

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	$(2808/3120) \times 100 = 90 \%$
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 _____ °C
Ans	221.2 bar and 374.15°C
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	<p>Pressure drop = $\frac{4fLV^2}{2gD}$</p> <p>Velocity of water in pipe of 300 mm diameter = $(0.25 \times 0.25 \times 2) / (0.3 \times 0.3)$ = 1.39 m/s</p> <p>Pressure drop with 300 mm = $4 \times 0.005 \times 600 \times 1.39^2 / (2 \times 9.81 \times 0.300)$ = 3.94 m</p>

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	$\% \text{ Loading} = \frac{\text{Slip}}{(S_s - S_r) \times (V_r / V)^2} \times 100\%$ <p>Synchronous speed = 120 x 49.8 / 4 = 1494 rpm</p> <p>Slip = Synchronous Speed – Measured speed in rpm. = 1494 – 1460 = 34 rpm.</p> $\% \text{ Loading} = \frac{34}{(1494 - 1440) \times (415/410)^2} \times 100\% = 61.45\%$

..... *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
	<p>a) Theoretical air required for complete combustion</p> $= \frac{(11.6 \times C) + \left\{ 34.8 \times \left(H_2 - \left(\frac{O_2}{8} \right) \right) \right\} + (4.35 \times S)}{100}$ $= \frac{(11.6 \times 33.95) + \left\{ 34.8 \times \left(5.01 - \left(\frac{32.52}{8} \right) \right) \right\} + (4.35 \times 0.09)}{100} = 4.27 \text{ kg / kg of paddy husk}$ <p>Moles of N₂ = $\frac{4.27 \times \left(\frac{77}{100} \right)}{28} + \left(\frac{0.0091}{28} \right) = 0.1178$</p> <p>% CO₂ theoretical = $\frac{\text{Moles of C}}{\text{Moles of N}_2 + \text{Moles of C} + \text{Moles of S}}$</p> $= \frac{\left(\frac{0.3395}{12} \right)}{0.1178 + \left(\frac{0.3395}{12} \right) + \left(\frac{0.0009}{32} \right)}$ <p>Max theoretical (CO₂)_t = 19.36 %</p> <p>Actual CO₂ measured in flue gas = 14.0%</p> <p>b) % Excess air supplied = $\frac{7900 \times [(CO_2)_t - (CO_2)_a]}{(CO_2)_a \times [100 - (CO_2)_t]} = 37.5 \%$</p> <p>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</p>

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

$$= \mathbf{6.15 \text{ kg / kg of coal}}$$

(or)

(actual mass of air supplied + 1) – mass of H₂O

$$(5.87 + 1) - (9H + M) = 6.87 - (9 \times 0.05 + 0.1079) = 6.87 - 0.5579 = \mathbf{6.31 \text{ kg/kg of coal}}$$

$$\begin{aligned} \text{\% Heat loss in dry flue gas} &= \frac{m \times C_p \times (T_f - T_a)}{\text{GCV of fuel}} \times 100 \\ &= \frac{6.15 \times 0.23 \times (160 - 32)}{3568} \times 100 \\ &= \mathbf{5.07 \%} \end{aligned}$$

$$\begin{aligned} \text{Loss due to CO} &= \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5654}{\text{GCV of fuel}} \times 100 \\ &= \frac{0.35 \times 0.3395}{(0.35 + 14)} \times \frac{5654}{3568} \end{aligned}$$

$$\text{L2} = 1.31 \%$$

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

	<p>Total heat loss in ash = 67.5 + 13.4 = 80.9 kcal/kg</p> <p>% loss in ash = 80.9/3568 = 2.26 %</p> <p>Total losses = 100 – (5.07 + 1.31 + 2.26) – (15.4)</p> <p>Boiler efficiency = 100 – 8.64 – 15.4 = 75.96 %</p>
N-2	KEY
	<p>Hot Water use per day : 20,000 L/day</p> <p>Water in = 20⁰C Water out = 60⁰C Temp. diff. = 40⁰C Total Heat required = mCpdt = 20000 x 1 x 40 = 8,00,000 kcal/day</p> <p>1. <u>Energy Requirement for 20KL/day of water for a temperature differential of 40 deg.C in an Electric Boiler/Geyser</u></p> <p>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</p> <p>2. <u>For 20 KL/day, of water flow with 40⁰C Temperature Diff. Energy to be drawn by Heat Pump</u></p> <p style="text-align: center;">= $\frac{8,00,000}{860 \times 0.95 \times 2.5}$ = 391.68 Kwh/day</p> <p>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</p> <p>Total Energy drawn by heat pump system = 391.68 + 89.76 + 22.4 = 503.8 kWh /day</p> <p><u>SAVINGS IN COMPARISON TO ELECTRIC WATER HEATER</u></p> <p>= 939.6 – 503.8 = 435.75 Kwh/day = 1,52,516 kWh/year (@ 350 days/year) = 12.20 lakhs (@ Rs8.0 per kWh)</p>

