PAPER-4 COLOUR CODE: PINK

24th NATIONAL CERTIFICATION EXAMINATION

FOR ENERGY MANAGERS AND ENERGY AUDITORS – SEPTEMBER, 2024

PAPER -4 – ENERGY PERFORMANCE ASSESSMEN T FOR EQUIPMENT AND UTILITY SYSTEMS

SECTION –I : BRIEF QUESTIONS **Marks 10x1=10**

State True or False (Each question carries 1 Mark)

1. The excess air in cement kiln combustion can be assessed by measuring CO_2 % in kiln exhaust- **False**
2. A higher Solar Cooling Load Factor (SCL) results in a lower air-conditioning load.- **False**
3. For a 20 MW co-generation plant, a backpressure turbine system configuration will have less steam rate (kg/kWh) compared to an extraction condensing turbine **- False**
4. The heat transfer coefficient of a shell and tube heat exchanger is reduced solely due to changes in the temperatures of the cold and hot fluids. **- False**
5. For a given motor rating, stray losses as a percentage decrease with a change in the output kW of the motor. **- False**
6. The air velocity is uniform across the cross section of a circular duct. **- False**
7. A pump operating with VFD at a low speed to accommodate a high static head does not adhere to the affinity laws **- True**
8. Lower CO percentage in flue gas indicates better combustion efficiency **- True**
9. Higher power factor results in higher power loss in the power system**- False**
10. Increasing the condenser vacuum will increase the heat rate of a thermal power plant.**- False**

******** End of Section -I ********

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

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

L-1

A medium-sized rerolling plant has installed a batch-type reheating furnace. The furnace operating details are as follows:

Average Furnace Oil Consumption : 1565 LPH
Average Production : 36 TPH
Cost of Furnace Oil : Rs 35/kg
Cost of Electricity : Rs 9.25/kWh
Furnace Oil Density : 0.93 kg/liter
GCV of Furnace Oil : 10,200 kCal/kg
Billet Loading Temperature : 35 °C
Billet Reheat Temperature : 1250 °C
Mean Specific Heat of Billet : 0.13 kCal/kg°C

The plant management has proposed replacing the reheating furnace with a 95% efficient electric furnace.

Calculate the following:

a) Oil fired furnace efficiency.
b) The specific energy consumption for both the cases and comment on the plant management proposal based on the cost benefits.

Solution: Heat to Billet = m cp Δt

Production	36	TPH
Production	36000	Kg/T
Sp Heat of Billet	0.13	kcal/kg
Billet Final Temperature	1250	Deg°c
Billet Loading temperature	35	Deg°c
Heat required for the Billet(mcpΔT)	5686200	kCal/hr
Furnace oil Consumption	1565	LPH
Density	0.93	
Furnace oil Consumption	1455.45	Kg/hr
GCV of Furnace Oil	10200	Kcal/Kg
Heat Input	14845590	Kcal/Hr
Furnace Efficiency	**38.3**	**%**

SEC Oil	***43.5***	***Ltrs/T***
	40.43	***Kg/T***
Cost/ton with FO	***=40.43x 35 =1415.05***	***Rs***
Electrical furnace Efficiency	95	%
Heat to billet	5686200	Kcal/hr
Electricity Heat	860	Kcal/kwh
Equivelent kWh required	6611.86	Kwh
kWh at 95 % Furnace Efficiency	6960	Kwh
SEC Electrical	***193***	***Kwh/Ton***
Cost/ton with electrical furnace	***1785***	***Rs***

Conversion to Electrical is not Economical.

L-2

In a chemical plant, a cooling water pump supplies cooled water to both the process and the refrigeration system. During performance testing, the following operating parameters were recorded:

Measured Data:

Rated Flow : 2124 m^3/hr
Rated Head : 70 m
Running Pump Flow (Q) : 1700 m^3/hr
Motor Input Parameters : V = 440 V, I = 480 A, Power Factor = 0.89,
Motor losses : 19.5 kW
Suction Head : 1 m
Delivery Head : 55 m

Calculate the following:

(a) Pump Efficiency (Hydraulic Efficiency)
(b) Overall Pump Set (Pump + Motor) Efficiency

Solution:

Flow Delivered by pump = 1700 m^3/hr = 0.47 m^3/s
Head Differential (h) = Delivery Head – Suction Head (m) = 55 – 1 = 54 m

Hydraulic Power = $\rho \; x \; g \; x \; Q \; x \; h$
= 1000 x 9.81 x 0.47x 54/1000 = 249 kW

Motor Input = 1.732 x V x I x Cos (phi) = 1.732 x 440 x 480 x 0.89/1000 = 325.5 kW

Motor Output = Motor Input – Motor Losses = 325.5 – 19.5 = 306 kW

Pump Input = Motor Output

(a) Pump Efficiency

Hydraulic Efficiency = Pump Output/Pump Input x 100

Hydraulic Efficiency = 249/306 x 100 = 81.4 %

(b) Overall Efficiency

Overall Efficiency = Pump Output/Motor Input x 100

Overall Efficiency = 249/325.5 x 100 = 76.5%

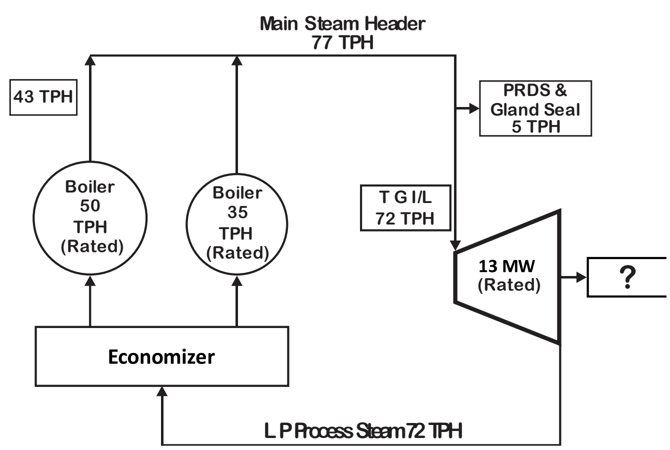
******** End of Section -II ********

SECTION –III: LONG NUMERICAL QUESTIONS **Marks 4 x 20 = 80**

- **(i) Answer all the <u>Four</u> questions**
- **(ii) Each question carries <u>Twenty</u> marks**

N-1

One of the sugar plant, operating at 4,000 TCD (Tonnes of Crushing per day), has installed a 13 MW back pressure turbine co-generation system. The co-generation plant comprises of one old bagasse-fired boilers with a capacity of 50 TPH and another with 35 TPH. This co-generation plant meets both the steam and power demands of the sugar plant and exports power to the grid during the crushing season. The power required for the sugar plant is 29 kW per tonne of crushing. The schematic of the present system is given below:



The plant management has conducted an energy audit of the sugar plant and the co-generation system. The energy auditor has recommended replacing the existing co-generation system with a high-pressure boiler of 80 TPH and a back pressure steam turbine to increase power export.

The operating details for both the existing and proposed systems are presented in the table below:

Description	Units	Present Co-Gen System	Proposed Co-Gen System
Bagasse GCV	kCal/kg	2270	2270
Boiler steam generation pressure	$kg/cm^2(g)$	42	85
Boiler super heat steam temperature	°C	485	520
Main steam pressure enthalpy	kCal/kg	815	823
Feed water temperature	°C	95	105
Turbine inlet steam pressure	$kg/cm^2(g)$	42	85
Turbine inlet steam temperature	°C	480	520
Turbine inlet steam flow	TPH	72	72
Inlet steam enthalpy	kCal/kg	812	823
Turbine back pressure	$kg/cm^2(g)$	1.5	1.5
Back pressure steam enthalpy	kCal/kg	676	676
Back pressure steam temperature	°C	178	178
Boilers operating efficiency	%	67 (Avg)	74
Turbine efficiency	%	90	92
Alternator efficiency	%	96	96
Cost realised for exported power	Rs./kWh	5.25	5.25
Auxiliary power consumption for the co-generation plant	%	6	6
Steam consumption for PRDS & Gland Seal	TPH	5	5

Calculate the following:

a) Power generation in the present and proposed system.

b) Power export with the present and proposed system.

c) Bagasse consumption in the present and proposed system.

d) Savings in bagasse with the proposed system.

e) Heat-to-power ratio (kW_{th}/kW_e) of the present and proposed co-generation system.

f) Heat-to-power ratio (kW_{th}/kW_e) of the sugar plant.

g) Steam rate (kg of steam per kW) for the present and proposed system.

h) Energy Utilization Factor (EUF) in the present and proposed system.

Solution :

Daily Crushing Load = 4000TCD

Crushing Load/Hour = 4000/24 =166.6 TPH

Power required = 29 kW /Tonne

= 29x166.66= 4833 Kw

Power Generation

Stem inlet to turbine = 72 TPH

Inlet Enthalpy = 812 Kcal/kg

Backpressure Enthalpy = 676 Kcal/kg

Power Generation potential in kW = 72 x1000 x (812-676)/860= 11386 Kw

Turbine and alternator efficiency = 11386 x 0.9 x0.96 = 9837 Kw (Gross Gen)

Auxiliary Power Consumption in Co-Gen: 6% of gross generation

Sugar Plant = 4833 kW

Power Export in Present System = (0.94*9837)-4833 = 4413.78 kW

Steam Rate Kg/kw = 72000/9837= 7.32 kg/kW

Present boiler Efficiency = 67 %

Bagasse Required = 77 x1000 (815-95)/2270 x 0.67

= 36.45 TPH

Heat to power ratio of cogenator =

kW Thermal = 72 x1000 x (676-95)/860 = 48641.86 kW

kW Electrical = 9837

Kwth/Kwe = 48641.86/9837= 4.94

Energy Utilisation Factor in Present system= (Q Elect+ Q ther)/ Q Fuel

= (9837x860+72000x(676-95))/ (36.35x1000 x2270) x100

= 60.95%

Heat to power ratio of Sugar Plant

Kw Thermal = (72 x1000 x (676-95))/860=48641.86 Kw

Kw Electrical = 4833

Kwth/Kwe = 48641.86/4833 = 10.1

Power generation with High Pressure Cogeneration System

= (72000 x(823-676))/860= 12307 Kw

Applying Turbine and Alternator Eff Actual Power Generation

= 0.92 x0.96 x 12307= 10869 kw

Steam Rate Kg/kw = 72000/ 10869 = 6.62 kg/kW

Export with High Pressure Cogeneration=(0.94*10869)-4833- Kw= 5383.86 kW

Additional Export with High Pressure Cogeneration Plant = 5383.86-4413.78= 970.08 Kw

Bagasse required for High pressure Cogeneration system= 77000*(823-105)/(2270 x0.74)

= 32.91 TPH

Savings in Bagasse =36.45-32.91 = 3.54 TPH

Energy utilisation with High Pressure Cogeneration= =(Q Elect+ Q therm)/ Q Fuel

= (10869x860+72000x(676-105))/ (32.91x1000 x2270) x100

= 67.5%

N-2

A medium-sized textile processing plant has installed a 20 TPH traveling grate coal-fired boiler. As part of a green energy initiative and to optimize steam costs, the plant management has proposed replacing the coal-fired boiler with a paddy husk boiler. The ultimate analysis of paddy husk and other boiler operating parameters are provided below.

Average Monthly Steam Demand	: 10800 Tonnes
Operating hours per month	: 720 Hours
Coal-Fired Boiler Efficiency	: 67 %
Steam Generation Pressure	: 12 kg/cm ^{2}
Steam Enthalpy	: 665 kcal/kg
Ambient temperature	:32 °c
Feed Water temperature	: 84 °C
Exit Flue Gas temperature after APH	: 225 °C
Oxygen % In Flue gas before APH with Coal as Fuel	: 8%
Oxygen % In Flue gas before APH with Paddy husk as Fuel	: 6%
Radiation loss accounted for Husk Boiler	:1.6%
Humidity factor	: 0.025 Kg/Kg dry air
GCV of Coal	: 4200 kcal/kg
GCV of Paddy Husk	: 3500 kcal/Kg
Cost of Coal	: Rs 12000/Tonne
Cost of Rice Husk	: Rs 4700/ Tonne
Auxiliary Cost for coal fired boiler	: Rs 750/tonne
Auxiliary Cost for paddy husk boiler	: Rs 550/tonne

Ultimate Analysis of Paddy Husk (%):

Moisture	:10.79
Mineral Matter	:16.73
Carbon	:33.95
Hydrogen	:5.01
Nitrogen	:0.91
Sulphur	:0.09
Oxygen	:32.52

Calculate the following:

a) Evaporation ratio of the coal-fired boiler

b) Steam cost (fuel cost + auxiliary cost) of the coal-fired boiler in Rs/tonne

c) Efficiency of the paddy husk boiler using the indirect method
d) Evaporation ratio of the paddy husk boiler
e) Steam cost (fuel cost + auxiliary cost) of the paddy husk boiler in Rs/tonne

Solution :

Coal Fired Boiler Efficiency	= 67 %
GCV of Coal	= 4200 Kcal/kg
Steam Generation Pressure	= 12 kg/Cm ^{2}
Steam Enthalpy	= 665 kcal/kg
Feed Water temperature	= 84 °**C**
Evaporation Ratio	= (4200 x 0.67)/ (665-84)
	= 4.84
Cost of Coal	= 12000/Tonne
Cost of Coal Fired Boiler Steam	=12000/4.84
	= Rs2479/Tonne
Auxiliary cost	= Rs 750/Tonne
Total cost of steam from Coal Boiler	*= Rs(2479+750) = Rs 3,229/Tonne*

Efficiency of Paddy Husk Boiler:

Theoretical air required for complete combustion Paddy Husk

= {11.6. C + [34.8 (H2 – O2/8)] + 4.35 S} / 100

= {11.6 x 33.52 [34.8 (5.01 –32.53/8)] + 4.35 x 0.09} / 100 = 4.27 Kg/ Kg of Husk

% O2 in fuel gas = 6

% Excess air = [%O2 / (21 - % O2)] x 100 = [6 / (21 –6)] x 100 = 40%

Actual Air Supplied (ASS) = (1 + 0.4) x 4.27 = 5.98 Kg/Kg fuel

Mass of dry flue gas = mdfg

Mass of dry flue gas = mass of combustion gases due to presence C, S, O2, N2 + mass of N2 in air supplied Mdfg = 0. 3395x (44 / 12) + 0.0009 x (64 / 32) + [(5.98 – 4.27) x (23 / 100)] + 5.98 x (77/100) Mdfg = 6.165 Kg/Kg fuel

Alternatively, Mdfg. = (AAS+1) – (9xH_2) – Mmoist = (5.98+1) – (9 x 0.0501) - 0.1079 = 6.34 kg/kg fuel

% heat loss in dry flue gas = mdfg x Cpf x (Tg – Ta) / GCV of fuel

Tg = flue gas temperature = 225°c

Ta = ambient temperature = 32°c

Cp = SP ht of flue gas = 0.24 Kcal/KgC (Value referred from the guidebook)

GCV = Gross Calorific Value of Paddy Husk =3500 Kcal/kg

L1 = % heat loss in dry flue gases = [(6.34 x 0.24 x (225-32))/3500] X 100 = 8.4 %

Heat loss due to evaporation of water due to H_2 in fuel = {9 x H_2 [584 + CPS (Tg – Ta)]} / GCV
CPS = Specific heat of superheated steam = 0.43 Kcal/Kg (Value referred from the guidebook)

L2 = {9 x 0.0501 [584 + 0.43 (225 – 32)] / 3500} x 100 = 8.59%

L3 = % heat loss due to moisture in fuel == M x[584 + CPS (Tg – Ta)/GCV

L3=0.1079 x (584+0.43(225-32)/3500=2.06 %

L4 = AAS x humidity factor x CPS x (Tg – Ta) / GCV Humidity factor = 0.025 Kg/Kg dry air

L4 = {[5.98 x 0.025 x 0.43 (225-32)] / 3500} x 100 = 0.35%

L5 = Radiation and convection loss from the boiler = 1.6% (given data)

Total losses in the boiler in %= L1 + L2 + L3 + L4 + L5 = 8.4+8.59+2.06+0.35+1.6=21
Efficiency of boiler by indirect method = 100 – 21% = 79 %

Evaporation Ratio of Paddy Husk Boiler = 3500 X 0.79/ (665-84) = 4.76

Cost of Paddy Husk = Rs 4700

Cost of steam from paddy Husk Boiler= 4700/4.76= Rs.987.4/Tonne

Auxiliary Cost = Rs 550/tonne

Total Steam Cost with Paddy husk Boiler = Rs 1537.4/Tonne

N-3

A steam turbine power plant utilizes a Circulating Water (CW) system with an Induced Draft Cooling Tower (IDCT) for condenser cooling. The steam flow rate to the condenser is 440 T/hr. It is observed that 45 m^3 of CW is needed to condense 1 T of steam.

To compensate for the water loss from the IDCT sump, two makeup water pumps each with a capacity of 220 m^3/hr are available in parallel. During operation, it was observed that a single pump delivers 200 m^3/hr and both pumps operating in parallel deliver 350 m^3/hr together. One pump operates continuously and the second pump switches on when the IDCT sump level falls below 90% of its full capacity. The second pump is switched off once the sump is full.

The TDS of circulating water is 2,000 ppm and the TDS of the makeup water is 500 ppm. The cooling tower operates with an effectiveness of 63% and an approach of 4°C. The size of the IDCT sump is 100 m x 15 m x 40 m and to maintain proper water chemistry, a continuous blowdown from the sump is given.

During steady state operation, calculate the following:

a) Evaporative loss in m^3/hr, blow down in m^3/hr and draw mass flow diagram of the system with all the flow rates and losses.

b) What is the time period in hours for which only one IDCT makeup pump is in service?

c) What is the time period in hours for which both the IDCT makeup pumps are in service?

Solution:

Total CW flow = 440 * 45 = 19800 m^3/hr

Effectiveness = Range / (Range + Approach)

Range = (4*0.63)/(1-0.63) = 6.81^0C

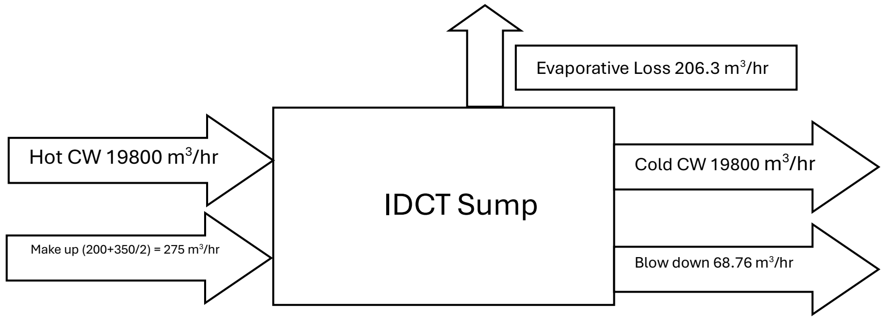
Evaporative loss = 0.00085*1.8*19800*6.81 = 206.3 m^3/hr

COC = 2000/500 = 4

Blow down from CT sump = Evaporation Loss/ (COC-1)

= 68.76 m^3/hr

Mass flow diagram of the system:



CT make up (one pump) = 200 m^3/hr

a) Calculation of time period for which only one pump is in service (2.5 marks)

Total volume of sump = 100*15*40 = 60000m^3

Volume change needed before 2nd make up pump is stared= (100-90)*60000 = 6000 m^3

Volume change in sump from mass flow diagram = 200-206.3-68.76 = -75 m^3/hr

Time period for which only one pump is in service = 6000/75= **80 hrs**

b) Calculation of time period for which both pumps are in service (2.5 marks)

When two pumps are in service, total make up flow will become 350m^3/hr, All other flows remain same

Volume change needed before 2nd make up pump is stopped= (100-90)*60000 = 6000 m^3

Volume change in sump from mass flow diagram = 350-206.3-68.76 = 75 m^3/hr

Time period for which both pumps are in service = 6000/75= **80hrs**

<u>Answer any ONE of the following among four questions given below:</u>

N 4 – (A)

The production data for a steel plant using the Direct Reduced Iron (DRI) route is outlined below. The DRI unit has a daily production capacity of 500 tonnes of sponge iron but operates at 60% of this capacity. The produced sponge iron is transported to the Steel Melting Shop (SMS) where it is processed into ingots, the final product. The plant also operates a captive power station to fulfill its energy requirements. The operational parameters for both the baseline year and the assessment year are provided as follows:

Parameter	Unit	Base Year (2022)	Assessment Year (2023)
Sponge Iron Full Production Capacity	T/Day	500	500
Plant operating Capacity	%	60	60
Specific Coal Consumption of DRI	T/T	1.3	1.15
Specific Power Consumption of DRI	kWh/T	110	95
Yield of Steel Melting Shop	%	85	88
SEC of Steel Melting Shop	kWh/Ton	850	830
Captive Power Station Efficiency	%	26.06	27.74
GCV of Coal	kCal/kg	5000	5200

Calculate the following:

(1) Specific Energy Consumption of the plant in Million kCal/Tonne of Finished Product for Base Year. 8 Marks

(2) Specific Energy Consumption of the plant in Million kCal/Tonne of finished product for assessment year. 8 Marks

(3) Reduction in coal consumption considering both DRI and captive power plant in tonnes per day for the assessment year. 4 Marks

Solution :

1. Base Year Performance

Specific Energy Consumption	= 1300 kg x 5000 + 110 kWh x 3300 = 6.863 million kCal/Tonne of SI
Plant Capacity	= 500 T/day
Plant Actual Running Capacity	= 60% = 0.6 x 500 = 300 Tonnes
Total Energy Consumption of Sponge Iron /day	= 300 x 6.863 = 2058.9 million kCal
Total production of Ingots from Sponge Iron considering	=300 x 0.85 = 255 Tonnes/Day
Heat Rate of the Captive Power Station	=860/0.2606 = 3300 kCal/kWh
Specific Energy Consumption for Ingot	=850 x 3300 = 2.805 million kCal/Tonne of Ingot
Total Specific Energy Consumption for Ingot Production per year	= 2.805 x 255 = 715.275 million kcal
Plant Specific Energy Consumption for production of finished product (ingot) during base year	= (2059 + 715.275)/255 = 10.88 million kcal/tonne

2. Assessment Year Performance

Revised Parameter

Specific Power Consumption	= (1 – 0.1363) x 110 = 95 kWh/Tonne

Yield	= (1 + 0.0352) x 85 = 88 %
The Specific Energy Consumption of SMS	= (1-0.0235) x 850 = 830 kwh/tonne
Plant Heat Rate	=3300 – 200 = 3100 kCal/kWh
GCV of Coal	=5200 kCal/kg

Specific Energy Consumption	= 1150 kg x 5200 + 95 kWh x 3100 =6.274 million kCal/Tonne of SI
Plant Capacity	= 500 T/day
Plant Actual Running Capacity	= 60% = 0.6 x 500 = 300 Tonnes
Total Energy Consumption of Sponge Iron /day	= 300 x 6.274 = 1882.2 million kCal
Total production of Ingots from Sponge Iron considering	= 300 x 0.88 = 264 Tonnes/Day
Heat Rate of the Captive Power Station during assessment year	= 860/0.2774 = 3100 kCal/kWh
Specific Energy Consumption for Ingot	= 830 x 3100 = 2.573 million kCal/Tonne of Ingot
Total Specific Energy Consumption for Ingot Production per year	= 2.573 x 264 = 679.27 million kcal
Plant Specific Energy Consumption for production of finished product (ingot) during base year	= (1882.2 + 679.27)/264 = 9.70 million kcal/tonne

3. Reduction in Coal Consumption

Energy Saving in Sponge Iron Plant	= (6.863 – 6.274) x 300 = 176.7 million kCal/day
Energy Saving in Steel Melting Plant	= (2.805 x 255 – 2.573 x 264) = 38.07 million kCal/day
Total Energy Saving	= 176.7 + 38.07 = 214.77 million kCal
Equivalent Coal Reduction (Saving)	= 214.77 x 10^6/ (5200 x 10^3) = 41.03 Tonnes per Day

Comment: The coal consumption is reduced by 41.03 Tonnes / Day

(Or)

N4- (B)

The management of a cement plant with a capacity of 7200 TPD has decided to install waste heat recovery boilers (WHRB) to generate steam from preheater gas and clinker cooler gas for power generation. The relevant data is given below:

Raw meal feed Rate	7200	TPD
Clinker Output	62	% of feed
Preheater Outlet temp	325	°c
Clinker Cooler Outlet temp	310	°c
WHRB Exit temperature	160	°c
Preheater Gas heat availability	152	Kcal/kg of clinker
Cooler gas heat availability	120	Kcal/kg of clinker
Enthalpy of Main Steam	815	Kcal/kg
Feed Water temperature	95	°c
Power plant Condensate return Temperature	46	°c
Heat recovery potential in WHRB	85	%
Turbine Cycle Efficiency	36	%
Gear Box Efficiency	95	%
Alternator Efficiency	96	%

The chemical analysis of clinker (Loss-free basis) is given below:

Constituents	%
SiO_2	***22.68***
Fe_2O3	***5.92***
Al_2O3	***5.29***
CaO	***63.00***
MgO	***1.25***

Calculate the following:

1. The power output from the co-generation plant in MW.
2. The heat of formation of the clinker.

Solution :

Clinker Output	= (7200x0.62/ 24hrs)	186	TPH
Heat in Pre Heater-Gas	= 152x186 x1000	28272000	kcal/kg/hr
Heat In cooler gas	= 120 x186x1000	22320000	kcal/kg/hr
Steam Enthalpy	given	815	Kcal/Kg
Feed Water temperature	given	95	°c
Power plant Condensate return Temp	given	46	°c
Heat recovery potential in WHRB	given	85	%
Steam from Preheater	=28272000x0.85/(815-95)/1000	33.38	TPH
Steam From Cooler gas	=22320000x0.85/(815-95)/1000	26.35	TPH
Total Steam Generation	=33.38 + 26.35	59.73	TPH
Turbine Cycle Efficiency	given	36	%
Gear Box Efficiency	given	95	%
Alternator Efficiency	given	96	%
Power generation	= 59.73x1000x(815-95)x0.36x0.95x0.96/860/1000	16.417	MW

Heat of Formation of clinker

= 2.22 X Al_2O3+6.48 MgO +7.646 Cao-5.116x SiO_2-0.59x Fe_2O3

= 2.22 x5.29+6.48 x1.25 +7.646 x63 – 5.116 x22.68 – 0.59 x5.92

= 382 kCal/kg of clinker

(Or)

N4- (C)

A textile processing unit currently operates a 5-chamber stenter with a dryer efficiency of 40%. The average amount of dry cloth processed by this stenter is 1,500 kg/hr, containing 4% moisture. The incoming cloth to the stenter has a moisture content of 42%, with a feed temperature of 37°C, and exits at 89°C. The management plans to upgrade to an 8-chamber stenter, which has a dryer efficiency of 52%. The heat required for both stenters is supplied by a thermic fluid heating system powered by furnace oil, which operates at an efficiency of 80%. The furnace oil has a gross calorific value (GCV) of 10,000 kcal/kg and a density of 0.92 kg/liter.

Calculate the following:

1. The dryer heat input (kcal/kg) for both the 5-chamber and 8-chamber stenters.

12 Marks

2. The amount of furnace oil required (in liters per hour) for the thermic fluid heater when using the 5-chamber stenter and when using the 8-chamber stenter.

8 Marks

Solution:

	Bone dry cloth weight	=1500*0.96	1440	kg/hr
	Inlet cloth weight with Moisture	=1440/(1-0.42)	2483	Kg/hr
	Inlet Moisture/kg dry cloth	=2483*0.42/1440	0.724	Kg moisture/Kg dry cloth
	Outlet Moisture/kg dry cloth	=1500*0.04/1440	0.042	Kg moisture/Kg dry cloth
	Mass of moisture evaporated	=1440*(0.724-0.042)	982	kg/hr
	Heat Load to stenter	=982*((89-37)+540)	581344	kCal/hr
	Five Chamber stenter drying Efficiency		40	%
1a	Input heat to stenter	=581344/0.4	1453360	kCal/hr
	Thermopack efficiency		80	%
	Heat Input to Thermopack	=1453360/0.8	1816700	kCal/hr
	Furnace Oil GCV		10000	Kcal/kg
	Furnace oil qty	=1816700/10000	181.67	Kg/hr
	Furnace oil density		0.92	Kg/lit
2a	Furnace oil required	=181.67/0.92	197	LPH
	Eight Chamber stenter drying efficiency		52	%
1b	Input heat required for 8 chamber stenter	=581344/0.52	1117969.23	kCal/hr

	Thermopack Efficiency		80	%
	Heat Input at Thermopack	=1117969.23/0.8	1397461.53	kCal/hr
	Furnace Oil GCV		10000	Kcl/kg
	Furnace oil qty	=1397461.53/10000	139.7	Kg/hr
	Furnace oil density		0.92	Kg/lit
2b	Furnace oil required	=139.7/0.92	151.9	LPH

(Or)

N4- (D)

i) A 500 MW power plant is operated with the turbine back pressure of 0.14 ata and after improving the condenser cooling system the turbine back pressure is maintained at 0.11 ata. The design heat rate of the turbine at backpressure of 0.14 ata is 2040 kcal/kwh and at 0.11 Back pressure will be 2000 kcal/kWh. The operating turbine efficiency is 93 % and the alternator efficiency is 96 % and the boiler efficiency is 87 %. The coal used in Power plant is having GCV of 4600 kCal/kg.

Calculate the following:

1. Condenser vacuum in mmHg at 0.14 ata turbine Back pressure 2 Marks
2. Condenser vacuum in mmHg at 0.11 ata turbine Back pressure 2 Marks
3. Improvement in gross heat Rate 4 Marks
4. At 74 % Power Plant Loading what will be the coal savings per day 4 Marks

Solution:

i)

1. Condenser vacuum in mmHg = 0.14 x 1.0332 kg/cm^2 =0.145 kg/cm^2 = 109.93 mm Hg

= 760-109.93 = 650 mmHg

2.Condenser vacuum in mmHg = 0.11 x 1.0332 kg/cm^2 =0.114 Kg/cm^2 = 86.37 mm Hg

=760-86.37= 674mmHg

3.Improvement in gross heat Rate
Gross Heat Rate with turbine Pressure O.14 ata = 2040/(0.87)= 2345 kCal/kW

Gross Heat Rate with O.11 ata = 2000/(0.87)= 2299 kCal/kW

Improvement = 2345-2299 = 46 Kcal/kWh

4.Heat savings at 74 % Loading = 500 X1000x 0.74 x (46) Kcal/Hr

= 17020000 kCal/hr

Coal savings = 17020000/4600 = 3700 kg/Hr
Daily Coal savings= 3700 kg x 24 hrs= 88.8 Ton/ Day

ii)

The operating Details of a 1000 MW thermal power plant are given below:

Plant Load Factor	: 76 %
Annual Operating Hours	: 7200 hours
Annual Coal Consumption	: 40,45,400 MT
Annual Furnace oil Consumption (Support Fuel)	: 3,500 MT
Annual HSD Consumption (Earthmoving Equipment)	: 150 MT
Coal GCV	: 4,200 kCal/ kg
Furnace Oil GCV	: 10,200 kCal/kg
HSD GCV	: 10,500 kCal/kg

Calculate the following:

1. Annual power generation in Million kWh. 2 Marks
2. Gross Heat Rate kCal/kWh, 3 Marks
3. Net Heat Rate kCal/kWh, if auxiliary power consumption is 8% of the running Load. 2 Marks

***Solution:* Thermal Power plant (b)**

Operating Load = 1000 x0.76 = 760 MW

Annual Units Generated = (760 x 1000 x7200)/1000000= 5472 million Units

Gross Heat Rate =[((4045400*1000)x 4200) + (3500*1000x10200))]/ 5472 million units

= 3112 kCal/kWh

Net Heat Rate = 3112/ (1-0.08)

= 3382.6 kCal/kg

Paper 4 Code :Pink

23rd NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS - MARCH, 2023

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

Date : 26.03.2023 Timings : 14:00-16:00 HRS Duration : 2 HRS Max. Marks : 100

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

(i) Answer all **Ten** questions

(ii) Each question carries **One** mark

1	If an electric motor is operated at the rated frequency and voltage without any shaft load, then the Power Factor will be high.	True/False	**False**
2	For the same head and flow, a pump operating with water will consume less power than operating with kerosene.	True/False	**False**
3	The higher the TTD (Terminal Temperature Difference) and the DCA (Drain Cooler Approach), the more efficient is the Rankine Cycle.	True/False	**False**
4	For a centralized air conditioning system with an air-cooled condenser the kW/TR will be lesser than the one with water cooled condenser.	True/False	**False**
5	The direct method of efficiency calculation of boilers does not require steam generation pressure.	True/False	**False**
~~6~~	A slight negative pressure is maintained in the heating zone of the furnace to maintain uniform heating of the stock.	True/False	**False**
7	In a thermal power plant, the boiler efficiency affects the turbine heat rate.	True/False	**False**
8	Higher the slip, higher will be the loading of motor.	True/False	**True**
9	A roof exhaust fan in an industrial shed belong to the category of axial flow fans.	True/False	**True**
10	A screw compressor designed for 7 bar if operated at 5 bar, then its FAD will decrease.	True/False	**False**

.... End of Section - I ....

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

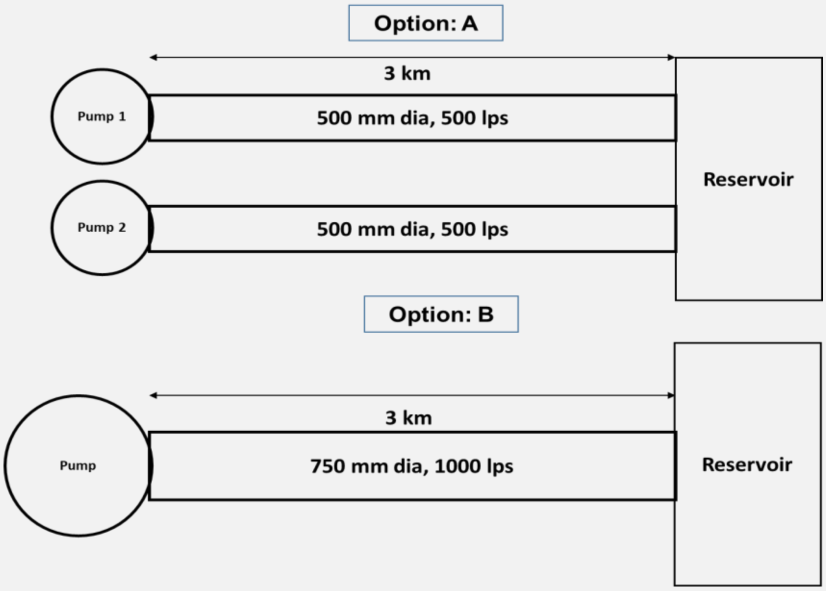
L1	The flue gas analysis of an Industrial Boiler revealed CO : 5000 PPM and CO_2 :14%. The Gross Calorific Value of the fuel is 4000 kCal/kg. The fuel has 36 kg of carbon per 100 kg of fuel. Estimate the percentage loss due incomplete combustion of C to CO.
Ans	The heat Loss due to Partial Combustion = [(%CO x C)/ (%CO + %CO_2)] x 5654 CO = 5000 PPM = 5000x100/1000000 = 0.5 CO_2= 14 = [(0.5 x 0.36)/ (0.5 +14)] x 5654 = 70.19 kCal GCV of Fuel = 4000 kCal **% loss due to incomplete combustion = 70.19/4000 x 100 = 1.75%**
L2	The operating data of Vapor Absorption Chiller is given below: Chilled Water Flow : 0.18 m^3/sec Specific Heat of Chilled Water : 4.18 kJ/kg/K Density of water : 1000 kg/m^3 Chilled Water Inlet Temperature : 9.0 ^oC Chilled Water Outlet Temperature : 7.0 ^oC Enthalpy of Steam : 2750 kJ/kg Steam Flow Rate : 1 kg/sec Condensate Temperature : 100 ^oC Calculate the following: A) Refrigeration effect in TR B) Thermal input energy in kJ/s C) Coefficient of performance (COP)
Ans	A) **Refrigeration Effect in TR** Refrigeration Effect = M_c x ρ x C_p x (t_{cin} – t_{cout}) kJ/s = 0.18 x 1000 x 4.18 x (9 – 7) = 1504.8 kJ/s = 1504.8/3.516 TR **= 428 TR** B) **Thermal Input Energy** Input Energy = M_{st} x (h_{st} – h_{cond}) = 1 x (2750 – 418) = **2332 kJ/s** C) **Coefficient of Performance (COP)** = Refrigeration Effect/Thermal Input Energy = 1504.8/2332 = 0.65

…………. End of Section - II …………

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

(i) Answer all the **Four** questions

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

N-1	**A)** A factory having a water requirement of 1000 lit/sec is planning to draw water from river basin located 3 km away from the plant. The following two options are evaluated: **Option A:** Two separate pumps connected to separate dedicated discharge line of 500 mm dia with 3 km length and each pump delivering 500 l/s. The efficiency of the pump is 80% and motor efficiency is 93%. **Option B:** Single pump connected to a discharge line of 750 mm diameter with 3 km length and delivering 1000 l/s. The efficiency of the pump is 80% and motor efficiency is 95%.  The other data's are follows: System static head : 12 m Pipe friction factor is : 0.006 Cost of energy : ₹10 /kWh Annual operating hours : 8000 As an energy auditor which option you will recommend considering the annual energy cost. [15 Marks] **B)** A cooling tower connected to the condenser of a refrigeration system is operating with a heat load of 280 x 10^3 kCal/hr. The hot water inlet temperature to the cooling tower and approach are 33ºC and 3ºC respectively. The wet bulb temperature is 25ºC. The condenser pump is operating at a total head of 25m. The combined efficiency of pump and motor is 54 %. Calculate the power drawn by the condenser pump. [5 Marks]

Ans	A)

Parameter	Two separate pumps connected to separate dedicated discharge line of 500 mm dia with 3 km length and each pump delivering 500 l/s. The efficiency of the pump is 80% and motor efficiency is 93%.	Single pump connected to a discharge line of 750 mm diameter with 3 km length and delivering 1000 l/s. The efficiency of the pump is 80% and motor efficiency is 95%.	Units
Discharge flow	500	1000	lps
(Q)	0.5	1	m^3/s
Diameter of pipe	0.5	0.75	m
Area	=3.141*0.5*0.5/4 = 0.196	=3.141*0.75*0.75/4 = 0.442	m^2
Velocity	=0.5/0.196 = 2.55	= 1/0.442 = 2.26	m/s
Length of Pipe	3000	3000	M
Pipe friction factor	0.006	0.006	
Friction resistance	$= 4flv^2/2gD$ $=4*0.006*3000*2.55^2/(2*9.81*0.5)$ =47.61	$= 4flv^2/2gD$ $=4*0.006*3000*2.26^2/(2*9.81*0.75)$ = 25.08	M
Static Head	12	12	M
Total head	= 47.61 + 12 = 59.61	= 25.08+12 = 37.08	M
Combined Efficiency (Pump & Motor)	= 0.8 x 0.93 = 0.744	= 0.8 x 0.95 =0.76	
Hydraulic power, P_h	$= Q*H*\rho*g/1000$ =0.5*59.61*1000*9.81/1000 = 292.39	$= Q*H*\rho*g/1000$ =1*37.08*1000*9.81/1000 = 363.75	kW
Motor input power	= Hydraulic Power / Combined Eff = 292.39/0.744 = 393.00	= Hydraulic Power / Combined Eff = 363.75/0.76 = 478.61	kW
No. of pumps	2	1	nos.
Total power drawn	= Motor input power x No of pumps = 393 x 2 = 786.00	= Motor input power x No of pumps = 478.61x 1 = 478.61	kw
No. of hours of operation	8000	8000	hours

Total units consumed	= Total power drawn x no of opr hrs = 786 x 8000 = 62,88,000	= Total power drawn x no of opr hrs = 478.61 x 8000 = 38,28,880	kWh
Energy Cost	10	10	₹/kWh
Annual Energy cost	= Total units consumed x Cost ₹ 6,28,80,000	= Total units consumed x Cost ₹ 3,82,88,800	**₹/year**
Cost Reduction	**₹ 2,45,91,200**		**₹**

Option B is recommended considering the annual energy cost.

