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**

General instructions:

- *Please check that this question paper contains **6** 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	A direct driven centrifugal fan delivers more air after replacing its standard motor drive with an energy efficient motor. Why?
Ans	Since motor slip is reduced, speed increases and hence fan flow increases.
S-2	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-3	Due to gradual choking of AHU filter, AHU fan power decreased. Why?
Ans	Due to increased resistance, the air flow decreased.
S-4	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-5	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-6	If the heat rate of a power plant is 2867 kCal/kWh, what is the efficiency of power plant?
Ans	860/2867 x 100 = 30%

S-7	In low load region, current measurements are not a right indicator of motor loading. Why?
Ans	PF will be low.
S-8	The dry bulb and wet bulb temperatures of air entering an air washer are 35 and 28 ^{0}C 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-9	Why can't a boiler in normal operating conditions deliver its rated capacity?
Ans	Because boiler are rated from and at 100^{o}C.
S-10	Why are water-cooled condensers more efficient than air-cooled condensers for refrigeration applications?
Ans	In water cooled condensers, the cooling water temperature can be bought below dry bulb temperature.

…………. 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	In a counter current heat exchanger, the hot stream enters at 70°C and leaves at 40°C. On the other hand, the cold stream enters at 20°C and leaves the heat exchanger at 50°C. Determine the heat transferred in Kcal/hour if the area is 30 m^2 and overall heat transfer coefficient is 800 W/m^2 K
Ans	**For counter-current type**: $LMTD = \frac{(70-50) - (40-20)}{\ln(70-50/40-20)}$ $= \frac{20 - 20}{\ln(20/20)}$ $= 0$ ---- (1.5 marks) In this case LMTD is the same as the temperature difference on each end of the heat exchanger (terminal temperature difference). Hence LMTD = 20^{o}C for counter-current flow. ---- (1.5 marks)

	Heat transfer = (800 /1000) x 30 x 20 x 860 = 4,12,800 kcal/hr ---- (2 marks)
L-2	The gross heat rate of a thermal power plant is 2550 kcal/kWh and its net heat rate is 2833.33 kcal/kWh. The plant is targeting to improve the net heat rate by 30 kcal/kWh through reduction in auxiliary power consumption. What will be its % auxiliary power consumption with the above improvement and incremental reduction in auxiliary power consumption.
	Solution: **Existing case:** Gross heat rate = 2550 kcal/kwh , Net heat rate: 2833.33 kcal/kwh % Auxiliary power consumption in the existing case = [I – (2550/2833.33)] x 100 = 10 ---- (2 marks) **Improved case:** Net heat rate = 2833.33 – 30.00 = 2803.33 kcal/kwh % Auxiliary power consumption in the improved case = [I – (2550/2803.33)] x 100 = 9 ---- (2 marks) Incremental reduction in Auxiliary power consumption = 10 - 9 = 1 % . ----- (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	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 975 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: (1) What is the average plant energy utilization factor (2) Calculate the useful energy produced daily by the trigeneration plant in MTOE (3) Determine the daily plant natural gas requirements based on average energy utilization factor (4) 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	**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_{Ele}	=	650 KW
	Q_{Heat}	=	975 x 530
		=	516750 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 +516750 x 10 + 644112 x 14)
		=	13416000 + 5137500 + 9017568
	The useful energy produced daily	=	27601068 kcal/day
	The useful energy produced in MTOE/day	=	**2.760**
			….(4 marks)
	3)The daily plant natural gas requirements		
	Input heat	=	27601068 / 0.78
		=	35385985 kcal/day
	Natural gas requirements	=	35385985 **/** 8500
		=	**4163 Sm^3/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-2	An engineering industry has a compressor of capacity 1700 m^3/h in operation. Free air delivery test of the compressor was carried out by filling the receiver. The test and other data are given		

