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 t**he 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 = $\dfrac{4fLV^2}{2gD}$ 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** $= \dfrac{(11.6\ x\,C) + \left\{34.8\ x\left(H_2 - \left(\dfrac{O_2}{8}\right)\right)\right\} + (4.35\ x\ S)}{100}$ $= \dfrac{(11.6\ x\,33.95) + \left\{34.8\ x\left(5.01 - \left(\dfrac{32.52}{8}\right)\right)\right\} + (4.35\ x\ 0.09)}{100}$ = 4.27 kg / kg of paddy husk Moles of N_2 $= \dfrac{4.27 \times \left(\dfrac{77}{100}\right)}{28} + \left(\dfrac{0.0091}{28}\right)$ = 0.1178 % CO_2 theoretical $= \dfrac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C} + \text{Moles of S}}$ $= \dfrac{\left(\dfrac{0.3395}{12}\right)}{0.1178 + \left(\dfrac{0.3395}{12}\right) + \left(\dfrac{0.0009}{32}\right)}$ Max theoretical $(CO_2)_t$ = 19.36 % Actual CO_2 measured in flue gas = 14.0% b) **% Excess air supplied** $= \dfrac{7900\ x\ [(CO_2)_t - (CO_2)_a}{(CO_2)_a\ x\ [100 - (CO_2)_t]}$ = 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. Energy Requirement for 20KL/day of water for a temperature differential of 40 deg.C in an Electric Boiler/Geyser Energy Requirement (for 20 KL/day) = Total heat required (800000) 860 kcal/kWh x 0.99 (efficiency of electric heating)) = 939.6 kWh/day 2. For 20 KL/day, of water flow with 40^0C Temperature Diff. Energy to be drawn by Heat Pump = 8,00,000 / 860x0.95x2.5 = 391.68 Kwh/day 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 SAVINGS IN COMPARISON TO ELECTRIC WATER HEATER = 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 Sm^3/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

	note: density of water is given as 0.95 g /cubic centimetre = 950 kg/ cubic meter cp = specific heat of cooling water, kcal/ kg. ^{o}C = 0.98 kcal /kg. ^{o}C dt = cooling water temperature rise, ^{o}C = 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
N4-B	**KEY**
Ans	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 = $\frac{23556309}{5540 \text{X} 1000}$ = 4.252 [tons of coal/hr] <u>Electrical Energy consumption of PH Fan</u> Volumetric flow rate of PH Gas at 370 ^{o}C temperature and -400 mm WC static pressure: V = $183750 \text{X} \frac{(273+370) \text{X} 10333}{273 \text{X} (10333-400)}$ = 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 $P = \frac{125 \text{X} 450}{102 \text{X} 0.72 \text{X} 0.95}$ = 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 = $\frac{18781381}{5540 \text{X} 1000}$ = 3.39 [tons of coal/hr] Electrical Energy consumption of PH Fan Volumetric flow rate of PH Gas at 295 ^{o}C temperature and -600 mm WC static pressure: V = $183750 \text{X} \frac{(273+295) \text{X} 10333}{273 \text{X} (10333-600)}$ = 405875 [m^3/hr] Or V = 405875/3600 = 112.75 [m^3/sec]

Pressure difference across PH fan = 50 – (- 600) = 650 [mm WC]

Power consumption of PH fan

$$P = \frac{112.75 \times 650}{102 \times 0.72 \times 0.95} = 1050.4 \quad \text{[kW]}$$

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 $= \dfrac{25000 \times 0.12 \times (1200-40)}{[(1500-256) \times 10000)]} \times 100$
= 28 %

b) <u>Calculate fuel oil reduction after charging hot ingot in reheating furnace</u>

Ingot charging temperature is increased from 40 ^{o}C to 500 ^{o}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) <u>Specific oil and power consumption after implementing both the above measure</u>

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 ---------