B)

Cooling Tower Heat Rejection	280000	kCal/hr
Cold water temperature of basin	= 25+3 =28	°C
Range of Cooling tower	= (33- 28) = 5	°C
Flow Rate of Cooling Water	= (280000/5)/1000 = 56.0	m^3/ hr
Head of Pump	25	m
Combined Efficiency	54	%
Hydraulic Power	= Q*H*ρ*g/1000 = ((56/3600)* 25*1000*9.81)/1000 = 3.82	kW
Power Drawn by the Pump	= Hydraulic Power / Combined Eff = 3.82/54*100 =7.1	kW

N-2 An oil refinery has captive power plant with pet coke fired boiler. The following are the data collected to assess the boiler performance.

Pet coke elementary analysis	
Carbon	88.8
Hydrogen	3.6
Nitrogen	1.2
Oxygen	1.4
Sulphur	3.6
Moisture	1.4

GCV of Petcoke : 8430 kCal/kg
Stack O_2 : 6.0 mol%
Stack Temperature : 250 °C
Heat loss due to radiation & convection : 1.0 %
Loss due to unburnt in fly ash & bottom ash : 0.5%
Specific heat of flue gas : 0.29 kCal/kg °C
Specific heat of water vapour : 0.45 kCal/kg °C
Ambient Temperature : 30 °C

	Humidity in ambient air : 0.0204 kg/kg dry air **Steam generation at 110 bar g & 520 ^oC** Steam enthalpy at generation pressure and temperature : 816 kCal/kg Feed water temperature : 200 ^oC Steam drum pressure : 115 bar g A) Calculate Boiler efficiency using indirect method. [12] B) Calculate evaporation ratio. [3] C) Calculate the quantity (kg) flash steam generated per kg of blow down if: [5] - Saturated liquid enthalpy at steam drum pressure: 352 kCal/kg - Total enthalpy flash steam at 2 bar (g) pressure: 646 kCal/kg - Latent heat of evaporation at 2 bar (g) pressure: 526 kCal/kg
Ans	

A)	Theoretical Air required	= {(11.6x 0.888)+[34.8x(0.036-0.014/8)]+4.35x0.036} = 11.65	kg air / kg of petcoke
	% Excess Air supplied	= 100 x 6.0/(21-6.0) = 40	%
	Actual Air supplied	= (1+40/100)x11.65 = 16.31	kg air / kg of petcoke
	Mass of dry flue gas	={(0.888x44/12)+0.012+(16.31x0.77) +(16.31 -11.65)x0.23+(0.036x64/32)} = 16.97 Or = (16.31+1)-(0.014+(9*0.036)) =16.97	kg air / kg of petcoke
	Stack losses, L1	= 16.97x0.29x(250-30)/8430x100 = 12.84	%
	Loss due to formation of water vapor from H_2 in fuel, L2	= 9x0.036x{584+0.45*(250-30)}/8430x100 = 2.63	%
	Loss due to moisture in fuel, L3	= 0.014x{584+0.45x(250-30)}/8430x100 = 0.11	%
	Loss due to moisture in Air, L4	= 16.31x0.0204x0.45x(250-30)/8430x100	%

		= 0.39	
	Loss due to radiation and convection	= 1.0	%
	Loss due to unburnt in fly ash & bottom ash	= 0.5	%
	Efficiency of boiler using indirect method	= (100-12.84-2.63-0.11-0.39-1-0.5) **= 82.53**	**%**
B)	Heat required per unit of steam generation	= (816-200) = 616.0	kcal/kg of Steam
	Heat supplied by fuel for steam generation	= (82.5/100)x8430 = 6957.28	kcal/kg of petcoke
	Evaporation Ratio	= 6957.28/616 **= 11.29**	**MT Steam/MT of petcoke**
C)	Quantity (kg) flash steam generated per kg of blow down	S1 = 352 Kcal/kg S2 = 646 – 526 = 120 kCal/kg L2 = 526 Kcal kg % Flash Steam quantity from blowdown: (352-120)/526 = 44.1% Quantity of flash steam per kg of blow down: 0.44 kg/ kg of blow down.	

N-3 In an engineering company, the compressed air is required for pneumatic equipment's and other processes. To meet the requirement, one reciprocating compressor of 500 CFM is installed. To assess the performance of compressor, Free Air Delivery test was carried out. The test and other data are given below.

Receiver Capacity : 10 m^3
Interconnecting pipe : 1 m^3
Initial Pressure in Receiver : 1.0 kg/cm^2 a
Atmospheric Pressure : 1.0 kg/cm^2 a
Final Pressure : 8.25 kg/cm^2 a
Time Taken to Fill Receiver : 6 Minute
Inlet air temperature (T_{in}) : 30 °C
Air temperature in the receiver (T_{out}) : 40 °C
Motor RPM : 1400 RPM
Motor Efficiency : 93%
Motor Pulley Diameter : 300 mm
Compressor RPM : 700 RPM
Compressor Pulley Diameter : 600 mm
Average Loading Time : 65%
Average Unloading Time : 35%
Power Consumption during loading : 82 kW
Power Consumption during unloading : 21 kW

	Cost of Energy : 10.00 Rs / kWh Answer the followings: A) Estimate the Free Air Deliver of Compressor? [5 Marks] B) Evaluate the operating energy cost per day (for 24 hours of operation) [2 Marks] C) Calculate the isothermal power and isothermal efficiency of the compressor. [5 Marks] D) To reduce the energy loss due to unloading, the maintenance team has decided to reduce the speed of the compressor by reducing the motor pulley size. Evaluate the speed of compressor required for 10 min unloading time and 50 min of loading time and accordingly evaluate the diameter of the pulley of the motor. [5 Marks] E) Estimate the hourly energy consumption, energy saving after replacement of the pulley and payback period. The cost of pulley and belts is Rs. 1.2 Lakhs. The operating hours of the compressor is 8000 in a year. Consider power consumption during loading is 64 kW and power consumption during unloading is 18 kW after motor pulley change. [3 Marks]
Ans	**A) Free Air Delivery (with temperature correction)** $Q = \frac{P_2-P_1}{P_0} \times \frac{V}{T} \times \frac{(273+t_1)}{(273+t_2)}$ $= 12.867\ m^3/min$ = 12.867 x 35.31 = **454.33 CFM** **B) To evaluate the operating energy cost per day (for 24 hours of operation)** Reciprocating compressor rated capacity = 500 CFM Percentage with respect to rated capacity = (500 – 454.33 / 500) x 100 = 9.1 % Loading energy (65% Loading) = Average loading time x Power consumption during loading = 65 % x 82 kW = 53.3 kWh Unloading energy (65% Loading) = Average unloading time x Power consumption during unloading = 35 % x 21 kW = 7.35 kWh Hourly energy consumption =53.3 + 7.35 = 60.65 kWh Energy cost per day = 60.65 x 10 x 24 = **Rs.14556/-** **C) Calculate the isothermal power and isothermal efficiency of the compressor.** To calculate Isothermal Power = $P_1 \times Q_1 \times \log_e r / 36.7$ r = Pressure ratio, P_2/P_1 P_1 = Absolute intake pressure, kg/cm^2 P_2 = Absolute delivery pressure, kg/cm^2 Q_1 = Free air delivered, m^3/hr = 1 x13.31x 60 x (Ln (8.25/1)/36.7) **= 44.39 kW**

To calculate Isothermal efficiency = $\frac{\text{Isothermal Power}}{\text{Actual measured input power}}$

= 44.39 / (82 x 0.93) = **58.21 %**

D)

Hourly air delivery = 454.3 CFM x 65%, Average loading time = 295.3 Cu.ft/hr

Loading Time Existing (T1) = 65%
New Loading Time after pully change(T2) = 83.3%

Existing RPM of Compressor (N1) = 700 RPM
New RPM of Compressor after Pully Change (N2) = (700x65%)/83.3% = **546 RPM**

Existing Motor Pully Size =300 MM
New Motor Pully Diameter = (300 x 546)/ 700 = **234 mm**

E)

New Loading Power = 64 kW (given)
Unloading Power = 18 kW (given)

Hourly Energy Consumption after pulley Change = (64 x 50/60) + (18 x 10/60) = 56.33 kWh
Reduction in Power Consumption = 60.65 – 56.33 = 4.32 kWh
Annual Energy reduction = 4.32 x 8000 = 34533.33 kWh
Annual Cost Reduction = 34533.33 x 10 **= Rs.3,45,333/-**

Cost of Pully & Belt Change = 120000 Rs.
Simple Payback Period = 120000/345333**= 4.17 Months**

Answer any ONE of the following among four questions given below:

N4 A The following is the data collected from a 500 MW Turbine unit by an Energy Auditor.

Main Steam Flow (TPH)	1561
Hot reheat Flow (TPH)	1413
Main steam pressure (kg/cm^2)/ Temperature (^{o}C)	166/529
Cold reheat (CRH) pressure (kg/cm^2)/ Temperature (^{o}C)	44.3/341
Hot reheat pressure (HRH) (kg/cm^2)/ Temperature (^{o}C)	42.4/540
Feed water temperature (^{o}C)	246
Main steam enthalpy (kCal/kg^{o}C)	806.47
Feed water enthalpy (kCal/kg^{o}C)	246
CRH Enthalpy (kCal/kg^{o}C)	730.71
HRH Enthalpy (kCal/kg^{o}C)	844.27
Generator output (MW)	501.7
Boiler Efficiency (%)	88%

Heater Reference	Steam			Feed water in		Feed water out		Design Values	
	Temp (°C)	Saturation Temp (°C)	Drain Temp (°C)	Temp (°C)	Pressure (kg/cm^2)	Temp (°C)	Pressure (kg/cm^2)	TTD (°C)	DCA (°C)
LP Heater 1	73	70	64.2	47.2	13.7	63.6	12.6	2.88	4.8
LP Heater 2	140	111.23	70.4	-	-	105	11.5	2.95	4.95
LP Heater 3	209	132.9	110	-	-	130	10.4	2.95	4.95
HP Heater 5	416	207.33	171	170	202	210	199	0	5
HP Heater 6	335	254.94	212	-	-	255	197	0.1	5

Calculate the following:

a.) Turbine cycle heat rate and unit gross heat rate. **(6 Marks)**

b.) Net heat rate and efficiency of the power plant if the auxiliary power consumption is 6%. **(2 Marks)**

c.) Loss/gain in the turbine heat rate because of the deviation of the TTD and DCA of the LP/HP Heater systems from the design values. **(12 Marks)**

Consider,

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

Ans

Turbine heat rate

Turbine heat rate is defined as the amount of heat input to the turbine in kCal for generating one unit of electricity.

$$\textbf{Turbine heat rate, kCal/kWh} = \frac{Q_1 \times (H_1 - h_2) + Q_2 \times (H_3 - H_2)}{\textbf{Gross Generator Output}}$$

Q_1 - Main steam flow, kg/hr
H_1 - Main steam enthalpy, kCal/kg
h_2 - Feed water enthalpy, kCal/kg
Q_2 - Reheat steam flow, kg/hr
H_3 - Hot reheat enthalpy, kCal/kg
H_2 - Cold reheat enthalpy, kCal/kg

Unit heat rate

$$\textbf{Unit heat rate, kCal/kWh} = \frac{\textbf{Turbine heat rate, kCal/kWh}}{\textbf{Boiler efficiency}}$$

a.) Turbine Heat Rate:

= {(1561000 X (806.47-246))+ (1413000 X (844.27 – 730.71))}/ (501700)
= 2063.72kCal/kWh

Unit Gross Heat Rate: = 2063.72 / 88%
= 2345.131 kCal/kWh

b.) Net Heat Rate = 2345.131/(1-0.06) = 2494.82 kCal/kWh
Power plant efficiency = 860 / 2494.82 * 100= 34.5%

c.) From the above data, the following heater data can be inferred

Heater Ref.	Feed water In-let Temp ^OC	Feed water Out-let Temp ^OC	Steam Inlet temp ^OC	Inlet steam Saturation Temp ^OC	Drain temp ^OC
LP Heater-1	47.2	63.6	73	70	64.2
LP Heater-2	63.6	105	140	111.23	70.4
LP Heater-3	105	130	209	132.9	110
HP Heater-5	170	210	416	207.33	171
HP Heater-6	210	255	335	254.94	212

So
TTD (Terminal Temperature Difference) = Inlet Steam Saturation Temp ^OC – Feed Outlet Temp ^OC
DCA (Drain Cooler Approach = Drain temperature ^oC – Feed Water Inlet Temperature ^oC

Heater Ref.	TTD ^oC (Design)	DCA ^OC (Design)	TTD ^oC (Calculated)	DCA ^OC (Calculated)
LP Heater -1	2.88	4.8	70-63.6 = 6.4	64.2-47.2 =17
LP Heater-2	2.95	4.95	6.23	6.8
LP Heater -3	2.95	4.95	2.9	5
HP Heater-5	0	5	-2.67	1
HP Heater -6	0.1	5	-0.06	2

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

Heater Ref.	$\mathbf{TTD_{Operating} - TTD_{Design}}$	$\mathbf{DCA_{Operating} - DCA_{Design}}$
LP Heater -1	3.52	12.2
LP Heater-2	3.28	1.85
LP Heater -3	-0.05	0.05
HP Heater-5	-2.67	-4
HP Heater -6	-0.16	-3
Total Difference	**3.92**	**7.1**

Change in Heat rate because of deviation in TTD =
(Net Change in TTD for All heaters X 0.014%/0.56^oC)
Since given, for every 0.56^oC change in TTD HR will increase by 0.014%
Increase in HR because of TTD deviation= 3.92 X 0.014 / 0.56 = 0.098 %

Change in Heat rate because of deviation in DCA =
(Net Change in DCA for All heaters X 0.005%/0.56^oC)
Since given, for every 0.56^oC change in TTD HR will increase by 0.005%
So Increase in HR because of DCA deviation = 7.1 X 0.005 / 0.56 = 0.063 %

Total % Increase in Turbine HR because of deviation in operation of TTD and DCA of Heaters from Design Values
= 0.161 %.
=0.161% X 2063.72 = 3.32 kCal/kWh

Or

N4 B	A cement company manufactures ordinary clinker and low heat clinker. The chemical composition of

the cement clinkers (loss free basis) are given in the following table:

Constituent	Percentage of constituent	
	Ordinary Clinker	Low Heat Clinker
SiO_2	20	44
Fe_2O_3	7	15
Al_2O_3	7	1
CaO	65	39
MgO	1	1

Following heat data is given for both types of manufacturing process.

Item	kCal/kg of Ordinary Clinker	kCal/kg of Low Heat Clinker
Heat output excluding heat of formation	$360+6.7m_{fuel}$	$400+7.1m_{fuel}$
Total Heat Input	$27+6000m_{fuel}$	$27+6000m_{fuel}$

Calculate the following:

1. Heat of formation of clinker of both the types. 8 marks
2. Total heat output in terms of m_{fuel} 2 marks
3. Amount of fuel needed per kg of clinker for each type of clinker from heat balance principle. …4 marks
4. Which type of clinker consumes more energy? 1 mark
5. If cost of coal is ₹ 6,000/- per ton, what is the difference between energy consumption cost per ton of clinker, in Ordinary Clinker and Low Heat Clinker? 5 marks

Ans	Heat of formation of clinker

$$\Delta H_R = 2.22\ Al_2O_3+6.48\ MgO+7.646\ CaO-5.116\ SiO_2-0.59\ Fe_2O_3.$$

Constituent	Percentage of constituent in		Multiplier	Heat in kcal/kg of Clinker	
	Ordinary Clinker	Low Heat Clinker		Ordinary Clinker	Low Heat Clinker
SiO_2	20	44	-5.116	-20x5.116= -102.32	-44x5.116= -225.10
Fe_2O_3	7	15	-0.59	-7x0.59= -4.13	-15x0.59= -8.85
Al_2O_3	7	1	2.22	7x2.22= 15.54	1x2.22= 2.22
CaO	65	39	7.646	65x7.646= 496.99	39x7.646= 298.19
MgO	1	1	6.48	1x6.48= 6.48	1x6.48= 6.48
Heat of formation of clinker				**412.56**	**72.94**
Additional Heat Output				$360+ 6.7m_{fuel}$	$400+ 7.1m_{fuel}$
Total Heat Output				$772.56+ 6.7m_{fuel}$	$472.94+ 7.1m_{fuel}$
Total Heat Input				$27+ 6000m_{fuel}$	$27+ 6000m_{fuel}$
Balancing the Heat Output with Heat Input				$772.56+6.7m_{fuel} =27+ 6000m_{fuel}$	$472.94+7.1m_{fuel} =27+ 6000m_{fuel}$
Mass of fuel consumed				**0.1244 kg/kg Clinker**	**0.0744 kg/kg Clinker**
Fuel Consumed per ton of clinker				0.1244 ton/ton Clinker	0.0744 ton/ton Clinker
Fuel cost				0.1244 x 6000= 746.4 ₹/ton	0.0744 x 6000= 446.4 ₹/ton

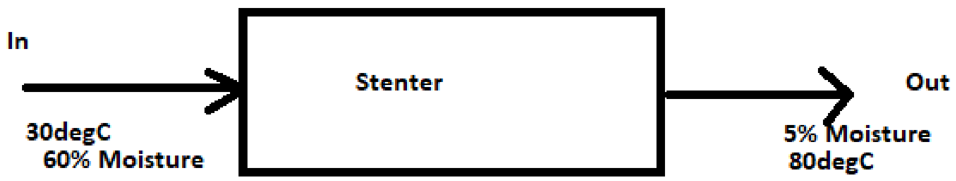
Therefore, the Ordinary Clinker consumes more energy.

The difference between energy consumption cost of Ordinary clinker and the Low Heat Clinker is

= 746.4-446.4

= 300 ₹/ton.

Or

N4 C	**A)** In a textile mill 150 kg of fabric is dyed per batch in a jigger. The dye liquor is heated from 25^0 C to 90^0 C. The specific steam consumption is 0.65 kg/kg (with enthalpy 660 kCal/kg). Calculate the liquor ratio allowing 15% margin for the losses. 5 marks **B)** In a textile mill a thermic fluid heater of 20 lakh kCal/hour is meeting process heat requirement. Outlet temperature of fluid : 280^0C Return temperature of fluid : 260^0C Specific Heat of fluid : 0.55 kcal/kg ^{0}C Density of fluid : 840 kg/m^3 Current coal consumption : 400 kg/hour GCV of coal : 4000 kcal/kg % loading of the thermic fluid heater : 45% 1) What is the thermic fluid circulation rate? …3 marks 2) What is the existing thermal efficiency? …2 marks 3) By providing an air pre-heater the efficiency of the thermic fluid heater improved to 62%. Calculate the coal savings for 6000 Hrs of annual operation? …5 marks **C)** The operating details of a stenter in a textile unit are given below: 1. The inlet and outlet conditions of the cloth are shown in the figure below. The feed rate of wet cloth to the stenter is 1000 kgs/hour. 2. The heat input to the stenter is provided by a thermic fluid heater fired by firewood as fuel. 3. Gross Calorific Value (GCV) of Firewood is 3500 kCal/kg. 4. Firewood Consumption is 300 kg/hr. 5. The efficiency of the thermic fluid heater is 65%.  Calculate the drying efficiency of the stenter. (5 Marks)
Ans	A) Steam quantity needed per batch = quantity of fabric x specific steam consumption = 150 kg x 0.65 kg/kg = 97.5 kg Heat energy consumed per batch = Quantity of steam x enthalpy of steam = 97.5 kg x 660 kcal/kg = 64350 kCal/batch Heat energy consumed per batch = textile mass x liq. Ratio x 1.15(incl margin) x ΔT

	64350 = 150 x L x 1.15 x (90-25) ∴ Liquor Ratio = 5.74 Therefore liquor ratio of the jigger is 1:5.74 B) 1) Capacity of thermic fluid heater = 20 lakh kcal/hour Heat Duty = Capacity x % loading =2000000 x 0.45 =900000 kcal/hr. Heat Duty = Circulation rate x density x sp. Heat x ΔT 900000 = Q x 840 x 0.55 x (280-260) ∴ Thermic fluid Circulation rate Q=97.40 m^3/hour 2) Input Energy = Coal consumption x GCV = 400 x 4000 = 1600000 or 1.6x 10^6 kcal/hour Efficiency of thermic fluid heater = 900000/1600000 = 0.5625 i.e. 56.25% 3) Efficiency of thermic fluid heater: 62% New coal consumption for thermic flid heater = 0.5625 * 400/0.62 = 363 kg/hr Annual Coal Savings = (400-363) * 6000/1000 = 222 T/Hr. C) Calculation of Stenter Efficiency 1. 1000 kg/hr wet cloth contains 60% moisture (water)=1000*0.6 = 600 kg/hr moisture. 2. 1000 kg/Hr wet cloth contains 40% Bone dry cloth= 1000*0.4 = 400 kg/hr Bone dry cloth. 3. Weight of wet cloth at outlet contains 5% moisture = 400/0.95=421 kg/hr 4. Quantity of Moisture at the outlet = 421-400 =21 kg/hr. 5. Moisture evaporated = (600-21)=579 kg/hr 6. Heat energy required to evaporate 579kg/hr of water = m*cp*deltaT + m*540 = 579*1*(80-30)+(579*540) = (579*50)+(579*540) =341610 kCal/hr 7. Heat Energy provided by firewood heated thermic fluid at 65% efficiency = 300 kg/hr*3500 kCal/kg*0.65 = 682500 kCal/hr 8. Stenter Efficiency =341610/682500 =50%
	Or
N4 D	**A)** Determine the cooling load of a commercial building based on the following data Outdoor Conditions

- DBT 36^{0}C
- WBT 26^{0}C
- Humidity 19 gm of water/kg of dry air

Desired Indoor Conditions

- DBT 25^{0}C
- RH 50%
- Humidity 11 gm of water/kg of dry air
- Total area of wall 45 m^2
- Total area of window 15 m^2
- U - Factor (Wall) 0.35 W/m^{2}K
- U - Factor (Roof) 0.363 W/m^{2}K
- U - Factor (Windows) 3.00 W/m^{2}K

Other Data

- Roof Area 20 m x 20 m
- CLTD
  - Wall 10^{0}C
  - Roof 40^{0}C
  - Window 8^{0}C
- SCL Window 500 W/m^2
- Shading coefficient (Window) 0.84
- Space occupancy 30 people
- Heat Gain/person
  - Sensible 80 W
  - Latent 50 W
- CLF for people 0.9
- Fluorescent light in space 21 W/m^2
- CLF for lighting 0.9
- Ballast factor 1.2
- Computers and office equipment heat production 6.3 W/m^2 of sensible heat
- Air changes/hr of infiltration 0.25
- Height of building 3.9 m
- Product of density and specific heat of air 1210 J/m^3 ^{0}K
- Latent heat factor 3010 J kg dry air/m^3 grams of water …14 marks

B) The management has decided to give additional insulation to the roof at the cost of ₹40,000/-. This treatment modifies the U factor of the roof to value 0.300 W/m2K. The other data is

- The COP of the vapour compression system 3.75
- The efficiency of the motor coupled with compressor 90%.

	• The number of hours of operation in a year for the building 6000 hours • The power cost is ₹ 10 /kWh Find out the simple payback period for this additional insulation.
Ans	**Sol^n:** **A)** External heat gain a) Conduction heat gain through the wall = U-factor x net area of wall x CLTD = 0.35 x (45-15) x 10 = 105 W b) Conduction heat gain through the roof = U-factor x area of roof x CLTD = 0.363 x (20 x 20) x 40= 5808 c) Conduction heat gain through the windows = U-fact. x net area of window xCLTD = 3 x 15 x 8 = 360 W d) Solar radiation through glass = surface area x shading coeff. xSCL = 15 x 0.84 x 500 = 6300 W 1. Internal heat gain a) Heat gain from people = sensible heat gain + latent heat gain Sensible heat gain = No. of people x sens. heat gain/person x CLF = 30 x 80 x 0.9 = 2160W Latent heat gain = No. of people x latent heat gain/person = 30 x 50 = 1500 W ∴ Heat gain from people = 2160 + 1500 = 3660 W b) Heat gain from lighting = (Energy Input x ballast factor x CLF) Energy Input = (Amount of lighting in space/ unit area) x floor area = 21 x (20 x 20) = 8400 W ∴ Heat gain from lighting = 8400 x 1.2 x 0.9 = 9072 W c) Heat generated by equipment 1. Sensible heat gain by computers and office equipment = 6.3 x 20 x 20 = 2520 W Total heat generated by equipment =2520 d) Heat gain by air infiltration = (Sensible + latent) heat gain Sensible heat gain = 1210 x airflow x ΔT Airflow = (Vol. of space x air change rate)/3600 ={(20 x 20 x 3.9) x 0.25}/3600 = 0.11 m^3/s ∴ Sensible heat gain = 1210 x 0.11 x (36-25) = 1464.1W

Latent heat gain = 3010 x airflow x Δh

= 3010 x 0.11 x (19-11)

= 2649 W

No.	Space Load Component	Heat Load	
		Sensile	Latent
1	Conduction through exterior wall	105	
2	Conduction through roof	5808	
3	Conduction through windows	360	
4	Solar radiation through windows	6300	
5	Heat gain from people	2160	1500
6	Heat gain from lighting	9072	
7	Heat gain from equipment	2520	
8	Heat gain by air infiltration	1464.1	2649
Total Space Cooling Load		27789.1	4149
Total Cooling Load = 31938.1 W			

B) Modified conduction heat gain through the roof = U-factor x net area of roof x CLTD

= 0.3 x (20 x 20) x 40 = 4800 W

Savings in cooling load = 5808 - 4800 = 1008 W

Savings in TR rating = Total savings in cooling load / 3516

= 1008/3516 = 0.287 TR

COP = (Refrigeration effect kCal/hr)/(Power input kCal/hr)

Savings in Power input = Refrigeration effect /COP

= 0.287 x 3024/(3.75 x 860)

= 0.270 kW

Annual energy savings = Energy savings x hours

= 0.270 x 6000

= 1620 kWh

Annual cost savings = Energy savings x Energy rate

	= 1620 x 10 = 16200 ₹/year Simple payback period = ₹40,000 / ₹16200 = 2.47 years

…………. End of Section - III …………

Paper 4 Code :Pink

22nd NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS - JULY, 2022

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

Date : 31.07.2022 Timings : 14:00-16:00 HRS Duration : 2 HRS Max. Marks : 100

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

(i) Answer all **Ten** questions

(ii) Each question carries **One** mark

1	Ideally the flow capacity of a forced draft fan of a pulverised fuel boiler operating on balanced draft when compared to an Induced draft fan is _________.	Lower/ Higher/ Same	**Lower**
2	If waste heat delivered to the heat pump is 3440 kcal/hr and power consumed by the heat pump compressor is 1.5 KW then the heat developed by heat pump is 6.6 kW.	True/False	**False**
3	Lower the terminal temperature difference in a steam condenser of a turbine _________ is the heat transfer rate between steam and cooling water.	Lower/Higher	**Higher**
4	In an extraction back pressure cogeneration system, higher the steam flow through the turbine extractions, lower is the energy utilisation factor.	True/False	**False**
5	Rated power of motor is power consumed by motor.	True/False	**False**
6	NPSH required of centrifugal pump increases with flow.	True/False	**True**
7	The lower the dew point of air the higher is the moisture in air.	True/False	**False**
8	In a boiler, higher the % of CO_2 in flue gas, the better is the combustion efficiency.	True/False	**True**
9	Air infiltration in an air-conditioned building, will increase both the latent heat and sensible heat load.	True/False	**True**
10	The turbine cycle efficiency of a thermal power plant will increase with decrease in inlet cooling water temperature to the condenser.	True/False	**True**

.... End of Section - I ....

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

L1	A process plant is importing 25 TPH of steam at 20 bar(g) pressure and reduces to 5 bar(g) through PRDS. The plant is also operating a motor driven gas compressor drawing a power of 900 kW. During an energy audit, it was suggested to evaluate the scheme of installing back pressure steam turbine instead of PRDS for driving the gas compressor. Calculate the steam required for operating the back pressure turbine and hourly monetary savings. Turbine power generation per unit of inlet steam: 0.045 kWh/kg steam Power cost : Rs.9.0/kWh Import steam cost : Rs.3500/MT

L1 Sol	<table><tr><td>Steam required for back pressure turbine</td><td>= (900/0.045)/1000 = 20 TPH</td></tr><tr><td>Hourly monetary saving</td><td>= (900 x 9) = Rs.8,100</td></tr></table>
L2	A medium size edible oil plant planning to install a thermic fluid heating system for their process requirements. The suggested operating parameters of thermic fluid system are given below: <u>Heat output data:</u> Flow rate of thermic fluid : 60 m^3/h Inlet temperature of thermic fluid : 210 ºC Outlet temperature of thermic fluid : 230 ºC Flue gas exit temperature of thermic fluid heater: 275 ºC Specific heat of thermic fluid : 2.223 kJ/kg ºC Density of the thermic fluid : 826 kg/m^3 The plant has to choose either oil or briquettes as a fuel. The following is the additional data: Efficiency of oil fired thermic fluid heater: 80% Efficiency of briquette fired thermic fluid heater: 65% GCV of fuel oil : 10000 kcal/kg Cost of oil :Rs.70/kg GCV of briquettes : 3200 kcal/kg Cost of briquettes : Rs.8/kg a) Calculate the heat load of the system in kcal/hr 3 marks b) As an energy auditor, based on operating cost, which system will you recommend? 2 marks
L2-Sol	Solution: Heat load of the system: Mass of thermic fluid = 60 x 826 = 49,560 kg/hr Q = mcpΔT = 49,560 x 2.233/4.186 x (230-210) = 528750.50 kcal/hr Operating Cost: 1. Fuel oil quantity required = 528750 / (10000 x 0.8) = 66.09 kg/hr Operating cost with fuel oil = 66.09 x 70 = Rs.4626.3 /hr 2. briquettes required = 528750.50 / (3200 x0.65) = 254.21 kg/hr Operating cost with briquettes = 254.21 x 8 = Rs.2033.68/hr As an energy auditor based on the operating cost, I recommend briquettes as fuel for thermic fluid heater system.

.... End of Section - II ....

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

(i) Answer all the **<u>Four</u>** questions

(ii) Each question carries **<u>Twenty</u>** marks

N-1 **(N1-A)** A large water tube boiler was assessed for its performance. The operating conditions and design conditions of the boiler are given below.

Parameter	Unit	Design conditions	Operating conditions
Steam generation	Tons/hr	210	210
Steam pressure	Kg/cm^2	100	100
Steam temperature	^{0}c	440	440
Coal firing rate	Tons/hr	43	--
Flue gas temp, at the inlet of Air preheater	^{0}C	370	--
Flue gas temp, at the outlet of Air preheater	^{0}C	145	165
Excess air at Air preheater inlet	%	20%	25%
Excess air at preheater outlet	%	--	44.8%
% Dry flue gas heat loss	%	4.67	--
GCV of coal	Kcal/kg	3585	3240
Specific heat of flue gas	Kcal/kg k	0.23	0.23
Dry flue gas flow at air preheater outlet	Tons/hr	--	324
Ambient temperature	^{0}C	36	37

Using the above data calculate the following:

i) Heat loss in dry flue gas in kcal /hr at design conditions **(4 Marks)**

ii) Heat loss in dry flue gas in kcal/hr at operating conditions **(3 Marks)**

iii) Increase in operating coal consumption in Tons/hr w.r.t design due to higher dry flue gas loss considering boiler efficiency of 86%. **(2 Marks)**

iv) Additional expenditure to meet increased heat loss towards coal for 7000 hours of operation of boiler in a year at a coal cost of Rs 9500/Ton. **(3 Marks)**

v) Air leakage in Air preheater in **%** during operation **(3 Marks)**

(N1-B) Calculate the following for the given operating parameters

i) Effectiveness of air preheater **(3 Marks)**

ii) Actual mass of air supplied in kg of air/kg of fuel the following operating parameters: **(2 Marks)**

S.NO	Description	Design	Operating
1.	Generation	500 MW	440 MW
2.	Flue Gas temperature inlet (°C)	356	315
3.	Flue Gas temperature outlet (°C)	147	178
4.	Air temperature inlet (°C)	36	40
5.	Air temperature outlet (°C)	316	294
6.	Measured O_2 % in flue gas	3.56	4.56
7.	Theoretical air kg of air/kg of fuel	5.0	5.0

N1-S **A.**

i) Calculation of dry flue gas heat loss at design conditions

We have,

% Heat loss in dry flue gas= 4.67% = m Cp (Tf—Ta)/GCV of coal--------------(i)

m= mass of dry flue gas, kg/kg of coal

Cp=Specific heat of flue gas, kcal/kg k=0.23

Tf=temp of flue gas deg,C=145

Ta=Ambient temp. Deg,C=36

GCV=3585 kcal/kg

Substituting the values in equation (i)

4.67/100= m x 0.23 x(145-36)/(3585)
m= 6.68 kg of dry flue gas/kg of coal (or) m= 6.67 kg of dry flue gas/kg of coal
coal firing rate= 43x 1000 kg/hr
mass flow rate of dry flue gas=6.68 x 43x1000 =287240 kg/hr=M
Heat loss in dry flue gas= M x Cp x (Tf-Ta)=287240x0.23x(145—36)
=7201106.8 kcal/hr (or) 7190326 kcal/hr

Alternate solution:

= 4.67 x 3585/100
Flue gas loss = 167.41 kcal/ kg
Design fuel firing rate = 43TPH
= 43x1000 x 167.41
= 7198630 kcal/hr

ii) Flue gas Heat loss at operating conditions =M x Cp x (Tf-Ta)-----------(ii)
M=324x 1000 kg/hr
Cp=0.23 kcal/kg K
Tf=165 deg C
Ta=37 deg.C
Substituting the values in equation (ii)
Flue gas heat loss= 324x1000x 0.23 x(165-37)=9538560 kcal/hr-------ANS

iii) Increase in dry flue gas heat loss=(9538560—7201106.8)
=2337453.2 kcal/h------ANS

Coal equivalent of heat loss= 2337453.2/3240kcal/kg=721.4 kg/h
Considering boiler efficiency of 86%,
Coal equivalent= 721.4/0.86=838.8 kg/hr =0.8388 Tons/hr--------ANS

iv) Additional expenditure to be incurred due increase in dry flue gas heat loss/year=
= 0.8388 x 7000 x 9500 Rs/ton=Rs 557.80 Lakhs ---------ANS

v) Air preheater leakage=(O_2 % in flue gas leaving APH—O_2 % in flue gas entering APH)/
(21—O_2 % in flue gas leaving APH)---------------(iii)

25% and 44.8 % excess air corresponds to 4.2% O_2 and 6.5% O_2 respectively as calculated from the equation, Excess Air = %O_2 /(21-%O_2)
From equation (iii)
% APH leakage=(6.5—4.2)/(21-6.5)x100 =15.86% ----------ANS

N1-B-S
Solution:
i).APH Effectiveness (4 Marks)
= (Air temp APH out - Air Temp APH in)/(Flue Gas temp. APH in - Air temp. APH in) x 100
= (294-40)/(315-40) x100
= 92.36 %
ii). Actual mass of air supplied in kg of air/kg of fuel (1 Mark)
Excess air = O_2%/(21-O_2%) = 4.56 % / (21-4.56%) x 100 = 27.73 %
AAS = (1+EA/100) x Theoretical Air
= (1+0.2773) x 5
= 6.386 kg of air/ kg of fuel

N-2 a) Two stage reciprocating belt driven air compressor is designed for the following conditions.

Air inlet pressure	: 1.033 kg/cm^2 (a)
Air inlet temperature	: 30 °C
Compressor discharge pressure	: 7.0 kg/cm^2 (g)
Isothermal efficiency	: 60%
Free air delivery	: 11.67 m^3/min
Motor efficiency	: 85%
Belt power transmission efficiency	: 97%

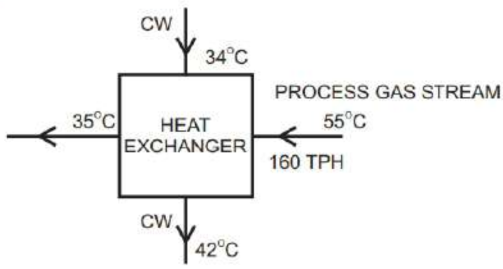
Based on the above data calculate:

(i) Power input to the motor (5 Marks)
(ii) Specific power consumption of the compressor in kW/m^3/hr (1 Mark)
(iii) If the discharge air pressure is reduced to 6 kg/cm^2 g, calculate the reduction in kW (2 Marks)

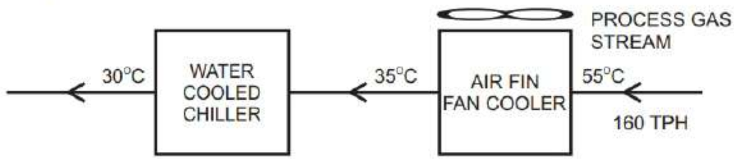
b) In a chemical plant, a 160 TPH process gas stream is being cooled from 55 deg.C to 35 deg.C through cooling water exchanger. The plant team would like to further cool this process gas stream upto 30 deg.C as the envisaged monetary saving potential is Rs.200 lakhs per annum due to process improvement.

Due to water scarcity, the plant team proposes to completely avoid the usage of existing water cooled heat exchanger and proposes to use air fin fan cooler followed by a water followed by a water-cooled chiller as shown in the schematic.