	below. Receiver capacity : 10 m^3 Interconnecting pipe : 1 m^3 Atmospheric pressure : 1.03 kg/cm^2a Initial pressure in receiver : 1.0 kg/cm^2a Inlet air pressure to compressor : 1.0 kg/cm^2a Final pressure : 3.5 kg/cm^2a Time taken to fill the receiver : 3 minutes (180 seconds) Inlet air temperature : 30 ^oC Air temperature in the receiver : 40 ^oC Motor rpm (N_1) : 1400 rpm Motor pulley diameter (D_1) : 300mm Compressor rpm (N_2) : 700 rpm Compressor Pulley diameter (D_2) : 600 mm Average duration of loading : 40 minutes in an hour Average duration of unloading : 20 minutes in an hour Power consumption during loading : 150 kW Power consumption during unloading : 45 kW Cost of energy : Rs. 5.00 per kWh A: What is the operating free air delivery of the compressor? B: Evaluate the cost of energy per day (24hrs operation). C: The Plant was interested in reducing the unloading time of the compressor by reducing the pulley diameter of the motor. Evaluate the speed of the compressor required for a cycle of 10 minutes unloading and 50 minutes loading and accordingly evaluate the diameter of the pulley of the motor. D: Estimate the hourly power consumption and energy savings after replacement of the pulley and payback period. Consider the cost of pulley and belt is Rs 40,000 and operating hours of the compressor is 8000 in a year. (consider that the power consumption was 120 kW during loading and 35 kW during unloading)
Ans	**A. Operating free air delivery of the compressor**, $Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T}$ $Nm^3/Minute$ Applying for temperature correction factor (273 + t_1) / (273 + t_2), Operating free air delivery is: $Q_1 = \frac{3.5 - 1.0}{1.03} \times \frac{11}{3} \times \frac{(273 + 30)}{(273 + 40)}$ = 8.9 **m^3/hr** x 0.968 = 8.6 Nm^3/min = **516 Nm^3/hr**. **---- (5 marks)**

B. Cost of energy per day

Average power consumption per hour = $\frac{(150 \times 40) + (45 \times 20)}{(40 + 20)}$

= **115 kW**.

Average energy consumption per day = 115 x 24

= **2760 kWh**.

Cost of energy per day = 2760 x 5 = **Rs. 13,800 per day**.

---- (5 marks)

C. Speed of compressor and Pulley diameter of motor

(for 10 minutes unloading and 50 minutes loading)

Air flow rate $Q_2 = \frac{(516 \times 50) + (0 \times 10)}{60}$

$= 430\ m^3/hr.$

$(Q_1 / Q_2)_{compressor} = (RPM_1 / RPM_2)_{compressor}$

$516 / 430 = 700 / RPM_2$

$RPM_2 = 583$ rpm.

$(RPM_1 / RPM_2)_{Compressor} = (D_1/D_2)_{Motor}$

$700/583=300/ D_2$

$D_2 = 250$ mm.

(or) $(Q_1 / Q_2)_{compressor} = (D_1 / D_2)_{Motor}$

$516 / 430 = 300 / D_2$

$D_2 = 250$ mm.

Reduced motor pulley diameter = **250 mm**

Reduced speed of the compressor = **583 rpm**

---- (5 marks)

D. Energy Savings and Payback period(after replacement of pulley)

Average power consumption per hour = $\frac{(120 \times 50) + (35 \times 10)}{(50 + 10)}$

	= **105.8 kW**. Power Savings = 115 – 105.8 = **9.2 kW.** **Annual energy savings = 9.2 x 8000 = 73600 kWh/year**. Annual cost savings = 73600 x 5 = **Rs. 3,68,000/year**. **Payback Period = 40,000 / 3,68,000 = 1.3 months.** **---- (5 marks)**
N-3	Chilled water is circulated through the evaporator of a vapor compression chiller and the outlet chilled water temperature is 7°C. The evaporator is maintained at 2.5°C. Terminal Temperature Difference (TTD) on the chilled water inlet side is 5°C higher than chilled water outlet side. Other given data: • Overall heat transfer coefficient of the evaporator is 542.42 kcal/hr $m^{2o}C$ • Area of the evaporator is 250 m^2 • Efficiency of the compressor motor is 88% • Condenser heat load is 20% more than the evaporator cooling load. Calculate a. LMTD of the evaporator b. Refrigeration load or evaporator cooling load in tonne of refrigeration(TR) c. C.O.P. of the chiller d. Compressor input kW/TR e. Indicate the operating parameters and the calculated values in a simple schematic diagram f. Find out the energy savings if the chilled water supply to one of the process heat exchanger with a heat load of 90,000 kcal/hr operating for 6000 hrs in a year is eliminated by process modification
	Solution a. $\Delta T_2 = T_o - T_E = 7 – 2.5 = 4.5^oC$ $\Delta T_1 = \Delta T_2 + 5 = 4.5 + 5 = 9.5^oC$ $\Delta T_1 = T_i - T_E = 9.5^oC$ $T_i = 9.5 + 2.5 = 12^oC$ $T_i – T_o = 12 – 7 = 5^oC$

$$\text{LMTD of evaporator} = \frac{\Delta T_1 - \Delta T_2}{\ln 9.5 / 4.5} = 6.69\ ^{o}C$$

