REGULAR **Paper 4 – Set A**

16th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS – September, 2015

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

Date: 20.09.2015 **Timings: 14:00-16:00 HRS** **Duration: 2 HRS** **Max. Marks: 100**

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

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

S-1	Why is the exhaust temperature of furnace oil fired systems limited to about 170^0C?
Ans	Acid dew point due to presence of sulphur
S-2	The net present value of a energy conservation project is Rs.48,784/- and the initial capital investment Rs,2,00,000/- calculate the profitability index of the project.
Ans	$PI = \frac{48784}{2,00,000} = 0.244$
S-3	The dry bulb and wet bulb temperatures of air entering an air washer are 35 and 28 ^0C respectively. If the saturation efficiency is 90 %, calculate the air temperature leaving the air washer.
Ans	$90\% = \frac{35 - T_{out}}{35-28}$ $T_{out} = 28.7^oC$
S-4	Other than exhaust gas what is the major source of waste heat recovery in a water cooled DG set?
Ans	Engine jacket cooling water
S-5	In poorly loaded motor, current measurements are not a right indicator of motor loading. Why?
Ans	PF will be low.
S-6	If the condenser back pressure is 76 mm Hg, calculate the condenser vacuum. if the atmospheric pressure is 745 mmHg.
Ans	Condenser vacuum, mmHg = (Atmospheric pressure, mmHg - Condenser back pressure, mmHg) = (745 - 76) = 669 mmHg.

S-7	If the coal GCV is 4000 kcal/kg and specific coal consumption is 0.65 kg/kWh, what is the power station gross efficiency?
	(860 /(4000 x 0.65)) x100 = 33.07%
S-8	For a process requiring indirect heating to 200°C, thermic fluid is preferred to steam as a heat carrier. Why?
Ans	Because for steam to be heated to high temperatures, the pressure required will be very high.
S-9	Between a natural gas fired boiler and oil fired boiler which will have a higher percentage of hydrogen loss in flue gas? Why ?
Ans	Gas fired boiler. Because the hydrogen percentage is more in natural gas compared to oil.
S-10	After cleaning of choked AHU filter, AHU fan power increased. Why?
Ans	Due to less resistance, the air flow increased.

………… 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 pump is drawing water through a 150 mm diameter pipe with a suction head of 3.5 m below the pump centre line. Find out the pump efficiency if the actual power input the motor is 17.6 kW at a motor efficiency of 90 %. The discharge pressure is 4.5 kg/cm^2 and the velocity of water through the pipe as measured by an ultrasonic flow meter is 1 m/s.

Ans

Discharge Head, kg/cm^2	=	4.5
Suction Head, m	=	- 3.5
Total Head	=	45 - (-3.5)
		48.5 m
Flow rate	=	$(22/7 \times D^2/4) \times 1$ m/s
	=	$(22/7 \times 0.15^2 / 4) \times 1$ m/s
	=	0.0177 m^3/sec
		….. 2 marks
Hydraulic Power	=	0.0177 x 1000 x 9.81 x 48.5/1000
	=	8.42 kW
		….. 1 mark
Pump Efficiency		8.42/(17.6x0.9)
	=	53.2 %
		….. 2 marks

L-2 A luxury hotel is using a diesel fired heater with an efficiency of 70% for supplying hot water at 55°C from an initial temperature of 20°C. The hot water requirement is 24,000 litres per day.

The management is considering to install a specially designed electric heat pump for the specific high hot water temperature requirement with a heat pump coefficient of performance (C. O. P.) of 2. Find out the reduction in daily operating cost with heat pump in place of diesel fired heater ignoring auxiliary energy consumption. The following data are given.

Electricity cost	=	Rs.10/kWh
Diesel cost	=	Rs.50/litre
G.C.V. of diesel	=	9100 kcal/litre

Ans **Solution:**

Diesel required
For hot water heater = $\frac{[24000\ Lit_{Hotwater}/\ day) \times (55-20^oC) \times (1\ kcal/Lit^oC)]}{(0.7\ Effy \times 9100\ kcal/Lit_{diesel})}$

= 131.9 Lit_{diesel} /day 1 Mark

Diesel cost / day = 131.9 x 50 = 6595 Rs./day

….. 1 mark

COP = Heat pump refrigeration effect / Input electrical energy

Or

Input electrical energy, kW = $\frac{\text{Heat pump refrigeration effect, kcal}}{\text{COP} \times 1\text{ kW}}$