EXISTING CASE :



PROPOSED CASE :



Specific heat of process stream	: 0.5 kcal/kg-deg.C
COP of chiller	: 4.2
Chiller compressor motor efficiency	: 94%
Range of the chiller cooling tower	: 5°C
Power consumption of Cooling Tower Pump and Fan	: 11 kW
Power cost	: Rs. 9/kWh
CW cost	: Rs.1.2/m^3
Volumetric flow rate through air fin fan cooler	: 300 m^3/sec
Fan differential static pressure	: 100 mmWC
Fan efficiency	: 70%
Fan motor efficiency	: 95%
Operating hours in year	: 8000 hrs

Calculate the following:

	i) Cooling water flow (m^3/hr) of existing cooling water exchanger for reducing process gas stream temperature from 55 deg.C to 35 deg.C. (1 Mark) ii) Proposed chiller capacity (TR) (3 Marks) iii) Circulating cooling water flow for the proposed chiller (m^3/hr). (3 Marks) iv) Power consumption (kW), for the proposed water-cooled chiller and air fin fan cooler (3 Marks) v) As an energy auditor economically evaluate the new proposal and give your recommendation. (2 Marks)
N2-S	(A)

(i) Power input to motor

We have Isothermal efficiency = Isothermal power/compressor shaft power = 0.6 -----(1)

Isothermal power =P1 X Qf x $\log_e$ r /36.7 kw---------------(2)

Where,

P1 = Compressor inlet air pressure kg/cm^2 a =1.033

Qf = FAD m^3 /min =11.67x60 m^3/hr

r=P2/P1=(7+1.033)/1.033 =7.776

Substituting the values in equation(2) we get

Isothermal power =1.033 x 11.67 x 60 x $\log_e$ 7.776/36.7 =40.4 kw

From equation(1), 0.6= 40.4/compressor shaft power

Compressor shaft power= 40.4/0.6=67.33 kW

Input power to motor= 67.33/(0.85 x 0.97)=81.66 kW -------ANS

(ii) Specific power consumption=Input power to motor, kW/m^3/hr

= 81.66/(11.67 x 60)

=0.1166 kW/(m^3/hr) –ANS

(iii) calculation of % Saving in power when discharge pressure reduced to 6 kg/cm^2 (g)

NOW, P2= 6 + 1.033 kg/cm^2 a

P1= 1.033 KG/CM^2 a

r= (6+1.033)/1.033=6.8

FAD=11.67 m^3 /min

Isothermal power=(1.033 x 11.67 x 60 x $\log_e$ 6.8)/(36.7)

=37.8 kw

From equation (1) above,

Isothermal efficiency= 0.6 = 37.8/compressor shaft power

Compressor shaft power=37.8/0.6=63 kW

Motor input power= 63/(0.97x0.85)=76.4 kW

Saving in power=(81.66—76.41)

= 5.25 kW

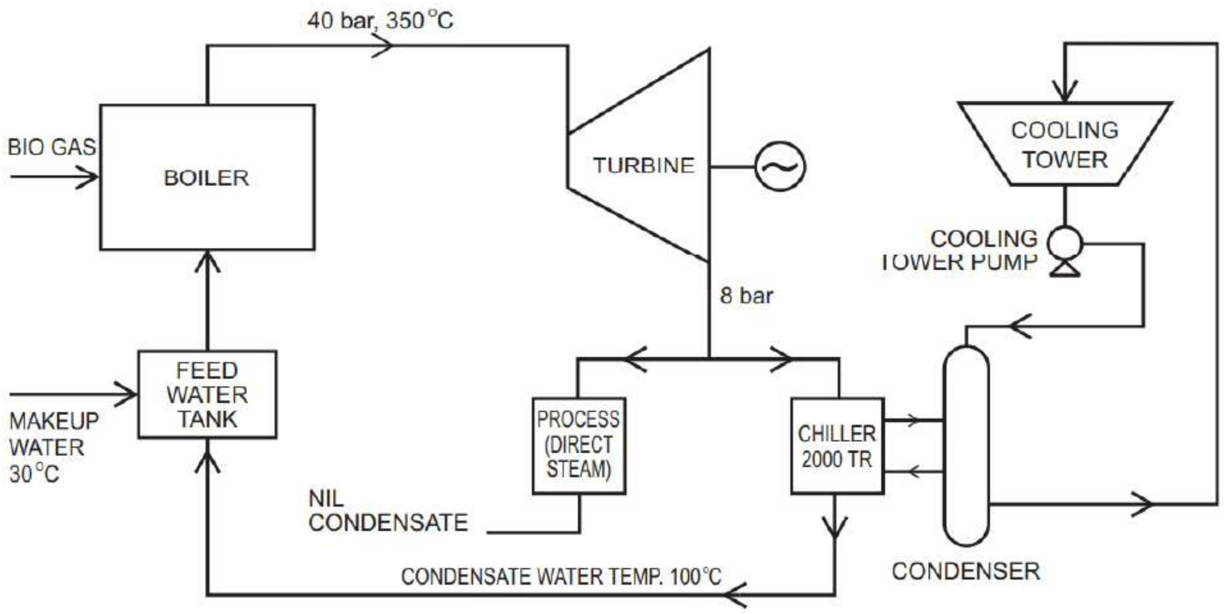
b)

i)	Cooling water flow rate to existing cooler	= 160 x 0.5 x (55-35)/(42-34) **= 200.0**	m^3/hr
ii)	Total required duty in new scheme	= 160 x 1000 x 0.5 x (55-30) /10^6 = 2.00	Gcal/hr
	Heat Duty of Air Fin fan cooler	= 160 x 1000 x 0.5 x (55-35) /10^6 = 1.6	Gcal/hr
	Residual duty required through chiller	= (2.0 – 1.6) x 10^6/3024 **= 132**	TR
iii)	Chiller condenser duty	= 132 x (1+ 1/4.2) = 163	TR
		= 163 x 3024 / 10^6 = 0.49	Gcal/hr

	Required CW flow for new chiller condenser	= $(0.49 \times 10^6)/\{1.0 \times (5)\}/1000$ **= 98**	m^3/hr
iv)	Centrifugal chiller power consumption	= (132 x 3024/4.2/860) /0.94 = 117.6	kW
	Fan power consumption of Air fin fan cooler	= 300 x100/(102x0.70 x 0.95) = 442	kW
	Power consumption of cooling tower pump and fan	= 11 kW	
	Total additional power consumption	= 117.6 + 442 +11 = 570.6	kW
v)	Power cost for the proposed scheme	= $570.6 \times 9 \times 8000/10^5$ = 410.832	Rs. Lakhs PA
	Process benefit of new scheme	= 200.0	Rs. Lakhs PA
	Potential monetary loss of new scheme	= (200 – (410.832)) **= -210.83**	Rs. Lakhs PA

Recommendation: Proposed scheme is not viable.

N-3 An effluent treatment plant is treating effluent from nearby industries and treated effluent is recycled back to nearby industries as raw water. The biogas generated from the effluent plant is used in a back pressure co-generation system. The operation details are shown in the schematic and tabulated below:



Steam enthalpy at generation pressure and temperature: 720 kcal/kg
Enthalpy of back pressure steam : 660 kcal/kg
Turbine efficiency : 85%
Generator efficiency :97%
Gear box efficiency : 98%
Power generated : 900 kW
Boiler efficiency : 75%
Bio gas GCV : 7000 kcal/sm^3
Capacity of absorption chiller : 2000 TR
COP of absorption chiller : 0.8
Efficiency of cooling tower pump : 75%
Efficiency of cooling tower pump motor : 93%
Head developed by the pump : 15 meter

	Cooling tower range	: 5°C	
	Calculate the following:		
	i) Steam flow to the turbine in TPH		4 Marks
	ii) Steam flow to the chiller in TPH		4 Marks
	iii) Steam flow to the process in TPH		2 Marks
	iv) Bio gas input to the boiler in sm^3/hr		4 Marks
	v) Calculate the input power drawn by the cooling tower pump in kW		6 Marks

N-3-S Solution:

i)	Heat Output of generator	= 900 kW x 860 kcal = 774000/(0.97x0.98x0.85) = 957909 kcal/hr Or = 900 kW/ (0.97x0.98x0.85) =1113.8 kW x 860 = 957909 kcal/hr
	Enthalpy drop across the turbine	= 720-660 = 60 kcal/ kg
	Steam flow to the turbine (m1)	= 957909 kcal/hr / 60 kcal/ kg = 15965 kg/ hr or 15.96 TPH
ii)	Heat required for the chiller	= 2000 x 3024 / (0.8) = 7560000 kcal/hr
	Steam flow to the chiller in TPH	= 7560000 kcal/hr / (660-100) kcal/kg = 13500 kg/h or 13.5 TPH
iii)	Steam flow to the process in TPH	= 15.96 -13.5 = 2.46 TPH
vi)	**Biogas consumption:**	
	When two liquids of different temperature are mixed in a tank, to calculate the final temperature	= ((m1xS1xT1) + (m2xS2xT2))/ (m1xS1 + m1xS1) = (13.5x100 + 2.46 x30)/ (13.5+2.46) = 89.2 °C
	The biogas flow rate,q	= 15.96 x 1000 x (720-89.2) / (0.75 x 7000) = 1917.6 sm^3/hr
		(or)
		= (13.5 x1000 (720-100))+ (2.46 x1000x (720-30)) / (0.75 x 7000) = 1917.6 sm^3/hr
v)	input power drawn by the cooling tower pump	
	Heat rejected by VAM chiller	= (2000 x 3024) + 13.5 x 1000 x (660-100) = 6048000 + 7560000 = 13608000 kcal/hr
	Pump flow rate (cooling tower range 5°C)	= 13608000 / 5 = 2721600/1000 = 2721.6 m^3/hr
	Power drawn by the motor	= ((2721.6 /3600) x15x 9.81))/(0.75x0.93) = 159.5 kW

	Answer any ONE of the following among four questions given below:
N4 A	The utility data for the upcoming commercial building is as follows • Total Power required for the whole building including centrifugal chiller load : 1000 kW • Building cooling load : 15,12,000 kCal/hr • Centrifugal chiller power consumption : 0.45 kW/TR • Cost of grid power including demand charges : Rs.10.35 /kWh The management is considering the following two options for operating the building loads Option 1: Operating all the loads through grid power Option 2: Installing an 850 kW natural gas engine generator operating at full load with a WHRB and steam operated absorption chiller to meet part of the cooling load. Details of gas engine cogeneration system are given below: • Total power generated from gas engine co-gen plant : 850 kW • Gas engine efficiency : 38 % • Heat absorbed for steam generation in WHRB (as a % of heat input to gas engine) : 22 % • Specific steam consumption for VAM : 4.2 kg/TR • Calorific value of Natural Gas : 8500 kcal/sm^3 • Cost of Natural Gas : Rs.45/sm^3 • Total enthalpy of steam : 660 kCal/kg • Feed water temperature to WHRB : 60 ^{0}C **Calculate the following:** i) Cost of generating one unit of electricity from the gas engine? (3 marks) ii) TR generated from Vapour Absorption Chiller driven by WHRB generated steam? (6 Marks) iii) Total energy cost per hour for option 1 & option 2. (10 Marks) iv) Which option is economically viable? (1 mark)
N4 A-S	**i) Cost of generating one unit of electricity from gas engine?** Fuel Consumption = 850 kW X 860 / (0.38 X 8500) = **226.31 sm^3/hr** Cost per unit of electricity from gas engine = (226.31 sm^3/hr X 45 Rs./ sm^3) / 850 kW = **Rs.11.98/ kWh** ii) TR generated from VAM driven by WHRB generated steam TR required by the building = 1512000/3024 = 500 TR Heat absorbed by WHRB for Steam generation = 22% x (226.31 x 8500) = **4,23,199.7 kcal /hr** Amount of steam generated = 423199.7/(660-60) = 705.33 kg/hr TR generated by VAM = 705.33/4.2 = **167.94 TR** iii) Total energy cost per hour for option 1 & option 2. Cost of electricity from Grid (Option 1) = 1000x 10.35 = **10,350 Rs./hr** Total energy cost (Option 2)

Additional TR required = (500-167.94) = 332.06 TR

Power required from the grid for the additional TR = 332.06 x 0.45 = 149.43 kW

Cost of additional TR required = 149.43x 10.35 = 1546.60 Rs/hr

Cost of NG for Electricity = 226.31 sm^3/hr X 45 Rs./ sm^3

= **10,184 Rs./hr**

= 10184+1546.60

= **11,730.6 Rs./hr**

iv) Which option is economically viable?

Option -1 is economically viable.

Or

N4 B

During an energy audit of 5 stage Pre-heater (PH) kiln cement plant, following data were collected:

S. No.	Description	UoM	Value
1.	Clinker output	Tph	55
2.	Return dust in PH gas (% of Kiln feed)	%	9.4
3.	Reference Temperature	Deg C	0
4.	Reference pressure and the barometric pressure	mmWC	10336
5.	NCV of coal	kcal/kg	5500
6.	Cost of coal	Rs./ MT	9500
7.	Power cost	Rs./kWh	5.5
8.	Kiln annual running hours	Hrs/annum	7200

S.No	Flow measurements		PH exit/fan inlet	Cooler exhaust air
1.	Average dynamic pressure	mmWC	16	17.13
2.	Static pressure	mmWC	-440	-28
3.	Temperature	Deg C	355	365
4.	Density of gas at Ref. temperature and pressure	kg/Nm3	1.4	1.293
5.	Pitot tube constant		0.85	
6.	Fan input power	kW	333	62
7.	Fan efficiency	%	80	78
8.	Fan motor efficiency	%	95	95
9.	Diameter of measuring point	M	2	1.6
10.	Specific heat of PH gas	kcal/kg °C	0.248	0.245

Calculate the following:

i. Heat loss in PH exit gas (kcal/kg clinker) [5 marks]

ii. Heat loss in cooler vent air (kcal/kg clinker) [5 marks]

iii. The recommendations made by energy auditor are as follows:

a) The 5 stage pre-heater may be upgraded to 6 stage, which will result in reduction in PH exit temperature by 50 °C and increase in pressure drop by 150 mm WC. Calculate the net annual monetary energy savings for proposed modification considering other parameters same as pre-modification. [8 marks]

b) To increase the cooler recuperation efficiency by reducing cooler exhaust temperature by 75 °C. Calculate the reduction in heat loss in cooler vent air (kcal/kg clinker) [2 marks]

N4 B-S

Density of Pre-heater gas at PH Fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} \text{ X } \frac{273 \text{ X} (10336 + P_S)}{(273 + T) \text{X} 10336}$$

$$\rho_{T,P} = 1.40 X \frac{273 X (10336 - 440)}{(273+355) X 10336} = 0.583 \text{ kg/m}^3$$

Velocity of PH gas

$$v = P_t \sqrt{\frac{2 g P_d}{\rho_{T,P}}}$$

$$v = 0.85 \sqrt{\frac{2 X 9.8 X 16}{0.583}} = 19.7 \text{ m/sec}$$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
= 19.7 X (3.14 x $(1)^2$)
= 61.858 m^3/sec
= 61.858 X 3600
= 222688 m^3/hr

Specific volume of PH gas = 222688.8 X 0.583/1.4
= 92733.97 Nm^3/hr
= 92733.97/55000 = **1.686 Nm^3/kg clinker**

i. Heat loss in PH exit gas

Q1 = $m_{ph}\ c_p\ \Delta T$ (C_p of PH gas = 0.248 kcal/kg ºC)

Q1= 1.686 X 1.4 X 0.248 (355-0)
= **207.81 kcal/kg clinker**

[5 marks]

Similarly density of cooler vent air at cooler vent air fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} X \frac{273 X (10336 + P_S)}{(273+T) X 10336}$$

$$\rho_{T,P} = 1.293 X \frac{273 X (10336 - 28)}{(273+365) X 10336} = 0.5518 \text{ kg/m}^3$$

Velocity of cooler vent air in the fan inlet duct

$$v = P_t \sqrt{\frac{2 g P_d}{\rho_{T,P}}}$$

$$v = 0.85 \sqrt{\frac{2 X 9.8 X 17.13}{0.5518}} = 20.96 \text{ m/sec}$$

Volumetric cooler vent air = velocity X duct cross-sectional area
= velocity x (π x d^2)/4
= 20.96 X (3.14×$(1.6)^2$) /4
= 42.12 m^3/sec
= 42.12 X 3600
= 151636 m^3/hr

Specific volume of cooler vent air = 151636 X 0.5518/1.293
= 64712 Nm^3/hr
= 64712/55000 = **1.176 Nm^3/kg clinker**

ii. Heat loss in cooler vent air

Q2 = $m_{CA}\ c_p\ \Delta T$

Q2= 1.176 x 1.293 x 0.245 x (365-0)
= **136 kcal/kg clinker**

[5 marks]

iii.

a) After up-gradation from 5 stage to 6 stage Pre-heater

Reduction in PH exit gas heat loss

Q = $m_{ph}\ c_p\ \Delta T$ (C_p of PH gas = 0.248 kcal/kg ºC)

Q1= 1.686 X 1.4 X 0.248 X 50
= **29.16 kcal/kg clinker**

	Equivalent coal savings (kg /hr) = $\text{Reduction heat loss}\,(kcal/kg\,clinker)\,X\,\frac{clinker\,output\,(kg/hr)}{NCV\,coal\,(kcal/kg\,coal)}$ Equivalent coal saving = $29.16\,X\,\frac{55000}{5500}$ kg coal/hr = 291.6 kg coal/hr Annual coal savings = $291.6\,X\,\frac{7200}{1000}$ = 2099.52 MT Annual monetary savings (Thermal) = 2099.52 X 9500 = Rs. 1,99,45,440 per annum **Increase in PH fan power due to increase in pressure drop by 150 mm WC** **Fan power** = $\frac{PH\,gas\,flow\,(m^3/hr)\,X\,Rise\,in\,pressure\,drop\,(mm\,WC)}{102\,X\,fan\,efficiency\,(\%)/100\,X\,motor\,efficiency(\%)/100}$ kW = $\frac{61.585\,X\,150}{102\,X\,80/100\,X\,95/100}$ = 119.16 kW **Increase in Annual Electrical energy cost = 119.16 X 7200 X 5.5** **= Rs. 47,18,974 per annum** **Net annual monetary savings = 1,99,45,440 - 47,18,974 = Rs. 1,52,26,466 per annum** b) **Improving cooler efficiency** Reduction in cooler vent air heat loss Q = $m_{cooler\,vent}\,c_p\,T$ (C_p of cooler vent air = 0.245 kcal/kg °C) Q1= 1.176 X 1.293 X 0.245 X 75 = 27.94 kcal/kg clinker
	Or
N4 C	Sponge iron is processed in a steel melting shop for production of ingots. The daily sponge iron production in the steel plant is 300 tons. The plant has a coal fired captive power station to meet the entire power demand of the steel plant. The base year (2020) and current year (2021) energy consumption data are given below:

Parameter	UoM	Base year (2020)	Current Year (2021)
Sponge Iron production	T/day	300	300
Specific coal consumption	T/T	1.3	1.15
Specific power consumption	kWh/T	110	95
Yield	%	85	88
SEC of Steel Melting Shop	kWh/ton	850	830
Captive power station heat rate	kcal/kWh	3300	3100
GCV of Coal	kCal/kg	5000	5200

Calculate the following:

i) Specific energy consumption of the plant in Million Kcals/ tonne of finished product for base year as well as for the current year. **15 Marks**

ii) Reduction in coal consumption per day in current compared to base year for the plant **5 Marks**

N4 C-S

i) Specific energy consumption of the plant For Base Year

Specific energy consumption for sponge iron	= 1300 kg x 5000 + 110 kWh x 3300 = 6.863 million kcal/ Ton of SI
Total energy consumption for sponge iron /day	= 300X 6.863 = 2059 million kcal

Actual production considering 85% yield from sponge iron to ingot conversion	= 300 Tons x 0.85 = 255 Tons/ day
Specific energy consumption for ingot	= 850 kWhx 3300 = 2.81 million kcal/ ton of ingot
Total energy consumption for ingot production per day	= 2.81 X 255 = 716.55 million kcal
Plant specific energy consumption for production of finished product (ingot) during base year	= (2059+716.55) / 255 = 10.89 million kcal/ ton

Specific energy consumption of the plant For Current Year

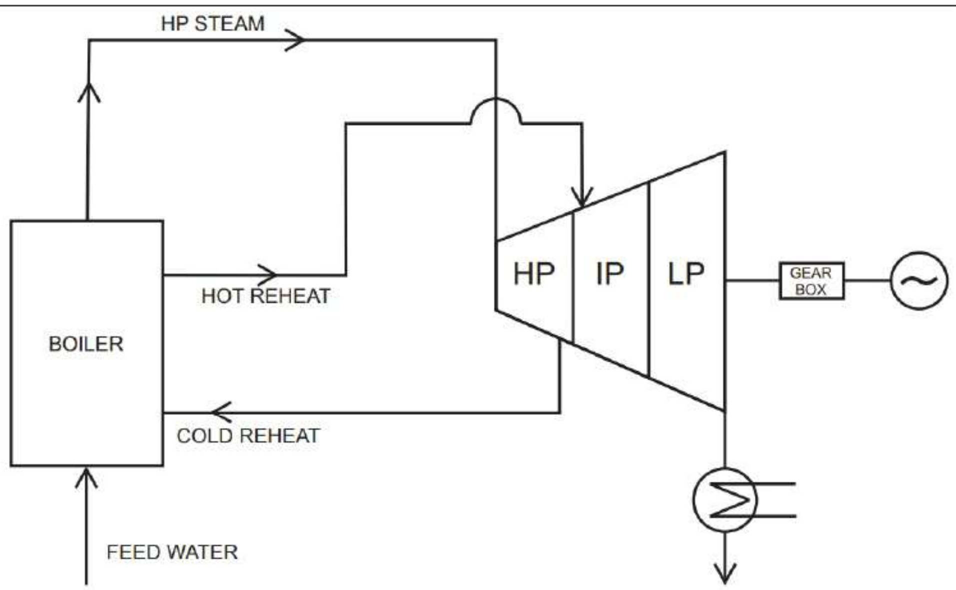
Specific energy consumption for sponge iron	= 1150 kgx 5200 + 95 kWhx 3100 = 6.28 million kcal Ton of SI
Total energy consumption for sponge iron /day	= 300 x 6.28 = 1884 million kcal
Actual production considering 88% yield from sponge iron to ingot conversion	= 300 T X 0.88 = 264 Tons / day
Specific energy consumption for ingot	= 830Kwh x 3100 = 2.573 million kcal/ ton of ingot
Total energy consumption for ingot production per day	2.573 X 264 = 679.27 million kcal
Plant specific energy consumption for production of finished product (ingot) during current year	= (1884+679.27)/264 = 9.70 million kcal/ ton

ii) Reduction in coal consumption

Energy saving in sponge iron plant = (6.863-6.28) x300 = 175 million kcals/day
Energy saving in steel melting plant = (2.81*255-2.57*264) = 38 million kcal/day
Total energy saving = 175 + 38 = 213 million kcal/day
Equivalent coal reduction (saving) = 213 x 10^6/5200 = 40.96 Tons per day

Or

N4 D A thermal power plant is equipped with boiler and reheat steam turbine with the following details



PARAMETER	UNITS	HP TURBINE (INLET)	HP TURBINE (OUTLET/ CRH)	IP TURBINE (INLET/ HRH)	LP TURBINE INLET	CONDENSER
Pressure	**Kg/cm²**	**145**	**36.7**	**33**	**7**	**0.125**
Temperature	**°C**	**516**	**340**	**516**	**322**	**49**
Enthalpy	**Kcal/kg**	**813**	**735**	**834**	**741**	**610**
Flow	**TPH**	**684**	**635**	**635**	**545**	**545**

LP turbine exhaust dryness fraction : 0.98
Isentropic efficiency of HP turbine : 79.6%
Isentropic enthalpy at LP turbine exhaust pressure : 559 kcal/kg
Boiler feed water temperature : 241 °C
Gear box efficiency : 98%
Generator efficiency : 97%

Calculate:

i) Isentropic enthalpy of HP turbine outlet steam. (4 Marks)

ii) Isentropic efficiency of LP turbine (5 Marks)

iii) Power generated from HP, IP and LP turbine in MW (6 Marks)

iv) Turbine heat rate and station Gross heat rate (kcal/kWh) (3 Marks)

v) If the auxiliary power consumption is 8%, calculate the Net heat rate of the power plant in kcal/kWh. (2 Marks)

N4 D-S

i)	**Isentropic efficiency of HP turbine**	= 79.6 %
	Isentropic enthalpy of HP turbine outlet steam	(813-x) = (813-735)/ 0.796 = 98 X = 813 -98 = 715 kcal/ kg
ii)	Enthalpy of exhaust of LP turbine	= 49+0.98 x (610-49) = 599 kcal/kg
	Isentropic Efficiency of LP turbine	= (741-599)/ (741-559) **= 78 %**
iii)	Power generated from HP, MW	= Mass flow rate x Enthalpy drop across HP turbine/860 = (684x1000x(813-735))/(860x1000)

			= 62.03 MW
		Power generated from IP, MW	= Mass flow rate x Enthalpy drop across IP turbine/860 = (635x1000x(834-741))/(860x1000) = 68.6 MW
		Power generated from LP, MW	= (545x1000x(741-599))/(860x1000) = 89.98 MW
	iv)	Gross heat rate (kcal/kWh)	
		Total Power generated by Turbine in MW	= 62.03+68.6+89.98 = 220.67 MW
		Power generated by generator	= 220.67 MW x 0.98 x 0.97 = 209.76 MW
		Turbine heat rate	= (684 x (813-241) + 635*(834-735))/209.76 = 454113/209.76 = 2164.9 kcal/kWh
		Station Gross heat rate	SGHR cannot be calculated since boiler efficiency not given Or Any candidate calculates SGHR, assuming boiler efficiency between 85-88% marks are awarded (Refer guide book-4, page no 175,181 & 193)
	v)	Station Net heat rate	Station net heat rate cannot be calculated since station gross heat rate could not be calculated Or Any candidate calculates SNHR by calculating SGHR on assuming boiler efficiency between 85-88% marks are awarded

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

21^{st} NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & AUDITOR

PAPER – 4: ENERGY PERFORMANCE ASSESMENT FOR EQIUIMENT AND UTILITY SYSTEM

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

i. Answer all **Ten** questions
ii. Each question carries **ONE** mark

1	Oxygen and nitrogen present in the fuel do not contribute to calorific value of the fuel.	True/False	**TRUE**
2	The difference between GCV and NCV of hydrogen fuel is Zero	True/False	**FALSE**
3	In a refrigeration plant the higher the kW/TR, the higher will be the COP.	True/False	**FALSE**
4	In an integrated steel plant, pig iron is produced from Blast furnace	True/False	**TRUE**
5	The copper loss in the transformer is the power consumed to sustain the magnetic field in the transformer core	True/False	**FALSE**
6	The head generated by the centrifugal pump is proportional to the square of the density of the liquid being pumped	True/False	**FALSE**
7	Current THD is the ratio of the root-mean-square value of the harmonic currents to the square of the fundamental current.	True/False	**TRUE**
8	Both Rotary hearth and walking beam-type furnaces are continuous furnaces	True/False	**TRUE**
9	% Oxygen or CO_2 in flue gas is not required to calculate the boiler efficiency by Direct method	True/False	**TRUE**
10	In the reheat cycle of a thermal power plant, partially expanded steam extracted from the turbine at various points are used to heat the condensate and feed water through HP/LP heaters on its way back to the boiler or steam generator.	True/False	**FALSE**

………………..**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

<table>
<tr><td>L1</td><td>An office complex with a total built-up area of 18000 m^2 is located in a warm and humid region which includes the car parking, road and basement area of around 7000 sq.m. The reported annual energy consumption is 9,73,569 units (kWh) from utility company and 25,167 units (kWh) from DG set. Calculate the EPI and AAHEPI if the facility operates for 2500 hours per year.</td></tr>
<tr><td>L1 S</td><td>Solution:
<table>
<tr><td>Annual Electricity Consumption, purchased from utilities</td><td>973569</td><td>kWh</td></tr>
<tr><td>Annual Electricity Consumption, through Diesel Generating sets</td><td>25167</td><td>kWh</td></tr>
<tr><td>Total built up area of the building</td><td>18000</td><td>sqm</td></tr>
<tr><td>Parking and Basement Area</td><td>7000</td><td>sqm</td></tr>
<tr><td>Annual Working hours</td><td>2500</td><td>hrs/yr</td></tr>
<tr><td>Total Annual Electricity Consumption Utilities + DG Sets/ GG Sets</td><td>998736</td><td>kWh</td></tr>
<tr><td>Built up area (Area of the building - Basement and Parking)</td><td>11000</td><td>sqm</td></tr>
<tr><td>EPI</td><td>91</td><td>kWh/sqm/yr</td></tr>
<tr><td>AAHEPI</td><td>36.32</td><td>Wh/sqm/h</td></tr>
</table></td></tr>
<tr><td>L2</td><td>In the cast house of an Aluminium smelting plant, there are two Billet Casting Machines. Holding cum Melting furnaces are used to meet the molten metal requirement of the Billet Casting Machine and the capacity of these furnaces are 40 Tonnes each.

One of the lines has fuel oil fired Holding cum Melting furnace and the other line has Electrical melting cum holding furnace, operated using electricity from the captive power plant.

Evaluate whether fuel oil fired furnace is economical or electrical furnace, with respect to operating energy cost in Rs./tonne.
<table>
<tr><td>1. Specific Oil Consumption</td><td>:</td><td>26 Ltr/T</td></tr>
<tr><td>2. Cost of Furnace Oil</td><td>:</td><td>38 Rs./ltr</td></tr>
<tr><td>3. Calorific Value of F.O</td><td>:</td><td>10000 kCal/Kg</td></tr>
<tr><td>4. Efficiency of FO fired melting cum holding furnace</td><td>:</td><td>65%</td></tr>
<tr><td>5. Efficiency of electrical melting and holding furnace</td><td>:</td><td>85%</td></tr>
<tr><td>6. Cost of electricity from Captive Power Plant</td><td>:</td><td>3.75 Rs./kWh</td></tr>
<tr><td>7. Density of Furnace Oil</td><td>:</td><td>0.95 kg/ltr</td></tr>
</table></td></tr>
<tr><td>L2 S</td><td>Solution:
<table>
<tr><th>Description</th><th>Value</th></tr>
<tr><td>Existing Specific Oil Consumption (Ltr/T)</td><td>26</td></tr>
<tr><td>Cost of Furnace Oil (Rs./ltr)</td><td>38</td></tr>
<tr><td>Calorific Value of F.O (kCal/Kg)</td><td>10000</td></tr>
<tr><td>Efficiency of FO fired melting cum holding furnace (%)</td><td>65%</td></tr>
<tr><td>Efficiency of Electrical Melting and Holding Furnace (%)</td><td>85%</td></tr>
<tr><td>Cost with F.O Heating (Rs./T)</td><td>26X 38= 988</td></tr>
<tr><td>Useful heat requirement (kCal/T)</td><td>=26X0.95X10000X0.65</td></tr>
</table></td></tr>
</table>

	=1,60,550
Equivalent Electricity input (kWh/T)	= 1,60,550/(0.85X860) = 219.63
Cost with electrical heating (Rs./t)	=219.63 X 3.75 = 823.61
Cost advantage with electrical heating (Rs./T)	= 988 – 823.61 = 164.39

Electrical heating is found more economical.

……………..**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

N1	A process plant is planning to install a 5 MW gas turbine cogeneration system with 12 TPH waste heat boiler to meet the power and steam demand of the plant. Presently the process steam demand of 14 TPH is met by the gas fired boiler and the plant electricity demand is met from the grid. The co-gen plant will operate at 90% electrical capacity to meet the entire power requirement of the plant and simultaneously supply 11 TPH of process steam requirement. The balance 3 TPH of process steam has to be supplied from the existing gas fired boiler, which is operating at 86% efficiency on NCV basis. If the investment for new 5 MW Co-Gen plant is Rs.30 Crores, calculate the Net Annual savings and payback period. **Additional data:** Operating Hours per year : 8000 hr NCV of Natural Gas : 8700 kcal/sm^3 Cost of Natural Gas : Rs.12/sm^3 Heat rate of gas turbine on NCV : 3050 kcal/kwh Cost of electricity from grid supply : Rs.9 /kwh Enthalpy of steam : 665 kcal/kg Feedwater temperature : 85 °C Expenditure towards depreciation & interest : Rs.500 Lakhs/Annum Expenditure for consumables & maintenance of co-gen plant: Rs 200 Lakhs/Annum
N1 S	**Solution:** **Existing System:** Annual Electricity Requirement of the plant from the grid = 5000 x 0.9 x 8000 = 36000000 kWh/yr Annual Steam Requirement from Gas fired boiler = 14 x 8000 = 112000 TPY Existing Annual Electrical Energy cost through Grid Supply = (36000000 x 9)/10^5 = Rs.3240 Lakhs Existing Gas Fired Boiler Evaporation Ratio = (8700x 0.86)/(665 – 85) = 12.9 kgs Steam/sm^3 gas

Annual Gas Requirement for the boiler = (112000 x1000)/12.9
= 8682171 sm^3/yr

Cost of Steam from Gas Fired Boiler = 12/12.9
= Rs.0.93 per kg steam
= Rs.930/ton

Total Steam cost from gas fired boiler = (930 x 14 x 8000)/10^5
= Rs.1041.6 Lakhs/yr

Total Cost of Grid Electricity plus gas for Steam = (3240 + 1041.6)
= Rs.4281.6 Lakhs/yr

Proposed System:

Annual Electricity Requirement of the plant from the grid = 5000 x 0.9 x 8000
= 36000000 kWh/yr

Annual Steam Generation from Co-Gen plant = 11 x 8000
= 88000 TPY

Power Generation from Co-Gen plant = 5000 x 0.9
= 4500 kW

Heat rate of Gas Turbine of Co-Gen plant = 3050 kcal/kWh

Gas requirement for generation of 4500 kW for Co-Gen Plant = (3050 x 4500)/ 8700
= 1577.58 sm^3/hr
= 1577.58 x 8000 hrs
= 12620640 sm^3 /yr

Fuel cost for Co-gen plant = (1577.58 x 8000 x 12)/10^5
= Rs.1514.5 Lakhs/Annum

Total Cost of Co-Generation (A) = (1514.5 + 500 + 200)
= Rs.2214.5 Lakhs/yr

Electricity cost from Co-Gen Plant = (2214.5 x 10^5)/(4500 x8000)
= Rs.6.15/kWh

Cost Differential Between Grid and Co-Gen Power = 9 – 6.15
= Rs.2.85/kWh

Gas for additional 3 TPH steam to be supplied from
the gas fired boiler = (3000/ 12.9) x 8000
= 1860465 sm^3

Cost of gas for additional 3 TPH steam to be supplied
from the gas fired boiler= 3 x 930 x 8000
= Rs. 223.2 Lakhs

Additional gas to be purchased with Co-gen Plant and boiler
=(12620640+1860465)- (8682171)
= 5798934 sm^3/yr

Overall Cost with Co-Generation system including additional steam from gas fired boiler
= 2214.5 + 223.2
= Rs. 2437.7 Lakhs

	Net Annual savings with Co-Gen plant = 4281.6 – 2437.7 = Rs. 1843.9 Lakhs/yr Payback period = 3000/ 1843.9 = 1.63 years or 19.5 months
N2	In a chemical plant after meeting all the steam requirements, it was found that there was an excess steam of 10 MT/hr at 8.5 bar(g) from a waste heat boiler, which is presently being condensed through Air fin fan cooler. The chemical plant is having a chilling load of 2400 TR which is met by centrifugal chillers with a COP of 4.4. Based on the recommendation of an energy audit, the management would like to review the scheme of installing absorption chillers. Part of the refrigeration load will be met by a double effect absorption chiller (VAM) with a COP of 1.2, utilizing the excess waste steam. Any additional steam required has to be supplied by the existing fuel fired boiler at a cost of Rs. 1200 /T of steam. The existing cooling towers in the plant have adequate capacity to absorb the higher quantity of heat rejection from the absorption chillers. Latent heat of steam at 8.5 bar(g) : 479 kcal/kg COP of double effect absorption chiller : 1.2 Centrifugal chiller motor efficiency : 94% Electricity cost : Rs. 8/kWh Cooling Water cost including pumping energy and chemicals : Rs.3/m^3 CW inlet temperature with VAM : 34 deg. C CW outlet temperature with VAM : 42 deg. C Volumetric flow rate through air fin fan cooler : 50 m^3/sec Fan differential static pressure : 100 mmWC Fan eff. : 70% Fan motor Eff. : 92% Annual operating hours : 8000 hrs **Calculate :** a) The air fin cooler fan motor input power (kW) **(2.5 Marks)** b) The centrifugal chiller motor input power (kW) **(2.5 Marks)** c) The additional steam requirement for double effect chiller (kg/hr) **(5 Marks)** d) The additional heat load on cooling tower due to double effect chiller in (kcal/hr) **(5 Marks)** e) The net annual monetary benefit of entire scheme. (Rs. Lakhs/year) **(5 Marks)**

N2 S

Solution:

a) Motor Input Power of Air Fin Fan Cooler	kW	(m^3/s) x (mmWC) / (102) x (Effy-Fan) x (Effy-Motor)	(50) x (100) / (102) x (0.7) x (0.92)	76.12
b) Motor Input Power of centrifugal chiller	kW	COP = Ref effect (kcal/hr) / Input power to chiller (kcal/hr) = (TR x 3024) kcal/hr / (kW x effy chiller motor) x (860 kcal/hr) kW = (TR x 3024) / (COP) x (effy chiller motor) x 860 kW = TR / COP x (effy chiller motor) x (860/3024) kW = TR / (4.4 x 0.94) (860/3024) kW = 2400 / (4.4 x 0.94) (860/3024) = 2400 / 1.176 Chiller input (absorbed) power = 2040.4 kW		2040.4
C) Additional steam for double effect chiller (kg/hr)				
Total heat required for proposed 2400 TR absorption water chiller	kcal/hr	COP = Ref effect (kcal/hr) / Input energy to chiller (kcal/hr) Input energy to chiller (kcal/hr) = Ref effect (kcal/hr) / COP Input energy to chiller (kcal/hr) = 2400 x 3024 / 1.2 = 6048000 kcals/hr		6048000 kcals/hr
Heat available from 10 TPH waste excess steam	kcal/hr	10 x 1000 x 479 = 4790000 kcals/hr		4790000 kcals/hr
Balance heat required from additional steam from regular steam header	kcal/hr	6048000 – 4790000 = 1258000 kcals/hr		1258000 kcals/hr
Additional steam required from regular steam header	kg/hr	1258000 / 479 = 2626.3 kg/hr		2626.3 kg/hr
d) Additional heat load on cooling tower, kcal/hr				
Condenser duty for centrifugal chiller	kcal/hr	Condenser heat duty = Heat Rejected in Chiller + Heat of Work by compressor = (TR x 3024) + (TR x 3024/COP) = (2400 x 3024) + (2400 x 3024 / 4.4) = (2400 x 3024) x (1+ (1/4.4)) = 8907055 kcals/hr		8907055 kcals/hr
Condenser duty for absorption chiller	kcal/hr	Condenser heat duty = Heat Rejected in Chiller + Thermal energy (steam) input to chiller = (TR x 3024) + (TR x 3024/COP) = (2400 x 3024) x (1+ (1/1.2)) = 13305600 kcals/hr		13305600 kcals/hr
Additional condenser load	kcal/hr	13305600 - 8907055 = 4398545 kcals/hr		4398545 kcals/hr
Additional Cooling Water required in condenser	m^3/hr	Additional heat load = (Cooling water in kgs/hr) x 1000 x (Cp of Water) x CW delT Cooling water in m^3/hr = (Additional heat load)/ (1000 x 1 x (42-34)) = (4398545)/ (1000 x 1 x (42-34)) = (4398545)/ (8000) = 549.82 m^3/hr		549.82 m^3/hr
Additional Cooling water cost due to double effect chiller	Rs/hr	= 549.82 x 3 =1649.46		1650 Rs./hr
e) Annual monetary benefit of entire scheme,	Rs. Lak/year	= ((76.12 + 2040.4) x 8000 x 8) - ((2626.3 /1000) x 8000 x 1200) - (1650 x 8000) = 135457280 – 25212480 – 13200000 = 97044800/10^5 = 970.45 Lakhs/Year		970.45 Lakhs/Year

N3

A Shopping mall is operating with a centralized 120 TR chiller. The mall is in operation for 4500 hours in a year. The average energy cost is Rs.9/kWh. The details of the chiller plant is given below:

Equipment	Load Current in Amps	Operating Power Factor
Chiller Compressor	135	0.9

Condenser Pump	32	0.88
Chiller Pump	21	0.9
CT Fan	20	0.65

Note: All the motors are three Phase induction motors and operating at 415 Volts

Efficiency of compressor Motor : 92 %
Temperature difference across chiller : 4.5° C
Chilled Water Flow : 23 Lit/s
Head Developed by Chiller Pump : 35 m
Condenser Water Flow : 41 Lit/s
Head Developed by condenser Pump : 30 m

Calculate the following for the existing system:

1. Power Consumed by Chiller Compressor, Chiller Pump, Condenser Pump and CT Fan (3 Marks)
2. TR Delivered by the system (3 Marks)
3. COP of chiller (3 Marks)
4. kW/TR for the chilling plant (2 Marks)
5. Combined efficiency of chiller Pumps and condenser Pumps (3 Marks)

The management has decided to replace the condenser and chiller pumps with efficient pumps. The combined efficiency of motor and pump in both the cases is 65 %.