---- 4 marks

b. Refrigeration load or evaporator heat load

Heat load = U(kcal/hr m^2 ^{o}C) x A (m^2) x LMTD ^{o}C

= 542.42 x 250 x 6.69

= 9,07,197.45 kcal/hr

Refrigeration load = 9,07,197.45/3024

= 300 TR

---- 4 marks

c. Condenser heat load = 300 x 1.2 = 360 TR

d. Compressor input (heat energy) equivalent = 360 – 300 = 60 TR

COP = 300 / 60 = 5

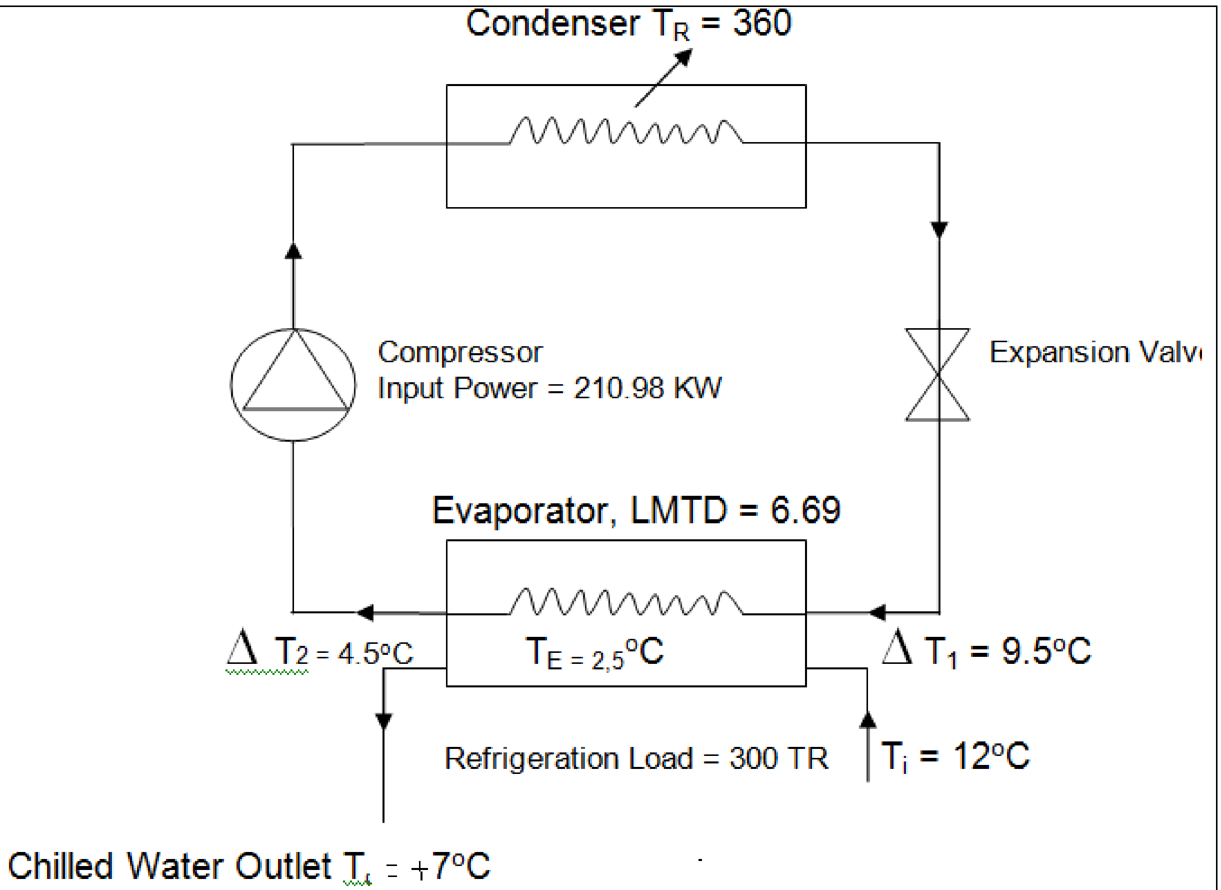
Electrical input power to compressor motor

Input KW for compressor = 60 x 3024 / 860 = 210.98

Compressor chiller KW / TR = 210.98 / 300 = 0.703

---- 4 marks

e.