	<p>3. SIMPLE PAY BACK PERIOD = Rs.16.0 LAKHS Investment/ Rs.12.20 lakhs per year savings</p> <p style="text-align: center;">= 1.30 years or 16 months</p>
N-3	KEY
Ans	<p>Power generation from cogen plant = $5000 \times 0.9 \times 8000 = 360 \text{ lac Kwh/yr}$</p> <p>Auxiliary power = 1%</p> <p>Net power generation = $0.99 \times 360 = 356.4 \text{ lac Kwh}$</p> <p>Natural gas requirement for power generation = $360 \times 3050 / 9500 = 115.57 \text{ lac sm}^3$</p> <p>Cost of fuel per annum = $115.57 \times 8 = \text{Rs.}924.56 \text{ lacs}$</p> <p>Annual expenditure for interest, depreciation and O&M = $500 + 200 = 700 \text{ lacs}$</p> <p>Total cost of generation = Rs.1624.56 lacs.</p> <p>Cost of cogeneration power = $1624.56 \times 10^5 / 356.4 \times 10^5$</p> <p style="text-align: center;">= Rs.4.56 / Kwh.</p> <p>Gas consumption in existing gas fired boiler = $[10000 (665 - 85) / (0.86 \times 9500)]$</p> <p style="text-align: center;">= $710 \text{ Sm}^3/\text{hr}$</p> <p style="text-align: center;">= $710 \times 24 = 17040 \text{ sm}^3/\text{day}$</p> <p>Cost of steam from existing boiler = $710 \times \text{Rs. } 8 \times 8000$</p> <p style="text-align: center;">= Rs. 454.4 Lacs /yr</p> <p>Cost of power generation after giving credit for steam generation = $1624.56 - 454.4 = \text{Rs.}1170.16 \text{ lacs}$</p> <p>Cost of power generation after accounting for steam cost = $1170.16 \times 10^5 / 356.4 \times 10^5$</p> <p style="text-align: center;">= Rs. 3.28 / Kwh</p> <p>Grid power cost = Rs. 4.5 / Kwh</p> <p>Cost advantage for cogen plant generation = $4.5 - 3.28 = \text{Rs.}1.22 / \text{Kwh}$</p> <p>Daily gas requirement for operating GT cogen plant = $5000 \times 0.9 \times \frac{3050}{9500} \times 24$</p> <p style="text-align: center;">= $34673.68 \text{ Sm}^3 / \text{day}$</p>

	<p>Additional gas requirement for co-gen plant = 34673.68 – 17040 = 17633.68 Sm³/day</p>
N-4	To attempt ANY ONE OF THE FOLLOWING among A, B, C and D
N4 A	KEY
Ans	<p>i) Turbine power output kW =</p> $\frac{\text{Steam flow to turbine kg/hr} \times \text{enthalpy drop across the turbine kcal/kg}}{860}$ <p>Inlet enthalpy of steam = 794.4 kcal/kg</p> <p>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</p> <p>ii) generator output kW = turbine output x combined efficiency of mechanical, gear transmission & generator</p> $= 32567.4 \times 0.92$ $= 29962 \text{ kW}$ <p>iii) turbine heat rate = heat input in to the turbine/ generator out put</p> $= q \times (h_1 - h_w) / \text{generator out put}$ <p>Where q = steam inflow to turbine kg/hr h₁ = enthalpy of turbine inlet steam = 794.4 kcal/kg h_w = enthalpy of feed water to boiler = 100 kcal/kg</p> <p>Turbine heat rate = ((120 x 1000 kg/hr) x (794.4 – 100) kcal/kg) / 29962 kw</p> $= 2781 \text{ kcal/kwh}$ <p>iv) unit heat rate = turbine heat rate /boiler efficiency</p> $= 2781 / 0.88 = 3160 \text{ kcal/ kwh}$ <p>v) turbine cycle efficiency = (860 / turbine heat rate) x 100</p> $= 860 / 2781 = 0.309$ $= 0.309 \times 100 = 30.9\%$ <p>vi) condenser heat load = m x cp x dt</p> <p>Where m = cooling water flow through condenser, kg/hr</p>