In addition the condenser has been cleaned resulting in 10 % energy reduction in chiller Power consumption.

Calculate the following after the above modification:

6. New kW/TR for the chilling plant (3 Marks)
7. Annual Energy saving and Monetary savings. (3 Marks)

N3 S **Solution:**

1. Power Consumption

Power Consumption of compressor Motor: 1.732 x 415 x 135 x 0.9 = 87.33 kW
Power Consumption of condenser pump Motor : 1.732 x 415 x 32 x 0.88 = 20.24 kW
Power Consumption of chiller pump Motor : 1.732 x 415 x 21 x 0.9 = 13.58 kW
Power Consumption of CT Fan Motor : 1.732 x 415 x 20 x 0.65 = 9.34 kW
Total Power consumption of chiller Plant : 87.33+20.24+13.58+9.34 = 130.5 kW

2. TR Delivered by the Chiller Plant:

=m*Cp*ΔT
=(23*3600)*1*4.5 = 372600 Kcal/hr
TR Delivered = 372600 Kcal/3024 = 123.2 TR
COP = Refrigeration effect /Input power to compressor= (372600)/ (87.33*0.92*860) = 5.4
Overall Chiller Plant, kW/TR = 130.5/123.2 =1.059
Combined efficiency of Chiller pumps = LKW/Power Drawn by the pump
=23 x 35 x 9.81 /1000 = 7.89 kW
= 7.89/13.58 = 58.03 %
Combined efficiency of condenser pumps = LKW/Power Drawn by the pump
= 41 x 30 x 9.81 /1000 = 12.06 kW
= 12.06/20.24 = 59.58 %

After Modifications:

Chiller compressor Power = 87.33 x 0.9 = 78.59 kW
Chiller Pump power with 65 % Combined Efficiency= 7.89/0.65 =12.13 Kw
Condenser Pump power with 65 % combined efficiency = 12.06 /0.65 = 18.55 kW
Chiller Plant total Power consumption after condenser cleaning and with new pumps =
78.59+ 12.13+18.55+9.34 =118.61 kW
Overall Chiller Plant, kW/TR (After Condenser Cleaning and with New efficient Pumps)

	= 118.61 /123.2 = 0.963 Kw/TR Annual Energy Savings for 4500 Hours operation = (1.059 – 0.963) *123.2*4500 = 53222.4 kWh Annual Monetary savings @ Rs 9 /kWh = 53222.4 x 9 = Rs 479002 (Or) Annual Energy Savings for 4500 Hours operation = (130.5 – 118.6)*4500 = 53550 kWh Annual Monetary savings @ Rs 9 /kWh = 53550 x 9 = Rs 481950
N4	**Answer any ONE of the following among four questions given below:**
A	A coal-based power plant has two units each of 200 MW. Each unit comprises of one turbine and one boiler. Both the units are using the same coal for power generation. **Unit 1 Running Parameters:** Main Steam flow : 670 TPH Main Steam Pressure &Temperature: 145 kg/cm^2 (g), 540 °C Feed Water Temperature: 150 °C Ambient Temperature= 30° C Fuel (Coal) Analysis: Ash : 35% Moisture : 13.3% Carbon:40% Hydrogen: 2.5% Nitrogen: 1.2% Oxygen: 7.5% Sulphur: 0.5% GCV of Coal : 4000 Kcal/kg Humidity in ambient air : 0.0199 kg/kg of dry air GCV of Bottom Ash = 500 kcal/kg GCV of Fly Ash = 200 kcal/kg Ratio of Bottom ash to Fly Ash = 1:4 Oxygen percentage in flue gas at Air heater inlet = 3% Specific Heat of Flue Gas = 0.24 kcal/kg.deg C CO in Flue gas = 150 ppm CO_2 in Flue Gas = 7% Heat loss due to radiation & other accounted losses = 0.45% Unit 1 Turbine Heat Rate = 2450 kcal/kwh Unit 2 Unit Heat Rate = 2790 kcal/kwh Average exit flue gas temperature = 170 °C Load Factor :75% **Calculate:** 1. Unit 1 Boiler efficiency? (10 Marks) 2. Which unit is more efficient? (2 Marks) 3. Find out the difference of coal consumed per day between unit 1 & unit 2 when each unit operates at 75% load. (5 Marks) 4. Calculate the net heat rate of the station with an overall station auxiliary power consumption of 10%. (3 Marks)
N4 A-Sol.	**Solution:** 1.Theoretical air required = [11.6 C + [34.8 ($H_2 – O_2/8$)] + 4.35 S] /100 kg air / kg coal = [11.6 x 40 + [34.8 (2.5 – 7.5/8)] + 4.35 x 0.5]/100 = 5.20 kg air /kg coal 2. Excess Air, % = (% O2) / (21 – % O2) x 100 = (3) / (21 – 3) x 100 = 16.66 % 3. Actual Air Supplied (AAS) = (1+(16.66/100)) x 5.20 = 6.06 kg air / kg coal 4. Mass of dry flue gas = ((0.4*44)/12) +(1.2/100) +(6.06*(77/100))+ ((6.06-5.2)*(23/100))+ ((0.5/100)*(64/32)) = 6.35 kg dry flue gas/kg coal **Boiler Losses:**

a) L1 = % heat loss due to dry flue gases
= (m*cp*(Tf-Ta)/ GCV of Coal)*100
= (6.35*0.24*(170-30)/ 4000)*100
= 5.3%

b) L2 = % heat loss due to formation of water from H2 in fuel
= ((9*H2*(584+(Cp *(Tf-Ta))/(GCV of Coal))*100
= ((9*0.025*(584+(0.45 *(170-30)))/(4000))*100
= 3.64%

c) L3 = % heat loss due to moisture in fuel
= ((m*(584+(Cp *(Tf-Ta)))/(GCV of Coal))*100
= ((0.133*(584+(0.45 *(170-30)))/(4000))*100
= 2.15%

d) L4 = % heat loss due to moisture in air
= ((AAS*Humidity*Cp*(Tf-Ta))/(GCV of Coal))*100
= ((6.06*0.0199*0.45*(170-30))/(4000))*100
= 0.19%

e) L5 = % heat loss due to partial conversion of C to CO
= (((% CO*C)/(%CO+%CO2))*((5654/GCV of Coal))*100
= (((0.015*0.4)/(0.015+7))*((5654/4000))*100
= 0.12%

f) L6 = % heat loss due to ash
Total ash in 1 kg coal = 0.35 kg
Bottom ash = 0.2*0.35 = 0.07kg
Fly ash = 0.80*0.35 = 0.28kg
% heat loss in ash = (((500*0.07) +(200*0.28))/4000) *100
= 2.275%

g) % Heat loss due to radiation & other accounted losses (L7) (Given)= 0.45%

1. Unit 1 Boiler Efficiency:

= 100-(L1+L2+L3+L4+L5+L6+L7)
= 100-(5.3+3.64+2.15+0.19+0.12+2.275+0.45)
= 85.875% = 85.88%

2. Determination of more efficient unit:
Unit heat rate of Unit 1 = (Turbine Heat Rate/Boiler Efficiency)
= (2450/(85.88/100))
= 2852.82 kcal/kWh

Heat rate of unit 1 (2852.82 kcal/kWh) is higher than heat rate of unit 2 (2790 kcal/kWh), hence unit 2 is more efficient than unit 1.

3. Determination of difference in coal consumption per day for same generation:
Coal consumed by Unit 1 = ((Heat rate of unit 1)*(200*1000*0.75*24))/(GCV Coal)
= ((2852.82)*(200*1000*0.75*24))/(4000)
= 2567538 kgs coal/day
= 2567.54 TPD
Coal consumed by Unit 2 = ((Heat rate of unit 2)*(200*1000*0.75*24))/(GCV Coal)
= ((2790)*(200*1000*0.75*24))/(4000)
= 2511000 kgs coal/day
= 2511 TPD
Difference in coal consumption = (2567.54 - 2511) TPD
= 56.54 TPD excess coal consumption by unit 1

4. Net heat rate of the station with an overall station auxiliary power consumption of 10%

	Station Gross Heat Rate = (2852.82+2790)/2 = 2821.4 kcal/kWh Net station heat rate = Gross station heat rate/ (1-% Aux Conspn) = 2821.4 / (1-0.10) = 3134.9 = 3135 kcal/kWh
N4	**OR**
B	In a textile process unit, a five chamber stenter is installed for drying the cloth. The hot air used for drying in the stenter is heated by furnace oil fired thermic fluid heater. The production output of the stenter is 70 meter/min. Dried finished cloth is leaving the stenter at 5% moisture & 80 °C temperature, whereas the wet cloth is entering at 30°C & 55% moisture. The stenter is operating for 7000 hours/yr. Towards reducing the fuel consumption in thermopack the management has decided to first take steps to improve the stenter drying efficiency followed by reducing the inlet moisture by mechanical roller squeezing. • Cost of Furnace Oil :36 Rs/Lit • GCV of Furnace Oil :10000 kcal/kg • Thermic fluid heater efficiency: 80%. • Average Furnace Oil Consumption rate = 85 litre/hr • Density of Furnace oil = 0.95 kg/litre • Weight of 1 meter of Outgoing dry cloth = 100 gms • The distribution loss in the thermic fluid system is 45000 kcal/hr **Calculate:** 1. Existing Drier Efficiency. (10 Marks) 2. Annual reduction in furnace oil consumption and the monetary savings if the dryer efficiency is improved by 10%? (5 Marks) 3. If the inlet moisture is reduced from 55% to 45%, after improving the dryer efficiency, Calculate the incremental (additional) reduction in furnace oil consumption on an annual basis. (5 Marks)
N4 B-Sol.	**Solution:** **1. <u>Existing Drier Efficiency with 55% inlet moisture</u>** Stenter Speed = 70 meter/min Therefore, Dried Cloth Output = 70 meter/min X 100 gm/meter = 7 kg/min = 7*60 kg/hr = 420 kg/hr Weight of material output of the dryer on bone dry basis per hour (W) = 420 * 0.95 = 399 kg/hr Therefore, inlet wet cloth flow rate = (Bone dry cloth rate/hr)/ (1-0.55) = (399/(1-0.55)) =886.67 kg/hr Therefore, weight of moisture in inlet material per kg of bone-dry basis weight: **(m_{in})** = (886.67-399)/(399) = 1.22 kg of moisture/ kg of bone dry material Weight of moisture in outlet material per kg of bone-dry basis weight: **(m_{out})** = (420-399)/(399) = 0.05 kg of moisture/ kg of bone-dry material <u>Heat input to the dryer **(Qin)**</u> = Heat output of the thermic fluid heater – distribution loss in the thermic fluid system = (Furnace oil consumption rate X density X GCV X Eff) – distribution loss in the thermic fluid sys = (85*0.95*10000*0.8)-45000 = 646000-45000

= 601000 kcal/hr

Heat Output to the dryer **(Qin)**

= (W (m_{in}-m_{out}) [(T_{out}-T_{in}] +540])
= (399(1.22-0.05) [(80-30]+540])
= 275430 kcal/hr

Therefore, Drier Efficiency

= (Heat Output / Heat Input) *100
= (275430 / 601000)*100
= 45.8%

2. **Fuel Savings due to Improved Drier Efficiency by 10% (i.e.,55.8% Eff)**

Heat input to the dryer **(Qin)**

= (Heat output from the dryer / new dryer efficiency)
= 275430 / 0.558
= 493602.15 kcal/hr

Heat loss in the thermic fluid system

= 45000

Total heat to supplied by the thermic fluid heater = (Heat req for drier + distribution system loss)
= 493602.15 + 45000
= 538602.15 kcal/hr

Fuel consumption in thermic fluid heater after improving dryer efficiency
Operating efficiency of thermic fluid heater is = 80%
= 538602.15/0.8
= 673252.7 kcal/hr

Fuel consumption in liters/hr

= 673252.7/(10000*0.95)
=70.87 lit/hr

Annual FO savings by improving dryer efficiency = (85 -70.87) x 7000 hours/yr
= 98910 lit/yr
= 98.91 kL/yr
Annual Monetary savings = 98910 * 36
= Rs.35,60760/yr
= Rs.35.61 Lakhs/yr

3. Incremental annual reduction in furnace oil consumption by reducing the Inlet moisture from 55% to 45%, after improving the dryer efficiency:

Stenter Speed = 70 meter/min
Therefore, Dried Cloth Output = 70 meter/min X 100 gm/meter
= 7 kg/min
= 7*60 kg/hr = 420 kg/hr

Weight of material output of the dryer on bone dry basis per hour (W)
= 420 * 0.95

= 399 kg/hr

Therefore, inlet wet cloth flow rate = (Bone dry cloth rate/hr)/ (1-0.45)
= (399/(1-0.45)) =725.45 kg/hr

Therefore, weight of moisture in inlet material per kg of bone-dry basis weight: **(m_{in})**

= (725.45-399)/(399) = 0.818 kg of moisture/ kg of bone dry material

Weight of moisture in outlet material per kg of bone-dry basis weight: **(m_{out})**

= (420-399)/(399) = 0.05 kg of moisture/ kg of bone-dry material

<u>Heat Output (Load) of the dryer **(Qout)**</u>

= (W (m_{in}-m_{out}) [(T_{out}-T_{in}] +540])
= (399(0.818-0.05) [(80-30] +540])
= 180794.9 kcal/hr

Heat input to Drier = Head load/ Improved Drier Efficiency
= 180794.9/0.558
= 324005.16 kcal/hr

Heat to be supplied by the thermic fluid heater

= 324005.16+45000
= 369005.16 kcal/hr

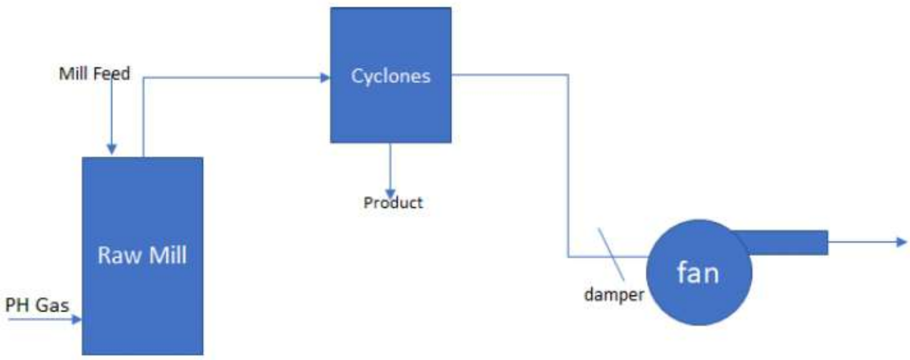
Fuel consumption in thermic fluid heater after inlet moisture reduction with improved dryer efficiency:

= 369005.16 / (10000*0.95*0.8)
= 48.55 lit/hr

Annual incremental FO savings by inlet moisture reduction = (70.87-48.55) x 7000
= 22.32 x 7000
= 156240 lit/yr
= 156.24 kL/yr

N4 **OR**

C The schematic of a Vertical Roller Mill (VRM) used for Raw Meal (RM) grinding in a 7800 TPD cement plant is given below.



The VRM is operating at 260 TPH whereas designed for 250 TPH. The following are the process measurements during a performance assessment study.

Parameters	Value

VRM motor input Power (kW)	2294
RM Fan motor input Power (kW)	1650
RM Fan Motor Efficiency (%)	95%
RMS value of Dynamic Pressure of the gas at Fan inlet (mmWC)	14.5
Pitot Tube Constant (Cp)	0.86
Duct diameter at the fan inlet (m)	3.5
Temperature of gas at fan inlet (^{O}C)	70
Static Pressure at Fan Inlet (before damper) (mmWC)	-710
Static Pressure at Fan Inlet (after damper) (mmWC)	-850
Static Pressure at Fan outlet (mmWC)	30
Density of RM Gas at Fan inlet (kg/m^3)	1.35

a. Calculate the specific power consumption of the raw mill (kWh/ton output) (2 Marks)
b. Specific power consumption of raw mill fan (kWh/ton output). (2 Marks)
c. Calculate the raw mill fan efficiency (%). (10 Marks)
d. The damper control was replaced by a VFD control, which resulted in an excess flow at 50 Hz operation. The flow was brought back to normal by reducing the VFD frequency to 40 Hz. Calculate the savings in fan power consumption. (Ignore the VFD losses) (6 Marks)

N4C-Sol.

Soln:

a.	**Specific Power Consumption of RM (kW/Ton)** (Raw Mill motor input Power/ Mill Output) = 2294 kW/ 260 TPH = 8.8 kWh/ton
b.	**Specific power consumption of RM Fan (kW/Ton)** (Raw Mill fan motor input Power/ Mill Output) =1650 kW/ 260 TPH =6.35 kWh/ton
C.	**Fan Efficiency** Correction Density ($\rho 2$)= ($\rho 1$) $* \left(\frac{P1}{P2}\right) * (\frac{T1}{T2})$ = 1.35*((10323-850)/10323) * (273/(273+70))=0.986 kg/m3 Velocity of Gas at Fan Inlet = Cp*$\sqrt{}$(2*g*P_{dymc}/$\rho 2$) = .86*$\sqrt{}$(2*9.81*14.5*/0.986) = 14.6 m/s Area of the duct = π*D^2/4 = 3.14*3.5*3.5/4 = 9.6163 m^2 Flow at fan Inlet, (m^3/sec) = Vel (m/sec) *area (m^2) = 14.6*9.616 =140.3936 m^3/sec

			Fan Static Efficiency= Flow (m^3/sec) * head (mmWC)/ (102* fan Motor Power(kW)* Motor Eff(%) = 140.4*(30+850) / (102*1650*95%)*100 = 77.3%
		D.	By using Affinity Law, $(P_1/P_2) = (N_1^3/N_2^3) = (Hz_1^3 / Hz_2^3)$ $(1650\ kW / P_2) = (50^3/40^3)$ $P_2 = (1650 \times 40^3) / 50^3$ $P_2 = (1650 \times 64000) / 125000$ $P_2 = 844.8\ kW = 845\ kW$ Savings in fan power consumption = 1650 – 845 = 805 kW.
N4			
D	A commercial building is using vapor compression refrigeration (VCR) chiller for meeting its cooling requirement. The following data pertaining to building is given below. **Outdoor Conditions:** DBT: 35 deg.C Humidity: 24.0 g of water/kg of dry air **Desired indoor conditions:** DBT: 23 deg.C RH: 50% Humidity: 9.3 g of water/kg of dry air **Other data** Total wall surface area: 140 m^2 Total window area: 50 m^2 Roof area: 15 X 25 m^2 U-factor (Wall): 0.34 W/ m^2-K U-factor (Roof): 0.32 W/ m^2-K U-factor (Window): 3.6 W/m^2-K CLTD at 17:00 hrs for Wall: 12 deg.C CLTD at 17:00 hrs for Roof: 44 deg.C CLTD at 17:00 hrs for Window: 7 deg.C SCL at 17:00 hrs for Glass window: 605 W/m^2 Shading coefficient of window: 0.75 Space is occupied from 09:00 to 17:00 hrs by 30 people doing moderately active work Sensible heat gain / person: 75 W Latent heat gain / person: 55 W CLF for people : 0.9		

LED light in space: 12 W/m^2

CLF for lighting: 0.9

Coffee maker latent heat: 600 W

Coffee maker sensible heat: 1800 W

Sensible heat of Computer and other office equipments: 3.4 W/m^2

Air changes /hr of infiltration: 2

Height of building: 3.5 m

Chiller COP: 3.5

Chiller motor Efficiency: 95%

Power cost: Rs. 7.5/kWh

Working days: 250 days/year

Operating hours : 8 hours/day

Calculate the following:

a) External heat gain of the building (kW) **(5 Marks)**

b) Internal heat gain of the building (kW) **(6 Marks)**

c) Total cooling load of building (kW) (3 **Marks)**

d) Additional cost Rs. Lakhs/year, if air change rate/hr is increased to 4. (6 **Marks)**

N4D-Sol.

a) External Heat Gain:		
Conduction heat gain through wall	= 0.34 x (140-50) x12 = 367.2	W
Conduction heat gain through roof	= 0.32 x (15 x 25) x 44 = 5280	W
Conduction heat gain through window	= 3.6 x 50 x 7 = 1260	W
Solar radiation through window	= 605 x 50 x 0.75 = 22687.5	W
Total external heat gain	= (367.2+5280+1260+22687.5) /1000 **= 29.6**	**kW**
b) Internal Heat Gain:		
Sensible heat gain from people	= 30 x 75 x 0.9 = 2025	W
Latent heat gain from people	= 30 x 55 = 1650	W
Total heat gain from people	= 2025 + 1650 = 3675	W
Total heat gain from lighting	= 12 x (15 x 25) x 0.9 = 4050	W
Heat gain from coffee maker	= 600 + 1800 = 2400	W
Heat gain from computers and other office equipments	= 3.4 x (15 x 25) = 1275	W
Total heat gain from equipment	= 2400 + 1275 = 3675	W
Air infiltration flow rate	= ((15x 25) x (3.5)) x (2.0)/3600 = 0.729	m^3/sec

Sensible heat gain from air infiltration	= 1210 x 0.729 x (35-23) = 10585	W
Latent heat gain from air infiltration	= 3010 x 0.729 x (24-9.3) = 32256	W
Total heat gain from air infiltration	= 10585 + 32256 = 42841	W
Total internal heat gain	= (3675+4050+3675+42841)/1000 = 54.24	kW
c) Total cooling load of building	= (29.6+54.24) **= <u>83.84</u>**	**kW**
d) Additional Cost due to air change rate:		
New Air infiltration flow rate	= (15 x 25) x (3.5)* (4.0)/3600 = 1.458	m^3/sec
New sensible heat gain from air infiltration	= 1210 x 1.458 x (35-23) = 21170.1	W
New latent heat gain from air infiltration	= 3010 x 1.458 x (24-9.3) = 64512.1	W
Total heat gain from air infiltration	= 21170.1+64512.1 = 85682.2	W
Additional cooling load due to change in air change rate/hr	=(85682.2-42841)/1000 = 42.8	kW
Additional cost due to change in air change rate/hr	$= \frac{\left(\frac{42.8}{3.5x0.95}\right) x\ 8\ x\ 250\ x\ 7.5}{10^5}$ **<u>= 1.9</u>**	Rs. Lakhs/year

………………..**End of Section III**………………..

Paper 4 Code: Pink

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

…………. End of Section - I ………….

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

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

(ii) Each question carries FIVE marks

L1	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 3,200 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 ^{O}C, whereas the ambient temperature is 30 ^{O}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 (3200/1000))
= Rs 169.95/ tonne steam

Final price of steam = (Rs.3200+ Rs.169.95)/ tonne
= Rs. 3369.95 / tonne steam

L2 A highly viscous oil which requires rapid initial heating, with a flow rate of 20 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.

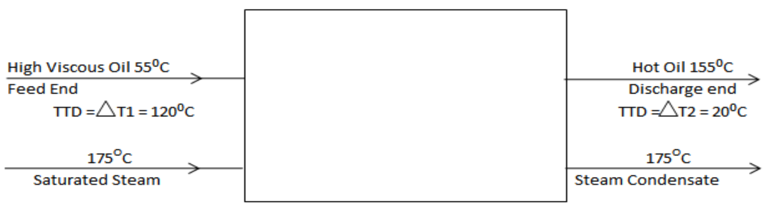
1. What type of heat exchanger is recommended? **(1 Mark)**
2. Draw a schematic of fluid flows with directions and temperatures. **(2 Marks)**
3. Find the LMTD for this application and also the steam requirement. **(2 Marks)**

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 ^{O}C ΔT_2 at discharge end = 175 – 155 = 20 ^{O}C LMTD (parallel) = $\frac{\Delta T_1 - \Delta T_2}{L_n \Delta T_1 / \Delta T_2}$ LMTD (parallel) = $\frac{120 - 20}{L_n 120 / 20}$ = **55.81 ^{O}C** Steam requirement = (20000 x 0.5 x (155 – 55)) / 485 = **2061.85 kg/hr**

………. 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	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 ^oC. % O_2 in dry flue gas = 4% Exit flue gas temperature = 215 ^oC. 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 ^oC Loss due to Hydrogen = 9.92% Radiation losses in the N.G. boiler = 1.52% Specific heat of flue gases = 0.29 kcal/kg ^oC Ambient temperature = 30 ^oC Density of air = 1.125 kg/m^3 Daily hours of operation = 24 hours Yearly operation = 330 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^{O}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
	=	$\dfrac{M_{dfg} \times C_p \times (T_q - T_a)}{\text{G.C.V. of fuel}} \times 100$
	=	$\dfrac{\mathbf{19.02} \times 0.29 \times (215 - 30)}{13500} \times 100$
	=	**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%**

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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^{O}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 330 x 27
	=	Rs. 30,79,296
	=	**Rs. 33.793 lakhs**

N2	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 60 °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 : 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** Temperature differential for heating in the existing case = 140 – 50 **= 90°C** Temp. differential when Initial temp is increased to 60°C = 140 – 60 **= 80°C** % reduction in start-up heating load = ((90 – 80) x 100)/ (90) = **11.11%** Savings in fuel due for each start up = (0.1111 X 1638677) / (10000 X 0.8) = **22.757 kg per start up** **(or)**

	Startup heating Load = *Heat required to heat water and steel from 60°C to 140°C* ***= (mass x Specific heat x temp. difference)*** *= [15700 x 1 x (140 – 60)] + [20896 x 0.12 x (140 – 60)]* *= [12,56,000 + 2,00,602]* *= 14,56,602 kcal* *% reduction in start-up heating load* *= ((**16,38,677** – 14,56,602) x 100)/ (**16,38,677**)* ***= 11.11%*** *Savings in fuel due for each start up* *= (**16,38,677** – 14,56,602) / (10000 X 0.8)* ***= 22.757 kg per start up***
N3	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 °C to 50 °C. The hot oil flow rate in the heat exchanger is 20,000 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 °C Motor efficiency = 87.5 % Annual operating hours = 7920 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 7920)
	=	Rs.52,27,200/-
	=	**Rs.52.27 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	=	20,000 X 0.5 X (110 – 50)
	=	**6,00,000 kcal/hr**
Total heat rejection load on the cooling tower	=	10,87,800 + 6,00,000
	=	**16,87,800 kcal/hr**

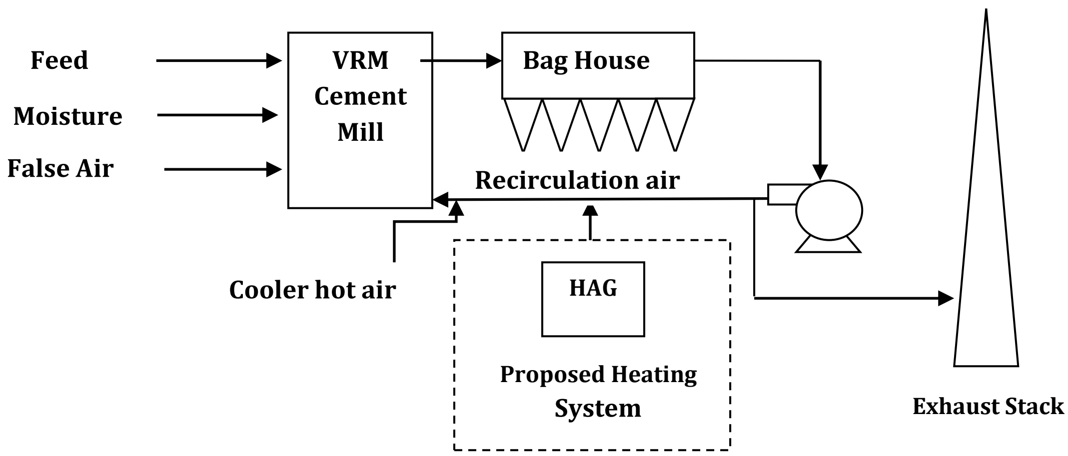
Cooling tower capacity is NOT adequate to take the heat load of process heat exchanger in addition to rejection load of the centrifugal chiller

N4 **Answer any ONE of the following**

A An integrated cement plant is having vertical roller mill (VRM) of 200 TPH capacity for cement grinding, drawing hot air (Temperature: 380 ºC and Sp.heat Cp : 0.246 kcal/kg ºC) 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	ºC	90
Average feed temperature	ºC	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	ºC	30	False air into the circuit (% of total fan flow)	%	15
VRM motor efficiency	%	95	Sp. heat (Cp) of material	kcal/kg ºC	0.21
Mill water spray	TPH	3.5	Sp. heat of mill false air	kcal/kg ºC	0.238
Coal NCV	kcal/kg	7000	Sp. heat of mill exit air	kcal/kg ºC	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)**

N4-A Sol

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 exhaust from stack
Recirculation air = 487490 – 128124 = 359366 kg/hr

Input Heat Components:			
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+$\Delta T\cancel{exit}$] = 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

N-4 B

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 85 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)**

N-4 B Sol

Ans:

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)
= (85 x 10,000) x 0.84 x 0.50
= 3,57,000 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)
3,57,000 kcal/hr = 423 x (m_i – 0.0638) x [(75 – 25) + 540]

Inlet moisture per kg of bone dry cloth, m_i = 1.494 kg moisture / 1 kg bone dry cloth
Total weight of inlet cloth = (1 + 1.494)]
Inlet moisture %, wet cloth = (Inlet moisture per kg of bone dry cloth) / (bone dry cloth + Inlet moisture per kg of bone dry cloth)
= (1.494 x 100)/(1+ 1.494)
= 60 %

	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 = 3,57,000 - 2,89,052 **= 67,948 kcal/hr** **% Reduction in stenter drying load** = (67,948 x100) / (3,57,000) **= 19%** Monthly furnace oil savings = 0.19 x 85 x 24 x 30 = 11,628 kgs / month **= 11.63 tonnes/month**
N-4 C	In a particular biomass power plant, 33.6 TPH of steam at 63 kg/cm²g, 450 °C is expanding to 0.1 kg/cm²(a), and temperature of 45 °C. The boiler and the turbine are designed for superheat temperature of 475 °C. The following data has been given. Enthalpy of steam at turbine inlet with 450 °C = 787.9 kcal/kg Actual enthalpy at turbine outlet at 0.1kg/cm²(a) = 564.78 kcal/kg Combined efficiency of gearbox and generator = 92% Enthalpy of steam at turbine inlet with temp of 475 °C = 802.4 kcal/kg Enthalpy at turbine outlet under isentropic condition (with 475 °C at inlet, exhaust pressure, 0.1 kg/cm²(a) = 511.77 kcal/kg Isentropic efficiency of the turbine with turbine inlet at 475 °C = 79% Biomass Boiler Efficiency = 72% Calorific value of biomass fuel = 3450 kcal/kg Cost of biomass fuel = Rs 3.3 /kg Electricity price for power sold = Rs 6/ 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 °C. b) Steam rate in kg/kWh with improved turbine inlet temperature of 475 °C. c) Additional power generated in kW with improved turbine inlet temperature of 475 °C, assuming steam flow rate remains the same. d) Increase in fuel consumption kg/hr with improved turbine inlet temperature of 475 °C, assuming steam flow rate remains the same. e) Yearly benefit by operating the turbine at inlet temperature of 475 °C.
N-4 C-	**Ans:** **a) Power generated in kW with turbine inlet temperature of 450 °C** Turbine power output with inlet temp 450°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 °C** Steam rate with improved turbine inlet temperature of 475°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 6 = Rs.1404/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 3.3 = Rs 647.25/hr Yearly benefit, net increase in revenue = (1404 – 647.25) x 8000 = Rs. 60,54,000 /- (or) = Rs **60. 54 lakhs**
	OR
N-4 D	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 7500 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 7500 hrs operation = Rs 541.9 / hr x 7500 hrs / yr

= Rs 40.64 lakhs /yr

………. End of Section - III …………

19th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS - September, 2018

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

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

(i) Section I contains **Ten** questions
(ii) Each question carries **One** mark

S-1	The speed of an energy efficient motor will be more than the standard motor of same capacity because _____ decreases.
Ans	**Slip**
S-2	A typical co-generation system in a cement plant will come under the category of topping cycle. **True or False**
Ans	**False**
S-3	To minimize scale losses in a reheating furnace, the furnace should be operated at a negative pressure. **True or False**
Ans	**False**
S-4	O2 % in flue gas is required in the direct method efficiency evaluation of a boiler. **True or False**
Ans	**False**
S-5	The heat rate of a power plant will reduce when there is an increase in the inlet cooling water temperature to the condenser. **True or False**
Ans	**False**
S-6	The capacity of a screw compressor cannot be controlled by discharge throttling. **True or False**
Ans	**True**
S-7	A package air conditioner of 5 TR capacity delivers a cooling effect of 4 TR. If Energy Efficiency Ratio (W/W) is 2.90, the power in kW drawn by compressor would be ___________
Ans	**=(4*3024)/860 = 14.065/2.90 = 4.85**
S-8	If the steam generation in a boiler is reduced to 45%, the radiation loss from the surface of the boiler will reduce by the same ratio. **True or False**

Ans	**False**
S-9	If the coal Gross Calorific Value is 4200 kcal/kg and specific coal consumption is 0.6 kg/kWh, what is the power station gross efficiency ?
Ans	**(860 /(4200 x 0.6)) x100 = 34.12%**
S-10	If the measured input power of a 90 kW motor is 45 kW, then the calculated loading of the motor is 50 %. **True or False**
Ans	**False**

.... End of Section - I ....

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

(i) Section II contains **Two** questions

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

L-1	Milk is flowing in a pipe cooler at a rate of 0.95 kg/sec. Initial temperature of the milk is 55 °C and it is cooled to 18 °C using a stirred water bath with a constant temperature of 10 °C around the pipe. Specific heat of milk is 3.86 kJ/kg °C. Calculate the heat transfer rate (kCal/hr) and also Logarithmic Mean Temperature Difference (LMTD) of the exchanger.
Ans	Heat transfer in cooling milk = 0.95 * 3.86 * (55 – 18) = 135.7 kJ/sec = (135.7 * 3600) = (488520 kJ/hr) / (4.18) = 116871 kcal/hr **LMTD:** DT1 = 55 – 10 = 45 °C DT2 = 18 – 10 = 8 °C LMTD of the heat exchanger = (45 – 8)/ ln(45 / 8) = 21.4 °C
L-2	A coal based power plant A is having a Gross Unit Heat Rate of 2400 kCal/kWh with Auxiliary power consumption of 7 % whereas Plant B of same size and make, has an operating Net Heat Rate of 2500 kCal/kWh. In your opinion, which plant is more efficient and why?
Ans	Gross Heat Rate of Plant A – 2400 kcal/kWh Auxiliary Power Consumption – 7% Net Heat Rate of Plant A = Gross Heat Rate/(1- APC) = 2400/(1- 0.07) = 2580.65 kcal/kWh Therefore, Plant B is more efficient with a lower Net Heat Rate of 2500 kcal/kWh than that of Plant A (2580.65 kcal/kWh).

.... End of Section - II ....