Schematic of the Vapor Compression Water Chiller indicating the operating parameters and the calculated values

---- 4 marks

f. Reduction in chiller load = 90,000.00 kcal/hr

Reduction in refrigeration load = (90000.00) / 3024 = 29.76 TR

Compressor input power is 0.703kW/TR, motor efficiency is 88%

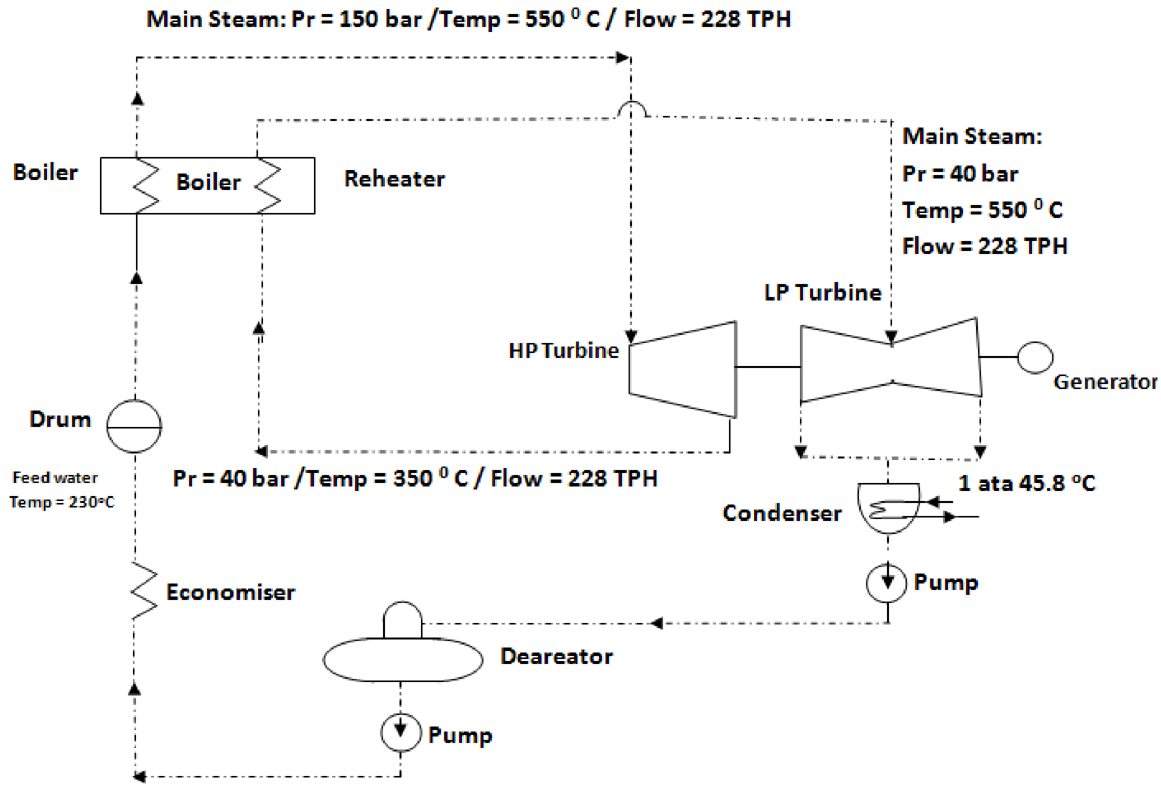
Saving in electrical energy = (29.76 x 0.703) / 0.88 = 23.774 KW

Annual energy savings = 23.774 x 6000 = 1,42,644 kWh

---- 4 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 reheatedin 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 efficiency of HP Turbine and LP Turbine is same and is 0.9. 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 45.8^{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 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 = 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=? ---- (1 mark) 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 ---- (3 marks) 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 ---- (3 marks) Substituting the values in equation-2,we get Turbine output = 228(3450—3090) + 228(3560—2426)/860 =75.73MW Generator output= 75.73 x 0.95= 71.5 MW ---- (3 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)/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 45.8^0C 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 of 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 from 80% to 82%, which was supplying heat energy from to the dryer. The other data and particulars are, Latent heat of water evaporated = 540kcal/kg, Inlet temperature of wet cloth = 28ºC , Outlet temperature of dried cloth = 80ºC, Dryer efficiency = 50% , G.C.V of fuel oil = 10,300.00 kcal/kg, Yearly operation of the stenter = 5000 hours Find out the % reduction in Dryer heat load , 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 only for dryer heat load
Ans	**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. Moisture in the dried output cloth = 7% Wt of bone- dry cloth = 480 X (1 – 0.07) i.e. W = 446.4 Kg/hr. ---- (1.5 mark) m_o = moisture in outlet cloth= (480 – 446.4) /446.4 = 0.0753 Kg/Kg bone-dry cloth ---- (1mark) Inlet moisture = 60% Wt of inlet cloth = 446.4 / (1 – 0.60) = 1116.00 Kg./hr. m_i = moisture in inlet cloth

