NATIONAL CERTIFICATION EXAMINATION 2005
FOR
ENERGY MANAGERS & ENERGY AUDITORS

Question Papers & Model solutions to the Question Papers

PAPER – 2: Energy Efficiency in Thermal Utilities	
Date: 28.05.2004 Timings: 1400-1700 HRS	**Duration: 3 HRS Max. Marks: 150**

General instructions:

- *Please check that this question paper contains **7** printed pages*
- *Please check that this question paper contains **65** 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: OBJECTIVE TYPE **Marks: 50 x 1 = 50**

(i) Answer all **50** questions
(ii) Each question carries **one** mark
(iii) Put a (√) tick mark in the appropriate box in the answer book

1.	The working fluid of a steam thermo-compressor is a) air b) low pressure steam **c) high pressure steam** d) water
2.	A shell and tube heat exchanger is most suitable if **a) a liquid is heating another liquid** b) a gas is heating another gas c) a gas is heating a liquid d) the hot gas is loaded with dust
3.	An economizer raises the boiler feed water by 60^0 C and therefore saves approximately ___ % of fuel. a) 5 **b) 10** c) 15 d) 20
4.	A heat pipe can transfer up to ____ times more thermal energy than copper a) 10 b) 20 c) 50 **d) 100**
5.	Heat wheels are mostly used in a situation of…. a) high temperature exhaust gases **b) heat exchange between large masses of air having small temperature differences** c) heat transfer between a liquid and gas d) corrosive gases

6.	Regenerators utilizing waste heat are widely used in… a) cement industry b) pulp and paper **c) glass melting furnaces** d) aluminium	
7.	Air compressor alone consumes about _____ of the energy generated in a gas turbine a) 20-30% b) 30-40% c) 40-50% **d) 50-60%**	
8.	Which CHP system has the smallest heat to power ratio with the least flexibility to increase or reduce the ratio? a) back pressure turbine **b) combined cycle** c) extraction condensing steam turbine d) reciprocating engine	
9.	The unit for heat-to-power ratio of a CHP plant is **a) kW_{th} / kW_e** b) BTU / kW c) kCal /kW d) kWh_{th} / kW_e	
10.	In glass industry waste heat is used for power generation. This type of cogeneration is called a) topping cycle **b) bottom cycle** c) gas turbine cycle d) none of the above.	
11.	Pick the wrong statement. The thermal efficiency of a furnace increases by a) preheating combustion air **b) increasing the excess air flow rate** c) reducing the surface heat loss d) minimizing the CO loss and un-burnt losses	
12.	The most economic insulation is the thickness where….. a) depreciation costs of insulation and energy cost due to losses are the same **b) the sum of energy cost due to losses and insulation depreciation cost is minimum** c) energy losses are minimized d) energy cost due to losses are minimized.	
13.	Which of the four refractories has the highest melting point temperature? **a) Lime (CaO)** b) Silica (SiO_2) c) Titania (TiO_2) d) Alumina (Al_2O_3)	
14.	The emissivity of refractory material…. a) increases sharply above 1000^0 C b) will be more or less independent of temperature c) will increase with increasing temperature **d) will decrease with increasing temperature**	
15.	High emissivity coatings are applied on a) outer surface of furnace b) refrigeration piping **c) inner surface of furnace** d) none of the above	
16.	The heat loss rate from a surface is expressed in **a) Watt** b) Watt/m^2 – ^{0}K c) Watt/m^2 – ^{0}C d) Joules	