	<p>note: density of water is given as 0.95 g /cubic centimetre = 950 kg/ cubic meter cp = specific heat of cooling water, kcal/ kg. °C = 0.98 kcal /kg. °C dt = cooling water temperature rise, °C = 10</p> <p>Condenser heat load = $6318 \times 950 \times 0.98 \times 10 = 5,88,20,580$ kcal /hr</p> <p>vii) specific steam consumption of turbine = $860 / (\text{enthalpy drop} \times \text{combined efficiency})$ $= 860 / ((794.4 - 561) \times 0.92)$ $= 860 / (233.4 \times 0.92) = 4.0$ kg/kwh $= 4.0$ kg / kwh</p>
N4-B	KEY
Ans	<p>Volumetric flow rate of PH gas at NTP = $1.47 \times 125 \times 1000 = 183750$ [Nm³/hr]</p> <p>Mass flow rate of PH gas = $183750 \times 1.42 = 260925$ [kg/hr]</p> <p><u>Calculation for 4 stage pre-heater kiln</u></p> <p>Heat loss in PH Gas = $m \times cp \times T$ [kcal/hr] $= 260925 \times 0.244 \times 370 = 23556309$ [kcal/hr]</p> <p>Equivalent coal wasted = $\frac{23556309}{5540 \times 1000} = 4.252$ [tons of coal/hr]</p> <p><u>Electrical Energy consumption of PH Fan</u></p> <p>Volumetric flow rate of PH Gas at 370 °C temperature and -400 mm WC static pressure:</p> $V = 183750 \times \frac{(273+370) \times 10333}{273 \times (10333 - 400)} = 450216 \text{ [m}^3\text{/hr]}$ <p>or $V = 450216/3600 = 125$ [m³/sec]</p> <p>Pressure difference across PH fan = $50 - (-400) = 450$ [mm WC]</p> <p>Power consumption of PH fan</p> $P = \frac{125 \times 450}{102 \times 0.72 \times 0.95} = 806.24 \text{ [kW]}$ <p><u>Calculation for 6 stage pre-heater kiln</u></p> <p>Heat loss in PH Gas = $m \times cp \times T$ [kcal/hr] $= 260925 \times 0.244 \times 295 = 18781381$ [kcal/hr]</p> <p>Equivalent coal wasted = $\frac{18781381}{5540 \times 1000} = 3.39$ [tons of coal/hr]</p> <p><u>Electrical Energy consumption of PH Fan</u></p> <p>Volumetric flow rate of PH Gas at 295 °C temperature and -600 mm WC static pressure:</p> $V = 183750 \times \frac{(273+295) \times 10333}{273 \times (10333 - 600)} = 405875 \text{ [m}^3\text{/hr]}$ <p>Or $V = 405875/3600 = 112.75$ [m³/sec]</p>