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

(i) Section III contains **Four** questions

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

N-1	In a process industry, the wet products are to be dried in a drier. The plant has a pressurized hot water boiler which supplies hot water at 145 ^{0}C to the heating coils in the drier. The return water to the boiler is at a temperature of 110 ^{0}C. The boiler is fired by saw dust briquettes. **The other relevant data are given below.** • Fuel firing rate = 375 kg/hr • O_2 in flue gas = 12.2 % • CO in flue gas = 189 ppm • CO_2 in flue gas = 8.5 % • Avg. exit flue gas temperature = 235 ^{0}C • Ambient temperature = 31 ^{0}C • Humidity in ambient air = 0.0204 kg / kg dry air • Gross Calorific Value of ash = 800 kCal/kg • Radiation & other unaccounted losses = 0.5 % • Specific heat of flue gas = 0.23 kCal/kg^{0}C **Fuel (briquettes) Ultimate Analysis (in %)** • Ash = 8.0 • Moisture = 7.5 • Carbon = 45.3 • Hydrogen = 4.4 • Nitrogen = 1.4 • Oxygen = 33.3 • Sulphur = 0.1 • Gross Calorific Value of saw dust briquette = 3500 kCal/kg Calculate the hot water circulation rate (m^3/hr) in the boiler.
Ans	1. Theoretical air required for complete combustion = $[(11.6 x C) + \{34.8 x (H_2 - O_2/8)\} + (4.35 x S)]/100$ kg/kg of coal = [(11.6 x 45.3) + {34.8 x (4.4 – 33.3/8)} + (4.35 x 0.1)] / 100 = **5.34 kg / kg of briquette**. 2. Excess air supplied

Actual O_2 measured in flue gas = 12.2 %

% Excess air supplied (EA) = $\frac{O_2\%}{21 - O_2\%} \times 100$

$$= \frac{12.2\%}{21 - 12.2\%} \times 100$$

= **138.6 %**

3. Actual mass of air supplied

= {1 + EA/100} x theoretical air

= {1 + 138.6/100} x 5.34

= **12.74 kg/kg of briquette**

4. To find actual mass of dry flue gas

Mass of dry flue gas = Mass of CO_2 +Mass of N_2 content in the fuel+ Mass of N_2 in the combustion air supplied + Mass of oxygen in flue gas + Mass of SO_2 in flue gas

$$= \frac{0.453\,x\,44}{12} + 0.014 + \frac{12.74\,x\,77}{100} + \frac{(12.74 - 5.34)\,x\,23}{100} + \frac{0.001x64}{32}$$

= **13.19 kg / kg of briquette**

5. To find all losses

a) % Heat loss in dry flue gas (L1) = $\frac{m\,x\,C_p\,x\,(T_f - T_a)}{GCV\ of\ fuel}\ x\,100$

$$= \frac{13.19 \text{ x } 0.23 \text{ x } (235 - 31)}{3500} \text{ x } 100$$

= **17.68 %**

b) % Heat loss due to formation of water from H_2 in fuel (L2)

$$= \frac{9 \text{ x } H_2 \text{ x} \{584 + C_p\,(T_f - T_a)\}}{\text{GCV of fuel}}\ x\ 100$$

$$= \frac{9 \text{ x } 0.044 \text{ x} \{584 + 0.45\,(235 - 31)\}}{3500} \text{ x } 100$$

= **7.65 %**

c) % Heat loss due to moisture in fuel (L3)

$$= \frac{M \text{ x } \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

$$= \frac{0.075 \text{ x } \{584 + 0.45 (235 - 31)\}}{3500} \text{ x } 100$$

= **1.45 %**

d) % Heat loss due to moisture in air (L4) $= \dfrac{AAS \, x \, humidity \, x \, C_p \, x (T_f - T_a)}{GCV \; of \; fuel} \, x \, 100$

$$= \frac{12.74 \text{ x } 0.0204 \text{ x } 0.45 \text{ x } (235 - 31)}{3500} \text{ x } 100$$

= **0.682 %**

e) % Heat loss due to partial conversion of C to CO (L5)

$$= \frac{\%CO \;\; x \;\; C}{\%CO \; + \; \%CO_2} \; x \; \frac{5654}{GCV \; of \; fuel} \; x \; 100$$

$$= \frac{0.0189 \text{ x } 0.453}{0.0189 + 8.5} \text{ x } \frac{5654}{3500} \text{ x } 100$$

= **0.162 %**

f) % Heat loss due to Ash (L6)

Gross Calorific Value of Ash	=	800 kCal/kg
Amount of Ash in 1 kg of coal	=	0.08 kg/kg coal
Heat loss in bottom ash	=	0.08 x 800
	=	**64 kcal/kg of coal**
% Heat loss in bottom ash	=	(64x 100) / (3500)
	=	**1.83 %**

g) % Heat loss due to radiation & other unaccounted losses (L7) = 0.5% (given)

HWG efficiency by indirect method	=	100 - (L1+ L2+ L3+ L4+ L5+ L6+ L7)
	=	100 - (17.685 + 7.65+ 1.45+ 0.682+

0.162+1.83+0.5)

$$= \mathbf{70.04\ \%}$$

Hot water circulation rate in m^3/hr:

$$\text{HWG efficiency \%} = \frac{(\text{Mass of hot water} \times C_p \times \Delta T)}{\text{Mass of fuel} \times \text{GCV of fuel}} \times 100$$

$$\text{Mass of hot water} = \frac{375 \times 3500 \times 0.7004}{(145 - 110) \times 1}$$

$$= \mathbf{26265\ kg/hr}$$

$$= \mathbf{26.265\ m^3/hr}$$

N-2

In a process plant, the hot effluent having a flow rate of 63450 kg/hr at 80 ^{0}C from the process is sent to a finned tube air cooled heat exchanger for cooling. The outlet temperature of the effluent from the heat exchanger is 38 ^{0}C.

Air at a temperature of 30 ^{0}C enters the heat exchanger and leaves at 60 ^{0}C. The fan develops a static pressure of 30 mmWC. The operating efficiency of the fan is 65 % and fan motor efficiency is 90 %. The plant operates for 5000 hours per year.

The management decided to replace the existing air-cooled heat exchanger with water-cooled Plate Heat Exchanger (PHE).

Following are the relevant data:

Existing:

- Specific heat of air : 0.24 kcal/kg ^{0}C
- Specific heat of hot effluent : same as water
- Density of air : 1.29 kg/m^3

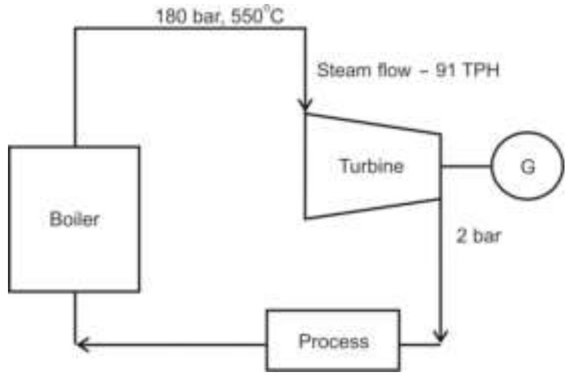
Proposed:

- Cooling water pump efficiency : 75 %
- Pump motor efficiency : 90 %
- Effectiveness of water cooled heat exchanger : 0.4
- Cooling water inlet temperature : 25 ^{0}C
- Total head developed by the cooling water pump : 30 m

	• Over all heat transfer coefficient of PHE : 23200 kcal/hr m^2 ^{0}C **Calculate the following:** • Annual energy savings due to replacement of existing air-cooled plate heat exchanger by water cooled counter flow plate heat exchanger. (15 Marks) • Area of the proposed water-cooled plate heat exchanger. (5 Marks)
Ans	Heat duty in hot fluid = M x Cp $_{hot}$ x (Ti - To) = 63450 x 1 x (80 - 38) = **2664900 kCal / hr** In a heat exchanger, **Heat duty in hot fluid = Heat duty in cold Air** Mass of the cold air = 2664900 / (0.24 X (60-30)) = **370125 kg/hr** **Existing System:** Fan Shaft Power $= \dfrac{\text{Volume,m}^3\text{/s X Static Pressure, mmWc}}{\text{102 X Fan Efficiency factor}}$ $= \dfrac{(370125/(3600 \times 1.29)) \times 30}{102 \times 0.65}$ = **36.06 kW** Motor Input Power = 36.06/ 0.9 = **40.07 kW** **Proposed System:** Effectiveness of water cooled heat exchanger = 0.4 Cold Water outlet temperature = T_{Wo} Cold water inlet temperature = T_{Wi} Hot effluent inlet temperature = $T_{Eff.in}$ Hot effluent outlet temperature = $T_{Eff.out}$ Effectiveness $= \dfrac{T_{Wo} - T_{Wi}}{T_{Eff.in} - T_{Wi}}$ Cold Water Outlet = (0.4 x (80 – 25)) + 25 = **47 ^{O}C** Mass flow rate of cooling water (M) $= \dfrac{\text{Heat duty in hot fluid}}{Cp \times (T_{Wo} - T_{Wi})}$

	$$= \frac{2664900}{1 \times (47 - 25) \times 1000}$$ $$= \mathbf{121.13\ m^3/hr}$$ Hydraulic Power Requirement for one Cooling Water Pump: $$= \frac{(\text{Flow in } m^3/hr \times \text{Head in m} \times \text{Density in } kg/m^3 \times g \text{ in } m/s^2)}{(1000 \times 3600)}$$ $$= \frac{(121.13 \times 30 \times 1000 \times 9.81)}{(1000 \times 3600)}$$ = 9.9 kW Pump input Power Requirement = 9.9 kW / 0.75 = 13.2 kW Pump Motor Input Power = 13.2 / 0.9 = 14.67 kW Thus savings = Power consumption by fans – Water Pumping Power = 40.07 – 14.67 = 25.4 kW Annual energy savings in kWh = 25.4 kW x 5000 hrs = 127000 kWh/annum **Calculations for LMTD for Proposed counter flow PHE:** LMTD for counter flow in PHE = {(80-47) – (38-25)} / ln {(80-47) / (38-25)} = **21.5 ^{0}C** Considering overall heat transfer coefficient (U) = 23200 kCal/hr $m^2\,^0C$ Heat transfer Area = Q / (U x ΔT_{lmtd}) = 2664900 /(23200 x 21.5) = **5.34 m^2**

N-3	The schematic and operating data of a steam turbine cogeneration plant with a back pressure turbine is given below.



Enthalpy of steam at 180 bar, 550 ^{0}C – 3420 kJ/kg

Exhaust steam enthalpy at isentropic expansion from 180 bar to 2 bar – 2430 kJ/kg

Enthalpy of boiler feed water – 504.7 kJ/kg

Efficiency of boiler - 80 %

Calorific value of coal – 4500 kcal/kg

Steam flow rate into the Turbine - 91 TPH

Turbine isentropic efficiency - 90 %

Generator efficiency - 97 %

Gear box efficiency - 98 %

Calculate: (each carries 5 Marks)

a) Electrical output from the generator in MW
b) Fuel consumption in Boiler in TPH
c) Energy Utilization factor of the cogeneration plant
d) Heat to power ratio of the cogeneration plant, kCal/kW

Ans

a) Electrical output from the generator in MW

Actual exhaust steam enthalpy = [3420 - (0.9 x (3420 - 2430))]

= 2529 kJ/kg

Turbine power output = [(91 x (1000/3600)) x (3420 - 2529)]/1000

= 22.52 MW

Electrical output = (22.52 x 0.97 x 0.98)

= 21.4 MW

b) Fuel consumption in Boiler in TPH

Fuel consumption in Boiler = (91,000 x (3420 – 504.7)) / (4.18 x 4500 x 0.80)

	= 17.6 TPH **c) Energy Utilization factor of the cogeneration plant** = [(21,400 x 860) + (91000 x ((2529 – 504.7)/ 4.18))] / (17,600 x 4500) = [(1,84,04,000 + 44069689) / (7,92,00,000)] = 0.79 **d) Heat to power ratio of the cogeneration plant, kCal/kW** Heat to power ratio, kcal/kW = = (91000 x (2529 - 504.7)/4.18) / 21400 = 2059 kCal/kWh (or) = 2.39 $kW_{thermal}/kW_{electrical}$
N-4 **A)**	**Answer any ONE of the following** In the energy audit of a 6-stage Preheater (PH) section of a 4000 TPD (clinker) Cement kiln operating at full load, the following were the field measurements taken.

S.No.	Description	Value
1.	Reference temperature (^{0}C)	0
2.	Reference pressure and the Barometric pressure (mmWG)	10323
3.	Average Dynamic Pressure (mmWC)	17.1
4.	Static Pressure at Fan Inlet (mmWC)	-860
5.	Static Pressure at Fan outlet (mmWC)	-16
6.	Temperature (^{0}C)	328
7.	Density of the PH Gas (NM^3/kg), at reference condition	1.422
8.	Pitot Tube constant	0.854
9.	Diameter of PH Duct (m)	3.2
10.	Cp of PH Gas (kcal/kg^{0}C)	0.245
11.	Power Input to the PH fan motor (kW)	1812
12.	PH fan Motor Efficiency (%)	95
13.	GCV of coal (kcal/kg)	5600
14.	Annual Operating Hours	7300

15.	Cost of Coal (Rs./Ton)	4836

a) Estimate the specific heat losses (kCal/kg clinker) carried away by PH gases. (5 Marks)

b) Estimate the PH fan Efficiency. (5 Marks)

c) Estimate the envisaged specific fuel savings (kCal/kg clinker), annual fuel savings and annual monetary savings by reduction in PH gas temperature to 290 ^{0}C by appropriate modification in the PH cyclones. (5 Marks)

d) Estimate energy savings in fan power consumption in the proposed case where PH exit temperature is reduced to 290 ^{0}C. Also consider the static pressure at the fan inlet will reduce by 6 % from the present level due to PH modification (Fan and motor efficiency in both the cases are same). (5 Marks)

Ans

a) Specific heat losses by PH gases (kCal/kg clinker)

Density of gas at Present operating Conditions (kg/m^3)	$\rho_{t,p} = \rho_{stp} \times \frac{10323*-P_S}{10323} \times \frac{273}{273+t_e}$ kg/m^3 = 1.422*(273/(273+328))*((10323 -860)/10323) kg/m^3	0.59
Velocity of PH Gas (m/s)	Velocity =$P_t \times \sqrt{(2g(\Delta P_{rms})_{avg} / \rho_{t,p})}$ m/sec =0.854 * ((2 * 9.81 * 17.1/0.59))$^{0.5}$	20.36
Area of the PH Duct (m^2)	= Pi/ 4 * D^2 = 3.14 * (3.2^2)/4	8.04
Flow rate of the PH Gas (m^3/hr)	= Area * Velocity = 8.04 * 20.36 *3600 m^3/hr	589299.8
Flow rate of the PH Gas (Nm^3/hr)	= Flow rate of the PH Gas (m^3/hr) x (0.59/1.422) = 589299.8 X (0.59/1.422)	244505.5
Specific PH Gas generation (Nm$^3_{PH\ gas}$/kg $_{Clinker}$)	= Flow rate of Ph gas (Nm^3/hr) / Clinker Production (kg/hr) = 244505.5/ ((4000x1000)/24)	1.467
Specific PH Gas generation (kg$_{PH\ gas}$/kg $_{Clinker}$)	= Specific PH Gas generation (Nm$^3_{PH\ gas}$/kg $_{Clinker}$) x 1.422 kg/Nm^3 =1.467 x 1.422	2.086
Specific Heat Loss in existing case (kcal/kg $_{Clinker}$)	= m C_p (T_{ph}-T_{ref}.) =2.086*0.245*(328-0)	167.6

b) PH fan efficiency

Air Power (kW)	= ((Q (m^3/hr)/3600)x (P_{st}(mmWC)))/102 = (589299.8/3600)* (-16+860)/102	1354.5
Fan Efficiency (%)	= Air power*100/(motor power *motor effi) = (1354.5*100)/(1812*0.95)	78.7

c) Envisaged fuel and monetary savings

Specific Heat Loss in the proposed case (Kcal/Kg $_{Clinker}$)	= M C_p (T_{ph-new}-T_{ref}.) =2.086 * 0.245 * (290-0)	148.21
Fuel Savings (Kcal/Kg Cli	=old heat loss/kg cli- new heat loss/kg cli =167.6-148.21	19.39
Annual Fuel Savings	=Clinker prod. * run hrs/yr* heat saving/kg cli /coal gcv	4212.79

	=166.67*7300*19.39/5600	
Annual Monetary savings (Rs. Lakhs/yr)	= fuel savings in tons * fuel cost in (Rs. Ton) = (4212.79 *4836)/100000	203.73
d) Fan energy savings		
Envisaged static pressure at Fan Inlet after PH modification (mmWC)	= 94% of Original Static pressure at Fan inlet (reduction in Friction loss due to temperature reduction- given) = 94% * 860	-808.4
Envisaged Fan Flow after PH modification	= Flow (Nm3/hr) * ((273+T_{ph-new})/273) * (10323/(10323+P_{st-new})) = 244505.5* ((273+290)/273)*(10323/(10323-808.4))	547078.7
Fan efficiency (%)	Already estimated above (considering the same)	78.7
Fan motor Input power in the proposed case (kW)	= ((Q (m^3/hr)/3600)x (P_{st}(mmWC)))/102 = ((547078.7/3600)* (-16+808.4))/(102*.787*.95)	1579
Fan Power saving (kW)	=Fan power (old-new) =1812 - 1579	233
Annual Energy saving (Lakh kWh/yr)	=(power saved * Annual operating hrs)/10^5 = (233* 7300) / 10^5	17.01

OR

B) A 60 MW captive power plant (CPP) of a chemical plant has a coal fired Boiler, condensing steam Turbine and Generator. The CPP after meeting its auxiliary power consumption is exporting power to the chemical plant. The operating data of CPP is as follows:

Generator output	: 60 MW
Auxiliary power consumption	: 6 MW
Steam flow to the turbine	: 231 Tons/hr
Steam inlet pressure and temperature	: 105 kg/cm^2 (a) and 480 ^{0}C
Enthalpy of inlet steam at operating pressure and temperature	: 793 kCal/kg
Enthalpy of feed water to boiler	: 130 kCal/kg
Condenser exhaust steam pressure and temperature	: 0.1 kg/cm^2(a) and 45.5 ^{0}C
Enthalpy of water at operating pressure and temperature of condenser	: 45.5 kCal/kg
Latent heat of vaporisation of steam at operating pressure and temperature of condenser	: 571.6 kCal/kg
Enthalpy of exhaust steam	: 554 kCal/kg
GCV of coal used	: 4240 kCal/kg
Efficiency of the boiler	: 86 %

Based on the above data, calculate the following parameters of the power plant:

a) Gross Heat Rate (8 Marks)
b) Net Heat Rate (3 Marks)
c) Dryness fraction of exhaust steam (2 Marks)
d) Condenser heat load (3 Marks)
e) Specific coal consumption (2 Marks)

	f) Overall efficiency (2 Marks)
Ans	**(a) Gross heat rate** We have, Gross heat rate= Coal consumption (kg/hr) x GCV of coal (kcal/kg) / Generator output (kW) --------------(1) Given Coal consumption=? GCV of coal=4240 Kcal/kg Generator output= 60 MW And Boiler efficiency= Q (H-h)/ (q x GCV) --------------(2) Where, Q= Quantity of steam generation (kg/hr)=231x1000 H= Enthalpy of steam (Kcal/kg) =793 h=Enthalpy of boiler feed water (kcal/kg) =130 q=Coal consumption (kg/hr) =? Boiler efficiency=0.86 Substituting the given values in equation (2) we get, 0.86=(231 x 1000 x (793—130))/q x 4240 q= 42001 kg/hr Substituting the calculated value of q in equation (1) we get, **Gross heat rate= (42001 x 4240) / (60x1000) =2968 kCal /kWh** **(b) Net heat rate** We have, Net heat rate = Gross heat rate / 1—(% Auxiliary consumption/100) --------------- (3) Auxiliary consumption =6 MW Generation= 60 MW % Auxiliary consumption=(6/60) x 100 = 10% Substituting the values in the equation (3) we get, **Net heat rate= 2968/(1—10/100)= 3298 kCal/KWh** **(C) Dryness fraction of exhaust steam** We have, Enthalpy of exhaust steam = Enthalpy of feed water + Dryness fraction of steam x L.H. of vaporisation of steam Substituting the given values in the above, we get 554= 45.5+ dryness fraction of steam x 571.6 **Dryness fraction of steam= (554—45.5)/571.6 = 0.889** **(d)Condenser heat load** We have, heat load on condenser= Steam flow rate x L.H of vaporisation of steam x dryness fraction of steam = 231x 1000 x 571.6 x 0.889 **=117383.2 MCal/hr**

(e) Calculation of specific coal consumption

We have,

Specific coal consumption = Total coal consumption/Gross generation

= 42001 kg/hr / (60 x 1000) kW

=0.7 kg/kWh

(f) Calculation of overall efficiency of plant

Overall efficiency = 860/Gross heat rate, kCal/kWh -----------------------(4)

Substituting the values we get**, 860/2968 =28.98% ~= 30%**

(OR)

Overall efficiency

= (Generator Output, kW x 860 kCal/kWh) / (Mass flow rate of coal kg/hr x GCV of coal, kCal/kg)

= (60 x 1000 x 860) / (42001 x 4240)

=29.98% ~= 30%

OR

C) In a textile process unit, a five chamber stenter is installed for drying the cloth. The inlet and outlet conditions of the cloth are shown in the figure below. The production output of the stenter is 10,000 kgs/day.

The heat input to the stenter is provided by a thermic fluid heater fired by fire wood as fuel.Gross Calorific Value (GCV) of Fire Wood is 3600 kcal/kg. The efficiency of the thermic fluid heater is 70% and distribution loss in the thermic fluid system is 20,000 kcal/hr. The average fire wood consumption rate is 427 kg/hr.

Calculate the following: (each carries 10 Marks)

a) Drier efficiency

b) Fuel savings in thermic fluid heater if the inlet moisture is reduced from 60 % to 50% by mechanical squeezing. (Assume that drier efficiency does not change)

Ans

Calculation of Stenter Efficiency

$$\text{Stenter Efficiency, \%} = \frac{W \times (m_{in} - m_{out}) \times \{(T_{out} - T_{in}) + 540\}}{Q_{in}} \times 100$$

OR

$$\text{Stenter Efficiency, \%} = \frac{(\text{moisture removed from fabric}) \times \{(T_{out} - T_{in}) + 540\}}{Q_{in}} \times 100$$

Where,

W =Bone dry weight of the fabric, kg/hr

m_{in} = kg moisture / kg bone dry fabric at inlet

m_{out} = kg moisture / kg bone dry fabric at outlet

Q_{in} = Thermal energy input to the stenter (kCal/hr)

(a) Drier Efficiency

Amount of moisture removed:

Bone dry weight of fabric = (10,000 x (95%)) = 9500 kg/day
Hence, Total weight of inlet fabric = (9500)/(0.4/1.0)
= 23,750 kg/day

Inlet Moisture weight = (23,750 – 9500)
= 14,250 kg/day

OR

m_{in} = (14,250 kg/day) / (9500 kg/day)
= 1.50 kg/kg dry fabric

Outlet Moisture weight = 10000 - 9500
= 500 kg/day

OR

m_{out} = (500 kg/day) / (9500 kg/day)
= 0.053 kg/kg dry fabric

Moisture removed from fabric in Stenter

$m_{in} - m_{out}$ = 1.5 – 0.053
= 1.447 kg/kg dry fabric
W x ($m_{in} - m_{out}$) = 9500 x 1.447
=13747 kg/day
= 573 kg/hr

OR

Moisture at I/L– moisture at O/L = (14,250-500)
= 13,750 kg/day
= 573 kg/hr

Heat required for removing the moisture = 573 x {(80-28) + 540}
= 3,39,216 kcal/hr

Heat input to the Thermic Fluid = (Firewood consumption rate x Calorific value x thermic fluid heater efficiency)
= (427 kg/hr x 3600 kcal/kg x 70%)
= 10,76,040 kcal/hr

Heat input to the Drier = 10,76,040 – 20,000 = 10,56,040 kCal/hr
Stenter Efficiency (%) = (Heat reqd. for removing moisture / Heat input to the stenter)
= (3,39,216 / 10,56,040) x 100
= 32%

	(b) Fuel savings if the inlet moisture reduced from 60 to 50% **Moisture removed in Drier** with **50% input moisture** (At 50 % moisture : Bone dry weight = moisture weight = 9500 kg) Moisture removed from the fabric in the Stenter = Inlet moisture – Outlet moisture = (9500-500) = 9000 kg/day = 375 kg/hr Drier efficiency, 32 % = [375 kg/hr x {(80-28) ^{0}C + 540 kCal/kg}] / [(Fuel consumption kg/hr x 0.70 x 3600 kCal/kg) – 20000kCal/hr] Therefore, Fuel consumption, kg/hr (for reduction of inlet moisture) = [{(375 kg/hr x {(80-28) ^{0}C + 540 kCal/kg}) /0.32} + 20000] / (0.70 x 3600) = (693750 + 20000)/ (0.70 x 3600) = 283 kg/hr **Fuel Savings = 427 – 283 = 144 kg/hr = 3456 kg/day**

OR

D)	A building is currently using Vapour Compression Refrigeration (VCR) chillers for meeting its cooling requirements. The following are the existing data pertaining to the building. **Existing System:** • Total Power drawn from grid for the whole building including chiller loads : 1300 kW • Grid Power required for VCR : 300 kW • Building cooling load : 7,56,000 kCal/hr • Cost of Grid Power : Rs.10 /kWh The management proposes to install a natural gas engine with a Waste Heat Recovery Boiler (WHRB), which will generate power as well as steam for an operating Vapour Absorption Machine (VAM). A part of the total chilling load and power requirement of the building is proposed to be met by this cogeneration system. The following are the data for the proposed system. **Proposed System:** • Total power generated from gas engine co-gen plant : 1000 kW • Gas engine efficiency : 40 % • Heat absorbed for steam generation in WHRB (as a % of heat input to gas engine) : 21 %

	• Specific steam consumption for VAM : 5 kg/TR • Calorific value of Natural Gas : 8500 kcal/sm^3 • Cost of Natural Gas : Rs.40/sm^3 • Annual operating hours : 4000 • Total enthalpy of steam : 660 kCal/kg • Feed water temperature to WHRB : 60 ^{0}C **Calculate the following:** • Cost of generating one unit of electricity from the gas engine? (5 marks) • TR generated from Vapour Absorption Chiller driven by WHRB generated steam? (5 Marks) • Total energy cost of existing & proposed system and state whether the proposed scheme is viable? (10 marks)
Ans	1. Cost of generating one unit of electricity from gas engine? • Fuel Consumption = 1000 kW X 860 / (0.4 X 8500) = **252.94 sm^3/hr** • Cost per unit of electricity from gas engine = (252.94 sm^3/hr X 40 Rs./ sm^3) / 1000 kW = **Rs.10.12/ kWh** 2. TR generated from VAM driven by WHRB generated steam? ▪ Heat absorbed by WHRB for Steam generation = 21% x (252.94 x 8500) = **451497.9 kcal /hr** ▪ Amount of steam generated = 451497.9/(660-60) = 752.49 kg/hr ▪ TR generated by VAM = 752.49/5 = **150.49 TR** 3. Techno-economic viability of the proposed scheme? ▪ Present cost of Electricity (Grid) = 1300 x 10 = **13,000 Rs./hr** **Proposed Scheme** • Cost of NG for Electricity = 252.94 sm^3/hr X 40 Rs./ sm^3 = **10,118 Rs./hr** • TR required by the building = 756000/3024 = 250 TR • Energy performance of chiller (VCR) = 300/250 = **1.2 kW/TR**

	• Cost of Electricity from Grid to meet the balance chiller load = (250-150.49) x 1.2 x 10 = **1194.12 Rs./ hr** • Total energy cost with proposed system = 10118 +1194.12 = **11,312.12 Rs./hr** Proposed project is viable, because total cost is less in proposed scheme than in present scheme.

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

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	A rise in conductivity of boiler feed water indicates a rise in ____ level of feed water.
Ans	TDS
S-2	In a parallel flow heat exchanger the hot fluid inlet temperature is 150 °C . The cold fluid inlet and outlet temperatures are 45 °C and 60 °C. Calculate the effectiveness.
Ans	Effectiveness, $S = (t_o - t_i) / (T_i - t_i)$ **= 15/105 =0.14**
S-3	Integrated Part Load Value (IPLV) in a vapour compression refrigeration refers to average of ____with partial loads
Ans	kW/TR
S-4	A pure resistive load in an alternating current (AC) circuit draws only reactive power – True or False
Ans	False (active power)

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	If slip of an induction motor increases, the shaft speed also increases – True or False
Ans	False
S-7	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-8	In a step down transformer for a given load the current in the primary will be more than the current in the secondary. True or false
Ans	False
S-9	For two pumps to be operated in parallel their ______heads should be the same
Ans	Shut off (or 'closed discharge valve' heads)
S-10	A fluid coupling changes the speed of the driven equipment without changing the speed of the motor. True or false
Ans	True

…………. 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 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	95^oC	105^oC

	The cost of steam fromL.Pboiler is Rs. 3000 per tonne. Find out the cost of steam from H.P boiler.
Ans	% Boiler Efficiency = $\frac{\text{(TPH of Stm) x 1000 x (Enth of Stm – Enth of FW)}}{\text{(Mass of Fuel x GCV Fuel)}}$ x 100 Evaporation ratio of LP Boiler; ER LP $= \frac{0.83 \times 10000}{(666 - 95)} = 14.53$ ………………..1.5 marks Evaporation ratio of HP Boiler; ER HP $= \frac{0.83 \times 10000}{(737 - 105)} = 13.13$ ………………..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 $= \frac{14.54 \times 3000}{13.13}$ = Rs.3322 per tonne ………2 marks **OR** 1 T of FO – 14.54 T of LP steam Cost of LP steam – Rs.3000/T ∴cost of 1 T of FO= Rs.3000 x 14.54 = Rs.43620/- ………………..1 mark 1 T of FO – 13.13 T of HP steam ∴cost of 1T of HP steam = Rs.43620/13.13 = Rs.3322/T ………………..1 mark
L-2	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·°C) in the tubes from 25°C to 70°C at a rate of 2.1 kg/s. The heating is to be done by water (c_p= 4190 J/kg·°C) that enters the shell side at 95°C and leaves at 45°C. The LMTD correction factor for this heat exchanger is 0.82 If the overall heat transfer coefficient is 950 W/m^2·°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 (ethyl alcohol)* Q_{cold}= 2.1 x 2670 x (70-25) J/s = 252315 Watts

	$= 252.315$ kW ………………..1 mark *Hot fluid (water)* $Q_{hot} = m_w \times 4190 \times (95 - 45)$ $= m_w \times 209500$ J/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 = U*A*LMTD A = 252315 / (950x 18.38) $= 14.5m^2$ ………………..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 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 is180^{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 84% 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 sourcinga 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^{0}C
- Heat loss due to Radiation and moisture in air -1.2%
- Specific heat of flue gases -0.29 kcal/kg^{0}C
- Specific heat of super heated water vapour -0.45 kcal/kg^{0}C
- G.C.V. of furnace oil - 10,000 kcal/kg
- Ambient temperature -30^{0}C

Substitution by 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 720 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
= 11.6x0.73 + [34.8 (0.23 – 0.01/8)]
= 16.43 kg. air / kg. gas

— Excess Air % = % O_2 / (21 - % O_2) x100
= [(4) / (21 – 4)] x100
= 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 PresenceofC,N,S + mass of N_2 in the fuel + mass of nitrogen in air supplied + mass of excess O_2in flue gas

	$=(0.73 \times 44/12) + 0.03 + (20.29 \times 0.77) + (20.29–16.43) \times 0.23$ $=$ 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 $= \frac{M_{dfg} \times C_p \times (T_g - T_a) \times 100}{GCV\ of\ fuel_{(NG)}}$ $= \frac{19.22 \times 0.29 \times (180 - 30) \times 100}{13000}$ = 6.43 % ………………..2 marks — L2 = % Loss due to water vapour from hydrogen $= \frac{9\ H\ [584 + C_{ps}\ (T_g - T_a)] \times 100}{13000}$ $= \frac{[9 \times 0.23 \times [584+0.45 \times (180-30)] \times 100}{13000}$ = 10.37 % ………………..2 marks — Heat loss due to Radiation and moisture in air= 1.2% (given) — Efficiency of natural gas boiler on GCV = 100 – [6.43 + 10.37 + 1.2] = 82% — Steam Load = 8 tonnes /hr. — Amount of Gas required= $\frac{8000\ (665 - 90)}{0.82 \times 13000}$ = 431.52 kg / hr ………………..2 marks — 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 $= \frac{8000\ (665 - 90)}{0.84 \times 10000}$

	= 547.62 kg / hr ………………..2 marks — Amount of CO_2 emission with F.O = (547.62 X 0.84 X 3.67) = 1688.2kg CO_2/hr ………………..2. marks (***Note: 1 Kg. Carbon Combustion emits 3.67 Kg. CO_2***) — Increase in CO_2 emission due to switchingfrom natural gas to furnace oil= (1688.2 – 1156.1) = 532.1 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= [(532.1x 720)/ 0.8] =**4,78,890 Kwh** ………………..2.5 marks
N-2	The monthly energy consumption for 30 days operation in a 25 TPD (Tonneper day) ice plant, producing block ice, is 37,950 kWh. The daily output of the ice plant is 15 Tonnes of block ice by freezing 16.5 m^3 of water at 30^oC. The higher water consumption is due to loss of ice, while removing the block ice from ice cans, for customer delivery. The following data has been given: • Temperature of ice block = (-) 8^oC • Latent heat of freezing of ice = 80 kcal/kg. • Specific heat of water = 1 kcal/kg^oC • Specific heat of ice = 0.5 kcal/kg^oC • Energy consumption in the ice plant chiller compressor = 85% of the total energy consumption • Efficiency of compressor motor = 88% Estimate the, 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 $30^oC$to 12^oC using a separate water chiller, drawing0.8 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 overall 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 = 37950 Kwh Daily energy consumption = 37950 / 30 = 1265 kWh ∴ **Energy consumption per tonne of ice delivered** = 1265/15 **= 84.33 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^oC to 0^oC in kcals Q_2 = Latent heat removed in freezing water to ice at 0^oC in kcals Q_3= Heat removed for sub-cooling of ice from 0^oC to -8^oC in kcals Q = (16,500 X 1 X (30-0)) + (16,500 X 80) + {16,500 X 0.5 X [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** = $\frac{18,81,000}{24 \times 3024}$ =**25.92 TR** ………………..3 marks

d)E.E.R. ice plant chiller		
Ice plant chiller consumption per day	=	0.85 X 1265
		1075.25 kWh
Ice plant auxiliary consumption per day	=	1265 – 1075.25
		189.75 kWh
Power consumption of the chiller	=	1075.25 / 24
		44.80 KW
∴ Input KW/TR Ice Plant chiller	=	44.80 / 25.92
		1.728
Motor Efficiency	=	88%
∴ Input power to the ice plant compressor	=	0.88 X 1.728

		1.52 KW / TR
∴ E.E.R. ice plant chiller		(3024)kcal/hr/(1.52X860) kcal/hr
		2.313
………………..4 marks		
e) Reduction in energy consumption per tonne of ice block output		
Condenser heat rejection load in the existing case Q1	=	$Q_E + Q_C$
		(25.92 X 3024) + (25.92 X 1.52 X 860)
		1,12,264 kcals/hr
Refrigeration load for pre-cooling from 30^{0}C to 12^{0}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 1.728 X 24 = 905.33 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
	=	905.33 + 189.75 + 78.53
		1173.61 kWh/day
∴ Reduction in energy consumption **kWh/tone** for ice delivered	=	(1265 – 1173.61) /15
		6.092
………………..4 marks		
f)		
Heat rejection load in the ice plant condenser	=	(21.83 X 3024) + (21.83 X 1.52 X 860)
		94550 kcal/hr
∴ % reduction in ice plant condenser heat load	=	(1,12,264–94,550)x100 /(1,12,264)
		15.8 %

………………..3 marks

N 3	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 = 48 Tonne/hr (without supplementary fuel firing) 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 82% efficiency on G.C.V. The plant operations are steady and continuous with 8760 yearly hours of operatior
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

$\therefore$ power to Steam ratio = 3 KW / Kg. steam

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

$\therefore$ Exhaust gas per Kg. of natural gas fired = 60 + 1 = 61 Kg. per Kg of natural gas

Efficiency of waste heat boiler (without supplementary fuel firing)

$$= \frac{48000 \times (665 - 105)}{6000 \times 0.236 \times 61 \times 0.3 \times 515}$$

= **75.5%**

………………..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 82% on GCV $= \dfrac{10000\,(665 - 105)}{0.82 \times 13000}$

= 525.33 Kg/hr

………………..5 marks

Operating separate gas fired boiler is economical.