Or

	Input electrical energy, kW = $\frac{\text{Heat pump refrigeration effect, kcal}}{\text{COP x 860 kcal/hr}}$ Electrical energy required with heat pump of COP = 2 = $\frac{24000 \times 1 \times (55 - 20)}{(2 \times 860)}$ ..1 Mark Energy input with heat pump = 488.372 kWh/day Operating cost with heat pump = 488.372 x 10 = 4883.72 Rs./day ….. 1 mark Reduction in operating cost = 6595 – 4883.72 = Rs.1711.28 /day ….. 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	In an organic chemical industry 10 Tonne per hour steam is generated at 10 Kgf/cm^2 in a 12 TPH natural gas fired smoke tube boiler. The % oxygen in the exit flue gas was 3.5% and the flue gas temperature was 190^{o}C. The following data have been provided. Ultimate analysis of natural gas per kg , Carbon = 0.72 kg/kg; Hydrogen = 0.236 kg/kg; Nitrogen = 0.03 kg/kg; Oxygen = 0.011 kg/kg; Specific heat of flue gas = 0.297 Kcal/kg^{o}C Specific heat of superheated water vapor = 0.45 Kcal/kg^{o}C G.C.V. of natural gas = 9100 Kcal/m^3 Density of natural gas = 0.7 Density of air = 1.12 kg/m^3 Enthalpy of steam at 10 kg/cm^2 = 665 Kcal/kg Temperature of feed water at inlet to boiler = 95^{o}C Yearly hours of operation = 6000 hours a. Find out the S/F (steam to fuel) ratio in kg steam/m^3 gas

	b. Estimate the annual reduction in carbon dioxide emission in tones/year compared to the furnace oil fired boiler of 83% efficiency on G.C.V. which was earlier used for delivering the same steam load. Assume G.C.V. of furnace oil as 10300 Kcal/kg and 0.86 carbon per kg. furnace oil.
Ans	Ultimate analysis of natural gas per kg. of gas Carbon = 0.72 kg/kg; Hydrogen = 0.236 kg/kg; Nitrogen = 0.03 kg/kg; Oxygen = 0.011 kg/kg; Theoretical air required = 11.6C + [34.8 (H_2 – O_2/8)] + 4.35S, = 11.6 X 0.72 + [34.8 (0.236 – 0.011/8)] (note S= sulfur in above composition is nil) = 16.524 kg air/kg gas ….. 1 Mark % Excess Air = [% O_2 / (21 - % O_2)] x 100 = [3.5 / (21 – 3.5)] x 100 = 20% ….. 1 Mark Actual Air Supplied (AAS) = [1 + 0.2] x 16.524 = 19.83kg air / kg gas …. (1 mark) Mass of dry flue gas; mdfg = mass of combustion gases due to presence C, N_2,S in the fuel+mass of residual O_2 in flue gas + mass of N_2 supplied with air = 0.72 X 44/12 + 0.03 + (19.83 – 16.524) x 0.23 + 19.83 x 0.77 = 18.70 kg dfg / kg gas …. (1.5 marks) L_1 = % heat loss due to dry flue gases $= \frac{\text{mdfg x cpfg x } (T_g - T_a)}{\text{G.C.V. of gas}} \times 100$ G.C.V. of gas $= \frac{\text{Kcal / m}^3}{\text{Density}} = \frac{9100}{0.7} = 13000$ Kcal/kg $= \frac{18.69 \times 0.297 \times (190 - 30)}{13000} \times 100 = 6.84$ % …..(2 marks)

L_2 = Loss due to presence of hydrogen forming water vapor

$$= \frac{9H [584 + Cps \times (T_g - T_a)}{G.C.V.} \times 100$$

$$= \frac{9 \times 0.236 [584 + 0.45 (190 - 30)}{13000} \times 100$$

L_2 = 10.72 %

….(2 marks)

Radiation and unaccounted losses in the boiler (given) = 1.45%

Total losses = 6.84 + 10.72 + 1.45 = 19%

Efficiency of natural gas fired boiler on G.C.V. by indicated method = 100 – 19 = 81%

…..(1.5 mark)

Steam to fuel ratio in kg steam/m^3 gas= 0.81 x 9100 / (665 – 95) = 12.93

…. (2 marks)

