11th NATIONAL CERTIFICATION EXAMINATION – February, 2011
FOR
ENERGY AUDITORS

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

Date: 06.02.2011 Timings: 1400-1600 HRS Duration: 2 HRS Max. Marks: 100

General instructions:

- *Please check that this question paper contains **12** 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: SHORT DESCRIPTIVE QUESTIONS Marks: 10 x 1 = 10

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

S-1	In what type of furnace, a top pressure recovery turbine is used? **Ans:** blast furnace
S-2	In a heat exchanger, the hot fluid inlet and outlet temperatures are 110 °C and 70 °C. The cold fluid inlet and outlet temperatures are 30 °C and 45 °C. The effectiveness of heat exchanger is **Ans:** Effectiveness, $S = (t_o - t_i) / (T_i - t_i)$ **= 15/80 = 0.1875**
S-3	Name two types of discounted cash-flow techniques used in the financial evaluation of energy saving projects **Ans:** 1 NPV: Net present value 2 IRR: Internal rate of return
S-4	Name two areas of major thermal energy consumption in a cement plant **Ans:** Rotary kiln and precalciner
S-5	For which fuel the difference between GCV and LCV will be higher, Coal or Natural Gas? **Ans:** Natural Gas

S-6	What are the two major functions of coke in a blast furnace? **Ans:** Coke is used in Blast Furnace (BF) both as a reductant (reduction of ore to liquid metal)and as a source of thermal energy.
S-7	For a thermal power plant, which type of heat rate (Gross or Net) has a higher value for the same generator output? **Ans:** Net heat rate
S-8	Why humidification is required in spinning and weaving sections of textile processing? **Ans:** Humidity is required to prevent yarn breakage and minimize build up of static charge to reduce dust and fibre fly (Fluff)
S-9	What is the purpose of 'reheat' in a thermal power plant cycle? **Ans:** There is a gain in net work and because of which the efficiency is enhanced.
S-10	In a rotary kiln of cement plant, why % CO_2 in exhaust gases cannot be an indicator of excess air? **Ans:** Because the process also emits CO_2

…………. End of Section - I ………….

Section - II: LONG DESCRIPTIVE QUESTIONS **Marks: 2 x 5 = 10**

(i) Answer all **Two** questions
(ii) Each question carries **Five** marks

L-1 The following are the operating parameters of a regenerative feedwater heater in a thermal power plant

Saturation temperature of steam to heater	- 84.3 °C
Inlet feedwater temperature	- 44 °C
Outlet feedwater temperature	- 75 °C
Drain outlet temperature	- 58.4 °C

Calculate the Terminal Temperature Difference (TTD) and Drain Cooler Approach (DCA).

Ans : TTD = 84.3 – 75

= 9.3 °C

DCA = 58.4 – 44
= 14.4 °C

L-2 In a 30 kW four pole induction motor operating at 49.9 Hz and rated for 415 V and 1470 RPM, the actual measured speed is 1485 RPM. Find out the percentage loading of the motor if the voltage applied is 425 V.

Ans:

$$\% \text{ Loading} = \frac{\text{Slip}}{(Ss - Sr) \times (Vr / V)^2} \times 100\%$$

Synchronous speed = 120 x 49.9 / 4 = 1497 rpm

Slip = Synchronous Speed – Measured speed in rpm.
= 1497– 1485 = 12 rpm.

$$\% \text{ Loading} = \frac{12}{(1497 - 1470) \times (415/425)^2} \times 100\% = 46.6\%$$

…………. End of Section - II ………….

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

(i) Answer all **Four** questions
(ii) Each question carries **Twenty** marks

N-1 Flow rates of the hot and the cold water streams flowing through a heat exchanger are 12 and 30 kg/min, respectively. Hot and cold water stream inlet temperatures are 72 °C and 27 °C, respectively. The exit temperature of the hot stream is required to be 52 °C. The specific heat of water is 4.179 kJ/kg K. The overall heat transfer coefficient is 800 W/m^2 K.