$\therefore$ **Saving in gas consumption by meeting additional steam through gas fired boiler** =

= 559.44 – 525.33

= 34.1 Kg/hr

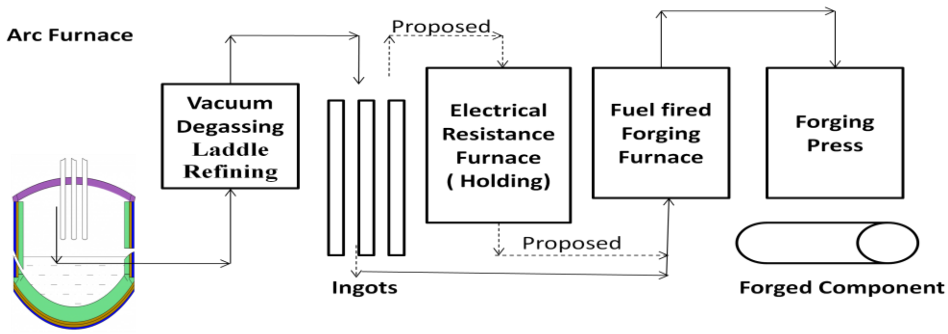
= 34.1 / 0.7

= 48.714 m^3/hr

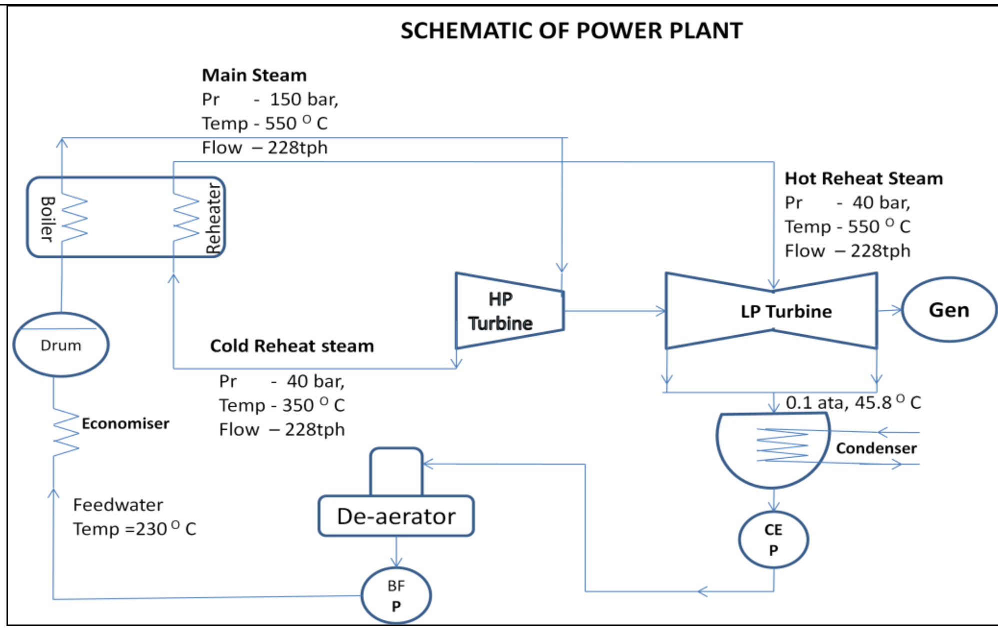
	∴Yearly monetary savings= 48.714 X 25 X 8760 = Rs.1,06,68,366 = **Say Rs.10.67 million** ……………….5 marks
N-4	**Answer any one of the following**
A)	The heat balance of a stenter in a textile industry is given below: Heat used for Drying = 48% Heat loss in exhaust air = 42% Heat loss through insulation = 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^{o}C and 75^{o}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 84%. 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 22 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 = 837kg/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 = Wx(m_i – m_o)X[(T_{out} – T_{in}) + 540] Kcal/hr T_{out}= Outlet cloth temperature = 75^{o}C T_{in}= Inlet cloth temperature = 25^{o}C ∴ **Heat load on the dryer**=418.5 kg/hrx (1 – 0.0753)kg/kg dry.clthx [(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/(0.84x10000) = **56.63 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/(0.5052x0.84x 10000) = 53.80 kg/hr ……………….4 marks ∴ Saving in Furnave oil consumption due to improved stenter efficiency = 56.63 – 53.80 = 2.83 kg/hr ∴ **AnnualFurnace oil savings** = 2.83x22x330

	= **20545.8 kgs/year** ………………..3 marks **∴ Annual monitory savings** = 20545.8x(1/0.95)x24 = **Rs.5,19,051.8** ………………..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.
B)	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 number 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 = 800 kWh 13. Electrical energy consumption for holding ingots at 600°C in electric furnace = 75kWh per batch 14. Cost of electricity = Rs.6 /kWh 15. Cost of Furnace oil = Rs. 30,000 / ton

	<u>Calculate</u> 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 * $$= \frac{1{,}000 \text{ x } [0.682 \text{ x } (1650-30)+272]}{3600}$$ {*kJ per ton of molten metal/(4.18kj / kcal x 860kcals/kwh)}* = 382.45 kWh per ton of molten steel ………………..3 marks Efficiency = 382.45 x 100 /800 = 47.8 % ………………..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^oC 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^oC = 75kWh 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) – (75 x 6) = Rs. 9646.2 per batch Annual Net savings in energy cost = 9646.2 x 12 x 160 = Rs. 185,20,704 /yr ………………..4 marks
C)	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 550^0C 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 550^0C 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 96% 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 45.8^0C Isentropic enthalpy of LP Turbine exhaust steam : 2300 kJ/kg Enthalpy of dry saturated steam at 0.1 bar(a) and 45.8^0C : 2584.9kJ/kg Enthalpy of water at 0.1 bar(a) and 45.8^0C: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) 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 0.96= 90.83 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)/90.83 =7354.08 KJ/kWhr------------------------------ANSWER (5 MARKS) (C) Turbine cycle efficiency= 860/Turbine heat rate =860/(7354.08/4.18) =48.95%------------------ANSWER (3MARKS) (d) Specific steam consumption of cycle=Steam flow/generator output =228/90.83 =2.51 tons/MWhr----ANSWER(3MARKS)
D)	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 : 0.9 kW/TR • Existing VCR condenser water pump power consumption : 2.8 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°C; outlet - 80 °C • Specific heat of exhaust cooler air : 0.24 kcal/ kg°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 : 8000 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}{}^oC$$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}xC_{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) • <u>Cooler Exhaust air temperature after heat recovery</u> 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 = 0.9 kW/TR • Existing VCR Chiller total power consumption = 50 x 0.9 = 45 kW • Existing VCR condenser water pump power consumption = 2.8 kW • Total Energy Saving = Existing VCR Chiller total power consumption – (Proposed VAM chiller power consumption) =(45+2.8) – (1.63+2.83+5.69) = 37.65 kW ………………..5 marks

	• Annual Energy savings = 37.65 x 8000 = 301200 kWh/yr • Annual Monetary savings = 301200 x 6 = Rs. 18.07 Lakhs /y • Investment towards 50TR VAM & its associated system = Rs 30 lakhs • Simple payback period = 30 / 18.07 = 1.7 yrs or 19.9 months ………………...3 marks

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

Regular set A

Regn No: ____________________
Name : ____________________
(To be written by the candidate)

17th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY MANAGERS & ENERGY AUDITORS – September, 2016

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

Date: 25.09.2016 Timings: 14:00-16:00 HRS Duration: 2 HRS

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

S-1	An air washer cools the water and a cooling tower cools the air. True or False.
Ans	**False.**
S-2	A 11 kW induction motor has an efficiency of 90% what will be its maximum delivered output?
Ans	**11 kW.**
S-3	The COP of a vapour absorption refrigeration system is lower than the COP of a vapour compression refrigeration system-True /false.
Ans	**True.**
S-4	An industrial electrical system is operating at unity power factor. Addition of further capacitors will reduce the maximum demand (kVA). True or False.
Ans	**False.**
S-5	Which parameter in the proximate analysis of coal is an index of ease of ignition?
Ans	**Volatile matter.**
S-6	The major source of heat loss in a coal fired thermal power plant is through flue gas losses in the boiler. True or false.
Ans	**False.**
S-7	With evaporative cooling, it is possible to attain water temperatures below the atmospheric wet bulb temperature. True or False
Ans	**False**
S-8	A pump is retrofitted with a VFD and operated at full speed. Will the power consumption increase or decrease or remain the same?
Ans	**Increase**
S-9	De-aeration in boiler refers to removal of dissolved gases. True or false
Ans	**True**

S-10	In a compressed air system, the function of the after cooler is to reduce the work of compression. True or False
Ans	**False**

…………. End of Section - I ………….

Section - II: SHORT NUMERICAL QUESTIONS

<table>
<tr><td>L-1</td><td>In a petrochemical industry the LP & HP boilers have the same evaporation ratio of 14 using the same fuel oil. The operating details of LP & HP boiler are given below:
<table>
<tr><th>Particulars</th><th>LP Boiler</th><th>HP Boiler</th></tr>
<tr><td>Pressure</td><td>10 Kg./cm²a</td><td>32 Kg./cm²a</td></tr>
<tr><td>Temperature</td><td>Saturated Steam</td><td>400°C</td></tr>
<tr><td>Enthalpy of steam</td><td>665 Kcal/kg</td><td>732 Kcal/kg</td></tr>
<tr><td>Enthalpy of feed water</td><td>80°C</td><td>105°C</td></tr>
<tr><td>Evaporation Ratio</td><td>14</td><td>14</td></tr>
</table>
Find out the efficiency of HP boiler if the LP boiler efficiency is 80%.</td></tr>
<tr><td>Ans</td><td>Effy η = ER. (hg – hf) / GCV
$\text{Effy}_{L.P}\ \eta_1$ = 0.8 = 14 x(665 – 80) / GCV
$\text{Effy}_{H.P}\ \eta_2$ = 14 x(732 – 105) / GCV
$\text{Effy}_{H.P}\ \eta_2$ / $\text{Effy}_{L.P}\ \eta_1$ = (732 – 105)0.8 / (665 – 80) = 0. 8574 =85.74%
Or
$\text{Effy}_{L.P}\ \eta_1$= 0.8 = 14 x(665 – 80) / GCV
GCV= 14x(665-80) / 0.8 = 10237.5kcal/kg
$\text{Effy}_{H.P}\ \eta_2$ = 14 x(732 – 105) / GCV
= 14 x(732 – 105) / 10237.5 = 0.8574 = 85.74%</td></tr>
<tr><td>L-2</td><td>While carrying out an energy audit of a pumping system, the treated water flow (in open channel) was measured by the tracer method. 20% salt solution was used as the tracer which was dosed @ 2 lts/min. The water analysis about 500 mtrs away revealed salt concentration of 0.5%. Assuming complete mixing and no losses, calculate the water flow rate.</td></tr>
<tr><td>Ans</td><td>20% salt solution = 200 gms of salt in 1 Litre of water
0.5% salt solution = 5 gms of salt in 1 litre of water
Dosing rate = 2 lts/min
Salt added in water = 2 x 200 = 400 gms/min
Total flow = 400/5 = 80 lts/min
Water flow rate = 80 – 2 = 78 lts/min
Or
C1V1 = C2V2
V2 = C1V1/C2 = 0.2x2/0.005 =80 lts/min
Actual flow = total flow – dosage flow = 80-2 =78 lts/min</td></tr>
</table>

…………. End of Section - II ………….

Regular set A

Section - III: LONG NUMERICAL QUESTIONS

N-1 In a chemical plant, a 3000 Million Cal/hr cooling tower with one CW pump caters to the cooling water requirements. The management had decided to refurbish the cooling tower as its performance is felt to be low. The operating parameters of the CW system before and after refurbishment are presented below.

S.No	Parameter	Before refurbishment	After refurbishment
1	CW inlet temp to CT	35°C	35°C
2	Atmospheric air conditions	WbT -25 °C, DbT - 38 °C	WbT -25 °C, DbT - 38 °C
3	COC	3.5	5
4	Suction head of CW pump	-1m	-1m
5	Discharge pressure of CW pump	4kg/cm^2(g)	4kg/cm^2(g)
6	Efficiency CW Pump CW Pump motor CT fan CT fan motor	 54% 89% 55% 90%	 53% 89% 54% 90%
7	Pressure developed by CT fan	20mmwc	20mmwc
8	Effectiveness of CT	60 %	70%
9	L/G ratio	1.5	1.5
10	Density of air	1.29kg/m^3	1.29kg/m^3

As a result of cooling tower refurbishment the effectiveness has increased from 60% to 70 %. Also with improved water treatment the COC has increased to 5.

Find out

1. Reduction in power consumption of pump and fan due to improvements in cooling tower.
2. Reduction in make up water consumption (ignoring drift losses) in KL/day

Regular set A

Ans

Parameter	Equation / formulae	Before refurbishment	After refurbishment	
Effectiveness	= **(T_{CWi}-T_{CW0})/(**T_{CWi}-WbT)	0.6=(35- T_{CWO})/(35-25) T_{CWO} = 29 ^oC	0.7=(35- T_{CWO})/(35-25) T_{CWO} = 28 ^oC	
CW flow rate Q	= heat load/(T_{CWi}-T_{CW0})	=(3000x10^6/10^3) / (35- 29) = 500000 kg/h = 500 m3/h	=(3000x10^6/10^3)/(35-28) = 428571 kg/h = 429 m^3/hr	
Evaporation loss	=1.8*.00085*CW flow x Range	1.8x0.00085x500x (35-29) = 4.59 m^3/h	1.8x.00085x429x(35-28) = 4.59 m^3/h	
Blow down loss	= Evaporation Loss/(COC-1)	= 4.59/(3.5-1) = 1.84 m^3/h	4.59/(5-1) = 1.15 m^3/h	
Total water loss	= Eva loss+ Blow down loss	= 4.59+1.84 =6.43 m^3/h	=4.59+1.15 =5.74 m^3/h	
Make-up water	***= Total water loss x 24hrs***	***= 6.43 x 24 = 154.2 m^3/day =154.2KL/day***	***= 5.74 x 24 = 137.76m^3/day =137.76 KL/day***	
Total head H	= discharge head-suction head	= 40-(-1) = 41 mWC	= 40-(-1) = 41 mWC	
Pump LKW	= ((Q*1000/3600)*(H*9.81))/1000	= (500*1000/3600)*(41*9.81)/1000 = 55.86KW	= (429*1000/3600)*(41*9.81)/1000 = 47.9 kW	
Pump input	= Pump LKW/Eff.Pump	=55.86/0.54 =103.4 kW	= 47.9/0.53 =90.4 kW	
Motor input	***= Pump input/motor eff***	***= 103.4/0.89 =116.2 kW***	***=90.4/0.89 = 101.6kW***	
Air flow in CT fan Q_f	=[(CW flow)x1000]/ [((L/G)]*1.29)	= (500x1000/(1.5x1.29) = 258398 m^3/h	= (429x1000/(1.5x1.29) = 221705m^3/h	
H_f	Pressure developed by fan H_f	= 20mmWC	= 20mmWC	
Air KW	= [(Qf in m^3/h)*(Hf in mmWC)]/(3600*102)	=(258398*20)/(3600*102) =14.07 kW	=(221705*20)/(3600*102) = 12.08 kW	
Fan motor input	*=Air KW/(FanEffi x Motor Eff)*	***=14.07/(0.55*0.9) = 28.43kW***	***=12.058/(0.54*0.9) = 24.9 kW***	

(1) Reduction in power of pump and motor = (116.2+28.43) - (101.6+24.9) = 18.13 kW

(2) Reduction in makeup water = 154.2-137.76 = 16.44 or 16.5 KL/day

Regular set A

N-2	In a beverages industry the product stream (liquid) flowing at a rate of 5000 kgs/hr at 90°C is first cooled in counter type cooling water (CW) heat exchanger to 55 °C and then by a chilled water (ChW) heat exchanger, to reduce temperature of the product to 11°C. The specific heat of the product is 0.9 kCal/kg°C. The other operating data and parameters are:

Cooling Water heat exchanger			**Chilled Water heat exchanger**		
	Inlet temp	Outlet temp		Inlet temp	Outlet temp
Product	90°C	55 °C	Product	55°C	11 °C
Cooling Water	25 °C	32 °C	Chilled water	7 °C	12 °C

The chilled water is supplied by a reciprocating chiller, whose motor is drawing 60 KW with a motor efficiency of 87%. The management decides to upgrade cooling water heat exchanger by providing additional heat exchanger area to further enhance heat recovery i.e. to reduce the temperature of product at its outlet to 40°C.

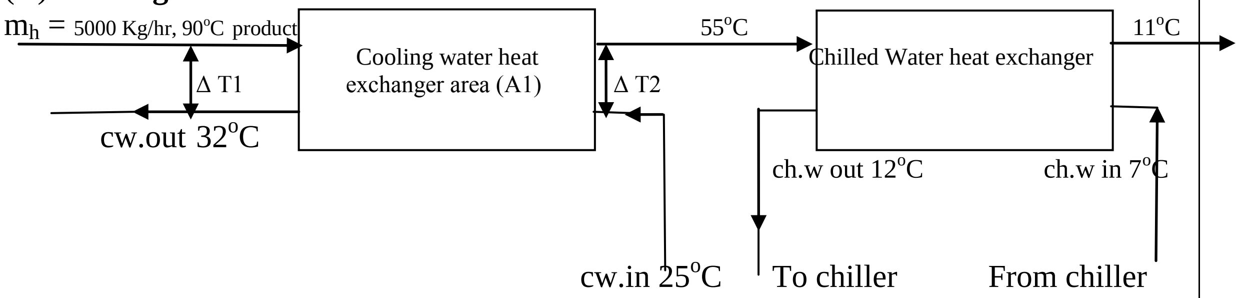
A. Depict the heat exchanger in existing and upgraded (improved) heat recovery case in a simple block diagram
B. Calculate

   i. The additional heat exchanger area (as a % of the existing area) for cooling water heat exchanger, assuming there is no change in cooling water circulation rate and the overall heat transfer coefficient.
   ii. The COP of the chiller.
   iii. Reduction in refrigeration /chiller load and yearly energy savings at 600 hours per month operation, assuming energy consumption is proportional to load delivered.

Regular set A

Ans

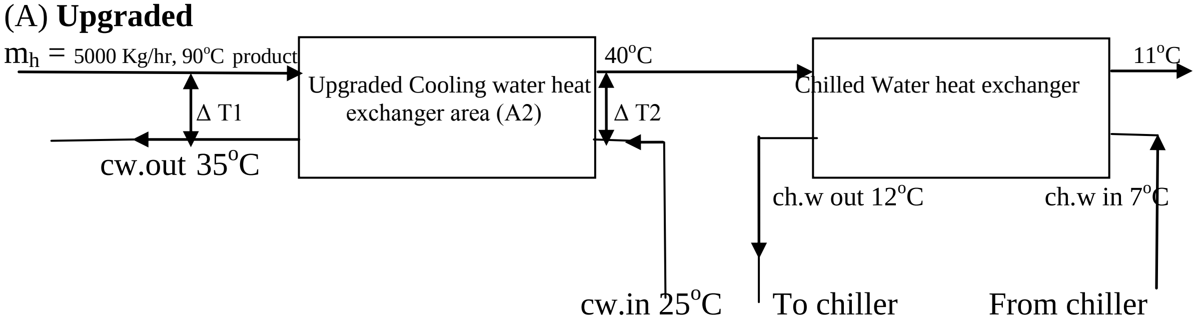
(A) **Existing**



Heat load on CW heat exchanger Heat rejected by product stream	=	heat gained by CW
$Q1 = m_c \times 1 \times (\Delta T_c)$	=	5000 X 0.9 X (90 – 55)
Q_1	=	1,57,500 Kcal/hr
m_c = Cooling Water flow rate	=	(5000X0.9 X 35)/(32 – 25) = 22,500 Kg/hr.
Heat exchanger duty with increased heat recovery Q_2	=	5000 X 0.9 X (90 – 40) = 2,25,000 Kcal/hr
Cooling water temp. Rise with increased heat exchanger duty for cooling product stream to 40°C	=	$\frac{5000 \times 0.9 \times (90 - 40)}{22{,}500} = 10^{o}C$

Cooling water outlet temp with the above case = 25 + 10 = 35°C

(A) **Upgraded**



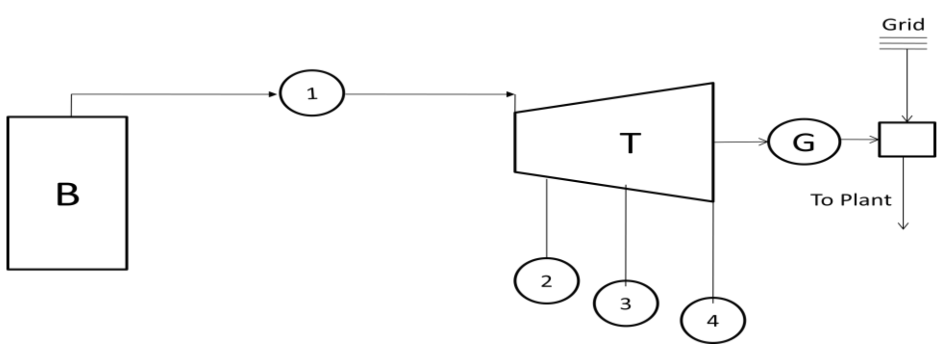
…..2.5 marks

$LMTD_1$ with existing case	$= \frac{\Delta T_1 - \Delta T_2}{L_n\, \Delta T_1 / \Delta T_2}$ $= \frac{(90 - 32) - (55 - 25)}{L_n\,(90 - 32) / (55 - 25)} = 42.49^{o}C$

$LMTD_2$ with additional heat recovery	$= \dfrac{(90 - 35) - (40 - 25)}{L_n (90 - 35) / (40 - 25)} = 30.77^oC$
$Q_2 = U X A_2 X LMTD_2$ $Q_2 = 2,25,000 = U X A_2 X 30.77$	$Q_1 = U X A_1 X LMTD_1$ $Q_1 = 1,57,500 = U X A_1 X 42.49$
$A_2 / A_1 = (2,25,000 /1,57,500) X (42.49 / 30.77) = 1.973$	

Additional area required	=	97.3% of existing heat exchanger area of CW heat exchanger
Refrigeration load in existing case	=	5000 X 0.9 X (55 – 11)
	=	1,98,000 Kcal/hr
	=	1,98,000 /3024
	=	65.476 TR
Motor input power	=	60 KW
Motor eff.	=	87%
C.O.P. of refrigeration chiller	= =	198000 /(60 X 0.87 X 860) 4.41
Input KW / TR	=	60 / 65.476 = 0.916
Reduction in refrigeration load due to lower input temperature of the product to chilled water heat exchanger	= =	5000 X 0.9 X (55 – 40) / 3024 22.32 TR
Yearly energy savings at 600 hrs. operation per month	= =	22.32 X 0.916 X 600 X 12 1,47,204.86 Kwh

N-3 In a continuous process industry Steam and Power are supplied through a cogeneration plant interconnected with grid. The design and actual operating parameters of the cogeneration plant as represented in the schematic are given in the table below.



Double Extraction – Condensing Steam Turbine Cogeneration System

		Design	actual
B -	Boiler	75tph,64kg/cm^2(a), 450^{o}C @82% efficiency	68.75tph, 64kg/cm^2(a), 450^{o}C @81% efficiency
T -	Steam Turbine	Double Extraction – Condensing type	
G -	Generator	10MW	7.2MW

Stream Ref	Steam flow location	Steam Flow (tph)	Steam Pressure (kg/cm^2)	Steam Temp (^{o}C)	Steam enthalpy (kCal/kg)
1	Steam input to turbine	68.75	64	450	745
2	First extraction	18.75	17	270	697
3	Second extraction	31.25	9	200	673
4	Condenser in	18.75	0.1	-	550
	Condenser out	18.75	-	-	46

The industry is installing a 1200 TR double effect absorption chiller to meet the refrigeration load due to product diversification. Additional steam will be generated by the boiler, which will go into the turbine and be extracted at 9kg/cm^2(a) to meet the VAM requirement. The additional power thus generated will reduce the imported grid power.

The following additional data has been provided:

Maximum allowable steam flow the extraction at 9 Kg/cm^{2}a	40 TPH
Minimum allowable steam to condenser	9 TPH
Critical power requirement of the plant	3800 KW
Power import from grid	500 KW
Cost of grid power	Rs.4.25 / Kwh
G.C.V. of coal	4000 Kcal/Kg.
Cost of coal	Rs. 4000/ton
Feed Water temperature	105^{o}C
Feed Water enthalpy	105 Kcal/Kg.
Combined efficiency of gear box and generator	96%
Steam requirement for double effect absorption chiller	4.5 Kg./TR hr at 9 Kg/cm^{2}a
Annual hours of operation.	8000 hrs/y
Steam rate at 9 Kg/cm^{2}a at 2nd extraction for 1 KW turbine output	12 (Kg/hr)/kW

Ignore auxiliary power consumption and also return condensate from extracted steam to process.

Calculate

(i) The Energy Utilization Factor (EUF) for the existing operating case

(ii) The net additional annual operating cost, after installation of VAM.

(iii) The Energy Utilization Factor (EUF) after installation of VAM.

Regular set A

Ans	(i) $$\text{Energy Utilization Factor (EUF) (before VAM installation)} = \frac{\text{Q thermal + P electrical}}{\text{Fuel Consumption X G.C.V.}}$$ Q thermal $= m_2 h_2 + m_3h_3 + m_4h'_4$ $$\text{Q in} = \frac{m (h_1 - h_f)}{\eta \text{ X G.C.V.}}$$ Q thermal = 18750 X 697 + 31250 X 673 + 18750 X 46 = (18.75 X 697 + 31.25 X 673 + 18.75 X 46) X 10^3 Kcal/hr = (13068 X 21031 + 862.5) X 10^3 Kcal/hr = 34962.5 X 10^3 Kcal/hr P_e = 7200 X 860 = 6192 X 10^3 Kcal/hr $$\text{Fuel Consumption} = \frac{(745 - 105) \text{ X } 68.750\text{x}1000}{0.81\text{X } 4000 \text{ X } 1000} = 13.58 \text{ TPH}$$ $$\text{EUF} = \frac{34962.5 \text{ X } 10^3 + 6192 \text{ X } 10^3}{13.58 \text{ X } 10^3 \text{ X } 4000} \text{ x } 100 = 75.76\%$$ (ii) Refrigeration Load = 1200 TR 1TR requires 4.5 Kg./hr steam at 9 Kg./cm^2a Steam consumption in double effect absorption chiller = 1200 X 4.5 = 5400 Kg./hr. Increase in steam extraction at 9 Kg./ cm^2a = 5400Kg/hr Every 12 Kg./hr extraction at 9 kg/ cm^2a gives 1 KW output at turbine , efficiency of generator and gear box = 0.96 Additional power recovery due to increase in extraction = (5400 / 12) X 0.96 = 432 KW Additional coal consumption due to increase in extraction = (745 – 105)X 5400/(0.81x4000) = 1066 kg/h Additional cost of coal = 4000x1.066 = Rs 4266.6 /hr ***…..2 marks*** Monetary realisation by reducing import cost of purchased electricity = 4.25 Rs./unit = 432 X 4.25 = 1836 Rs./hr

Net additional annual operating cost after VAM installation = (4266.6-1836)*8000
= Rs 1.94 crore/y

(iii)

Stream Ref	Steam flow location	Steam Flow (tph)	Steam Pressure (kg/cm^2)	Steam Temp (^oC)	Steam enthalpy (kCal/kg)
1	Steam input to turbine	68.75+5.4 =74.15	64	450	745
2	First extraction	18.75	17	270	697
3	Second extraction	31.25+5.4 =36.65	9	200	673
4	Condenser in	18.75	0.1	-	550
	Condenser out	18.75	-	-	46

Energy Utilization Factor (EUF) (after VAM installation) $= \dfrac{\text{Q thermal + P electrical}}{\text{Fuel Consumption X G.C.V.}}$

Q thermal $= m_2 h_2 + m_3h_3 + m_4h'_4$

Q in $= \dfrac{m (h_1 - h_f)}{\eta \text{ X G.C.V.}}$

Q thermal = 18750 X 697 + 36650 X 673 + 18750 X 46
=(18.75 X 697 + 36.65 X 673 + 18.75 X 46) X 10^3 Kcal/hr
= (13068 X 21031 + 862.5) X 10^3 Kcal/hr
= 38596.7 X 10^3 Kcal/hr

P_e = (7200+432) X 860
= 6563.5 X 10^3 Kcal/hr

Fuel Consumption = 13.58 TPH +1.066 TPH = 14.646TPH

EUF $= \dfrac{38596.7 \text{ X } 10^3 + 6563.5 \text{ X } 10^3}{14.646 \text{ X } 10^3 \text{ X } 4000} \text{x100} = 77.08\%$

N-4 **Answer ANY ONE OF THE FOLLOWING among A, B, C and D**

A) The operating parameters observed w.r.t. design in a 110 MW power generation unit are given below:

Regular set A

	(see parameter table below)

Parameters	Design	Operation
Generator output	110 MW	110 MW
Steam generator outlet super heat temperature	540°C	525°C
Steam generator outlet pressure	140 Kg/cm²a	130 Kg/cm²a
Feed water inlet temperature	135°C	135°C
Boiler η	87.5%	87.5%
GCV of Coal	3800	3800
Turbine exhaust pressure	0.09 Kg./cm²a	0.11 Kg./cm²a
Dryness fraction of exhaust steam	0.87	0.89
Turbine heat rate	2362.5 Kcal /Kwh	------
Efficiency generator	96%	96%
Energy loss in gear box	4420 KW	4420 KW
Enthalpy of steam at 520°C, 130 Kg/cm²a,		810 Kcal/Kg.
Enthalpy of steam at 0.11 Kg./cm²a		550 Kcal/Kg

Calculate the

I. Actual steam flow to the turbine
II. Specific steam consumption of turbine
III. % increase in gross unit heat rate compared to design
IV. Increase in monthly (720 hours/month) coal consumption due to deviation in operation w.r.t. design at a plant load factor of 80%

Ans

Generator output	=	110 MW	
η of generator		96%	
Generator input	= =	110 / 0.96 114.58 MW	
Energy loss in gear box	= =	4420 KW 4.42 MW	
Turbine output	=	Total input at gear box + energy loss in gear box	
Turbine out put	= =	114.58 + 4.42 119 MW	
Turbine out put	=	m_s (810 – 550) X (1 / 860)	

		m_s (810 – 550) X (1 / 860)	=	119 X 1000	
		Steam flow rate through the turbine	= =	***3,93,615 Kg /hr*** ***393.615 Tonne/hr***	
		Specific steam consumption	= =	***(393.615 X 1000) / (110 X 1000)*** ***3.58 Kg./kW***	
		Boiler η	=	$\dfrac{M_s (h_g – h_w)}{GCV \times m_f} \times 100$	
		Coal consumption m_f		$\dfrac{393615 (810 – 135)}{0.875 \times 3800}$ ***79906.8 Kg./hr***	
		Specific coal consumption	= =	***79906.8 / (110 X 1000)*** ***0.726 Kg./Kwh***	
		Actual unit heat rate	= =	***0.726 X 3800*** ***2758.8 Kcal/Kwh***	
		Design turbine heat rate η of steam generator or boiler		***2362.5 Kcal / KW*** ***87.5%***	
		Design unit heat rate	= =	***2362.5 / 0.875*** ***2700 Kcal/Kwh***	
		% increase in heat rate w.r.t. design	= =	***[(2758.8 – 2700) / 2700] X 100*** ***2.17 %***	
		Specific coal consumption for design heat rate	= =	***2700/3800*** ***0.71kg/kwh***	
		Additional coal consumption per month with a PLF of 80%	= =	$\dfrac{(0.726 – 0.71) \times 110 \times 1000 \times 0.8 \times 720}{1000}$ ***1013.76 tonnes***	
	Or				
B)	In a textile process house the production from the stenter machine is 72000 mtrs per day. The effective operation of stenter is 20 hours per day. The percentage moisture in the dried cloth (output) is 6% and its temperature is 75°C and wet cloth inlet is at 25°C . The stenter is heated by steam at 8 kg/cm²a and the daily steam consumption for the stenter is 16.5 tonnes. The efficiency of the stenter dryer is 47%. Calculate the (i) Linear speed of the stenter machine (ii) Inlet moisture (iii) Feed rate of the stenter. The following data have been provided Weight of 10 meter of dried cloth = 1 kg. Enthalpy of the steam to the stenter = 665 kcal/kg.				

	Enthalpy of condensate at the exit of stenter = 130 kcal/kg. Ignore losses in start-up and stoppage.
Ans	Production per day = 72000 meters Actual hours of operation = 20 hours/ day **Linear speed of the stenter = 72000 / (20x60) = 60 meters per min** Dried cloth output = 72000 / (20x10) = 360 kg/hr. Moisture in dry cloth = 6% Bone dry cloth = 360 x 0.94 = 338.4 kg/hr Moisture in outlet cloth m_o = (360 – 338.4) / 338.4 = 0.0638 Kg./Kg. bone dry cloth Steam consumption per day = 16.5 tonnes = 16500 / 20 = 825 Kg./hr. Heat load on the dryer =Energy input in steam x Dryer Efficiency = Steam flow rate x (Enthalpy steam – Enthalpy condensate) x Efficiency Dryer = 825 x (665 – 130) x 0.47 = 207446.3 Kcal/hr. Further Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr. w =weight of bone dry cloth rate kg/hr m_i = weight of cloth inlet moisture Kg./Kg. bone dry cloth T_{out} = dried cloth outlet temperature= 75^{o}C T_{in} = wet cloth inlet temperature = 25^{o}C 338.4 x (m_i – 0.0638) X [(75 – 25) + 540] = 207446.3 Kcal/hr m_i = 1.1028 Kg./Kg. bone dry cloth(1.1028) / (1.1028+1)x100 % inlet moisture in wet cloth = 52.44 % total moisture in inlet cloth = 1.1028x338.4= 373.2 kg/hr feed rate(inlet cloth rate), = total inlet moisture/hr +bone dry cloth/hr = 373.2+338.4 = 711.6 Kg./hr.
	or
C)	The preheater exhaust gas from a cement kiln has the following composition on dry basis :CO2 – 23.9%, O2 – 5.9%, CO – 0.2%, remaining is N2. The static pressure and temperature measured in the duct are -730 mmWC and 350^{0}C respectively. The velocity pressure measured with a pitot tube is 19 mmWC in a duct of 2800 mm diameter (Pitot tube constant = 0.89). The atmospheric pressure at the site is 10350 mmWC and universal gas constant is 847.84 mmWCm^3/kg mol k. The specific heat capacity of preheater exhaust gas is 0.25 kcals/kg^{0}C.

	The static pressure developed by PH exhaust fan is 630mmWC and power drawn is 1582 kW. Calculate the efficiency of fan given that the motor efficiency is 92%. The management had decided to install a 1.3 MW power plant with a cycle efficiency of 15% by using this preheater exhaust gas. Calculate the exhaust gas temperature at the outlet of waste heat recovery boiler of the power plant.
Ans	Molecular weight exhaust gas (dry basis) M = $\%CO_2 x M_{CO2} + \%O_2 x M_{O2} + \%CO x M_{CO} + \%N_2 \text{ x } MN_2$ = {(23.9 x 44) + (5.9 x 32) + (0.2 x 28) + (70 x 28)}/100 = 32.06 kg/kg mole Exhaust Gas density at operating temperature = γ= [PM / RT] = [(10350 – 730) x 32.06) / { 847.84 x (273+350) } = 0.584 kg/m^3 Duct Area = 3.14 x(2.8/2) ^{2}= 6.15 m^2 Volume flow rate $=A\ Cp\ (2 \times g \times \Delta P / \gamma)^{1/2} = 6.15 \times 0.89\ (2 \times 9.81 \times 19 / 0.584)^{1/2}$ = 138.3 m^3/s Volume flow rate= 497880 m^3/h Fan efficiency = $\frac{\text{volumetric flow rate x pressure developed}}{\text{(102 x power drawn x motor eff)}}$ = $\frac{138.3 \times 630}{(102 \times 1582 \times 0.92)}$ x100 = 58.69% Mass flow rate of preheater exhaust gas = Volume flow rate x density = 497880*0.584 = 2,90,762 kg/hr Heat equivalent of power generated from power plant =1.3MW =1300 x 860 = 1118000 kCals/hr Heat given up to power plant by exhaust gas = 290762 x0.25 x(350-T_o)x0.15 T_o = 350 - (1118000/(290945x0.25x0.15)) = 247.5^0**C**
	or
D)	For a commercial building, using the following data, (i) Determine the building cooling load in TR (ii) Calculate the supply air quantity to the cooling space in m^3/s Outdoor conditions : DBT = 40°C, WBT = 28°C, Humidity = 19 g of water / kg of dry air Desired indoor conditions : DBT = 25°C, RH = 60 %, Humidity = 12 g of water / kg of dry air

Regular set A

	Total area of wall = 324 m^2, out of which 50% is window area. U – Factor (Wall) = 0.33 W/m^2K U – Factor (Roof) = 0.323 W/m^2K U – factor [fixed windows with aluminium frames and a thermal break] = 3.56 W/m^2K Other data: • 20 m x 25 m roof constructed of 100 mm concrete with 90 mm insulation & steel decking. • CLTD at 17:00 hr : Details : Wall = 12°C; Roof = 44°C; Glass Window = 7°C • SCL at 17 : 00 hr : Details : Glass Window = 605 W/ m^2 • Shading coefficient of Window = 0.74 • Space is occupied from 8:00 to 17:00 hr by 30 people doing moderately active work. • Sensible heat gain / person = 75 W ; Latent heat gain / person = 55 W ; CLF for people = 0.9 • Fluorescent light in space = 21.5 W/m^2 ; CLF for lighting = 0.9 • Ballast factor details = 1.2 for fluorescent lights & 1.0 for incandescent lights • Computers and office equipment in space produces 5.4 W/m^2 of sensible heat • One coffee maker produces 1050 W of sensible heat and 450 W of latent heat. • Air changes/hr of infiltration = 0.3 • Height of building = 3.6 m • Supply air dry bulb temperature is 15^0C
Ans	**(i) Cooling Load Determination:** **I. External Heat Gain** (i) Conduction heat gain through the wall = U – factor x net area of wall x CLTD = 0.33 x (324*0.5) x 12] = 641.5 W (ii) Conduction heat gain through the roof = U – factor x net area of roof x CLTD = 0.323 x (20 x 25) x 44 = 7106 W (iii) Conduction heat gain through the windows = U – factor x net area of windows x CLTD = (3.56 x 162 x 7) = 4037 W (iv) Solar radiation through glass = Surface area x Shading coefficient x SCL = (162 x 0.74 x 605) = 72527 W **II. Internal Heat Gain** (i) Heat gain from people =Sensible heat gain + Latent heat gain

Sensible heat gain = (No. of people x Sensible heat gain / person x CLF)
=(30 x 75 x 0.9) = 2025 W

Latent heat gain = No. of people x Latent heat gain / person
= (30 x 55) = 1650 W
Therefore, Heat gain from people = (2025 + 1650) = 3675 W

(ii) Heat gain from lighting = (Energy input x Ballast factor x CLF)
Energy input = (Amount of lighting in space / unit area)x Floor area
= 21.5 x (20 x 25) = 10750 W

Therefore, heat gain from lighting = (10750 x 1.2 x 0.9) =11610 W

(iii) Heat generated by equipment :

Sensible heat generated by coffee maker =1050 W
Latent heat generated by coffee maker = 450 W
Sensible heat gain by computers and office equipment = 5.4 x 500 = 2700 W
Therefore, Heat generated by equipment = 4200 W

(iv)Heat gain through air infiltration = (Sensible heat gain + Latent heat gain)

Sensible heat gain =(1210 x airflow x ΔT)
Airflow = (Volume of space x air change rate) / 3600
= { (20 x 25 x 3.6) x 0.3 } / 3600
= 0.15 m^3 / s

Therefore, sensible heat gain =1210 x 0.15 x (40 – 25) =2722.5 W

Latent heat gain =3010 x 0.15 x (19 – 12) =3160.5 W

No.	Space Load Components	Sensible Heat Load (W)	Latent Heat Load (W)
1.	Conduction through exterior wall	641.5	---
2.	Conduction through roof	7106	---
3.	Conduction through windows	4037.0	---
4.	Solar radiation through windows	72527	---
5.	Heat gained from people	2025	1650
6.	Heat gained from lighting	11610	---
7.	Heat gained from equipment	3750	450
8.	Heat gained by air infiltration	2722.5	3160.5
	Total space cooling load	**104419**	**5260.5**
Total Cooling Load = **109679.5W/3516 =31.2 TR**			

(ii) Supply Air Quantity Calculation:
Supply air flow = Sensible heat gain / {1210 * (Room dry bulb temperature – Supply dry bulb temperature)}
= 104419 W / {1210 J/m^{30}K*(25 – 15)^{0}C}
= 8.63 m^3/s

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

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**

○

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^{0}C?
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 ^{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-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 = $\dfrac{[24000\ Lit_{Hotwater}/\ day) \times (55-20^{o}C) \times (1\ kcal/Lit^{o}C)]}{(0.7\ Effy \times 9100\ kcal/Lit_{\ diesel})}$

= 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 = $\dfrac{\text{Heat pump refrigeration effect, kcal}}{\text{COP} \times 1\ \text{kW}}$