Amount of gas required for generation 10 tonne/hr of steam = (10,000 / 12.93) x 0.7

= 541.38 kg/hour …(1.5 Marks)

CO_2 emission with natural gas firing = 0.72 x 3.67 x 541.38

(1 kg carbon gives 44/12 i.e. 3.67 kg CO_2)

= 1430.54 kg/hr

…. (1.5 marks)

Furnace oil required for 10000 kg steam = (10,000 x 570) / (0.83 x 10,300)

= 666.74 kg/hr … (1.5 Marks)

CO_2 emission with furnace oil firing = 0.86 x 3.67 x 666.74

= 2104.36 kg/hr

….(1.5 marks)

Net reduction in CO_2 emission with natural gas compared to furnace oil firing = 2104.36 – 1430.54

	= 673.82 kg/hr ….. (1 mark) **Annual reduction in CO_2 for 6000 hrs. operation** = 673.82 x 6000 **= 4042.920 Tonnes** ….. (1 mark)
N-2	A gas engine-based trigeneration plant operates in two modes: • Power and heating mode (10 hours per day) : P_{el}= 650 kW of electricity and 325 kg/h of steam with enthalpy addition of 530 kcal/kg of steam & EUF_{heat} = 0.85 • Power and cooling mode (14 hours per day) : P_{el} = 650 kW of electricity and chilling load of 213 TR for absorption chillers & EUF_{cool} = 0.73 • Calorific value of natural gas = 8500 kcal/Sm^3 • Average operating days/year = 330 • Alternator efficiency = 0.95 • The energy loss in the flue gas and that in the cooling water is same as engine power output and other losses are negligible Answer the following: a. What is the average plant energy utilization factor b. Calculate the useful energy produced daily by the trigeneration plant in Gcal c. Determine the daily plant natural gas requirements based on average energy utilization factor d. The plant proposes to install a 60 TR hot water driven Vapour absorption chiller with a COP of 0.5 using waste heat from jacket cooling water. Check if it is feasible with supporting calculations.
Ans	(see table below)

1) Plant average energy utilization factor		
Plant average energy utilization factor	=	**(0.85 x 10 + 0.73 x 14)/24**
	=	**0.78**
		….(3 marks)
2) The useful energy produced daily by the trigeneration plant in Gcal		
P_{Elect}	=	650 KW
Q_{Heat}	=	325 x 530
	=	172250 kcal/h
Q_{Cool}	=	213 x 3024
	=	644112 kcal/h

		….(2 marks)
Total daily useful energy production of the plant	=	(650 x 860 x 24 +172250 x 10 + 644112 x 14)
	=	13416000 + 1722500 + 9017568
The useful energy produced daily	=	24156068 kcal/day …(2 Marks)
The useful energy produced in Gcal	=	24156068x 330 / 10^6
	=	**7971.5 Gcal**
		….(2 marks)
3)The daily plant natural gas requirements		
Input heat	=	24156068 / 0.78
	=	3096931795 kcal/day (2 Marks)
Natural gas requirements	=	3096931795 **/ 8500**
	=	**3643 Sm³/day**
		….(4 marks)
4) Justification for a 60 TR Vapour Absorption chiller from waste heat of the jacket cooling water		
Heat required for operating 60 TR at COP of 0.5	= =	**60 x 3024/0.5** **362880 Kcal/hr**
		….(2 marks)
Power output of the engine	=	**650 /0.95** **684.2 KW**
		….(2 marks)
Heat in the jacket cooling water	= =	**684.2 x 860** **588412 kcal/hr**
		….(2 marks)
Since the heat requirement (**362880 kcal/hr)** is much less than heat available (**588412 kcal/hr**) the proposal is feasible. ….(1 mark)		

