000} = 431.52 \text{ kg./hr.}$$

………………..2marks

	Amount of CO_2 emission with natural gas = 431.52 X 0.73 X 3.67 = 1156.1 kg/hr. Amount of furnace oil required for the same steam load = $\frac{8000 (665 – 90)}{0.82 \times 10000}$ = 560.97 kg./hr ……………….2 marks Amount of CO_2 emission with F.O = 560.96 X 0.82 X 3.67 = 1688.15 kg. CO_2/hr ……………….2 marks (Note: 1 Kg. Carbon Combustion emits 3.67 Kg. CO_2) **Increase in CO_2 emission due to switching from natural gas to furnace oil** =1729.39 – 1156.1 = **532.05 kg. CO_2/hr**. ……………….2.5 marks [Substituting 1 kWh grid (Thermal) electrical energy by green electrical energy reduces 0.80 Kg. of CO_2) **Green energy to be purchased to offset higher CO_2 emissions per month** = 532.05 X (1/0.8) X 700 =**465543.75 kWh** …………….2.5 marks
N-4	**Answer any one of the following**
A)	In a secondary steel manufacturing unit, steel scrap is melted in an arc furnace. The molten metal is then taken for ladle refining followed by vacuum degassing, before being cast into ingots. After the ingots are cooled down to ambient temperature, the entire lot is loaded in a batch forging furnace and heated to 1150°C. The heated ingots are forged into desired shapes. The monthly numbers of batches are 160. The management has decided to improve energy efficiency of the system by incorporating a holding furnace (electric resistance furnace) in between the electric arc furnace and the fuel fired forging furnace, in order that the hot ingots (after casting) could directly fed into the intermediate holding furnace to maintain temperature and be fed at high temperature to the forging furnace, instead of at atmospheric temperature. Following are the data obtained in the energy audit study of the unit. 1. Scrap material fed into the arc furnace = 10 tons per heat 2. Yield of ingot casting from scrap = 95% 3. Temperature of casting after removal of mould = 600°C 4. Ambient temperature = 30°C 5. Specific heat of steel = 0.682 kJ/ kg°C

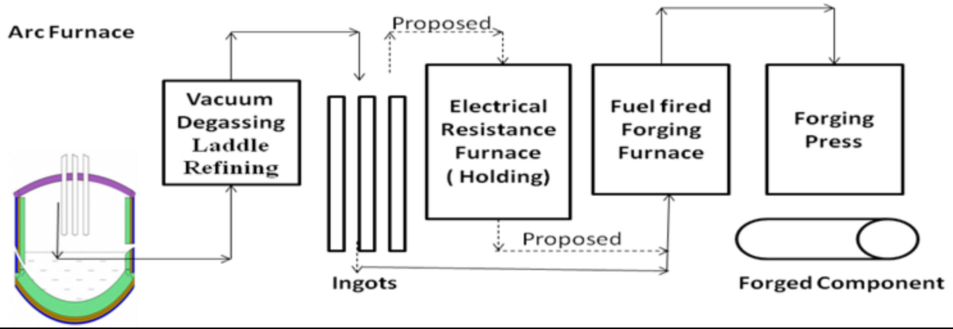
6. Efficiency of forging furnace = 25 %
7. Calorific value of Furnace oil fuel = 10500 kcal/ kg
8. Specific gravity of F.O = 0.9
9. Yield of forged steel in forging furnace = 97 %
10. Melting point of steel = 1650°C
11. Latent heat of melting of steel = 272 kJ/kg
12. Electrical energy consumption measured per ton of steel melted = 850 kWh
13. Electrical energy consumption for holding ingots at 600°C in electric furnace = 85 kWh per batch
14. Cost of electricity = Rs.6 /kWh
15. Cost of Furnace oil = Rs. 30,000 / ton

Calculate

a. Efficiency of electric arc furnace ignoring heat loss due to slag

b. Specific oil consumption in litres per ton of finished forged product.

c. Annual net savings in energy cost by holding the hot forged casting in an intermediate electric furnace at 600°C before feeding into forging furnace.



