PAPER-4 CODE: GREEN

21st 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.	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**
2.	Both Rotary hearth and walking beam-type furnaces are continuous furnaces	True/False	**TRUE**
3.	% Oxygen or CO_2 in flue gas is not required to calculate the boiler efficiency by Direct method	True/False	**TRUE**
4.	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**
5.	Oxygen and nitrogen present in the fuel do not contribute to calorific value of the fuel.	True/False	**TRUE**
6.	The difference between GCV and NCV of hydrogen fuel is Zero	True/False	**FALSE**
7.	In a refrigeration plant the higher the kW/TR, the higher will be the COP.	True/False	**FALSE**
8.	In an integrated steel plant, pig iron is produced from Blast furnace	True/False	**TRUE**
9.	The copper loss in the transformer is the power consumed to sustain the magnetic field in the transformer core	True/False	**FALSE**
10.	The head generated by the centrifugal pump is proportional to the square of the density of the liquid being pumped	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

L1

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.

1. Specific Oil Consumption,	:	26 Ltr/T
2. Cost of Furnace Oil	:	38 Rs./ltr
3. Calorific Value of F.O	:	10000 kCal/Kg
4. Efficiency of FO fired melting cum holding furnace	:	65 %
5. Efficiency of electrical melting and holding furnace (%)	:	90 %
6. Cost of electricity from Captive Power Plant	:	3.75 Rs./kWh
7. Density of Furnace Oil	:	0.95 kg/ltr

L1 Sol

Solution:

Description	**Value**
Existing Specific Oil Consumption (Ltr/T)	26
Cost of Furnace Oil (Rs./ltr)	38
Calorific Value of F.O (kCal/Kg)	10000
Efficiency of FO fired melting cum holding furnace (%)	65%
Efficiency of Electrical Melting and Holding Furnace (%)	90%
Cost with F.O Heating (Rs./T)	26X 38 = 988
Useful heat requirement (kCal/T)	=26X0.95X10000X0.65 =1,60,550
Equivalent Electricity input (kWh/T)	= 1,60,550/(0.9 X860) = 207.43
Cost with electrical heating (Rs./t)	=207.43 X 3.75 = 777.86
Cost advantage with electrical heating (Rs./T)	= 988 – 777.86 = 210.14

Electrical heating is found more economical.

L2

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 8000 m^2. 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.

L2 Sol	**Solution:**

Annual Electricity Consumption, purchased from utilities	973569	kWh
Annual Electricity Consumption, through Diesel Generating sets	25167	kWh
Total built up area of the building	18000	sqm
Parking and Basement Area	8000	sqm
Annual Working hours	2500	hrs/yr
Total Annual Electricity Consumption Utilities + DG Sets/ GG Sets	998736	kWh
Built up area (Area of the building - Basement and Parking)	10000	sqm
EPI	100	kWh/ yr / sqm
AAHEPI	40	Wh/ h / sqm

…………….**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 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 60 %.

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)

N1 Sol

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 60 % Combined Efficiency= 7.89/0.60 =13.15 kW
Condenser Pump power with 60 % combined efficiency = 12.06 /0.60 = 20.1 kW
Chiller Plant total Power consumption after condenser cleaning and with new pumps
= 78.59+ 13.15+20.1+9.34 =121.18 kW
Overall Chiller Plant, kW/TR (After Condenser Cleaning and with New efficient Pumps)
= 121.18 /123.2 = 0.984 kW/TR
Annual Energy Savings for 4500 Hours operation = (1.059 – 0.984) *123.2*4500 = 41580 kWh
Annual Monetary savings @ Rs 9 /kWh = 41850 x 9 = Rs 374220
(Or)
Annual Energy Savings for 4500 Hours operation = (130.5 – 121.18)*4500 = 41940 kWh
Annual Monetary savings @ Rs 9 /kWh = 41940 x 9 = Rs 377460

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 an Airfin fan cooler.

The chemical plant is having a chilling load of 2400 TR which is met by the 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. 1600/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 Sol

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. Lakh/ year	= ((76.12 + 2040.4) x 8000 x 8) - ((2626.3 /1000) x 8000 x 1600) - (1650 x 8000) = 135457280 – 33616640 – 13200000 = 88640640/10^5 = 886.41 Lakhs/Year	886.41 Lakhs/Year

N3 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 83% efficiency on NCV basis.

If the investment for the new 5 MW Co-Gen plant is Rs.30 Crores, calculate the Net Annual savings and payback period.

(20 Marks)

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 ^{o}C
Expenditure towards depreciation & interest : Rs.500 Lakhs/Annum
Expenditure for consumables & maintenance of co-gen plant: Rs 200 Lakhs/Annum

N3 Sol

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 0.83)/(665 – 85)
= 12.45 kgs Steam/sm^3 gas

Annual Gas Requirement for the boiler = (112000 x1000)/12.45
= 8995983.94 sm^3/yr

Cost of Steam from Gas Fired Boiler = 12/12.45
= Rs. 0.964 per kg steam
= Rs. 964/ton

Total Steam cost from gas fired boiler = (964 x 14 x 8000)/10^5
= Rs. 1079.7 Lakhs/yr

Total Cost of Grid Electricity plus gas for Steam = (3240 + 1079.7)
= Rs. 4319.7 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/ 12.45) x 8000
= 1927680 sm^3

Cost of gas for additional 3 TPH steam to be supplied from the gas fired boiler= 3 x 964 x 8000
= Rs. 231.36 Lakhs

Additional gas to be purchased with Co-gen Plant and boiler
=(12620640+1927680)- (8995983.94)
= 5552336.06 sm^3/yr