N-3	Hot effluent having a flow rate of 63450 Kg/hr at 80^{O}C from the process is sent to a heat exchanger for cooling. The outlet temperature of effluent in the heat exchanger is 38 ^{O}C. Air having a flow rate of 370057 Kg/hr enters the heat exchanger at a temperature of 30^{O}C and leaves at 60 ^{O}C. Power drawn by the fan is 30 KW. The plant works for 16 hours a day for 330 days per year. Now plant has decided to replace air cooled heat exchanger with a water cooled counter current Heat Exchanger. Given that Pump Efficiency = 75%, Motor efficiency = 90 %, Effectiveness of water cooled heat exchanger is 0.4, water is available at 25 ^{O}C & Pressure drop in plate heat exchanger is 1.2 kg/cm^2 , Over all heat transfer coefficient of heat exchanger is 22300 Kcal/m^2/^{O}C. 1. Calculate the savings due to replacement by water cooled heat exchanger 2. Calculate the heat transfer area of heat exchanger.
Ans	**Solution:** **Heat Duty** Heat duty in hot fluid = M x Cp_h x (T_i - T_o) = 63450 x 1 x (80 - 38) = 2664900 kcal / Kg …. (2 marks) Heat duty in cold Air = M x Cp_{air} x (to – ti) = 370057 x 0.24 x (60 – 30) = 2664410 Kcal / Kg …. (2 marks) In heat exchanger, Heat duty in hot fluid = Heat duty in cold Air Effectiveness of water cooled heat exchanger = 0.4 Effectiveness = $\frac{\text{Cold Water outlet – Cold water inlet}}{\text{Hot effluent inlet – Cold water inlet}}$ Cold Water Outlet = (0.4 x (80 – 25)) + 25 = 47 ^{O}C …. (2.5 marks) Mass flow rate of cooling water (M) = $\frac{\text{Heat duty in hot fluid}}{\text{Cp x (Cold water outlet – Cold water inlet)}}$ = $\frac{2664900}{1 \times (47 - 25) \times 1000}$ = 121.13 m^3 /hr …. (2.5 marks)

Pressure drop in Plate Heat exchanger = 12 m

Hydraulic Power Requirement for one Cooling Water Pump:

$$= \frac{(\text{Flow in } m^3/\text{Hr x Head in m x Density in } Kg/m^3 \text{ x g in } m/s^2)}{(1000 \times 3600)}$$

$$= \frac{(121.13 \times 12 \times 1000 \times 9.81)}{(1000 \times 3600)}$$

= 3.96 KW

…. (3 marks)

Pump Power Requirement at 75% pump efficiency $= \frac{3.96 \text{ KW}}{0.75}$

= 5.28 KW

…. (1 mark)

Motor Input Power Required at 90% Efficiency $= \frac{5.28}{0.9}$

= 5.87 KW

…. (1 mark)

Savings = Power consumption by fans – Water Pumping Power
= 30 – 5.87
= 24.13 KW

Annual Saving in kWh = 24.13 KW x 16 Hrs x 330 Days = 127406 KWh/Annum

…. (2 marks)

Calculations for LMTD for Proposed HEx:

LMTD for counter current flow in HEx

= {(80-47) – (38-25)} / ln {(80-47) / (38-25)}
= 21.5 Deg C

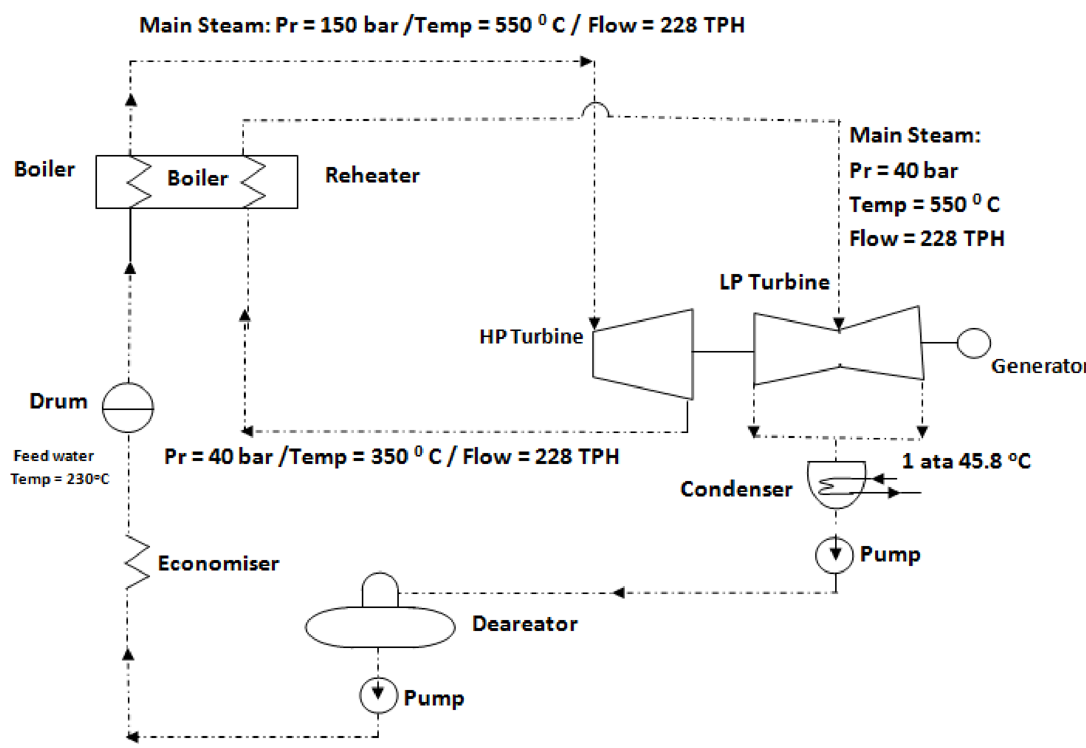
…. (2 marks)