Ans

a) Efficiency of the arc furnace.

Theoretical heat required for melting one ton of steel

$$= \frac{1,000 \text{ x } [0.682 \text{ x } (1650 - 30) + 272]}{3600}$$

= 382.45 kWh per ton of molten steel

……………….3 marks

Efficiency = 382.45 x 100 /850 = 45 %

………………2 marks

b) Specific oil consumption in liters per ton of finished forged product from the forging furnace

Amount of material heated in forging furnace

= 10,000 kg x (0.95) = 9500 kg steel / batch

Oil consumption = 9500 x (0.682 /4.18) x (1150-30) / (10500 x 0.25)

= 661.3 kg FO ………………3 marks

Amount of material forged = 9500 kg x (0.97) = 9215 kg steel / batch

Specific oil consumption = 661.3 kg FO / 9.215 tons steel = 71.76 kg FO/ton

= 71.76 / 0.9 = 79.73 Lts FO / ton of forged steel

………………3 marks

c) **Net Savings in energy cost by holding the hot forged casting in an intermediate electric furnace at 600°C before feeding into forging furnace**

Oil consumption = 9500 x (0.682 /4.18) x (1150-600) / (10500 x 0.25)

= 324.76 kg FO per batch ………………2.5 marks

Additional electrical energy consumption for holding ingots at 600°C

= 85 kWh per batch

Reduction in FO consumption by hot charging the forge furnace

= 661.3 - 324.76 = 336.54 kg FO per batch

………………2.5 marks

Net savings in energy cost = (336.54 x 30) – (85 x 6) = Rs. 9586.2 per batch

Annual net savings in energy cost = 9586.2 x 160 x 12 = Rs.184,05,504 /yr

………………4 marks

B) The heat balance of a stenter in a textile industry is given below:

Heat used for Drying = 48%
Heat loss in exhaust air = 42%
Heat loss through insulation = 6%
Heat loss due to air infiltration = 4%

The above stenter is drying 75 meters per min. of cloth to final moisture of 7 % with inlet moisture of 50%. Temperature of cloth at inlet and outlet is 25°C and 75°C respectively.

The hot air for drying in the stenter is heated by thermic fluid. The thermic fluid heater is fired by furnace oil , having an efficiency of 82%. The following data has been given:

Density of furnace oil = 0.95 Kg/litre
GCV = 10000 kcal/kg
Cost of furnace oil = Rs.24 per litre

Weight of 10 mts of outgoing dried cloth = 1 Kg

a) Find out the existing furnace oil consumption for stenter drying.

b) What will be the annual furnace oil savings and annual monetary saving if the overall thermal efficiency of the stenter is improved by reducing the combined thermal insulation loss and the loss due to air infiltration, by half, for operations at 20 hours per day and 330 days per year.

Ans

Stenter speed = 75 meters / min

Dried cloth output = 75 x 60 /10

= 450 kg/hr

Weight of bone dry cloth per hr. = 450 x 0.93

i.e. W = 418.5 kg./hr

……………….2.5 marks

∴Weight of outlet moisture per kg. of bone dry cloth

m_o = (450 – 418.5) / 450

= 0.0753 kg/kg

……………….2.5 marks

Inlet moisture = 50%

∴Inlet wet cloth flow rate = 418.5/ 0.5 = 837 kg/hr

m_i inlet moisture per kg.

of bone dry cloth = (837 - 418.5) / 418.5

m_i = 1 kg/kg bone dry cloth

∴Heat load on the dryer = $W \times (m_i - m_o) \times [(T_{out} - T_{in}) + 540]$ kcal/hr

T_{out} = Outlet cloth temperature

= 75 °C

T_{in} = Inlet cloth temperature

= 25 °C

∴Heat load on the dryer = 418.5 x (1 – 0.0753) x [(75 – 25) + 540]

= **2,28,322.3 kcal/hr**

……………….2.5 marks

Based on heat balance, dryer efficiency is 48%.