= (1116-446.4) ÷ 446.4
= 1.5 Kg./Kg. bone- dry cloth

---- (1 mark)

Inlet temperature of cloth T_{in} = 28^oC
Final temperature of clothT_{out} = 80^oC

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

---- (3 marks)

Efficiency of the dryer is50%, 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)

Improve 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.

m_i = moisture in inlet cloth
= (992-446.4) ÷ 446.4
= 1.22 Kg./Kg. bone-dry cloth

---- (1.5 marks)

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

---- (3 marks)

Efficiency of the dryer is50%, 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)

% 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)

Saving in fuel oil consumption in improved case
= 91.4- 71.63
= 19.77 kg/hr

	Yearly fuel oil savings =19.77x5000 x1/1000 =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) <u>Stoichiometric air for combustion</u>: $\left.\begin{array}{l} C + O_2 \text{ ------ } CO_2 + 8{,}084 \text{ kcal/kg Carbon} \\ 2C + O_2 \text{ ------ } 2\,CO + 2{,}430 \text{ kcal/kg Carbon} \\ H_2 + ½O_2 \text{ -------} H_2O + 28{,}922 \text{ kcal/kg Hydrogen} \\ CO + ½\,O_2 \text{ -------} CO_2 + 5{,}654 \text{ kcal/kg Carbon} \end{array}\right\}$ Available in Book-2 ---- (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) <u>Gross calorific value of gas</u>: 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/ kg Clinker).

S.No.	Parameter	Value
1.	Reference temperature	20^{O}C
2.	Barometric pressure	10329 mmWC
3.	Density of the gas at Pre-heater at NTP	1.436 kg/m^3
4.	Density of Air	1.293 kg/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	640 mmWC
8.	Dynamic pressure of the pre-heater gas in the duct	15.8 mmWC
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	5500 kcal/kg

Ans

Solution:

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

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

$$= 0.85 \times \frac{\sqrt{2 \times 9.81 \times 15.8}}{\sqrt{0.6198}} \text{ m/sec}$$

= 19.0 m/sec

$V_{PH\ gas}$ = $19.0m^3/s$ X 8.5 m^2

= 161.5 m^3/sec

= 5,81,400m3/hr

$M_{ph\ gas}$ = 581400 m^3/hr X 0.6198 kg/m^3

= 3,60,351/72 kg/hr

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)
= 155.24 $kcal/kg_{Clinker}$

---- (7 marks)

Heat Lost 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 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:

$$\rho_{Cooler\ Exhaust\ gas} = 1.293 \times \frac{10329 - 42}{10334} \times \frac{273}{273 + 290}$$
= 0.624 kg/ m^3

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

$$= 0.85 \times \frac{\sqrt{2 \times 9.81 \times 15.5}}{\sqrt{0.624}} \text{ m/sec}$$
= 18.76 m/sec

$V_{coolerExhaustgas}$ = 18.76m/s X 7.1 m^2
= 133.196 m^3/sec
= 4,79,505m3/hr

$M_{coolerExhaustgas}$ = 479505 m3/hr X 0.624 kg/m^3
=2,99,211 Kg/hr

$m_{coolerExhaustgas}$ = 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)
= 114.63$Kcal/Kg_{Clinker}$

---- (7 marks)

Heat Input = Heat output
$Heat\ Input_{coal} + Heat\ input_{others} = Heat_{Clikerfrmtn} + Heat_{PH\ gas} + Heat_{Cliker} + Heat_{cooler\ exhaust\ gas} + Heat_{others}$

	$GCV_{coal} X\ m_{coal} + 29 = 405 + 155.24 + 20.84 + 114.63 + 84.3$ $m_{coal} = 751 / 5500$ $= 0.137\ Kg_{coal}/Kg_{clinker}$ ---- (4 marks)

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