Considering overall heat transfer coefficient (U) = 22300 kcal/$m^2/{}^0C$

Heat transfer Area $= \frac{Q}{(U \times \Delta Tlm)}$

$$= \frac{2664900}{(22300 \times 21.5)}$$

	= 5.6 m^2 (Say 6 m^2) …. (2 marks)
N-4	**Answer ANY ONE OF THE FOLLOWING among A, B, C and D**
A)	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 the LP Turbine. The exhaust steam from LP Turbine is condensed in a condenser at a pressure of 0.1 bar (a).The isentropic efficiency of HP Turbine and LP Turbine is same and is 90%. Generator efficiency is 95%



The other data of the power plant is as 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 45.80C
Isentropic enthalpy of LP Turbine exhaust steam : 2300 KJ/kg
Enthalpy of dry saturated steam at 0.1 bar(a) and 45.80C : 2584.9KJ/kg
Enthalpy of water at 0.1 bar(a) and 45.80C:191.9 KJ/kg

	Based on the above data calculate the following parameters (a) Power developed by the Generator (b) Turbine heat rate (c) Turbine cycle efficiency (d)Dryness fraction of LP Turbine Exhaust steam (e) Specific steam consumption of turbine cycle.
Ans	SOLUTION: (A) Power developed by the Generator: Turbine output x Generator efficiency--(1) Turbine output = Q_1 (H_1 – h_2) + Q_2(H_3 – h_4)/860 MW ----------- (2) Where, Q_1= main steam flow rate =228 TPH H_1=main steam enthalpy=3450 KJ/Kg h_2=actual enthalpy at HP Turbine outlet (cold reheat enthalpy) Q_2=steam flow through reheater = 228TPH H_3=enthalpy of hot reheat steam = 3560 KJ/kg h_4= actual enthalpy of LP turbine exhaust steam --- (1 mark) HP Turbine isentropic efficiency= Actual enthalpy drop/isentropic enthalpy drop 0.9 = (H_1- h_2) / (H_1-$h_2$is) $h_2$is = isentropic enthalpy of cold reheat steam = 3050KJ/kg 0.9 = (3450 – h_2) / (3450 - 3050) h_2= 3090 KJ/kg ---- (3 marks) LP Turbine isentropic efficiency= (H_3—h_4)/(H_3—$h_4$is), $h_4$is = isentropic enthalpy of LP Turbine Exhaust steam = 2300 KJ/kg 0.9 = (3560 - h_4) / (3560 - 2300) h_4 = 2426 KJ/kg ---- (3 marks) Substituting the values in equation-2,we get Turbine output = 228 x (3450 - 3090) + 228 x (3560 - 2426) / 860 = 75.73 MW Generator output = 75.73 x 0.95 = 71.5 MW ---- (3 marks) (B) Turbine heat rate = Q_1(H_1- hfw) + Q_2(H_3 - h_2)/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) / 71.5 = 9342 KJ/kWhr ---- (3 marks) (C) Turbine cycle efficiency = 860/Turbine heat rate = 860x 4.18 / 9342 = 38.5**%**