∴Heat input to the dryer = 228322.3 / 0.48

= 4,75,671.46 kcal/hr

∴Furnace oil consumption in Thermic fluid heater = 4,75,671.46 / (0.82 x 10000)

= **58.01 kg./hr**

……………….2.5 marks

After reducing insulation and air infiltration loss by half, the heat energy input will reduce by 100% – 0.5 (6 + 4)% = 95%

∴ Dryer efficiency will increase to = (48/0.95) x 100

= 50.52%

∴ Furnace oil consumption with improved dryer efficiency = 2,28,322.3 / (0.5052 x 0.82 x 10000)

= 55.12 kg/hr

……………….4 marks

∴ Saving fuel consumption due to improved dryer efficiency = 58.01 – 55.12

= 2.89 kg/hr

∴ Annual Furnace oil savings = 2.89 x 20 x 330

= **19074 kgs/year**

……………….3 marks

∴ Annual monitory savings = 19074 x (1/0.95) x 24

= **Rs.4,81,870/year**

……………….3 marks

Note:

If candidates had done the calculation with temperature of cloth at inlet at 75°C and outlet at 25°C. the marks can be awarded according the steps.

C) In a cement kiln producing 4500 TPD of clinker output, the grate cooler hot exhaust air temperature is vented to atmosphere at 275°C.

It is proposed to generate hot water from this waste exhaust for operating a Vapour Absorption Machine (VAM) chiller. This will replace the existing Vapour Compression Chiller (VCR) of 50 TR capacity used for air-conditioning of control rooms and office buildings.

The following are the data:

- Diameter of the cooler vent : 2 m
- Velocity of cooler exhaust air : 18.6 m/s
- Density of cooler exhaust air at 275°C : 0.64 kg / m^3
- Existing VCR Chiller Specific power consumption : 0.88 kW/TR
- Existing VCR condenser water pump power consumption : 3.1 kW
- Investment towards 50TR VAM & its associated system : Rs 30 lakhs
- CoP of VAM system : 0.75

- Power consumption of VAM auxillaries : 2.83 kW
- Temperature of circulating hot water of VAM generator : Inlet - 90 ^{o}C; Outlet - 80 ^{o}C
- Specific heat of exhaust cooler air : 0.24 kcal/ kg ^{o}C
- The efficiency of all pumps and their drive motors are 75% & 90% respectively.
- The cost of electricity : Rs.6/kWh
- No of hours of operation : 8200 hrs/ yr

Calculate

a) Cooler Exhaust air temperature after heat recovery
b) Payback period by replacement of VCR by VAM

Ans

a) Cooler Exhaust air temperature after heat recovery

- Area of the duct = πr^2 = 3.14 x (2/2)^2 = 3.14 m^2
- Volume of cooler exhaust air$_{275}$0$_{C}$ = 3.14 x 18.6 = 58.4 m^3/s = 2,10,240 m^3/h
- Mass flow rate of cooler exhaust air$_{275}{}^{0}{}_{C}$ m$_{cxa}$= 210240 x 0.64 = 134553 kg/ hr

Capacity of existing chiller = 50 TR

- Cooling load = 50 x 3024 = 151200 kcal/ hr

CoP of VAM = 0.75

= (Cooling Load / Heat Input)

- Heat Input to VAM generator = 151200 / 0.75 = 201600 kcal/hr

201600 kcal/hr = m$_{hw}$ x C$_{p-hw}$ x (90 ^{o}C -80 ^{o}C)

- Hot water flow rate m$_{hw}$ = 201600 / (1 x 10) = 20160 kg/hr
- Heat input to VAM generator = Heat recovered from Cooler Exhaust Air (m$_{cxa}$xC$_{p-cxa}$x (275-T$_o$)
- Cooler Exhaust air temperature after heat recovery

