

Paper 4 – Energy Auditor – Set B Key

Regn No: _____

Name: _____

(To be written by the candidate)

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	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-2	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-3	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-4	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-5	Name two areas of major thermal energy consumption in a cement plant Ans: Rotary kiln and precalciner

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S-6	In what type of furnace, a top pressure recovery turbine is used? Ans: blast furnace
S-7	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
S-8	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-9	For which fuel the difference between GCV and LCV will be higher, Coal or Natural Gas? Ans: Natural Gas
S-10	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

..... **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 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 1475 RPM. Find out the percentage loading of the motor if the voltage applied is 425 V.

Ans:

$$\% \text{ Loading} = \frac{\text{Slip}}{(S_s - S_r) \times (V_r / V)^2} \times 100\%$$

$$\text{Synchronous speed} = 120 \times 49.9 / 4 = 1497 \text{ rpm}$$

$$\begin{aligned} \text{Slip} &= \text{Synchronous Speed} - \text{Measured speed in rpm.} \\ &= 1497 - 1475 = 22 \text{ rpm.} \end{aligned}$$

$$\% \text{ Loading} = \frac{22}{(1497 - 1470) \times (415/425)^2} \times 100\% = 85.43\%$$

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- L-2 The following are the operating parameters of a regenerative feedwater heater in a thermal power plant

Saturation temperature of steam to heater	- 80.8 °C
Inlet feedwater temperature	- 46 °C
Outlet feedwater temperature	- 73 °C
Drain outlet temperature	- 59.2 °C

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

Ans : TTD = $80.8 - 73$
= 7.8 °C

DCA = $59.2 - 46$
= 13.2 °C

..... **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 900 W/m² K.

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

- a) Parallel-flow
b) Counter-flow

a)

Rate of heat transfer	$M \times c_p \times \Delta T$ $(12/60) \times 4.179 \times 1000 \times (72 - 52) = 16716 \text{ W}$
Cold water exit temperature	$27 + [16716 / (4.179 \times 1000 \times (30/60))] = 27 + 8 = 35 \text{ °C}$

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Terminal temperature differences for parallel flow heat exchangers	(72 – 27) and (52 – 35) °C i.e., 45 °C and 17 °C respectively.
LMTD	$(45 - 17)/\ln(45/17) = 28.76$
Overall heat transfer coefficient U	900 W/m ² K
Heat transfer area required for parallel flow	$[16716 / (900 \times 28.76)]$
	0.64 m ²

b)

Terminal temperature differences for counter flow heat exchangers	(72 – 35) and (52 – 27) °C i.e., 37 °C and 25 °C respectively.
LMTD	$(37 - 25)/\ln(37/25) = 30.6$
Overall heat transfer coefficient U	900 W/m ² K
Heat transfer area required for counter flow	$[16716 / (900 \times 30.6)]$
	0.601 m ²

N-2 Two energy conservation projects have been proposed.

For the first project, a capital investment of Rs.2,00,000/- 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. 2,00,000/- 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:

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

Ans:

a)

$$\text{NPV for project 1} = -200000 + 50000/1.09 + 50000/(1.09)^2 + 50000/(1.09)^3 + 50000/(1.09)^4 + 50000/(1.09)^5 = -5517.4$$

$$\text{NPV for project 2} = -200000 + 50000/1.09 + 50000/(1.09)^2 + 60000/(1.09)^3 + 60000/(1.09)^4 + 60000/(1.09)^5 + 10000/(1.09)^5 = +22287.3$$

b)

$$\text{Profitability index for project 1} = -5517.4 / 200000 = -0.0276$$

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Profitability index for project 2 = $22287.3 / 200000 = 0.111$

c)

IRR for project 1 = 7.93 %

IRR for project 2 = 12.96 %

N-3 In an air conditioning system of a food processing industry, the cold air flow rate is 20,000 m³/hr at a density of 1.2 kg/m³. 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. 22 lakhs. The investment for waste heat boiler is Rs. 8 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	$= \frac{(20,000 \text{ m}^3/\text{hr} \times 1.2 \text{ kg/m}^3) (105-80) \text{ kJ/kg}}{3024 \times 4.187}$
	= 47.38 TR
COP	= 3.75
COP	$= \frac{\text{Refrigeration effect} \quad \text{kCal/hr}}{\text{Power Input} \quad \text{kCal/hr}}$
Compressor power input	$= \frac{47.38 \times 3024 \text{ kCal}}{3.75 \times 860}$
	= 44.43 kW