Neglecting the effect of fouling, calculate the heat transfer area for

a) Parallel-flow

b) Counter-flow

a)

Rate of heat transfer	M x cp x delt T (12/60) × 4.179 x 1000 × (72 – 52) = 16716 W
Cold water exit temperature	27 + [16716 / (4.179 x 1000 × (30/60))]
	27 + 8 = 35 °C

Terminal temperature differences for	(72 – 27) and (52 – 35) ^{0}C i.e., 45 °C

parallel flow heat exchangers	and 17 °C respectively.
LMTD	(45 – 17)/ln(45/17) = 28.76
Overall heat transfer coefficient U	800 W/m^2 K
Heat transfer area required for parallel flow	[16716 / (800 × 28.76)]
	0.72 m^2

b)

Terminal temperature differences for counter flow heat exchangers	(72 – 35) and (52 – 27) ^{0}C i.e., 37 °C and 25 °C respectively.
LMTD	(37 – 25)/ln(37/25) = 30.6
Overall heat transfer coefficient U	800 W/m^2 K
Heat transfer area required for counter flow	[16716 / (800 × 30.6)]
	0.684 m^2

N-2 Two energy conservation projects have been proposed.

For the first project, a capital investment of Rs.1,50,000/- is required and the net annual saving is Rs. 50,000/- for 5 years. The salvage value at the end of 5 years for the first project is Nil.

For the second project, a capital investment of Rs. 1,50,000/- yields savings of Rs. 50,000/- for first 2 years each and Rs. 60,000/- for next 3 years each. The salvage value at the end of 5 years for the second project is Rs. 10,000/-. Determine:

a) Net present value for both the projects with a discount factor of 9%.
b) Profitability index for both the projects with a discount factor of 9%.
c) Internal rate of return for both the projects.

Ans:

a)

NPV for project 1 = – 150000 + 50000/1.09 + 50000/$(1.09)^2$ + 50000/$(1.09)^3$ + 50000/$(1.09)^4$ + 50000/$(1.09)^5$ = + 44483

NPV for project 2 = – 150000 + 50000/1.09 + 50000/$(1.09)^2$ + 60000/$(1.09)^3$ + 60000/$(1.09)^4$ + 60000/$(1.09)^5$ + 10000/$(1.09)^5$ = + 72287

b)

Profitability index for project 1 = 44483 / 150000 = 0.297

Profitability index for project 2 = 72287 / 150000 = 0.481

c)

IRR for project 1 = 19.86 %

IRR for project 2 = 25.07 %

N-3 In an air conditioning system of a food processing industry, the cold air flow rate is 20,000 m^3/hr at a density of 1.2 kg/m^3 .The inlet and outlet enthalpy of the air are 105 kJ/kg and 80 kJ/kg. The COP of the existing vapour compression system is 3.75. The efficiency of the motor coupled with the compressor is 90%.

The management wants to install a Vapour Absorption System (VAR).The saturated steam for VAR will be supplied either from a new waste heat boiler to be installed with the existing DG sets or from the existing FO fuel fired boiler. The plant is operating for 8000 hr/annum. The investment of VAR system is Rs. 20 lakhs. The investment for waste heat boiler is Rs. 6 lakhs. The power cost is Rs. 6/kWh.

As an energy auditor which one of the following options will you recommend to the management?

Option1: Supply steam from the existing FO fuel fired boiler to VAR system and avoid the investment of waste heat boiler

Option2 - Supply steam from the waste heat boiler, which needs an investment in addition to VAR system

The steam consumption per TR will be 5.5 kg/TR. The cost of FO is Rs.32,000/ tonne. The evaporation ratio of the existing FO fired boiler is 14. Neglect losses in transmission of steam and chilled water.