	---- (2 marks) (D) Dryness fraction of steam at 0.1 bar(a) and 45.8 ^{o}C Actual enthalpy of LP Exhaust steam = enthalpy of water + dryness fraction of steam x L.H of vaporisation of steam 2426 = 191.9 + dryness fraction of steam x (2584.9 - 191.9) Dryness fraction of steam = 93.35% ---- (3 marks) (E) Specific steam consumption of cycle = Steam flow / generator output = 228 / 71.5 = 3.19 tons/MWhr --- (2 marks)
	Or
B)	Stenter operations in a textile process were significantly improved to reduce inlet moisture from 60% to 55% in wet cloth while maintaining the same outlet moisture of 7% in the dried cloth. The Stenter was operated at 80 meters/min in both the cases. The dried cloth weighs 0.1 kg /meter. Further steps were taken to improve the efficiency of the fuel oil fired thermic fluid heater from 80% to 82%, which was supplying heat energy to the dryer. The other data and particulars are Latent heat of water evaporated = 540kcal/kg, Inlet temperature of wet cloth = 28^{o}C , Outlet temperature of dried cloth = 80^{o}C, Dryer efficiency = 50% , G.C.V of fuel oil = 10,300 kcal/kg, Yearly operation of the stenter = 5000 hours a) Find out the % reduction in Dryer heat load , b) Estimate the overall yearly fuel savings in tonnes by reducing moisture and efficiency improvement compared to the initial case. Assume only energy for moisture evaporation for dryer heat load
	Solution: **Initial case:** *Inlet moisture, 60%, outlet moisture 7%, dryer efficiency 50%, thermic fluid heater efficiency 80%* Output of stenter = 80 mts/min x 0.1 x 60 = 480 Kg/hr. …. (1 Mark) Moisture in the dried output cloth = 7% Wt. of bone- dry cloth = 480 X (1 – 0.07) i.e. W = 446.4 Kg/hr. ---- (1 mark) m_o= moisture in outlet cloth = (480–446.4) /446.4 = 0.0753 Kg/Kg.bone-dry cloth ---- (1 mark)

Inlet moisture = 60%
Wt. of inlet cloth = 446.4 / (1 – 0.60) = 1116.00 Kg./hr.

m_i = moisture in inlet cloth
= ((60/40) x 446.4)/446.4 = 1.5 Kg./Kg. bone- dry cloth
---- (1 mark)

Inlet temperature of cloth T_{in} = 28°C
Final temperature of cloth T_{out} = 80°C

Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr.
∴ Heat load on the dryer = 446.4 (1.5 – 0.0753) X [(80 – 28) + 540]
= 3,76,503.76 Kcal/hr
----(2.5 marks)

Efficiency of the dryer is 50%, Efficiency of the thermic fluid heater is 80%

Fuel oil consumption in the thermic fluid heater
= 3,76503.76/(0.5x 0.8x10300) = 91.40 kg/hr

---- (2.5 marks)

Improved case: *Inlet moisture, 55%, outlet moisture 7%, dryer efficiency 50%, thermic fluid heater efficiency 82%*

Inlet moisture = 55%
Wt of inlet cloth = 446.4 / (1 – 0.55) = 992.00 Kg./hr. ..(1 Mark)

m_i = moisture in inlet cloth
= ((55/45) x 446.4)) / 446.4
= 1.22 Kg./Kg. bone-dry cloth
---- (1 mark)

Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr.
∴ Heat load on the dryer = 446.4 (1.22 – 0.0753) X [(80 – 28) + 540]
= 3,02508.00 Kcal/hr
----(2.5 marks)

Efficiency of the dryer is 50%, Efficiency of the thermic fluid heater is 82%

Fuel oil consumption in the thermic fluid heater in impoved case
= 3,02,508.00/(0.5x 0.82x10300) = 71.63 kg/hr

---- (2.5 marks)