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Motor input power	= $44.43/0.9 = 49.37$ kW
Annual Energy Consumption	= $49.37 \times 8000 = 3.95$ Lakhs kWh
Annual cost in VCR system (Base Case)	= $3.95 \times 6 = \text{Rs. } 23.7$ Lakhs
Option – 1 : VAR System with Steam Supply from Existing Boiler	
Steam Consumption /TR	= 5.5 kg/TR
Steam Consumption per hr	= $5.5 \times 47.38 = 261$ 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.22.00 Lakhs
Electricity cost saving per hr	= $49.37 \times 6 = \text{Rs. } 296.22$
Steam cost per hr	= $261 \times 2.29 = \text{Rs. } 598$
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. 22.00 + 8.00 = 30.00 Lakhs
Annual Savings	= Rs.23.7 lakhs
Simple Pay back period	= $30/23.7 = 1.27$ 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 °C
Main steam flow rate	: 624 TPH
Enthalpy of main steam	: 815.2 kCal/kg
Feed water temperature	: 229 °C
Cold reheat steam pressure and temperature	: 36 kg/cm ² (g), 330 °C
Enthalpy of cold reheat steam	: 730 kCal/kg
Hot reheat steam pressure and temperature	: 35 kg/cm ² (g), 540 °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 °C
Condenser CW outlet temperature	: 37 °C
Exhaust steam saturation temperature	: 45.4 °C
Enthalpy of wet steam at vacuum	: 508 kCal/kg
Condenser CW flow	: 24800 m ³ /hr

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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)

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

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

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

Condenser heat load, MCal/hr = $Q \times T \times C_p$

Q - Water flow rate, kg/hr

T - Average CW temperature rise, °C

C_p - Specific heat, kcal/kg °C

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

$$\text{Condenser heat load} = 272800 \text{ MCal/hr}$$

Calculated condenser vacuum, kg/cm² (a)

$$= \text{Atmospheric pressure} - \text{Condenser back pressure}$$

$$\text{Calculated condenser vacuum} = 1 - 0.9$$

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

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Condenser Effectiveness, %

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

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

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

CO₂ – 13 %, CO – 25 %, H₂ - 3.5 %, N₂ – 58.5 %

Calculate the percentage of excess air when the dry product of combustion contains 3.5 % O₂

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 y₁ = kg mol of dry flue gas obtained

Z = kg mol of combustion air used

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- a) N_2 from combustion air = $0.79x$
 O_2 from combustion air = $0.21x$

$$\begin{aligned} O_2 \text{ excess in flue gas} &= 0.21z - 14.25 \\ \text{Dry flue gas} &= (100 - \text{water vapour}) + 0.79z + (0.21z - 14.25) \\ &= (100 - 3.5) + z - 14.25 = 82.25 + z = y_1 \end{aligned}$$

$$\text{Oxygen / dry flue gas} = (0.21z - 14.25) / (82.25 + z) = 3.5/100$$

Solving $z = 97.88 \text{ kg mol}$

$$\text{Oxygen from air} = 97.88 \times 0.21 = 20.65$$

$$\text{Oxygen excess} = 20.55 - 14.25 = 6.3 \text{ kg mol}$$

$$\% \text{ Excess air} = \% \text{ excess oxygen} = 6.3/14.25 \times 100 = 44.2$$

or

- C) a) 125 kg of fabric is to be dyed in a jigger. The dye liquor is heated from 30°C to 90°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	- $100 \text{ m}^3/\text{hr}$
Outlet temperature of fluid	- 270°C
Return temperature of fluid	- 256°C
Specific heat of fluid	- $0.55 \text{ kCal/kg } ^\circ\text{C}$
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)