Ans.	
Existing Base Case VCR System	
TR Rating	$= \frac{(20{,}000\ m^3/hr \times 1.2\ kg/m^3)\ (105-80)\ kJ/kg}{3024 \times 4.187}$
	= 47.38 TR
COP	= 3.75
COP	$= \frac{\text{Refrigeration effect kCal/hr}}{\text{Power Input kCal/hr}}$
Compressor power input	$= \frac{47.38 \times 3024\ kCal}{3.75 \times 860}$
	= 44.43 kW
Motor input power	= 44.43/0.9 = 49.37 kW
Annual Energy Consumption	= 49.37 x 8000 = 3.95 Lakhs kWh
Annual cost in VCR system (Base Case)	=3.95 x 6 = Rs. 23.7 Lakhs

Option – 1 : **VAR System with Steam Supply from Existing Boiler**	
Steam Consumption /TR	= 5.5 kg/TR
Steam Consumption per hr	= 5.5 x 47.38 = 261 kg/hr
Evaporation Ratio IN THE EXISTING BOILER	= 14
1 ton of steam cost	= Rs.32000 ------------- = Rs.2.29 /kg of steam 14
Investment for VAR system	= Rs.20.00 Lakhs
Electricity cost saving per hr	= 49.37 x 6 =Rs. 296.22
Steam cost per hr	= 261 x 2.29 = Rs. 598
Since the steam cost per hour is higher than electricity cost this option is not feasible	
Option-2: With VAR & steam supply from WHR steam boiler of DG set	
Total Investment	= Rs. 20.00 + 6.00 = 26.00 Lakhs
Annual Savings	= Rs.23.7 lakhs
Simple Pay back period	= 26/23.7 = 1.09 years.
Solution : Option 2 should be selected	

N -4 The candidate may answer **ANY ONE OF THE FOLLOWING** among A, B, C and D

A) The following are the data obtained from a pulverized coal fired thermal power plant

Main steam pressure and temperature	: 155 kg/cm^2 (g), 540 ^{o}C
Main steam flow rate	: 624 TPH
Enthalpy of main steam	: 815.2 kCal/kg
Feed water temperature	: 229 ^{o}C
Cold reheat steam pressure and temperature	: 36 kg/cm^2(g), 330 ^{o}C
Enthalpy of cold reheat steam	: 730 kCal/kg
Hot reheat steam pressure and temperature	: 35 kg/cm^2(g), 540 ^{o}C
Enthalpy of hot reheat steam	: 844.5 kCal/kg
Reheat steam flow	: 563 TPH
Generator output	: 207.3 MW
Boiler efficiency	: 85.5%
Back pressure	: 0.9 kg/cm^2 (g)
Condenser CW inlet temperature	: 26 ^{o}C
Condenser CW outlet temperature	: 37 ^{o}C
Exhaust steam saturation temperature	: 45.4 ^{o}C
Enthalpy of wet steam at vacuum	: 508 kCal/kg
Condenser CW flow	: 24800 m^3/hr

Calculate

a) Turbine heat rate, unit heat rate and turbine cycle efficiency
b) Condenser heat load, effectiveness and calculated condenser vacuum in millibar

Ans:

Turbine heat rate and unit heat rate

$$\text{Turbine heat rate, kCal/kWh} = \frac{624000 \times (815.2 - 229) + 563000 \times (844.5 - 730)}{207300}$$

$$\text{Turbine heat rate} = 2075.5 \text{ kCal/kWh}$$

$$\text{Unit heat rate} = \frac{2075.5}{0.855} = 2427.5 \text{ kCal/kWh}$$

Turbine cycle efficiency (thermal efficiency)

$$\textbf{Turbine cycle efficiency, \%} = \frac{\textbf{860}}{\textbf{Turbine heat rate}} \times \textbf{100}$$

$$\text{Turbine cycle efficiency, \%} = \frac{860}{2075.5} \times 100$$

$$\text{Turbine cycle efficiency} = 41.4 \ \%$$

$$\textbf{Condenser heat load, MCal/hr} = \mathbf{Q} \times \mathbf{T} \times \mathbf{C}p$$