	(a) % reduction in dryer load due to reduction inlet moisture $= \frac{(3,76,504 - 3,02,508) \times 100}{(3,76,504)}$ = **19.65%** ---- (2 marks) (b) Saving in fuel oil consumption in improved case = 91.4 - 71.63 = 19.77 kg/hr **Yearly fuel oil savings = 19.77x 5000 x 1/1000** **= 98.85 tonnes** --- (2 marks)
	or
C)	In a steel industry, the composition of blast furnace gas by volume is as follows CO – 27%, H_2 - 2%, CO_2 – 11%, N_2 - 60%. i) Calculate the stoichiometric air for combustion ii) Calculate the gross calorific value of gas in kcal/Nm^3 iii) Calculate the net calorific value of gas in kcal/Nm^3 iv) If 3,00,000 Nm^3/hr of gas is available and is to be co-fired in a coal fired boiler. How much coal it can replace if the GCV of coal is 4000 kcal/kg.
Ans	(i) Stoichiometric air for combustion: C + O_2 ------ CO_2 + 8,084 kcal/kg Carbon 2C + O_2 ------ 2 CO + 2,430 kcal/kg Carbon H_2 + ½O_2 -------H_2O + 28,922 kcal/kg Hydrogen CO + ½ O_2 -------CO_2 + 5,654 kcal/kg Carbon ---- (2 marks) 1 mole CO + 0.5 mole O_2 ------ 1 mole CO_2 + 5654 kCal/kg For 27% CO, O_2 required is (0.5/1) x 0.27 = 0.135 O_2 ---- (2 marks)\\ 1 mole H_2 + 0.5 mole O_2 ------ 1 mole H_2O + 28922 Kcal/kg For 2 % of H_2, O_2 required is (0.5/1) x 0.02 = 0.01 O_2 ---- (2 marks) Total stoichiometric oxygen required = 0.135 + 0.01 = 0.145 O_2

	Stoichiometric air required = $\frac{100}{21}$ x 0.145 = **0.690 m^3 air / m^3 blast furnace gas** ---- (3 marks) (ii) Gross calorific value of gas: 1 kg mole of any gas at STP occupies 22.4 m^3 of volume. ---- (1 mark) Therefore, ((5654 x 12) / 22.4) x 0.27 = 817,83 kCal/m^3 (molecular weight of Carbon = 12) ---- (2 marks) ((28922 x 2) / 22.4) x 0.02 = 51.64 kCal/m^3 (molecular weight of Hydrogen = 2) ---- (2 marks) Gross Calorific Value = 817.83 + 51.64 = **869.5 kcal/m^3** ---- (1 mark) (iii) Replacement of coal by blast furnace gas: Gross calorific value of coal = 4000 kcal/kg (given) Blast furnace gas available = 3,00,000 m^3/hr (given) Heat content available from gas = 3,00,000 m^3/hr x 869.5 kcal/m^3 = 2608.5 x 10^5 kcal/hr ---- (2.5 marks) If X is the coal quantity to be replaced, then 4000 kcal/kg x X = 2608.5 x 10^5 kcal/hr **X = 65212 kg/hr of coal can be replaced by gas of 3,00,000 m^3/hr**. ---- (2.5 marks)
	or
D)	As an energy auditor, auditing a cement plant, it is essential to assess the specific coal consumption for the production of the clinker. With the following data available, calculate the specific coal consumption (kgCoal/ KgClinker).

S.No	Parameter	Value
1.	Reference temperature	20^{O}c
2.	Barometric pressure	10329 mmWC
3.	Density of the Pre-heater at NTP	1.436kg/m^3

4.	Density of Air	1.293Kg/m^3
5.	Pitot Tube Constant	0.85
6.	Clinker production rate	4127 TPD
7.	Static Pressure of the Pre-heater gas in the pre-heater duct	640mmWC
8.	Dynamic pressure of the pre-heater gas in the duct	15.8mmWC
9.	Temperature of the Pre-heater gas	320^{O}C
10.	Specific heat of the Pre-heater gas	0.247kCal/kg ^{0}C
11.	Area of the Pre-heater Duct	8.5 m^2
12.	Temperature of the exit clinker	128^{O}C
13.	Specific heat of the clinker	0.193 kCal/kg ^{0}C
14.	Static Pressure of the Cooler Exhaust gas in the duct	42mmWC
15.	Dynamic pressure of the Cooler Exhaust gas in the duct	15.5mmWC
16.	Temperature of the Cooler Exhaust gas gas	290
17.	Specific heat of the Cooler Exhaust gas	0.247kCal/kg ^{0}C
18.	Area of the Cooler exhaust duct	7.1m^2
19.	Heat of Formation of Clinker	405 Kcal/$Kg_{Clinker}$
20.	All other heat loss except heat loss through Pre-heater gas, exiting clinker and cooler exhaust gases	84.3 Kcal/Kg Clinker
21.	All heat inputs except heat due to Combustion of fuel (Coal)	29 Kcal/Kg Clinker
22.	GCV of the Coal	5500Kcal/Kg

Ans

Heat Lost in the along with the Exiting pre-heater gases:

$Q_{PH\ Gas} = m_{phgas} \times Cp_{phgas} \times (t_{ephgas} - t_r)$

$m_{phgas} = V_{phgas} X\ \rho_{Phgas}$

$V_{phgas} = v_{ph\ gas}$ X A

Corrected density of the pre-heater gas:

$$\rho_{Phgas} = 1.436 \times \frac{10329-640}{10334} \times \frac{273}{273+320}$$

$= 0.6198$ kg/ m^3 …… (1 Mark)

Velocity (v) $= P_t \times [(2g(\Delta P_{dynamic})_{avg} / \rho_{Phgas})]^{0.5}$ m/sec

$$= 0.85 \times \frac{\sqrt{2\times 9.81\times 15.8}}{\sqrt{0.6198}} \text{ m/sec}$$ …..(2 Marks)

= 19.0 m/sec

$V_{PH\ gas}$ = 19.0m^3/s X 8.5 m^2
= 161.5 m^3/sec
= 5,81,400m^3/hr ……(1 Mark)

$M_{ph\ gas}$ = 581400 m^3/hr X 0.6198 kg/m^3
=3,60,351/72 Kg/hr ……(1 Mark)

m_{phgas} = 3,60,351 kg/hr / 1,71,958 kg/hr = 2.095$Kg_{ph\ gas}$/ $Kg_{clinker}$

$Q_{PH\ Gas}$ = 2.095 X 0.247 X (320 -20)
= 155.24Kcal/$Kg_{Clinker}$

---- (1 mark)

Heat Lost in the along with the Exiting Hot Clinker:

$Q_{Hot\ clinker} = m_{clinker} \times Cp_{clinker} \times (t_{clinker} - t_r)$
= 1 x 0.193 x (128 – 20),
= 20.84 kCal/$kg_{Clinker}$

---- (2 marks)

Heat Lost in the along with the Exiting Cooler Exhaust gases:

$Q_{Cooler\ Exhaust\ Gas} = m_{Cooler\ Exhaust\ Gas} \times Cp_{Cooler\ Exhaust\ Gas} \times (t_{Cooler\ Exhaust\ Gas} - t_r)$
$m_{Cooler\ Exhaust\ Gas} = V_{Cooler\ Exhaust\ Gas}$ X $\rho_{Cooler\ Exhaust\ Gas}$
$V_{Cooler\ Exhaust\ Gas} = v_{Cooler\ Exhaust\ Gas}$ X A

Corrected density of the pre-heater gas:

ρ Cooler Exhaust gas $= 1.293 \times \frac{10329 - 42}{10334} \times \frac{273}{273 + 290}$

$= 0.624$ kg/ m^3 ….. (1 Mark)

Velocity (v) $= P_t \times \sqrt{(2g(\Delta P_{dynamic})_{avg} / \rho_{\text{Cooler Exhausts}})}$ m/sec

$= 0.85 \times \frac{\sqrt{2 \times 9.81 \times 15.5}}{\sqrt{0.624}}$ m/sec

$=$ 18.76 m/sec ……(2 Marks)

$V_{coolerExhaustgas}$ = 18.76m/s X 7.1 m^2

= 133.196 m^3/sec

= 4,79,505m3/hr ……..(1 Mark)

$M_{coolerExhaustgas}$ = 479505 m^3/hr X 0.624 kg/m^3

=2,99,211 Kg/hr ……(1 Mark)

$m_{coolerExhaustgas}$ = 2,99,211 kg/hr / 1,71,958 kg/hr =1.74 $Kg_{coolerExhaustgas}$/ $Kg_{clinker}$

$Q_{coolerExhaustgas}$ = 1.74 X 0.244 X (290 -20) ……(1 Mark)

= 114.63Kcal/$Kg_{Clinker}$

---- (1 mark)

Heat Input = Heat output

Heat Input_{coal} + $\text{Heat input}_{others}$ = $\text{Heat}_{\text{Clinker formation}}$ + $\text{Heat}_{\text{PH gas}}$ + $\text{Heat}_{\text{Clinker}}$ + $\text{Heat}_{\text{cooler exhaust gas}}$ + Heat_{others}

GCV_{coal} X m_{coal} + 29 = 405 + 155.24 + 20.84 +114.63 + 84.3

m_{coal} = 751 / 5500

= 0.137 Kg_{coal}/$Kg_{clinker}$

---- (4 marks)

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