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$$\begin{aligned}
 \text{Heat energy required / batch} &= 125 \text{ kg} \times 6.5 \text{ liq.ratio} \times 1.10 \text{ (including margin)} \\
 &\times (90 - 30) \\
 &= 53625 \text{ kCal/batch} \\
 &= \text{steam quantity needed / batch} \\
 &= 53625/660 \\
 &= 81.25 \text{ kg} \\
 \text{Specific steam consumption} &= 81.25/125 = 0.65 \text{ kg/kg}
 \end{aligned}$$

b)

Ans:

$$\begin{aligned}
 \text{i)} \\
 \text{Heat duty} &= 100 \text{ m}^3/\text{hr} \times 830 \text{ kg/m}^3 \times 0.55 \times 14 \\
 &= 6,39,100 \text{ kCal/hr}
 \end{aligned}$$

$$\begin{aligned}
 \% \text{ loading} &= 6,39,100/15,00,000 \\
 &= 42.60 \%
 \end{aligned}$$

$$\begin{aligned}
 \text{ii)} \\
 \text{Input energy} &= 300 \text{ kg/hr} \times 3500 \text{ kCal} \\
 &= 10,50,000 \text{ kCal/hr} \\
 \text{Efficiency of the heater} &= 6,39,100/10,50,000 \\
 &= 60.86\%
 \end{aligned}$$

$$\begin{aligned}
 \text{iii)} \\
 \text{New chamber heat duty} &= 5 \times 1,00,000 \\
 &= 5,00,000 \text{ kCal/hr}
 \end{aligned}$$

$$\begin{aligned}
 \text{The total heat duty with new stenter loading} &= 6,39,100 + 5,00,000 \\
 &= 11,39,100 \text{ kCal/hr}
 \end{aligned}$$

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 ₂ O ₃	Al ₂ O ₃	CaO	MgO
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(%)	20.54	4.14	5.53	63.79	3.8
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Preheater exit gas analysis

Oxygen (% v/v)	CO (% v/v)	CO ₂ (% v/v)
5.6	0.1	23.2

Preheater exit temperature – 328°C

Atmospheric 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 Nm³/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

$$\Delta H_R = 2.22\text{Al}_2\text{O}_3 + 6.48\text{MgO} + 7.646\text{CaO} - 5.116\text{SiO}_2 - 0.59\text{Fe}_2\text{O}_3$$

$$= (2.22 \times 5.53) + (6.48 \times 3.8) + (7.646 \times 63.79) - (5.116 \times 20.54) - (0.59 \times 4.14)$$

$$= 417.11 \text{ kCal/kg Clinker}$$

ii) Density of gases at preheater exit

$$\rho_{\text{stp}} = \frac{(\text{O}_2\% \times \text{MW}) + (\text{CO}_2\% \times \text{MW}) + ((\text{N}_2 + \text{CO})\% \times \text{MW})}{22.4 \times 100} \quad \text{kg/Nm}^3$$

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

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

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

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

$$\begin{aligned}\rho_{t,p} &= 1.436 \times \frac{10334 - 655}{10334} \times \frac{273}{273 + 316} \text{ kg/m}^3 \\ &= 0.623 \text{ kg/m}^3\end{aligned}$$

b)

$$Q = 1,60,000 \text{ Nm}^3 / \text{hr.} = 44.44 \text{ m}^3/\text{sec} ,$$

$$\text{SP} = 65 \text{ mmWC},$$

$$\eta_{\text{st}} = ? ,$$

$$\text{Power input to 3 phase motor} = 20 \times 3 = 60 \text{ kW}$$

$$\text{Power input to fan shaft} = 60 \times 0.90 = 54 \text{ kW}$$

$$\begin{aligned}\text{Fan static } \eta &= \frac{\text{Volume in m}^3/\text{sec} \times \Delta P_{\text{st}} \text{ in mmWc} \times 100}{102 \times \text{Power I/p to shaft}} \\ &= \frac{44.44 \times 65 \times 100}{102 \times 54} \\ &= 0.524 \times 100 \\ &= 52.4\%\end{aligned}$$

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