T$_o$ = 275- [201600 / (134553 x 0.24)]
= 268.76 ^{o}C

………………5 marks

b) Payback period by replacement of VCR by VAM

Hot water circulation pump capacity

- motor input power P_m = m_{hw} x head developed x 9.81 / (1000 x Pump η x motor η_m)

  P_m= [(20160 /3600) x 20 x 9.81/ (1000 x 0.75x 0.9)] = **1.63 kW**

Heat load in the cooling tower = heat load from chilled water + heat load from generator hot water

= 151200 + 201600 = 352800 kcal/ hr

- Condenser water circulation rate = 352800 / 5 = 70560 kg / hr

……………….3 marks

Condenser water circulation pump capacity

- motor input power P_m = m_{hw} x head developed x 9.81 / (1000 x Pump η x motor η_m)

  P_m= [(70560 /3600) x 20 x 9.81/ (1000 x 0.75x 0.9)] = **5.69 kW**

……………….4 marks

Savings

- Existing VCR Chiller Specific power consumption = 0.88 kW/TR
- Existing VCR Chiller total power consumption = 50 x 0.88 = 44 kW
- Existing VCR condenser water pump power consumption = 3.1 kW
- Total Energy Saving = Existing VCR Chiller total power consumption – (Proposed VAM chiller power consumption)

  = (44+3.1) – (1.63+2.83+5.69) = 36.95 kW

……………….5 marks

- Annual Energy savings = 36.95 x 8200 = 302990 kWh/yr
- Annual Monetary savings = 302990x 6 = Rs. 18.18 Lakhs /y
- Investment towards 50TR VAM & its associated system = Rs 30 lakhs
- Simple payback period = 30 / 18.18 = 1.65 yrs or 19.8 months

……………….3 marks

D) A steam power plant consisting of high pressure Turbine (HP Turbine) and low pressure Turbine (LP Turbine) is operating on Reheat cycle (schematic of power plant is represented below).

Steam from Boiler at a pressure of 150 bar(a) and a temperature of 550^{0}C expands through the HP Turbine. The exhaust steam from HP Turbine is reheated in a reheater at a constant pressure of 40 bar (a) to 550^{0}C and then expanded through LP Turbine. The exhaust steam from LP Turbine is condensed in a condenser at a pressure of 0.1 bar (a).

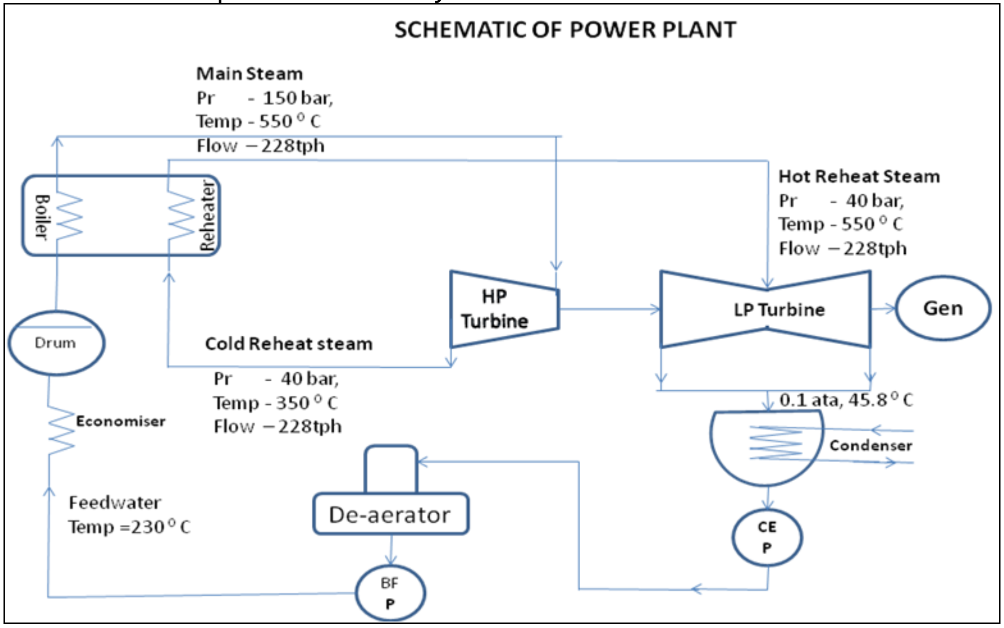
The isentropic efficiencies of HP Turbine and LP Turbine are same and is 90%. The generator efficiency is 94%