Or

	Input electrical energy, kW = $\dfrac{\text{Heat pump refrigeration effect, kcal}}{\text{COP x 860 kcal/hr}}$ Electrical energy required with heat pump of COP = 2 = $\dfrac{24000 \times 1 \times (55 - 20)}{(2 \times 860)}$ ..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 $= 11.6C + [34.8 (H_2 – O_2/8)] + 4.35S$, $= 11.6 \times 0.72 + [34.8 (0.236 – 0.011/8)]$ (note S= sulfur in above composition is nil) = 16.524 kg air/kg gas ….. 1 Mark % Excess Air = $[\% O_2 / (21 - \% O_2)] \times 100$ $= [3.5 / (21 – 3.5)] \times 100 = 20\%$ ….. 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 $= 0.72 \times 44/12 + 0.03 + (19.83 – 16.524) \times 0.23 + 19.83 \times 0.77$ = 18.70 kg dfg / kg gas …. (1.5 marks) L_1 = % heat loss due to dry flue gases $= \dfrac{\text{mdfg} \times \text{cpfg} \times (T_g – T_a)}{\text{G.C.V. of gas}} \times 100$ G.C.V. of gas $= \dfrac{\text{Kcal / m}^3}{\text{Density}} = \dfrac{9100}{0.7} = 13000$ Kcal/kg $= \dfrac{18.69 \times 0.297 \times (190 – 30)}{13000} \times 100 = 6.84\ \%$ …..(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 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-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 $$\text{Effectiveness} = \frac{\text{Cold Water outlet – Cold water inlet}}{\text{Hot effluent inlet – Cold water inlet}}$$ Cold Water Outlet = (0.4 x (80 – 25)) + 25 = 47 ^{O}C …. (2.5 marks) $$\text{Mass flow rate of cooling water (M)} = \frac{\text{Heat duty in hot fluid}}{\text{Cp x (Cold water outlet – Cold water inlet)}}$$ $$= \frac{2664900}{1 \times (47 - 25) \times 1000}$$ = 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

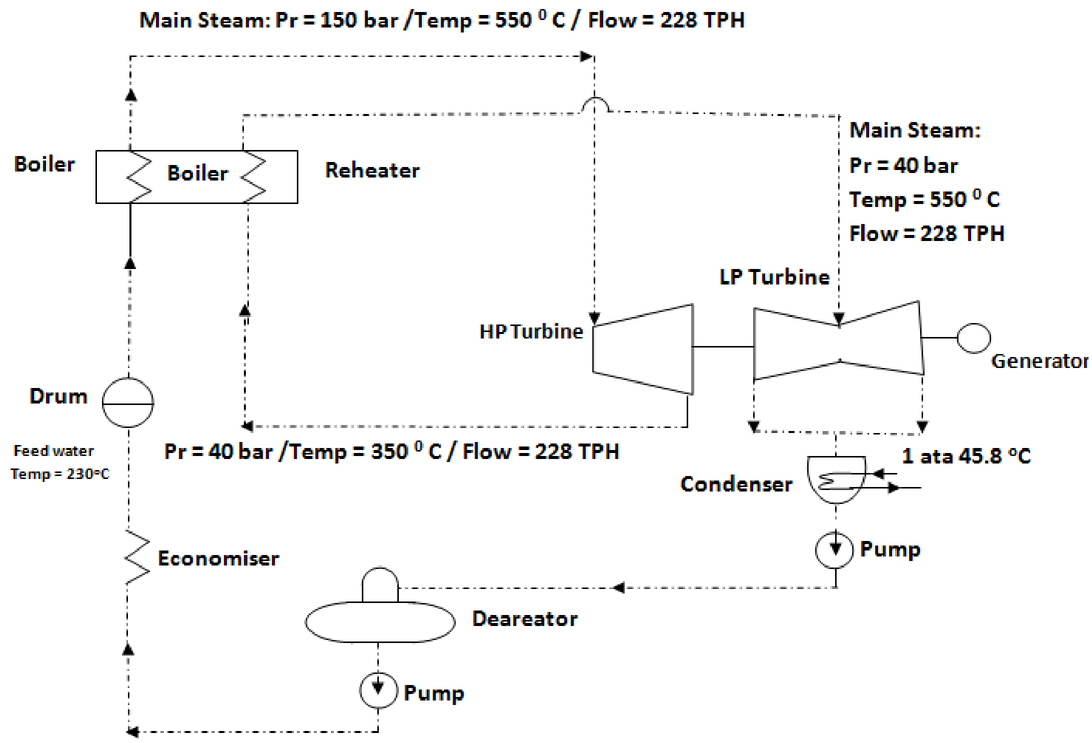
…. (2 marks)

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 ^oC 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^oC , Outlet temperature of dried cloth = 80^oC, 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) <u>Stoichiometric air for combustion</u>: $C + O_2$ ------ 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	$1.293 Kg/m^3$
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	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	$0.247 kCal/kg\ ^0C$
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	$0.193\ kCal/kg\ ^0C$
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	$0.247 kCal/kg\ ^0C$
18.	Area of the Cooler exhaust duct	$7.1 m^2$
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

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

15th NATIONAL CERTIFICATION EXAMINATION FOR ENERGY AUDITORS – August, 2014

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

Date: 24.8.2013 Timings: 14:00-16:00 Hrs Duration: 2 Hrs Max. Marks: 100

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

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

S-1	Which loss is not considered while evaluating boiler efficiency by "Indirect Method"?
Ans	Blow down loss
S-2	What will be the synchronous speed of a VFD driven 4-pole induction motor operating at 40 Hz ?
Ans	Ns = 120 x f/P = 120 x 40/4= 1200 RPM
S-3	What is the refrigerant used in a vapour absorption system with lithium bromide as an absorbent?
Ans	Water
S-4	Other than rated kW of motor and the actual power drawn, what other parameter is required to determine the percentage loading of the motor ?
Ans	Motor Efficiency or rated motor efficiency
S-5	Inclined tube manometer is used for measuring gas flow in a duct when the air velocity is very high: True or False?
Ans	False.
S-6	A pump will cavitate if the $NPSH_{required}$ is __________ than the $NPSH_{available}$.
Ans	More
S-7	To determine the effectiveness of the cooling tower, it is required to measure cooling water inlet, outlet and _____temperatures.
Ans	Ambient Wet bulb
S-8	The ratio of actual heat transfer to the heat that could be transferred by heat exchanger of infinite size is termed as ………

Ans	Effectiveness
S-9	If the unit heat rate of a power plant is 3070 kcal/kWh ,what is the power plant efficiency ?
Ans	(860/3070) x 100 = 28 %
S-10	The difference between GCV and NCV of hydrogen fuel is Zero: True or False
Ans	False

………… 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	Hot water at 80 ^{O}C is used for room heating in a 5 Star hotel for 4 months in a year. About 200 litres per minute of hot water is maintained in circulation with the return temperature at 50 ^{O}C. The hot water is generated using a 'hot waste stream', through a Plate Heat Exchanger (PHE). The hot stream enters the PHE in counterflow direction at 95 ^{O}C and leaves at 60 ^{O}C. The area of the heat exchanger is 20 m^2. Calculate the LMTD and the overall heat transfer coefficient.
Ans	Heat load, Q = 200 * 60 * (80 – 50) = 360000 Kcals/hr (or) 418.7 kW LMTD (for counter flow) $= \dfrac{(95 - 80)/(60 - 50)}{\ln(15/10)} = 3.7\ ^{O}C$ Overall Heat Transfer Coefficient, U = Q/(AxLMTD) = 418.7/(20 x 3.7) = 5.66 kW/$m^2.^{O}C$ (OR) = 4864.8 kcal/hr.$m^2.^{O}C$
L-2	A gas turbine generator is delivering an output of 20 MW in an open cycle with a heat rate of 3440 kcal/kWh. It is converted to combined cycle plant by adding heat recovery steam generator and a steam turbine raising the power generation output to 28 MW. However, with this retrofitting and increased auxiliary consumption, the fuel consumption increases by 5% in the gas turbine.

	Calculate the combined cycle gross heat rate and efficiency.
Ans	Gas turbine output = 20 MW Combined cycle output = 28 MW Heat rate in GT open cycle for 20 MW = 3440 kcal/kwh Increase in fuel consumption in combined cycle operation = 5% Combined cycle heat rate = (3440 X 1.05) X(20 / 28) = 2580 kcal/kwh Combined cycle plant efficiency = (860 / 2580) X 100 = 33.33%

…………. End of Section - II ………….

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

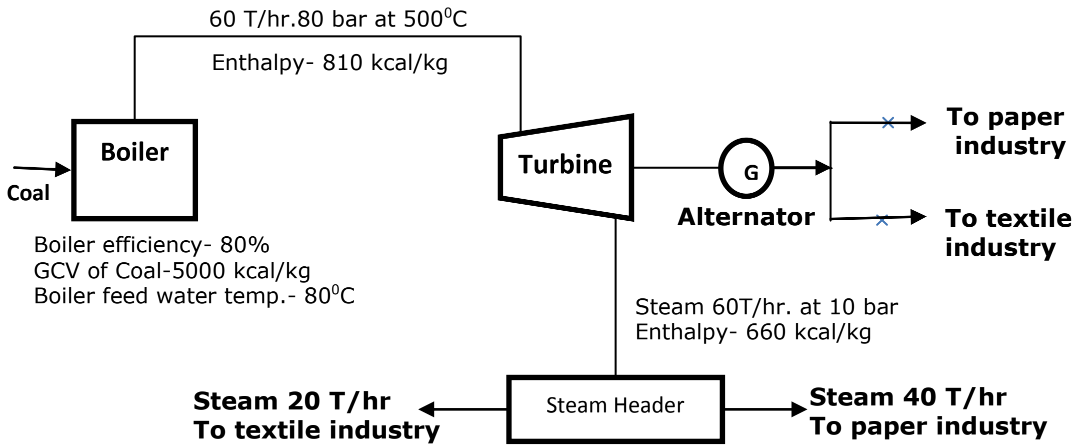
(i) Answer all **Four** questions

N-1	The steam requirement of an export oriented unit is met by a 6 TPH oil fired package boiler generating steam at 10 kg/cm^2. The monthly steam consumption of the unit is 3000 tonnes. Other data are given below: Fuel oil composition: Carbon = 86%; Hydrogen = 12%; Oxygen= 0.5%; Sulphur =1.5% Specific heat of flue gases, Cp = 0.27 kcal/kg^{o}C G.C.V. of fuel oil = 10,000 kcal/kg Sp.heat of super heated water vapour = 0.45 kcal/kg^{o}C Enthalpy of steam at 10 kg/cm^2 = 665kcal/kg Feed water temperature = 85 ^{o}C % O_2 in dry flue gas = 6% Flue gas temperature at boiler outlet = 240 ^{o}C Ambient temperature = 30^{o}C Cost of fuel oil = Rs.43 per kg. Radiation and other unaccounted losses = 2.45% The export oriented unit is costing its steam cost based on the fuel consumption cost with additional 15% to account for the auxiliary and consumables. A neighbouring continuous process plant now offers to supply the required steam at 10

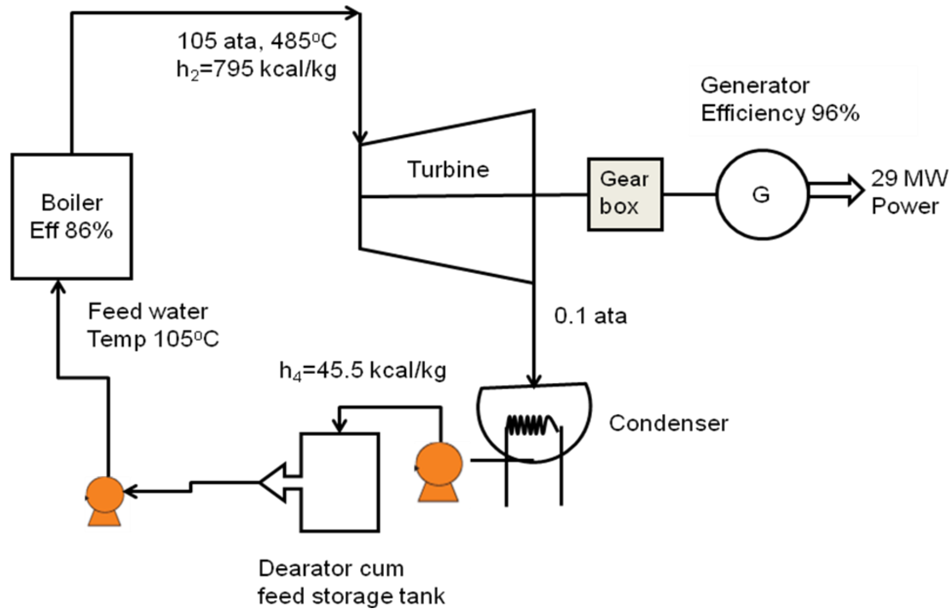
	kg/cm2 to the export oriented unit at a cost of Rs 3300 per tonne with a condition that all the condensate will be returned back. Calculate the following: a) Boiler efficiency b) Cost advantage per tonne of availing steam from neighbouring plant in place of in-house generation and also monthly monetary saving.
Ans	<u>First calculate the efficiency of Boiler (in EOU)</u> Theoretical air required = = 11.6 C + 34.8 (H – O/8) + 4.35 S = [11.6 X 86 + 34.8 (12 – 0.5/8) + 4.35 X 1.5] x 1/100 = 14.195 = Say 14.2 % Excess Air = [% O_2 / (21 - % O_2)] X 100 = [6 / (21 – 6)] X 100 = 40% AAS = Actual amount of air supplied = 14.2 X 1.4 = **19.88 kg per kg. of fuel oil** Mass of dry flue gas m_{dfg} = Mass of combustion gases due to presence of C,H,S +Mass of N_2 supplied = (0.86 X 44/12) + (0.015 X 64 / 32) + [(19.88 – 14.2) X 23 / 100] + (19.88 X 77/100) = 19.797 Mass dry flue gas ,say = 19.8 Kg / kg fuel Or Alternatively mass of dry flue gas = (AAS + 1) – 9 H = (19.88 + 1) – 9 X 0.12 = 19.8 Kg./Kg. fuel L1 = % heat loss in dry flue gas = [m_{dfg} x Cp x (T_q – T_a) / GCV] x 100 $= \frac{19.8 \times 0.27 \times (240 - 30)}{10{,}000} \times 100$ L1 = **11.23%** L2 = Loss due to presence of hydrogen forming water vapour $= \frac{9 \times H\ [584 + Cps\ (T_g - T_a)]}{GCV} \times 100$ $= \frac{9 \times 0.12\ [584 + 0.45\ (240 - 30)]}{10000} \times 100$ L2 **= 7.33%** L3 = Radiation and other unaccounted losses **= 2.45%** Total losses = L1 + L2 + L3

	= 11.23 + 7.33 + 2.45 = **21.05 %** Efficiency of the EOU boiler by indirect method = 100 – 21.05 =78.99 % = **Say 79 %** <u>Secondly calculate the cost of steam in the EOU plant</u> Evaporation Ratio = [(n X GCV) / (h_g – h_f)] X 100 = [(0.79 X 10000) / (665 – 85)] X 100 **= 13.62 kg Steam / kg. Fuel** Fuel oil consumption = 1000 / 13.62 kg. per tonne of steam Fuel oil consumption = 73.42 kg./tonne of steam gen Cost of fuel oil. = Rs. 43 per kg Cost of steam in EOU = Fuel cost + 15% fuel cost = 73.42 x 1.15 x 43 = Rs.3,599 per tonne **Say = Rs 3600 per tonne** Selling cost of steam from neighboring plant = Rs 3300 per tonne Cost advantage = 3600 – 3300 = Rs.300 per tonne Annual Savings = Rs.300 per tonne x 3000tonne/month X 12 month **= Rs.108 Lacs**
N-2	**a)** The operating parameters of a Vapour Compression Refrigeration system are indicated below. (see table below) Find the COP of the Refrigeration system ignoring heat losses. **b)** A 6 pole, 415 volt, 3 Φ, 50 Hz induction motor delivers 22 kW power at rotor shaft at a speed of 950 rpm with PF of 0.88. The total loss in the stator including core, copper and other losses, is 2 kW. Calculate the following. i) Slip ii) Rotor Copper Loss iii) Total Input to motor ivi) Line current at 415 V and motor pf of 0.88 v) Motor operating efficiency
	a) Refrigeration Effect = 89 x 1000 x (10.1 – 6.8)

Parameter	Chiller side	Condenser side
Water Flow (m^3/hr)	89	87
Inlet Temperature (^OC)	10.1	32.3
Outlet Temperature (^OC)	6.8	36.6
Density (kg/m^3)	1000	990

Ans	**= 293700 kcal/hr** Condenser load = 87 x 990 x (36.6 – 32.3) = **370359 kcal/hr** Compressor work = Condenser load – Refrigeration effect = 370359 – 293700 = **76659 Kcal/hr** C.O.P. = Refrigeration Effect/ Compressor work = 293700/76659 = **3.83** b) Synchronous Speed = (120 x 50 / 6) = 1000 rpm Motor Speed = 950 rpm (i) Slip = (1000 – 950) / 1000 = **5%** Power input to rotor = { (22 / (1 – 0.05) } = 23.16 kW (ii) Rotor Copper Loss = (0.05 x 23.16) = **1.158kW** **Or** = 23.16-22 =1.16 kW (iii) Total Input to motor = (23.16 + 2) = **25.16 kW** (iv) Line Current = (25.16 x 1000) /(√3 x 415 x0.88) = **39.75 Amps** (v) Motor Efficiency = (22 / 25.16) = **87.44 %**
N-3	A common plant facility is installed to provide steam and power to textile and paper plant with a co-generation system. The details and operating parameters are given below:  Other data: - Turbine, alternator and other losses = 8% - Specific steam consumption in paper industry= 5 Tons/Ton of paper - Specific power consumption in paper industry= 600 kWh/Ton of paper Calculate:

	i. Coal consumption in boiler per hour or per day. ii. Power generation from co-generation plant iii. If 10% is auxiliary power consumption in co-generation plant, how much power is consumed by the textile industry per hour? iv. What is the gross heat rate of turbine?
Ans	i) Boiler efficiency = Steam production (steam enthalpy- Feed water enthalpy) / Quantity of coal x G.C.V. of coal Quantity of coal = 60,000 (810-80)/ 0.8 x 5000 **= 10.95 tons/hr**. ii) Gross power generation from co-generation plant Total enthalpy input to turbine = 60,000 x 810 = 48.6 Million kcal. Total enthalpy out put through back pressure= 60,000* 660 = 39.6 Million kcal Enthalpy difference = 48.6- 39.6 = 9 Million kcal/hr Turbine,alternator and other losses =8% or 9x0.08 = 0.72 Million kcal/hr Useful energy for power generation = 9- 0.72 = 8.28 Million kcal/hr Power generation from co-generation plant = 8.28 x 10^6/860 = **9628kWh** iii) If 10% is auxiliary power consumption in co-generation plant, power consumed by textile industry 10% of total power generation = 9628 x 0.10 = 962.8kWh Total power consumed by industries = 9628 – 962.8 = 8665.2kWh Total steam consumption in paper plant 40 tons/hr. and specific steam consumption 5 ton/ton of paper. So Paper production per hour is 8 tons. Specific power consumption = 600kWh/ton. Total power consumption in paper industry = 8 x 600 = 4800kWh Total power consumption in textile industry = 8665.2- 4800 = **3865.2 kWh** iv) Gross heat rate= Input enthalpy – output enthalpy/ gross generation =(48.6- 39.6) 10^6/ 9628 = **934.7 kCal/kWh**
N-4	To attempt **ANY ONE OF THE FOLLOWING** among A, B, C and D
A	A captive thermal plant is delivering an output of 29 MW at the generator terminal. The generator efficiency is 96%. The steam generated in a utility boiler with an efficiency of 86% at 105 ata and 485°C is fed to the turbine. The turbine exhausts steam to condenser maintained at 0.1 ata and 45.5°C. The feed water temperature at inlet to the boiler is 105°C.

	 The other data pertaining to captive power plant are, Enthalpy of steam at 105 ata 485°C = 795 kcal/kg. Dryness fraction of steam at inlet to condenser = 0.9 Enthalpy of dry saturated steam at 0.1ata =618 kcal/Kg. Enthalpy of water at 0.1 ata & at 45.5°C = 45.5 kcal/Kg. Loss in the gear box connecting turbine and generator = 1100 kW Enthalpy of feed water at inlet to the boiler , = 105 kcal/Kg. Based on the above data determine: i. Output of the steam turbine in kW ii. Steam flow through the turbine iii. Turbine heat rate iv. Unit heat rate
Ans	Enthalpy of steam at turbine exhaust = 45.5 +0.9 (618 – 45.5) i.e. h_3 = 560.75 Kcal/Kg. Generator electric output = 29000 KW Generator input = 29000 / 0.96 = 30208.33 KW Loss in gear box = 1100 KW Output of steam turbine = Generator input + Gear box loss = 30208.33 + 1100 = 31308.33 KW i) Output of the steam turbine **Say = 31308 KW** ms = Steam flow through turbine

	$= \frac{\text{(Turbine output x 860)}}{(h_2 - h_3) \text{ Turbine enthalpy drop}}$ h_2 = Enthalpy at turbine inlet = 795 kcal/kg h_3 = Enthalpy at turbine exhaust = 560.75 kcal/Kg. m_s = 31308 x 860 / 795 – 560.75) = 114940.78 kg/Hr. = 114.94 TPH ii) Steam flow through the turbine **Say = 115 TPH** iii) Turbine heat rate = Heat input to turbine / Generator output = [m_s (h_2 – h_1)] / 29000 = 115000 (795 – 105) / 29000 = 2736.2 kcal/ kWh iv)Unit heat rate = Turbine heat rate / Efficiency of boiler Unit heat rate = 2736.2 / 0.86 = **3181.63 kcal/ kWh**
	Or
B	In a textile unit a stenter is delivering 80 meters/min of dried cloth at 5% moisture. The moisture of wet cloth at inlet is 50%. The stenter is heated by steam at 7 kg/cm^2 with inlet enthalpy of 660 kcal/kg. and condensate exits the stenter at 135 kcal/kg. Other data • Latent heat of water evaporated from the wet cloth = 540 kcal/kg • Weight of 10 meters of dried cloth = 1 kg • Inlet temperature of wet cloth = 27^{o}C • Outlet temperature of dried cloth at stenter outlet = 80^{o}C. i) Estimate the steam consumption in the stenter considering a dryer efficiency of 48%. ii) Determine the specific steam consumption kg/kg of dried cloth
Ans	Output of stenter = 80 mts/min. = 80 x 60 /10 = 480 Kg/hr. Moisture in the dried output cloth = 5% Wt of bone dry cloth = 480 X (1 – 0.05) i.e. W = 456 Kg/hr. m_o =moisture in outlet cloth =(480 – 456)/456 =0.0526 Kg./Kg. of bone dried cloth Inlet moisture = 50% Wt of inlet cloth = 456 / (1 – 0.50) = 912 Kg./hr. m_i = moisture in inlet cloth = 912 X 0.5 / 456 = 1.00 Kg./Kg. bone dried cloth Inlet temperature of cloth = 27^{o}C

	Final temperature of cloth = 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 = 456 (1 – 0.0526) X [(80 – 27) + 540] = 2,56,184.5 Kcal/hr Efficiency of the dryer = 48% Heat input to the stenter = 2,56,184.5 / 0.48 = 5,33,717.71 Kcal/hr Steam consumption in the stenter = 5,33,717.71 / (660 – 135) = 1016.61 Kg/hr Steam consumption per Kg. of dried at stenter outlet cloth = 1016.61 / 480 = 2.12 Kg./Kg. dried cloth
	Or
C	Determine the **cooling load** of a commercial building for the following given data. Outdoor conditions : DBT = 35°C ; WBT = 25°C; Humidity = 18 g of water / kg of dry air Desired indoor conditions : DBT = 25.6°C ; RH = 50 %; Humidity = 10 g of water / kg of dry air Total area of wall = 40 m^2 Total area of window = 20m^2 U – Factor (Wall) = 0.33 W / m^2K U – Factor (Roof) = 0.323 W / m^2K U – factor [fixed windows with aluminum frames and a thermal break] = 3.56 W / m^2K • 15 m x 25 m roof constructed of 100 mm concrete with 90 mm insulation & steel decking. • CLTD at 17:00 h :Details : Wall = 12°C Roof = 44°C Glass Window = 7°C • SCL at 17 : 00 h :Details : Glass Window = 605 W/ m^2 • Shading coefficient of Window = 0.74 • Space is occupied from 8:00 to 17:00 h by 25 people doing moderately active work. • Sensible heat gain / person = 75 W ; Latent heat gain / person = 55 W ; CLF for people = 0.9

	• Fluorescent light in space = 21.5 W/m^2 FLF for lighting = 0.9 • Ballast factor details = 1.2 for fluorescent lights & 1.0 for incandescent lights • Computers and office equipment in space produces 5.4 W/m^2 of sensible heat • One coffee maker produces 1050 W of sensible heat and 450 W of latent heat. • Air changes / hr of infiltration = 0.3 • Height of building = 3.6 m
Ans	**I External Heat Gain** (i) Conduction heat gain through the wall =U – factor x net area of wall x CLTD =[0.33 x 40 x 12] = 158.4 W (ii) Conduction heat gain through the roof =U – factor x net area of roof x CLTD =0.323 x (15 x 25) x 44 = 5 329.5 W (iii) Conduction heat gain through the windows =U – factor x net area of windows x CLTD = (3.56 x 20 x 7) = 498.4 W (i) Solar radiation through glass = Surface area c Shading coefficient x SCL =(20 x 0.74 x 605) = 8 954 W **II Internal Heat Gain** (i) Heat gain from people =Sensible heat gain + Latent heat gain Sensible heat gain =(No.of people x Sensible heat gain / person x CLF) =(25 x 75 x 0.9) = 1 687.5 W Latent heat gain =No.of people x Latent heat gain / person =(25 x 55) = 1 375 W Therefore, Heat gain from people=(1687.5 + 1375) = 3 062.5 W (ii) Heat gain from lighting =(Energy input x Ballast factor x CLF) Energy input =(Amount of lighting in space / unit area) x Floor area =21.5 x (15 x 25) =8 062.5 W Therefore, heat gain from lighting =(8062.5 x 1.2 x 0.9) =8 707.5 W

(iii) Heat generated by equipment :

Sensible heat generated by coffee maker =1050 W

Latent heat generated by coffee maker =450 W

Sensible heat gain by computers and office equipment = 5.4 x 375 = 2025 W

Therefore, Heat generated by equipment = **3 525 h**

(iv) Heat gain through air infiltration=(Sensible heat gain + Latent heat gain)

Sensible heat gain =(1210 x airflow x ΔT)

Airflow =(Volume of space x air change rate) / 3600

={ (15 x 25 x 3.6) x 0.3 } / 3600

=0.1125 m^3 / s

Therefore, sensible heat gain =1210 x 0.1125 x (35 – 25.6) =1 279.58 W

Latent heat gain =3010 x 0.1125 x (18 – 10) = 2 709 W

No	Space Load Components	Sensible Heat Load (W)	Latent Heat Load (W)
1	Conduction through exterior wall	158.4	------
2	Conduction through roof	5 329.5	------
3	Conduction through windows	498.4	------
4	Solar radiation through windows	8954	------
5	Heat gained from people	1 687.5	1 375
6	Heat gained from lighting	8 707.5	------
7	Heat gained from equipment	3 075	450
8	Heat gained by air infiltration	1 279.58	2 709
Total space cooling load		**29 689.88**	**4 534**

Or

D During heat balance of a 5 stage preheater Kiln in a cement plant, the following data was measured at Preheater (PH) Fan Inlet and clinker cooler vent air fan inlet:

Parameter measured	Temperature	Static Pressure	Avg. Dynamic Pressure	Specific heat	Gas Density at STP	Duct Area
Unit	^oC	(P_s) mm WC	(P_d) mm WC	kcal/kg ^oC	kg/m^3	m^2
PH Exit Gas at PH fan Inlet	316	-650	28.6	0.248	1.4	2.27
Clinker cooler vent air at cooler Stack Fan Inlet	268	-56	9.7	0.24	1.29	2.01

Note: take Pitot tube constant as 0.85, reference temperature 20 ^oC and atmospheric pressure 9908 mm WC.

Other Data

Clinker Production	Designed specific volume of PH gas	NCV of Coal	Cost of coal	Annual Operation
TPH	Nm^3/kg clinker	kcal/kg	Rs./ton	hrs
45.16	1.75	5500	6500	8000

Calculate the following:

i. Specific volume of PH gas as well as cooler vent air (Nm^3/kg clinker)

ii. Heat loss in pre-heater exit gas (kcal/kg clinker)

iii. Heat loss in cooler vent air (kcal/kg clinker)

iv. If the measured specific volume of PH gas (Nm^3/kg clinker) exceeds the design value, calculate the heat loss (kcal/kg clinker) and annual monetary loss due to excessive specific volume of PH gas.

Ans

i. Density of Pre-heater gas at PH Fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} \, X \frac{273 \, X (9908 + P_S)}{(273 + T) \, X 10334}$$

$$\rho_{T,P} = 1.40 \, X \frac{273 \, X (9908 - 650)}{(273 + 316) \, X 10334} = 0.581 \text{ kg/m}^3$$

Velocity of PH gas

$$v = P_t \sqrt{\frac{2 g P_d}{\rho_{T,P}}}$$

$$v = 0.85\sqrt{\frac{2 \text{X} 9.8 \text{X} 28.6}{0.581}} = 26.4 \text{ m/sec}$$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
= 26.4 X 2.27
= 59.9 m^3/sec
= 59.9 X 3600
= 215640 m^3/hr

Specific volume of PH gas = 215640 X 0.58/1.4
= 89491 Nm^3/hr
= 89491/45160 = **1.98 Nm^3/kg clinker**

Similarly density of cooler vent air at cooler vent air fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} \text{X} \frac{273 \text{X} (9908 + P_S)}{(273 + T) \text{X} 10334}$$

$$\rho_{T,P} = 1.29 \text{X} \frac{273 \text{X} (9908 - 56)}{(273 + 268) \text{X} 10334} = 0.62 \text{ kg/m}^3$$

Velocity of cooler vent air in the fan inlet duct

$$v = P_t\sqrt{\frac{2 g P_d}{\rho_{T,P}}}$$

$$v = 0.85\sqrt{\frac{2 \text{X} 9.8 \text{X} 9.7}{0.62}} = 14.88 \text{ m/sec}$$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
= 14.88 X 2.01
= 29.9 m^3/sec
= 29.9 X 3600
= 107640 m^3/hr

Specific volume of cooler vent air = 107640 X 0.62/1.29
= 51734 Nm^3/hr
= 51734/45160 = **1.15 Nm^3/kg clinker**

ii)Heat loss in PH exit gas

Q1 = $m_{ph}\ c_p\ \Delta T$ (C_p of PH gas = 0.248 kcal/kg ^oC)
Q1= 1.98 X 1.4 X 0.248 x (316-20)
= 203.5 kcal/kg clinker

iii) Heat loss in cooler vent air

Q2 = $m_{CA}\ c_p\ \Delta T$ (C_p of cooler vent air = 0.24 kcal/kg ^oC)
Q2= 1.15 x 1.29 x 0.24 x (268-20)
= 88.3 kcal/kg clinker

	iv) Heat Loss due to excess specific volume of PH gas V_{excess} =1.98 – 1.75 = 0.23 **Nm^3/kg clinker** Heat loss Q = 0.23 x 1.4 x 0.248 x (316-20) = 23.6 **kcal/kg clinker** Equivalent coal saving = 23.6/5500 = 0.0043 kg coal/kg clinker or ton of coal/ton of clinker Coal saving in one hour = 0.0043 x 45.16 = 0.194 TPH Annual Coal Saving = 0.194 x 8000= 1552 tons of coal per annum **Annual Monitory Saving = 1552 x 6500 = Rs. 100.88 lakhs**

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

14th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY AUDITORS – August, 2013

PAPER – 4: Energy Performance Assessment for Equipment and Utility Systems
Date: 25.8.2013 Timings: 14:00-16:00 Hrs Duration: 2 Hrs Max. Marks: 100

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

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

S-1	**If EER of a 1.5 TR window airconditioner is 2.5 what will be the power input?**
Ans	1.5 x 3.516/2.5 = 2.11 kW
S-2	**What is the significance of monitoring dew point of compressed air for pneumatic instruments application?**
Ans	To check the moisture level/dryness in instrument air
S-3	**For a thermal power plant, the percentage auxiliary consumption of a 500 MW unit is ____than that of a 110 MW unit.**
Ans	Less
S-4	**Between one litre of 'liquid hydrogen' and one litre of 'liquid gasoline' which will have a higher heat content?**
Ans	Liquid gasoline
S-5	**Why is the COP of a vapour absorption refrigeration system always less than one?**
Ans	COP is given by (heat taken by evaporator/ heat given to generator). The heat given to generator of VAR is always more than heat taken away in the evaporator (refrigeration effect)
S-6	**Regenerators utilising waste heat are widely used in _________furnaces**
Ans	Glass melting or Open hearth furnaces
S-7	**Why small bypass lines are provided in a centrifugal pump?**

Ans	To avoid pump running at zero flow
S-8	**If the speed of a reciprocating pump is reduced by 50 %, what will be its effect on the head?**
Ans	The head will remain the same
S-9	**As the 'approach' increases, the other parameters remaining constant, the effectiveness of cooling tower will _____________**
Ans	Decrease
S-10	**In a DG set, waste heat is used for steam generation. This type of cogeneration is called _________cycle.**
Ans	Topping

………… 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	**An automobile plant has a maximum demand of 5000 kVA at a PF of 0.95. The plant has shifted its electric annealing furnace with a steady resistive load of 600 kW to its foundry unit in a nearby location after suitable modifications. What will be the new PF of the automobile plant without the electric annealing furnace?**
Ans	Existing maximum demand in kW, 5000 x 0.95 = 4750 KW Existing reactive power load in the plant $(KVAR)^2 = KVA^2 – KW^2 = (5000)^2 – (4750)^2$ KVAR = 1561 Electrical load after shifting 600 KW annealing furnace = 4750 – 600 = 4150 KW However, KVAR load will remain same as 600 kW annealing furnace did not impose any kVAr loading. KVA = SQRT $[(4150)^2 + (1561)^2]$ = 4434 PF = 4150 / 4434 = 0.936

L-2	**In a medium sized engineering industry a 340 m^3/hr reciprocating compressor is operated to meet compressed air requirement at 7 bar. The compressor is in loaded condition for 80% of the time. The compressor draws 32 kW during load and 7 kW during unload cycle.** **After arresting the system leakages the loading time of the compressor came down to 60%.** **Calculate the annual energy savings at 6000 hours of operation per year.**
Ans	Average power consumption with 80% loading = = [0.8 x 32 + 0.2 x 7] = 27 KW Average power consumption with 60% loading after leakage reduction = = [0.6 x 32 + 0.4 x 7] = 22 KW Saving in electrical power = 5 KW Yearly savings = 5 x 6000 = 30,000 kWH

…………. End of Section - II ………….