Q -Water flow rate, kg/hr
T - Average CW temperature rise, ^{o}C
C_p - Specific heat, kcal/kg ^{o}C

$$\text{Condenser heat load} = 24800 \times (37 - 26) \times 1$$
$$\text{Condenser heat load} = 272800 \text{ MCal/hr}$$

$$\textbf{Calculated condenser vacuum, kg/cm}^2 (a)$$
$$= \textbf{Atmospheric pressure} - \textbf{Condenser back pressure}$$

$$\text{Calculated condenser vacuum} = 1 - 0.9$$
$$\text{Calculated condenser vacuum} = 0.1 \text{kg/cm}^2 (a) = 98.06 \, millibar$$

Condenser Effectiveness, %

$$= \frac{\textbf{Rise in cooling water temperature}}{\textbf{Saturation temperature of steam} - \textbf{Cooling water inlet temperature}} \times 100$$

$$\text{Condenser Effectiveness} = \frac{37 - 26}{45.4 - 26} \times 100 = 56.7\%$$

or

B) a) What are the major advantages of using sinter in a Blast furnace
b) A furnace is fired with blast furnace gas having an analysis by volume as follows

CO_2 – 13 %, CO – 25 %, H_2 - 3.5 %, N_2 – 58.5 %

Calculate the percentage of excess air when the dry product of combustion contains 3.5 % O_2

Ans:

a) The major advantages of using sinter in Blast Furnaces are :

- Use of iron ore fines, coke breeze, metallurgical wastes, lime, dolomite for hot metal production
- Better reducibility and other high temperature properties
- Increased BF productivity
- Improved quality of hot metal
- Reduction in coke rate in blast furnaces

b)

Basis : 100 kg mol. of blast furnace gas

Oxygen demand and flue gas formed are computed as under

Constituents	**Amount, kg mol.**	**Oxygen required kg mol**	**Flue gas obtained, kg mol.**
CO_2	13.0	0	13.0 (CO_2)
CO	25.0	12.50	25.0 (CO_2)
H_2	3.5	1.75	3.5 (H_2)
N_2	58.5	0	58.5 (N_2)
Total	100.0	14.25	100.0

Let y_1 = kg mol of dry flue gas obtained
Z = kg mol of combustion air used

N_2 from combustion air = 0.79x
O_2 from combustion air = 0.21x

O_2 excess in flue gas = 0.21 z – 14.25
Dry flue gas = (100 – water vapour) + 0.79z + (0.21z-14.25)
= (100-3.5) +z-14.25= 82.25 + z = y_1

Oxygen / dry flue gas = (0.21z-14.25)/ (82.25+z) = 3.5/100

Solving z= 97.88 kg mol

Oxygen from air	= 97.88 x 0.21 = 20.65
Oxygen excess	= 20.55 – 14.25 = 6.3 kg mol
% Excess air	= % excess oxygen = 6.3/14.25 x100 = 44.2

or

C) a) 125 kg of fabric is to be dyed in a jigger. The dye liquor is heated from 30 ^{0}C to 90 ^{0}C. Calculate steam (steam enthalpy 660 kCal/kg) requirement per batch and specific steam consumption (kg of steam per kg of cloth), if liquor ratio is 1:6.5; allowing 10% margin for losses.

b) In a textile mill, a thermic fluid heater of 15 lakh kCal/hr capacity is meeting process heat requirements.

The observed parameters of thermic fluid heater are:

Thermic fluid circulation rate	- 100 m^3/hr
Outlet temperature of fluid	- 270 ^{0}C
Return temperature of fluid	- 256 ^{0}C
Specific heat of fluid	- 0.55 kCal/kg ^{0}C
Density of fluid	- 830 kg/m^3
Present coal consumption	- 300 kg /hr
GCV of coal	- 3500 kCal/hr

i) What is the % loading of the thermic fluid heater?
ii) What is the existing thermal efficiency?
iii) The management is proposing to add a five chamber, (each chamber 1 Lakh kCal/hr duty) to the heater. Will it be able to take the load?