The other data of the power plant is given below:

Main steam flow rate	: 228 TPH
Enthalpy of main steam	: 3450 KJ/kg
Enthalpy of feed water	: 990.3KJ/kg
Isentropic Enthalpy of cold reheat steam	: 3050 KJ/kg
Enthalpy of hot reheat steam	: 3560 KJ/kg
Condenser pressure and temperature	: 0.1 bar(a) and 45.8^{0}C
Isentropic enthalpy of LP Turbine exhaust steam	: 2300 KJ/kg
Enthalpy of dry saturated steam at 0.1 bar(a) and 45.8^{0}C	: 2584.9KJ/kg
Enthalpy of water at 0.1 bar(a) and 45.8^{0}C	:191.9 KJ/kg

Based on the above data calculate the following -:

(a) Power developed by the Generator
(b) Turbine heat rate
(c) Turbine cycle efficiency
(d) Specific steam consumption of turbine cycle.



Ans

(a) Power developed by the Generator: Turbine output x Generator efficiency------------ (1)

Turbine output = Q1 (H1 – h2) + Q2(H3 – h4)/860 MW ---------------------------------------(2)

Where, Q1=main steam flow rate =228 TPH
H1=main steam enthalpy=3450 KJ/Kg
h2=actual enthalpy at HP Turbine outlet= ?(*cold reheat enthalpy*)
Q2=steam flow through reheater=228TPH
H3=enthalpy of hot reheat steam=3560 KJ/kg
h4= actual enthalpy of LP turbine exhaust steam=?

HP Turbine isentropic efficiency= Actual enthalpy drop/isentropic enthalpy drop
0.9= (H1- h2)/(H1-h2is) , h2is=isentropic enthalpy of cold reheat Steam=3050KJ/kg
0.9= (3450 –h2)/(3450—3050)
h2= 3090KJ/kg

LP Turbine isentropic efficiency= (H3—h4)/(H3—h4is), h4is=isentropic enthalpy of LP Turbine

Exhaust steam=2300KJ/kg

0.9=(3560-h4)/(3560—2300)

h4= 2426 KJ/kg

Substituting the values in equation-2,we get

Turbine output = 228(3450—3090) + 228(3560—2426)/3600 =94.62MW

Generator output= 94.62 x 0.94= 88.94 MW--------------------ANSWER (9 MARKS)

(b) Turbine heat rate=Q1 (H1—hfw) +Q2(H3—h2)/Generator output =KJ/kwhr-------------(3)

hfw=enthalpy of feed water=990.3KJ/kg

Substituting the values in the above equation-3, we get

Turbine heat rate=228 (3450—990.3) + 228(3560—3090)/88.94

=7510.4 KJ/kwhr------------------------------ANSWER (5 MARKS)

(C) Turbine cycle efficiency= 860 x4.18/Turbine heat rate

=860 x4.18 /7510.4=47.8%------------------ANSWER (3MARKS)

(d) Specific steam consumption of cycle=Steam flow/generator output

=228/88.94=2.56 tons/MW hr-------ANSWER (3MARKS)

-------- End of Section - III ---------