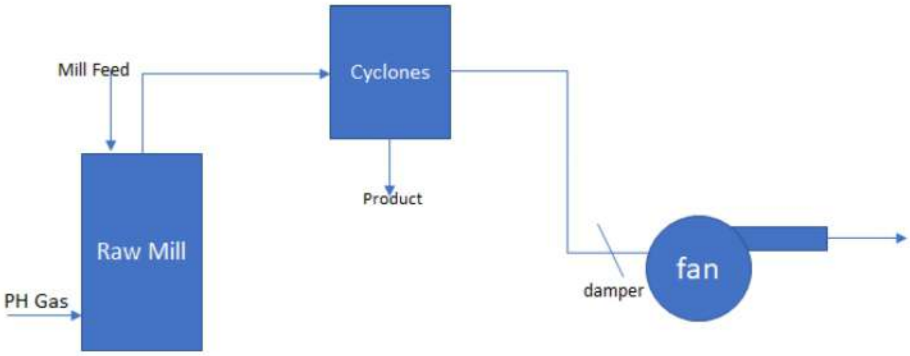
Overall Cost with Co-Generation system including additional steam from gas fired boiler
= 2214.5 + 231.36
= Rs. 2445.86 Lakhs

Net Annual savings with Co-Gen plant = 4319.7 – 2445.86
= Rs. 1873.84 Lakhs/yr

Payback period = 3000/ 1873.84
= 1.60 years or 19.2 months

N4 **Answer any ONE of the following among four questions given below:**

A 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)	1450
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 (^oC)	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)

N4 A-Sol.

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)
=1450 kW/ 260 TPH
= 5.77 kWh/ton

C. **Fan Efficiency**
Correction Density $(\rho 2) = (\rho 1) * \left(\frac{P1}{P2}\right) * \left(\frac{T1}{T2}\right)$
= 1.35*((10323-850)/10323) * (273/(273+70))=0.986 kg/m^3

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
$= \pi * D^2/4$
= 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*1450*95%)*100
= 87.9 %

D. By using Affinity Law, $(P_1/P_2) = (N_1^3/N_2^3) = (Hz_1{}^3 / Hz_2{}^3)$

$(1450 \text{ kW} / P_2) = (50^3/40^3)$
$P_2 = (1450 \times 40^3) / 50^3$
$P_2 = (1450 \times 64000) / 125000$
$P_2 = 742.4$ kW

Savings in fan power consumption = 1450 – 742.4 = 707.6 kW.

N4	OR
B	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: 300 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**)

N4-B-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) **= 83.84**	**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	$= \frac{(\frac{42.8}{3.5x0.95})x\ 8\ x\ 300\ x\ 7.5}{10^5}$ **= 2.32**	Rs. Lakhs/year

N4 **OR**

C

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 : 85%

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)
   Calculate the net heat rate of the station with an overall station auxiliary power consumption of 10%. (3 Marks)

Note:
*(Marks were awarded to candidates who had solve this question correctly either by using 75% load or 85% load)

N4 C-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: (75% load)
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

(or)

3. Determination of difference in coal consumption per day for same generation: (85% load)

Coal consumed by Unit 1 = ((Heat rate of unit 1)*(200*1000*0.85*24))/(GCV Coal)
= ((2852.82)*(200*1000*0.85*24))/(4000)
= 2909876.4 kgs coal/day
= 2909.876 TPD

Coal consumed by Unit 2 = ((Heat rate of unit 2)*(200*1000*0.85*24))/(GCV Coal)
= ((2790)*(200*1000*0.85*24))/(4000)
= 2845800 kgs coal/day
= 2845.8 TPD

Difference in coal consumption = (2909.876 – 2845.8) TPD
= 64.08 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

D

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 :10,000 kcal/kg
- Thermic fluid heater efficiency: 85%.
- 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 = 45,000 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 D-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*0.85)-45000
= 686375-45000
= 641375 kcal/hr

<u>Heat Output to the dryer **(Qin)**</u>

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

Therefore, Drier Efficiency

= (Heat Output / Heat Input) *100
= (275430 / 641375)*100
= 42.9% = 43%

2. <u>**Fuel Savings due to Improved Drier Efficiency by 10% (i.e.,53% Eff)**</u>

<u>Heat input to the dryer **(Qin)**</u>

= (Heat output from the dryer / new dryer efficiency)
= 275430 / 0.53
= 519679.25 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)
= 519679.25 + 45000
= 564679.25 kcal/hr

Fuel consumption in thermic fluid heater after improving dryer efficiency
Operating efficiency of thermic fluid heater is = 80%
= 564679.25/0.85
= 664328.8 kcal/hr

Fuel consumption in liters/hr
= 664328.8 / (10000*0.95)
= 69.93 lit/hr = 70 lit/hr

Annual FO savings by improving dryer efficiency = (85 - 70) x 7000 hours/yr
= 105000 lit/yr
= 105 kL/yr

Annual Monetary savings = 105000 * 36
= Rs.3780000/yr
= Rs.37.8 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

Heat Output (Load) of the dryer **(Qout)**

= (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
= 180794.9/0.53
= 341122.45 kcal/hr

Heat to be supplied by the thermic fluid heater

= 341122.45+45000
= 386122.45 kcal/hr

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

= 386122.45 / (10000*0.95*0.85)
= 47.82 lit/hr

Annual incremental FO savings by inlet moisture reduction = (70 – 47.82) x 7000
= 22.32 x 7000
= 155260 lit/yr
= 155.26 kL/yr

……………….**End of Section III**……………….