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

(i) Answer all **Four** questions

N1	**A multi-product chemical plant has an oil fired boiler for meeting its steam requirements for process heating. The average fuel oil consumption for the boiler was found to be 950 litres per hour. Calculate the cost of steam per tonne considering only the fuel cost.** **The performance and other associated data are given below:** **O_2 in the flue gas (dry) at boiler exit = 6%** **Temperature of the flue gas at boiler exit = 200°C** **Enthalpy of steam = 665 kcal/kg** **Enthalpy of feed water = 80 kcal/kg** **Steam is dry saturated.** **Fuel analysis data:** **Carbon (C) = 85% Hydrogen (H_2) = 12% Nitrogen (N_2) = 0.5%** **Oxygen (O_2) = 1% Sulfur (S) = 1.5%** **Gross calorific value of fuel oil = 10,000 kcal/kg** **Specific gravity of fuel oil = 0.95** **Cost of fuel oil per KL = Rs.40,850/-** **Specific heat of flue gas = 0.262 kcal/kg°C**

	Specific heat of superheated vapour in flue gas = 0.43 kcal/kg^{o}C **Humidity in combustion air = 0.025 kg/kg dry air** **Ambient air temperature = 30^{o}C** **Radiation & convection loss from boiler = 1.8%**
ANS	Calculate boiler efficiency by indirect method ↓ Calculate evaporation ratio Kg steam / Kg fuel oil ↓ And then compute fuel cost of steam **Boiler efficiency by indirect method:** Theoretical air required for complete combustion of fuel oil = {11.6. C + [34.8 (H_2 – O_2/8)] + 4.35 S} / 100 = {11.6 x 85 [34.8 (12 – 1/8)] + 4.35 x 1.5} / 100 = 14.05 Kg/Kg fuel oil % O_2 in fuel gas = 6 % Excess air = [%O_2 / (21 - % O_2)] x 100 = [6 / (21 – 6)] x 100 = 40% Actual Air Supplied (ASS) = (1 + 0.4) x 14.05 = 19.67 Kg/Kg fuel oil Mass of dry flue gas = m_{dfg} Mass of dry flue gas = mass of combustion gases due to presence C, S, O_2, N_2 + mass of N_2 in air supplied M_{dfg} = 0.85 x (44 / 12) + 0.015 x (64 / 32) + .005 + [(19.67 – 14.05) x (23 / 100)] + 19.67 x (77/100) M_{dfg} = 19.59 Kg/Kg fuel oil Alternatively M_{dfg} = (AAS+1) – (9xH_2) = (19.67+1) – (9 x 0.12) = 19.59 kg/kg fuel oil % heat loss in dry flue gas = m_{dfg} x C_{pf} x (Tg – Ta) / GCV of fuel Tg = flue gas temperature = 200^{o}C Ta = ambient temperature = 30^{o}C Cp = SP ht of flue gas = 0.26 Kcal/Kg^{o}C GCV = Gross Calorific Value of fuel oil = 10,000 Kcal/kg L1 = % heat loss in dry flue gases = [(19.59 x 0.262 x (200-30))/10,000] X 100 = 8.73 % Heat loss due to evaporation of water due to H_2 in fuel = {9 x H_2 [584 + C_{PS} (Tg – Ta)]} / GCV C_{PS} = Specific heat of superheated steam = 0.43 Kcal/Kg^{o}C

L2 = {9 x 0.12 [584 + 0.43 (200 – 30)] / 10000} x 100 = 7.09%
L3 = % heat loss due to moisture in fuel = 0
As % moisture in fuel is nil (not given)

% heat loss due to moisture in air

L4 = AAS x humidity factor x C_{PS} x (Tg – Ta) / GCV
Humidity factor = 0.025 Kg/Kg dry air

L4 = {[19.67 x 0.025 x 0.43 (200-30)] / 10000} x 100 = 0.36%

L5 = Radiation and convection loss from the boiler = 1.8% (given data)

Total losses in the boiler in %= L1 + L2 + L3 + L4 + L5
= 8.73 + 7.09 + 0 + 0.36 + 1.8
= 17.98 say 18 %
Efficiency of boiler by indirect method = 100 - % total loss = 100 – 18 = 82%

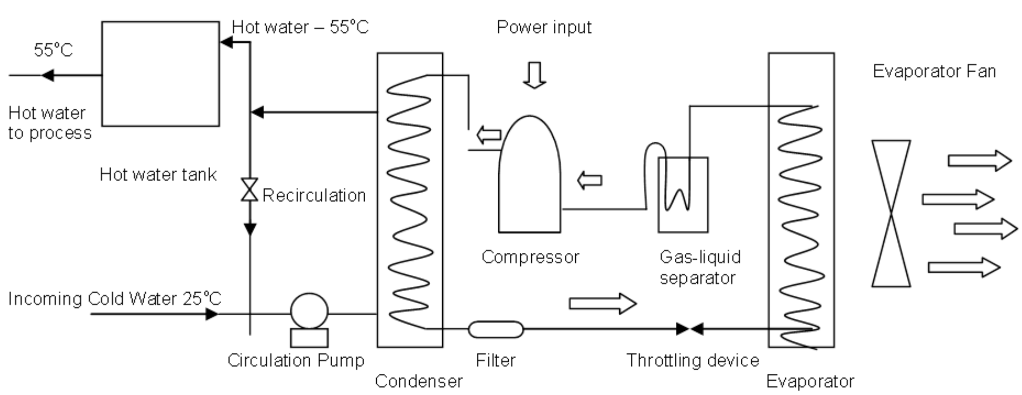
Boiler n = E.R. (hs – hw) / GCV x 100
ER = Evaporation Ratio = Kg steam / Kg fuel oil
hs = Enthalpy of Steam = 665 Kcal/Kg
hw = feed water enthalpy = 80 Kcal/Kg
Boiler Efficiency = 82%

ER = 0.82 x 10000 / (665-80) = 14.02 = Say 14 Kg steam / Kg fuel oil

Cost of fuel oil per KL = Rs.40,850/-
S.G. of fuel oil = 0.95
Cost of fuel oil per tonne = 40,850 / 0.95 = Rs.43,000/-

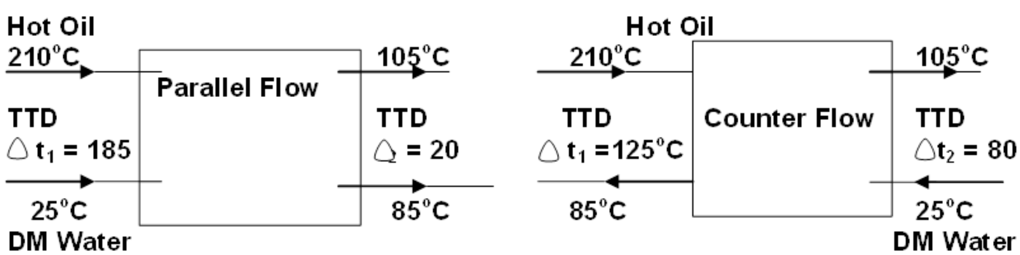
Fuel cost of steam per tonne = 43000 / 14 = Rs.3071.45

N2 **In a food processing unit, 24,000 litres of water per day is to be heated from 25°C to 55°C. Presently this requirement is met by an electrical heater. The management is planning to install a vapour compression heat pump system having a COP of 2.3 which includes the compressor motor losses. The schematic of the heat pump hot water system is given below:**



Schematic of Heat Pump

	Hours of operation of water circulation pump = 24 hours/day **Evaporator fan operation = 20 hours/day** **Energy consumption of water circulation pump and evaporator fan per day = 50 kWh** **Compressor motor efficiency = 88 %** **Annual operating days of heat pump = 330 days** **Cost of electrical energy = Rs.10/kWh** **Heat loss in the condenser and hot water tank in addition to the heat load = 5%** **Investment for heat pump = Rs.15 Lakhs** **The compressor and evaporator fan are interlocked in operation.** **Find out** **i) Heat pump capacity in TR in terms of heat delivered** **ii) The payback period of investment towards heat pump** **iii) Evaporator capacity in TR**
ANS	i) Hot water requirement per day = 24000 litres = 24000 kgs. Inlet water temperature = 25^{o}C Outlet water temperature = 55^{o}C Energy required for electrical heating per day = 24000 (55 – 25) / 860 = 837.2 Kwh Heat load on the condenser per day including 5% loss (in the condenser & hot water tank) = 24000 (55 – 25) x 1.05 = 756000 Kcals/day Heat pump capacity based on delivered heat =756000/(24 x 3024) = 10.4 TR Electrical energy equivalent of heat delivered = 756000 / 860 = 879.07 Kwh Daily energy consumption in the heat pump with a COP of 2.3 = 879.07 / 2.3 = 382.2 Kwh Daily energy consumption in the circulating water pump and evaporator fan = 50 Kwh (given data) Total energy consumption for operation of heat pump per day = 432.2 Kwh Energy saving with heat pump compared to electrical heating per day = 837.2 – 432.2 = 405 Kwh Cost of electricity per kwh = Rs.10 Monetary saving per day = 405 x 10 = Rs.4,050/- Annual savings with 330 days operation = 4050 x 330 = Rs.13,36,500/- = Rs.13.365 lacs Investment for heat pump = Rs.15 lacs

	Simple pay back period = 15 / 13.365 = 13 months The investment is attractive and justifiable. Evaporator capacity in tonne refrigeration = Heat delivered at the condenser – Input energy to the compressor = [{879 – (382.17 x 0.88)} x 860] / (3024 x 20) = 7.72 TR
N-3	**In an organic chemical industry 10 tonne per hour of hot oil is to be cooled from 210°C to 105°C by DM water. The DM water enters the heat exchanger at 25°C and exits at 85°C after which it is fed to the feed water storage tank of the boiler.** **i. Depict the heat exchanger process on a schematic for the parallel and counter flow indicating the hot and cold stream temperatures along with terminal temperature difference.** **ii. Find out the LMTD for parallel and counter flow heat exchange and justify the choice of the heat exchanger.** **iii. Estimate the DM water flow rate through the heat exchanger. The specific heat of oil is 0.5 kcal/kg°C.**
Ans	I)  **ii)** $$\textbf{LMTD parallel flow} = \frac{\Delta t_1 - \Delta t_2}{\text{Ln } \Delta t_1 / \Delta t_2}$$ = (185 – 20) / ln (185 / 20) = 74.19°C LMTD Counter flow = (125 – 80) / ln (125/80) = 100.9°C Counter flow heat exchange will yield higher LMTD and hence heat exchanger area will be less and hence preferred. iii) m_c = mass flow rate of DM water m_c x 1 x (85 – 25) = m_h x 0.5 x (210 – 105) m_c x 1 x (85 – 25) = 10000 x 0.5 x (210 – 105) m_c = 8750 kg/hour

N-4	To attempt **ANY ONE OF THE FOLLOWING** among A, B, C and D
A	**An energy audit was conducted on a 110 MW thermal power generating unit. The details of design parameters and operating parameters observed during the audit are given below.**

Parameters	**Design**	**Operating**
Generator output	**110 MW**	**110 MW**
Boiler outlet superheated steam temperature	**540^{o}C**	**520^{o}C**
Boiler outlet steam pressure	**140 kg/cm^2(a)**	**130 kg/cm^2(a)**
Feed water inlet temperature to Boiler	**120 ^{o}C**	**120 ^{o}C**
Feed water enthalpy	**120 kcal/kg**	**120 kcal/kg**
Boiler efficiency	**87%**	**87%**
GCV of coal	**3650 kcal/Kg**	**3650 kcal/Kg**
Turbine exhaust steam pressure	**0.09 kg/cm^2(a)**	**0.12 kg/cm^2(a)**
Dryness fraction of exhaust steam	**88%**	**88%**
Unit gross heat rate	**2815 kcal/kWh**	**?**
Efficiency of turbine & generator (including gear box)	**-**	**90 %**

Steam properties are as under:

Enthalpy of steam at 520^{o}C and 130 kg/cm^2(a) is 808.4 kcal/kg
Enthalpy of Exhaust steam at 0.12 kg/cm^2(a) is 550 kcal/kg

For the changed current operating parameters calculate the following..

I. **Steam flow rate to the Turbine**

II. **Specific steam consumption of Turbine**

III. **Specific coal consumption and unit gross heat rate**

IV. **Additional quantity of coal required based on 8000 hours/year of operation of the plant**

V. **Increase in annual coal cost due to increase in coal consumption at a cost of Rs. 3400 per tonne of coal.**

Ans

(i) Calculation of Steam flow rate to Turbine

Turbine output, KW = m x (Hs – Hf)/ 860

Where, m = steam flow to turbine, Kg/hr
Hs = Enthalpy of steam at 520 Deg.C& 130 Kg/cm2 = 808.4 Kcal/Kg

	Hf = Enthalpy of turbine exhaust steam =550 Kcal/kg Turbine output = Generator output/ Efficiency of Turbine & Generator = 110 / 0.9 =122.2 MW 122.2 x 1000 = (m x (808.4 – 550))/860 Steam flow rate to Turbine, m = 406.7 Tonnes/hr **(ii) Calculation of specific steam consumption of Turbine, kg/kwh** Specific steam consumption = Steam flow to turbine, Kg/hr / Generator output, Kw = 406.7 x 1000/(110 x 1000) = 3.697 Kg/Kwh (OR) ALTERNATE PROCEDURE Specific steam consumption = 860/((Hs – Hf) x Efficiency of Turbine & Generator) = 860/((808.4 – 550) x 0.9) = 3.697 Kg/Kwh **(iii) Calculation of specific coal consumption, Kg/kWh** Boiler efficiency = m kg/hr (Hs – Hw) Kcal/kg / (Q x GCV)------------(2) 0.87 = (406.7 x1000 (808.4 – 120))/ (Q X 3650) Coal consumption Q = 88166 Kg/hr Specific coal consumption = Coal consumption, Kg/hr / Generator output, Kw Specific coal consumption = 88166/ (110 x 1000)= 0.801 Kg /Kwh Unit gross Heat rate= 0.801x3650=2923.6 kcal/kWh **(iv) Additional quantity of coal required** Specific coal consumption at design conditions = unit heat rate / GCV of coal 2815/3650 =0.771 kg/kwh Additional coal consumption/year = (0.801 – 0.771) x 110 x 1000 x 8000 =26400000 kg Additional quantity of coal required /year = 26400 Tonnes **(v) Annual increase in coal cost** Additional cost of coal = 26400Tonnes x 3400 Rs/Tonne =Rs. 8,97,60,000
B	During the conduct of heat balance of a 5 stage inline calciner Kiln of a cement plant , the following data were measured at **preheater outlet** using pitot tube and flue gas analyser.

Temp	Static Pressure	Avg. Dynamic Pressure	Oxygen	CO_2	CO	Duct Area
^oC	(P_s) mm WC	(P_d) mm WC	% (v/v) dry	% (v/v) dry	% (v/v) dry	m^2
350	-435	16.9	6.0	19.2	0.06	3.098

Note: take Pitot tube constant as 0.85, reference temperature as 20 ^oC and atmospheric pressure same as at sea level i.e. 10334 mm WC.

Other Data obtained

Kiln Feed	Clinker Production	Return Dust in PH gas	NCV of Coal	Cost of coal	Annual Operation
TPH	TPH	% of Kiln Feed	kcal/kg	~~INR~~ (Rs)/tonne	hrs
88.5	55	6.8	5356	6950	8000

C_p of PH gas = 0.25 kcal/kg °C) , (C_p of return dust = 0.23 kcal/kg °C)

Calculate the following:

a. Specific volume of Preheater gas (Nm^3/kg clinker)

b. Heat loss in pre-heater exit gas (kcal/kg clinker)

c. Heat loss in pre-heater return dust (kcal/kg clinker)

d. Heat loss due to CO formation (kcal/kg clinker)

e. Reduction in above mentioned heat losses (kcal/kg clinker) and the annual thermal monitory savings if the Preheater exit gas temperature is reduced to 330 °C and there is no CO formation in the system.

Ans :

a. Density of Pre-heater gas at STP:

$$\rho_{STP} = \frac{(O_2\% X MW_{O_2}) + (CO_2\% X MW_{CO_2}) + ((N_2 + CO)\% X MW_{CO})}{22.4 X 100}$$

$$\rho_{STP} = \frac{(6.0 X 32) + (19.2 X 44) + ((74.74 + 0.06) X 28)}{22.4 X 100} = \mathbf{1.398\ kg/Nm^3}$$

$$\rho_{T,P} = \rho_{STP}\ X \frac{273 X (10334 + P_S)}{(273 + T) X 10334}$$

$$\rho_{T,P} = 1.393 X \frac{273 X (10334 - 435)}{(273 + 350) X 10334} = \mathbf{0.587\ kg/m^3}$$

Velocity of Preheater gas

$$v = P_t \sqrt{\frac{2 g P_d}{\rho_{T,P}}}$$

$$v = 0.85 \sqrt{\frac{2 X 9.8 X 16.9}{0.585}} = \mathbf{20.19\ m/sec}$$

Volumetric flow rate of PH gas = velocity x duct cross-sectional area

= 20.22 x 3.098

= 62.55 m^3/sec

= 62.55 x 3600

= 225180 m^3/hr

= 225180 x 0.587/1.398

= 94550 Nm^3/hr

Specific volume of PH gas = 94550/55000 = **1.72 Nm^3/kg clinker**

b. Heat loss in pre-heater exit gas

$Q1 = m_{ph}\ c_p\ \Delta T$ (C_p of PH gas = 0.25 kcal/kg ^oC)

Q1= 1.72 x 1.398 x 0.25 (350-20)

= 198.37 kcal/kg clinker

c. Heat loss in return dust

$Q2 = m_{dust}\ c_p\ \Delta T$ (C_p of return dust = 0.23 kcal/kg ^oC)

m_{dust} = clinker factor x % return dust/100

= (88.5/55) x (6.8/100)

= 1.609 x 0.068

= 0.1094 kg dust/ kg clinker

Q2= 0.1094 x 0.23 x (350-20)

= 8.3 kcal/kg clinker

d. Heat Loss due to CO Formation

$Q3 = m_{co}$ X 67636

$$m_{co} = \frac{CO\%}{22.4\,X\,100}\,X\ sp.volume\ of\ PH\ Gas$$

= [0.06/(22.4 x100)] x 1.72

Q3= 2.68 x 10^{-5} x 1.72 x 67636

= 3.12 kcal/kg clinker

e. At exit temperature 330 ^oC the above losses would be

Q1'= 1.72 x 1.398 x 0.25 x (330-20)

= **186.35 kcal/clinker**

Thermal saving = Q1- Q1'= 197.95 – 186.35 = 12.02 kcal/kg clinker

Q2'= 0.1094 x 0.23 x (330-20)

= **7.8 kcal/kg clinker**

Thermal Saving = Q2 – Q2' = 8.3 – 7.8 = 0.5 kcal/kg clinker

Overall Thermal Savings = 12.02 + 0.5 + 3.12

= 15.64 kcal/kg clinker

Equivalent coal saving = 14.56/5356 = 0.0029 kg coal/kg clinker

Coal saving in one hour = 0.0029 x 55 = 0.1595 TPH

Annual Coal Saving = 0.1595 x 8000= 1276 tons of coal

	Annual Monitory Saving = 1276 x 6950 = INR 88,68,200
	or
C	**In a textile process house a new stenter is being installed with a feed rate of 1000 kg/hr of wet cloth having a moisture content of 55%. The outlet (final) moisture of the dried cloth is 7%. The inlet and outlet temperature of the cloth is 25°C and 75°C respectively. The drying efficiency of the stenter is 50%. It is proposed to connect the stenter to the existing thermic fluid heater of 10,00,000 kcal/hr capacity, which is already loaded to 60% of its capacity. The thermic fluid heater has an efficiency of 75%. Check whether the thermic fluid heater will be able to cater to the input heat requirements of the stenter.**
Ans	Feed rate of wet cloth to the stenter = 1000 Kg/hr Initial moisture = 55% Quantity of moisture at inlet = 0.55 x 1000 = 550 Kg/hr Wt of bone dry cloth = 1000 – 550 = 450 Kg/hr Final moisture in outlet cloth = 7% Quantity of moisture (final) at outlet = (450 / 0.93)– 450 = 483.87 – 450 = 33.87 Kg/hr m_i = inlet moisture in bone dry cloth = 550 / 450 = 1.22 kg moisture / kg cloth m_o = Outlet (final) moisture in bone dry cloth = 33.87 / 450 = 0.0753 Kg moisture/Kg cloth Heat load of the stenter for drying process = W x (m_i – m_o) x [(T_{in} – T_{out}) + 540] W = Wt of bone dry cloth Kg/hr T_{in} = Inlet temperature of cloth to stenter T_{out} = Outlet temperature of cloth from stenter Latent heat of evaporation of water = 540 Kcal/Kg Heat load of the stenter for drying = 450 (1.22 – 0.0753) x [(75 – 25) + 540] = 303917.85 Kcal/hr. Input heat requirement of the stenter with 50% efficiency for drying (heat to be supplied) = 303917.85 / 0.5 = 607835.7 Kcal/hr. Capacity of the thermic flue heater = 1000000 Kcal/hr Existing load = 60% x 1000000 = 600000 Kcal/hr Balance capacity = 400000 Kcal/hr. The thermic fluid heater capacity is not sufficient to cater to the input heat requirement of the new stenter.
D	In a steel plant, daily sponge iron production is 500 tons. The sponge iron is further processed in a steel melting shop for production of ingots. The yield from converting sponge iron into ingots is 88%. The plant has a coal fired captive power station to meet the entire power demand of the steel plant. The base year (2011) and current year (2012) energy consumption data are given below:

Parameters	Base Year (2011)	Current Year (2012)

Sponge iron production	500 T/day	500 T/day
Specific coal consumption for sponge iron production	1.2 T/ T of Sponge Iron	1.1 T/T of Sponge Iron
Specific power consumption for sponge iron production	120 kWh/ T of Sponge Iron	100 kWh/ T of Sponge Iron
Yield ,in converting sponge iron into ingot in steel melting shop	88%	88%
Specific power consumption in steel melting shop to produce ingots	950 kWh / T of Ingot	900 kWh / T of Ingot
Captive power station heat rate	3500 kcal/ kWh	3200 kcal / kWh
GCV of coal	5000 kcal /kg	5000 kcal /kg

i) Calculate the specific energy consumption of the plant in Million kcals / Ton of finished product (Ingot) for the base year as well as for the current year

ii) Reduction in Coal consumption per day in current year compared to base year for the plant

Ans

i) specific energy consumption of the plant

For Base Year

Specific energy consumption for sponge iron	= 1200 kgx 5000 + 120 Kwhx 3500 = 6.42 million K Cal/ Ton of SI
Total energy consumption for sponge iron /day	6.42 X 500 = 3210 million kCal
Actual production considering 88% yield from sponge iron to ingot conversion	= 500 Tons x 0.88 = 440 Tons / day
Specific energy consumption for ingot	= 950 kWhx 3500 = 3.325 million Kcal/ ton of ingot
Total energy consumption for ingot production per day	3.325X 440=1463 million kCal
Plant specific energy consumption for production of finished product (ingot) during base year	(3210+1463)/440 = 10.62 million kCal/ ton

For Current Year

Specific energy consumption for sponge iron	= 1100 kgx 5000 + 100 Kwhx 3200 = 5.82 million K Cal Ton of SI
Total energy consumption for sponge iron /day	5.82 X 500 = 2910 million kCal
Actual production considering 88% yield from sponge iron to ingot conversion	= 500 T X 0.88 = 440 Tons / day
Specific energy consumption for ingot	= 900Kwh x 3200 = 2.88 million Kcal/ ton of ingot
Total energy consumption for ingot production per day	2.88 X 440 = 1267.2 million kCal
Plant specific energy consumption for production of	= (2910+1267.2)/440

finished product (ingot) during current year	= 9.49 million Kcal/ ton

ii) Reduction in coal consumption

Energy saving in sponge iron plant = (6.42-5.82) x500 = 300 million Kcals/day
Energy saving in steel melting plant = (3.325-2.88) x 440 = 195.8 million Kcal/day
Total energy saving = 300 + 195.8 = 495.8 million Kcals/day
Equivalent coal reduction(saving) = 495.8 x 10^6 /5000 = 99.16 Tons per day

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

13th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY AUDITORS – September, 2012

PAPER – 4: Energy Performance Assessment for Equipment and Utility Systems	
Date: 16.9.2012	**Timings: 14:00-16:00 HRS Duration: 2 HRS Max. Marks: 100**

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

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

S-1	In a vapour compression refrigeration system, why the heat rejected in the condenser is more than the heat absorbed in the evaporator ?
Ans	Because heat of compression is also added to it
S-2	If the unit heat rate is 3120 kcal/kWh and the turbine heat rate is 2808 kCal/kWh what is the boiler efficiency ?
Ans	(2808/3120) x 100 = 90 %
S-3	A rise in conductivity of boiler feed water indicates ____ .
Ans	Rise in the TDS level of feed water
S-4	Why is it preferable to measure the flow at the inlet side of the fan?
Ans	Less turbulence
S-5	The critical point of steam occurs at ____bar and _______ ^oC
Ans	221.2 bar and 374.15^oC
S-6	In a heat exchanger _______ **is** the ratio of actual heat transfer rate to the maximum heat transfer rate.

Ans	Effectiveness
S-7	In an integrated steel plant pig iron is produced from __________furnace?
Ans	Blast furnace
S-8	PLF of a 210 MW power plant is 80% , what is the annual gross generation in MWh
Ans	1,471,680 MWH
S-9	A pump operates on water with a total head of 12 m. If water is replaced by brine with a specific gravity of 1.2 what will be the total head developed by the pump ?
Ans	12 m or same
S-10	A draft system in a boiler which uses both FD and ID fan is called…….
Ans	Balanced Draft

…………. 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	**Calculate pressure drop in meters when pipe diameter is increased from 250 mm to 300 mm for a length of 600 meters. Water velocity is 2 m/s in the 250 mm diameter pipe and friction factor is 0.005.**
Ans	Pressure drop = $\frac{4fLV^2}{2gD}$ Velocity of water in pipe of 300 mm diameter = (0.25 x 0.25 x 2) /(0.3 x 0.3) = 1.39 m/s Pressure drop with 300 mm = 4 x 0.005 x 600 x 1.39^2 / (2 x 9.81 x 0.300) = 3.94 m

L-2	A three phase 37 kW four pole induction motor operating at 49.8 Hz is rated for 415 V, 50 Hz and 1440 RPM. The actual measured speed is 1460 RPM. Find out the percentage loading of the motor if the voltage applied is 410 V.
Ans	**% Loading =** $\dfrac{\text{Slip}}{(Ss - Sr) \times (Vr / V)^2} \times 100\%$ **Synchronous speed = 120 x** 49.8 **/ 4 = 1494 rpm** **Slip = Synchronous Speed – Measured speed in rpm.** **= 1494 – 1460 = 34 rpm.** **% Loading =** $\dfrac{34}{(1494 - 1440) \times (415/410)^2} \times 100\% = 61.45\%$

…………. End of Section - II …………

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

(i) Answer all **Four** questions

- Refer Original question paper for questions

N1	**Key**
	a) **Theoretical air required for complete combustion** $$= \frac{(11.6\ x C) + \left\{34.8\ x \left(H_2 - \left(\frac{O_2}{8}\right)\right)\right\} + (4.35\ x\ S)}{100}$$ $$= \frac{(11.6\ x 33.95) + \left\{34.8\ x \left(5.01 - \left(\frac{32.52}{8}\right)\right)\right\} + (4.35\ x\ 0.09)}{100} = 4.27 \text{ kg / kg of paddy husk}$$ Moles of N_2 $= \frac{4.27 \times \left(\frac{77}{100}\right)}{28} + \left(\frac{0.0091}{28}\right) = 0.1178$ % CO_2 theoretical $= \frac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C} + \text{Moles of S}}$ $$= \frac{\left(\frac{0.3395}{12}\right)}{0.1178 + \left(\frac{0.3395}{12}\right) + \left(\frac{0.0009}{32}\right)}$$ Max theoretical $(CO_2)_t$ = 19.36 % Actual CO_2 measured in flue gas = 14.0% b) **% Excess air supplied** $= \frac{7900\ x\ [(CO_2)_t - (CO_2)_a}{(CO_2)_a\ x\ [100 - (CO_2)_t]} = 37.5\ \%$ c) **Actual mass of air supplied** = {1 + EA/100} x theoretical air = {1 + 37.5/100} x 4.27 = 5.87 kg/kg of coal

Mass of dry flue gas= $\frac{0.3395 \times 44}{12} + 0.0091 + \frac{5.87 \times 77}{100} + \frac{(5.87 - 4.27) \times 23}{100}$

= **6.15** kg / kg of coal

(or)

(actual mass of air supplied + 1) – mass of H_20

(5.87 + 1) – (9H + M) = 6.87 – (9x.05 + 0.1079)= 6.87 – 0.5579 = **6.31** kg/kg of coal

% Heat loss in dry flue gas $= \frac{m \ x \ C_P \ x \ (T_f - T_a)}{GCV \ of \ fuel} \ x \ 100$

$= \frac{6.15 \ x \ 0.23 \ x \ (160 - 32)}{3568} \ x \ 100$

= 5.07 %

Loss due to CO **=**

$$\frac{\%CO \ x \ C}{\%CO + \%CO_2} \ x \ \frac{5654}{GCV \ of \ fuel} \ x \ 100$$

$= \frac{0.35 \ x \ 0.3395 \ \ x \ 5654}{(0.35+14) \ x \ 3568}$

L2 = 1.31 %

Heat Loss in ash

% heat loss due to unburnt flyash

% ash in paddy husk = 16.73
Ratio of bottom ash to flyash = 10:90
GCV of flyash = 450 kcal/kg
Amount of flyash in 1 kg of husk = 0.9 x 0.1673
= 0.15 kg
Heat loss in flyash = 0.15 x 450
= 67.5 kcal/kg of husk
GCV of bottom ash = 800 kcal/kg

Amount of bottom ash in 1 kg of husk = 0.1 x 0.1673
= 0.01673 kg
Heat loss in bottom ash = 0.01673 x 800
= 13.4 kcal/kg of husk

	Total heat loss in ash = 67.5 + 13.4 = 80.9 kcal/kg % loss in ash = 80.9/3568 = 2.26 % Total losses = 100 – (5.07 + 1.31 +2.26) – (15.4) Boiler efficiency = 100 – 8.64 – 15.4 = 75.96 %
N-2	**KEY**
	Hot Water use per day : 20,000 L/day Water in = 20^0C Water out = 60^0C Temp. diff. = 40^0C Total Heat required = mCpdt = 20000 x 1 x 40 = 8,00,000 kcal/day 1. <u>Energy Requirement for 20KL/day of water for a temperature differential of 40 deg.C in an Electric Boiler/Geyser</u> Energy Requirement (for 20 KL/day) = <u>Total heat required</u> (800000) 860 kcal/kWh x 0.99 (efficiency of electric heating)) = 939.6 kWh/day 2. <u>For 20 KL/day, of water flow with 40^0C Temperature Diff.</u> Energy to be drawn by Heat Pump = <u>8,00,000</u> = 391.68 Kwh/day 860x0.95x2.5 Energy drawn by circulation pump = 3.74 x 24 hr = 89.76 kWh/day Energy drawn by evaporator fan = 1.4 kW x 16 hr = 22.4 kWh/day Total Energy drawn by heat pump system = 391.68 +89.76+22.4 = 503.8 kWh /day <u>SAVINGS IN COMPARISON TO ELECTRIC WATER HEATER</u> = 939.6 – 503.8 = 435.75 Kwh/day = 1,52,516 kWh/year (@ 350 days/year) = 12.20 lakhs (@ Rs8.0 per kWh)

	3. SIMPLE PAY BACK PERIOD = Rs.16.0 LAKHS Investment/ Rs.12.20 lakhs per year savings = 1.30 years or 16 months
N-3	**KEY**
Ans	

Power generation from cogen plant	**=**	**5000X 0.9 X 8000 = 360 lac Kwh/yr**
Auxiliary power	**=**	**1%**
Net power generation	**=**	**0.99 X 360 = 356.4 lac Kwh**
Natural gas requirement for power generation	**=**	**360 X 3050 / 9500 = 115.57 lac sm^3**
Cost of fuel per annum	**=**	**115.57 X 8 = Rs.924.56 lacs**
Annual expenditure for interest, depreciation and O&M	**=**	**500 + 200 = 700 lacs**
Total cost of generation	**=**	**Rs.1624.56 lacs.**
Cost of cogeneration power	**=**	**1624.56 X 10^5 / 356.4 X 10^5**
	=	**Rs.4.56 / Kwh.**
Gas consumption in existing gas fired boiler	**=**	**[10000 (665 – 85) / (0.86 X 9500)]**
	=	**710 Sm^3/hr**
	=	**710 x 24 = 17040 sm^3/day**
Cost of steam from existing boiler	**=**	**710*Rs. 8 x8000**
	=	**Rs. 454.4 Lacs /yr**
Cost of power generation after giving credit for steam generation	**=**	**1624.56 – 454.4 = Rs.1170.16 lacs**
Cost of power generation after accounting for steam cost	**=**	**1170.16 X 10^5 / 356.4 X 10^5**
	=	**Rs. 3.28 / Kwh**
Grid power cost	**=**	**Rs. 4.5 / Kwh**
Cost advantage for cogen plant generation	**=**	**4.5 – 3.28 = Rs.1.22 / Kwh**
Daily gas requirement for operating GT cogen plant	**=**	**5000 X 0.9 X $\frac{3050}{9500}$ X 24**
	=	**34673.68 Sm^3 / day**

	Additional gas requirement for co-gen plant = 34673.68 – 17040 = 17633.68 Sm³/day
N-4	To attempt **ANY ONE OF THE FOLLOWING** among A, B, C and D
N4 A	**KEY**
Ans	i) Turbine power output kW = Steam flow to turbine kg/hr x enthalpy drop across the turbine kcal/kg --- 860 Inlet enthalpy of steam =794.4 kcal/kg Enthalpy of exhaust steam is calculated as given below exhaust steam dryness fraction = 90% enthalpy of exhaust steam = (45.9 + 0.9 x 572.5) = 561 kcal/kg turbine out put = ((120 x 1000 kg/hr x (794.4 – 561) kcal/kg) /860 turbine output = 32567.4 kW ii) generator output kW = turbine output x combined efficiency of mechanical, gear transmission & generator = 32567.4 x 0.92 =29962 kW iii) turbine heat rate = heat input in to the turbine/ generator out put =q x (h1 – hw)/generator out put Where q = steam inflow to turbine kg/hr h1= enthalpy of turbine inlet steam =794.4 kcal/kg hw= enthalpy of feed water to boiler = 100 kcal/kg Turbine heat rate = ((120 x 1000 kg/hr) x (794.4 – 100) kcal/kg))/ 29962 kw = 2781 kcal/kwh iv) unit heat rate = turbine heat rate /boiler efficiency = 2781 / 0.88 = 3160 kcal/ kwh v) turbine cycle efficiency = (860 / turbine heat rate) x 100 = 860 /2781 =0.309 =0.309 x 100 = 30.9% vi) condenser heat load = m x cp x dt Where m = cooling water flow through condenser, kg/hr

<table>
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note: density of water is given as 0.95 g /cubic centimetre = 950 kg/ cubic meter
cp = specific heat of cooling water, kcal/ kg. ^oC = 0.98 kcal /kg. ^oC
dt = cooling water temperature rise, ^oC = 10

Condenser heat load =6318 x 950 x 0.98 x 10 = 5,88,20,580 kcal /hr

vii) specific steam consumption of turbine = 860 / (enthalpy drop x combined efficiency)
= 860/ ((794.4 – 561) x 0.92))
=860 / (233.4 x 0.92) =4.0 kg/kwh
= 4.0 kg / kwh
</td></tr>
<tr><th>N4-B</th><th>KEY</th></tr>
<tr><td>Ans</td><td>
Volumetric flow rate of PH gas at NTP = 1.47 x 125 x 1000 = 183750 [Nm3/hr]

Mass flow rate of PH gas = 183750 x 1.42 = 260925 [kg/hr]

<u>Calculation for 4 stage pre-heater kiln</u>

Heat loss in PH Gas = m x cp x T [kcal/hr]
= 260925 x 0.244 x 370 = 23556309 [kcal/hr]
Equivalent coal wasted = $\frac{23556309}{5540 X 1000}$ = 4.252 [tons of coal/hr]

<u>Electrical Energy consumption of PH Fan</u>

Volumetric flow rate of PH Gas at 370 ^oC temperature and -400 mm WC static pressure:

V = $183750 X \frac{(273+370) X 10333}{273 X (10333-400)}$ = 450216 [m^3/hr]
or V = 450216/3600 = 125 [m^3/sec]

Pressure difference across PH fan = 50 – (- 400) = 450 [mm WC]
Power consumption of PH fan
$P = \frac{125 X 450}{102 X 0.72 X 0.95}$ = 806.24 [kW]

<u>Calculation for 6 stage pre-heater kiln</u>

Heat loss in PH Gas = m x cp x T [kcal/hr]
= 260925 x 0.244 x 295 = 18781381 [kcal/hr]

Equivalent coal wasted = $\frac{18781381}{5540 X 1000}$ = 3.39 [tons of coal/hr]

Electrical Energy consumption of PH Fan
Volumetric flow rate of PH Gas at 295 ^oC temperature and -600 mm WC static pressure:
V = $183750 X \frac{(273+295) X 10333}{273 X (10333-600)}$ = 405875 [m^3/hr]

Or V = 405875/3600 = 112.75 [m^3/sec]
</td></tr>
</table>

Pressure difference across PH fan = 50 – (- 600) = 650 [mm WC]
Power consumption of PH fan

$$P = \frac{112.75 \times 650}{102 \times 0.72 \times 0.95} = 1050.4 \quad [kW]$$

The above kilns can be compared as follows:

Item	6 Stage PH Kiln	4 stage PH kiln
PH Gas heat loss (kcal/hr)	18781381	23556309
Equivalent coal wasted (tons of coal)	3.39	4.252
Power consumption in PH Gas (kW)	1050	806.24

Calculation for annual Monetary savings

Coal savings in 6 stage PH Kiln = 4.252 – 3.39 = 0.862 [ton of coal/hr]

Annual monetary savings (Thermal) = 0.862 x 8000 x 6150 = 4,24,10,400 [Rs.]

Additional Electrical energy requirement for 6 stage PH Kiln = 1050.4 – 806.24 = 244.16 [kW]

Annual additional electrical cost = 244.16 x 8000 x 5 = 97,66,400 [Rs.]

It is obvious that in monetary terms, thermal energy saving in 6 stage pre-heater kiln is higher than the additional electrical energy cost in 4 stage kiln. Therefore, 6 stage pre-heater kiln is better option than 4 stage pre-heater kiln.

So the net annual monetary saving in case of 6 stage pre-heater kiln is
= 4,24,10,400 – 97,66,400 = 3,26,44,000 [Rs.]

N4-C	KEY

Ans **a)**

Before insulation

Surface heat loss, S = [10 + (TS-Ta)/20] x (Ts –Ta)
Total heat Loss = S x A where A= Surface area, m^2
Surface heat loss , S = [10 + (110-25)/20] x (110-25) = 1211.25 K.Cal/m^2/hr
Total heat loss = 1211.25 x 20 m^2 = 24225 kCal/hr

After insulation

Surface heat loss ,S = [10 + (55-25)/20] x (55-25) =345 K.Cal/m^2/hr
Total heat loss = 345 x 20 m^2 = 6900 kCal/hr
Heat reduction per hour after proper insulation = 24225- 6900 = 17325 kCal/hr
Annual heat loss reduction = 17325 x 8000 = 138600000
= 138.6 million kCal/year

Steam distribution loss = 20%
Heat loss = 138.6 million kCal/ 0.8 = 173.25 million kcal/year
Boiler efficiency = 70%

Equivalent coal consumption reduction = 173.25 x10^6 /0.7 x 4800 = **51.56 Ton /year**

	Monetary Cost savings per year = 51.5 x 5000 = Rs **2.575 lacs** Investment @ Rs 1000 per M^2 = 20 x 1000 = Rs 20000 **Condensate recovery** Reduction in coal consumption through heat recovered from condensate return = 2000 x 1 x (80 – 40) / 0.7 x 4800 = 23.8 kg of coal per hour Annual coal savings = 23.8 x 8000/1000 = **190.4 ton / year** Annual savings = 23.8 x 8000 x Rs.5/kg coal = Rs. **9.52 lacs** **b)Simple payback period** Total savings from both the measures = 2.575 + 9.52 = 12.1 lakhs Total investment = Rs. 20,000 + Rs 2 lakhs = Rs.2.2 lakhs Simple payback period (combined) = 2.2/12.1= 2.2 months **c)GHG emission reduction** Carbon content in the coal = 40% by weight Total Coal saving /year = 51.5 + 190.4 = 241.9 Ton per year CO_2 reduction = 241.9 x 0.4 x 44/12 = 355 Ton of CO_2/year
N4-D	**KEY**
Ans	Theoretical air required for complete combustion =[(11.6x85.9)x(34.8x(12-0.7/8))+4.35x0.5]/100 =996.44+414.12+2.175/100 **=14.1 kg/kg of oil** Existing oxygen % in flue gas =6% % excess air supplied =6 x100/(21-6) =**40%** Actual mass of air supplied =(1+Excess air/100)x Theoretical air =(1+40/100)x 14.1 =**19.74 kg/kg of oil** After modification, oxygen % in flue gas =3% % excess air supplied =3 x100/(21-3) =**16.67%** Actual mass of air supplied =(1+Excess air/100)x Theoretical air =(1+16.67/100)x 14.1 =**16.45 kg/kg of oil** **a) Heat loss reduction through actual mass of air supplied**

Actual mass of air supplied before WHR =19.74 kg/kg of oil
Actual mass of air supplied AFTER WHR =16.45 kg/kg of oil

Existing oil consumption per hour = 25 ton/hr x 60kg/ton = 1500 kg of oil /hr

Flue gas loss before WHR = [1500 kg oil + (1500 x 19.74 kg air)] x 0.24 x (600-30)
= 4255848 kcal/hr

Flue gas loss after WHR = [1500 kg oil + (1500 x 16.45 kg air)] x 0.24 x (300-30)
= 1696140 kcal/hr

Flue gas heat loss reduction after WHR implementation = 4255848-1696140
= **2559708 kcal/hr**

Reduction in fuel oil consumption after installing
Waste heat recovery and reduction in excess air = **256 kg/hr**

Furnace efficiency after WHR = $\frac{25000 \times 0.12 \times (1200-40)}{[(1500-256) \times 10000)]} \times 100$
= 28 %

b) Calculate fuel oil reduction after charging hot ingot in reheating furnace

Ingot charging temperature is increased from 40 °C to 500 °C

Fuel oil reduction due to increased charge temperature =
= 25 x 1000 x 0.12 x(500-40)/0.28 x10,000
= 492.86 kg/hr = 493 kg/hr

c) Specific oil and power consumption after implementing both the above measure

Fuel oil **reduction** after implementation of both measures
= 256 + 493 = 749 **kg oil/hr**

Fuel oil **consumption** after implementation of both measures
= 1500 – 749 = 751 **kg oil/hr**

Yield improvement = 3%
Production after implementation of both measures = 25 x 1.03 = 25.75 ton/hr

Specific oil consumption = 751/ 25.75 = **29.2 kg/Ton**

Specific power consumption = 25x90 / 25.75 = **87.37 kWh/ton**

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