Ans:

a)

Heat energy required / batch	= 125 kg x 6.5 liq.ratio x 1.10 (including margin) x (90 – 30)
	= 53625 kCal/batch
	= steam quantity needed / batch
	= 53625/660
	= 81.25 kg
Specific steam consumption	= 81.25/125 = 0.65 kg/kg

Ans:

i)
Heat duty = 100 m^3/hr x 830 kg/m^3 x 0.55 x 14
= 6,39,100 kCal/hr
% loading = 6,39,100/15,00,000
= 42.60 %

ii)
Input energy = 300 kg/hr x 3500 kCal
= 10,50,000 kCal/hr
Efficiency of the heater = 6,39,100/10,50,000
= 60.86%

iii)
New chamber heat duty = 5 x 1,00,000
= 5,00,000 kCal/hr

The total heat duty with new stenter loading = 6,39,100 + 5,00,000
= 11,39,100 kCal/hr

It is possible to comment new stenter since this is within 15 Lakh kCal/hr capacity of the TFH

or

D) a) The following are the data obtained from the energy audit of a cement plant

Clinker analysis (loss free basis)

Constituents Determined	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
(%)	20.54	4.14	5.53	63.79	3.8

Preheater exit gas analysis

Oxygen (% v/v)	CO (% v/v)	CO_2 (% v/v)
5.6	0.1	23.2

Preheater exit temperature – 328^{o}C
Atomospheric pressure at site – 10.318 m
Static pressure – (-684 mmwg)

i) Calculate the heat of formation of clinker
ii) Calculate the density of preheater exit gases

b) An energy audit of a coal mill fan was carried out. It was observed that fan was delivering 1,60,000 Nm^3/hr of air at static pressure rise of 65 mm WC. The power measurement of the 3-phase induction motor coupled with the fan recorded 20 kW/

phase on an average. The motor operating efficiency was assessed as 0.90 from the motor performance curves. What would be the fan static efficiency?

Ans:

a)

i) **Heat of formation of Clinker**

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

= (2.22 x 5.53)+(6.48 x 3.8)+(7.646 x 63.79)–(5.116x 20.54)–(0.59 x 4.14)
= 417.11 kCal/kg Clinker

ii) Density of gases at preheater exit

$$\rho_{stp} = \frac{(O_2\% \times MW) + (CO_2\% \times MW) + ((N_2 + CO)\% \times MW)}{22.4 \times 100} \text{ kg/Nm}^3$$

$$\rho_{stp} = \frac{5.6 \times 32) + (23.2 \times 44) + (71.2 \times 28)}{22.4 \times 100} \text{ kg/Nm}^3$$

$$= 1.4257 \text{ kg/Nm}^3$$

$$\rho_{t,p} = 1.4257 \times \frac{10318 * -684_S}{10318} \times \frac{273}{273 + 328_e} \text{ kg/m}^3$$

(* as per the altitude of the plant above MSL)

$$\rho_{t,p} = 1.436 \times \frac{10334 - 655}{10334} \times \frac{273}{273 + 316} \text{ kg/m}^3$$

$$= 0.623 \text{ kg/m}^3$$

b)

Q = 1,60000 Nm^3 / hr.= 44.44 m^3/sec ,
SP = 65 mmWC,
η_{St} = ?,

Power input to 3 phase motor= 20 x 3 = 60 kW
Power input to fan shaft = 60 x 0.90 = 54 kW

$$\text{Fan static } \eta = \frac{\text{Volume in m}^3\text{/sec} \times \Delta P_{st} \text{ in mmWc}}{102 \times \text{Power I/p to shaft}} \times 100$$

$$= \frac{44.44 \times 65}{102 \times 54} \times 100$$

$$= 0.524 \times 100$$

$$= 52.4\%$$

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