	<p>Pressure difference across PH fan = $50 - (-600) = 650$ [mm WC] Power consumption of PH fan $P = \frac{112.75 \times 650}{102 \times 0.72 \times 0.95} = 1050.4$ [kW]</p> <p>The above kilns can be compared as follows:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">Item</th> <th style="text-align: center;">6 Stage PH Kiln</th> <th style="text-align: center;">4 stage PH kiln</th> </tr> </thead> <tbody> <tr> <td>PH Gas heat loss (kcal/hr)</td> <td style="text-align: center;">18781381</td> <td style="text-align: center;">23556309</td> </tr> <tr> <td>Equivalent coal wasted (tons of coal)</td> <td style="text-align: center;">3.39</td> <td style="text-align: center;">4.252</td> </tr> <tr> <td>Power consumption in PH Gas (kW)</td> <td style="text-align: center;">1050</td> <td style="text-align: center;">806.24</td> </tr> </tbody> </table> <p>Calculation for annual Monetary savings</p> <p>Coal savings in 6 stage PH Kiln = $4.252 - 3.39 = 0.862$ [ton of coal/hr] Annual monetary savings (Thermal) = $0.862 \times 8000 \times 6150 = 4,24,10,400$ [Rs.] Additional Electrical energy requirement for 6 stage PH Kiln = $1050.4 - 806.24 = 244.16$ [kW] Annual additional electrical cost = $244.16 \times 8000 \times 5 = 97,66,400$ [Rs.]</p> <p>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.</p> <p>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.]</p>	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
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											
N4-C	KEY												
Ans	<p>a) <u>Before insulation</u> Surface heat loss, $S = [10 + (TS - Ta)/20] \times (Ts - Ta)$ Total heat Loss = $S \times A$ where $A =$ Surface area, m^2 Surface heat loss, $S = [10 + (110 - 25)/20] \times (110 - 25) = 1211.25$ K.Cal/m^2/hr Total heat loss = $1211.25 \times 20 m^2 = 24225$ kCal/hr</p> <p><u>After insulation</u> Surface heat loss, $S = [10 + (55 - 25)/20] \times (55 - 25) = 345$ K.Cal/m^2/hr Total heat loss = $345 \times 20 m^2 = 6900$ kCal/hr Heat reduction per hour after proper insulation = $24225 - 6900 = 17325$ kCal/hr Annual heat loss reduction = $17325 \times 8000 = 138600000$ $= 138.6$ million kCal/year</p> <p>Steam distribution loss = 20% Heat loss = 138.6 million kCal / $0.8 = 173.25$ million kcal/year Boiler efficiency = 70%</p> <p>Equivalent coal consumption reduction = $173.25 \times 10^6 / 0.7 \times 4800 = 51.56$ Ton /year</p>												

	<p> Monetary Cost savings per year = $51.5 \times 5000 = \text{Rs } 2.575 \text{ lacs}$ Investment @ Rs 1000 per M² = $20 \times 1000 = \text{Rs } 20000$ </p> <p> Condensate recovery Reduction in coal consumption through heat recovered from condensate return = $2000 \times 1 \times (80 - 40) / 0.7 \times 4800$ = 23.8 kg of coal per hour Annual coal savings = $23.8 \times 8000/1000$ = 190.4 ton / year Annual savings = $23.8 \times 8000 \times \text{Rs.}5/\text{kg coal}$ = Rs. 9.52 lacs </p> <p> b) Simple payback period Total savings from both the measures = $2.575 + 9.52 = 12.1 \text{ lakhs}$ Total investment = $\text{Rs. } 20,000 + \text{Rs } 2 \text{ lakhs} = \text{Rs.}2.2 \text{ lakhs}$ Simple payback period (combined) = $2.2/12.1 = 2.2 \text{ months}$ </p> <p> c) GHG emission reduction Carbon content in the coal = 40% by weight Total Coal saving /year = $51.5 + 190.4 = 241.9 \text{ Ton per year}$ CO₂ reduction = $241.9 \times 0.4 \times 44/12 = 355 \text{ Ton of CO}_2/\text{year}$ </p>
N4-D	KEY
Ans	<p> Theoretical air required for complete combustion $= [(11.6 \times 85.9) \times (34.8 \times (12 - 0.7/8)) + 4.35 \times 0.5] / 100$ $= 996.44 + 414.12 + 2.175 / 100$ = 14.1 kg/kg of oil </p> <p> Existing oxygen % in flue gas = 6% </p> <p> % excess air supplied = $6 \times 100 / (21 - 6) = 40\%$ Actual mass of air supplied = $(1 + \text{Excess air}/100) \times \text{Theoretical air}$ = $(1 + 40/100) \times 14.1$ = 19.74 kg/kg of oil </p> <p> After modification, oxygen % in flue gas = 3% % excess air supplied = $3 \times 100 / (21 - 3) = 16.67\%$ </p> <p> Actual mass of air supplied = $(1 + \text{Excess air}/100) \times \text{Theoretical air}$ = $(1 + 16.67/100) \times 14.1$ = 16.45 kg/kg of oil </p> <p> <u>a) Heat loss reduction through actual mass of air supplied</u> </p>

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 x 10,000
 = **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 -----