17.	Which statement is incorrect a) higher density refractory has a lower thermal conductivity b) a higher emissivity means higher radiation of heat **c) a higher emissivity means lower absorption of heat** d) a black colored body radiates more than a glossy white colored one.
18.	Fluidized bed combustion takes place in a temperature range of a) 600^0C - 700^0C **b) 850^0C - 950^0C** c) above 1000^0C d) about 500^0C
19.	The low combustion temperatures in fluidized bed combustion boilers results in minimal formation of **a) NO_x** b) NO_x and SO_x c) CO_2 d) CO
20.	SO_x emissions in a FBC boiler fired with high sulfur coal are controlled by adding ____ to the bed a) Magnesia **b) Limestone** c) Sand d) Silica
21.	In circulating fluidized bed combustion boilers most of the heat transfer takes place… a) inside the combustion zone b) bed tubes **c) outside of the combustion zone** d) super heater tubes
22.	De-aeration of boiler feed water is referred to as **a) removal of dissolved gases** b) removal of silica from feed water c) removal of TDS from feed water d) phosphate treatment of feed water
23.	Pre-heating of combustion air in an oil fired furnace by 20^0 C will save about ___% of fuel a) 0.3 **b) 1** c) 1.5 d) 0.6
24.	To drain condensate from main steam line, the following type of trap is a suitable trap. a) float b) bimetallic **c) thermodynamic** d) none of the above
25.	Increase in stack gas temperature of 22^0 C due to tube fouling or other causes will increase oil consumption in an oil fired boiler by about. **a) 1%** b) 2% c) 3.5% d) 4%
26.	Water hammer in a steam system is caused by **a) collected condensate hits obstructions** b) leaking pipe joints c) slow moving steam d) continuous slope in direction of flow
27.	Which data is not required to calculate boiler efficiency by the indirect method **a) steam flow rate** b) stack gas temperature c) ambient temperature d) energy content of fuel

28.	Latent heat at the critical point of a steam phase diagram is a) infinite b) 540 kCal/kg **c) zero** d) none of the above
29.	Increase of steam pressure has which of the following effect on steam **a) steam temperature goes up and enthalpy of evaporation goes down** b) steam temperature and enthalpy of evaporation go down c) steam temperature goes up and enthalpy of evaporation goes up d) specific volume goes down and enthalpy of evaporation goes up
30.	Scale losses in reheating furnaces will increase with a) decrease in excess air b) decrease in furnace temperature **c) increase with excess air** d) are not correlated to temperature
31.	An air film inside in a steam pipe may be _______ times more resistant to heat transfer then the steel the steam pipe is made of. a) 200 – 1000 **b) 1500 – 3000** c) 4000 – 8000 d) 8000 – 16000
32.	The best steam for indirect heating in most industrial process is **a) as dry as possible** b) super heated steam c) wet steam d) as wet as possible
33.	Pressure drop through a steam pipe is inversely proportional to a) diameter b) square of diameter **c) fifth power of diameter** d) cube of diameter
34.	In an oil fired burner, the excess air level _____ towards the highest turndown ratio for efficient combustion. a) decreases **b) increases** c) not affected d) none of the above
35.	What is the most effective way to avoid ambient air infiltration into a continuous furnace a) close all openings b) increase the chimney height c) operate at about 90% capacity **d) reduce negative pressure inside the furnace**
36.	Black body radiation is a) linear proportional to temperature b) proportional to the fourth power of the temperature of the body **c) proportional to the fourth power of the absolute temperature of the body** d) proportional to the square of the body surface area
37.	Steam at 6 bar has a sensible heat of 159.33 kCal/ kg and latent heat of 498.59 kCal/ kg. If the steam is 95% dry than the total enthalpy is a) 625 kCal/ kg b) 649.95 kCal/ kg c) 553 kCal/ kg **d) 633 kCal/ kg**
38.	In which type of furnace operation is a low mass ceramic fiber insulation most suitable to reduce specific fuel consumption **a) batch type furnace** b) continuous Hoffmann tunnel kiln

	c) rotary high temperature furnace d) low temperature furnace
39.	Which loss is the highest in a typical re-heating furnace operating at 1300^0 C? **a) flue gas loss** b) wall loss c) necessary opening loss d)cooling water loss
40.	In a batch type furnace the following energy efficiency measure would be the most controversial a) increasing the insulation at the hot temperature side **b) increasing the insulation at the outer surface of the furnace** c) pre-heating the combustion air d) reducing excess air.
41.	Specific heat in kCal/kg -^{0}C of fuel oil is in the range of a) 0.15 – 0.20 **b) 0.22 – 0.28** c) 0.29 – 0.32 d) none of the above
42.	Grade B Indian coal has a energy content range (in kcal/kg) of a) 3360-4200 b) 4200-4900 c) 4940-5600 **d) 5600-6200**
43.	Which is the common coal firing system used in Indian thermal power plants? **a) pulverized coal firing** b) stoker firing c) fluidized bed d) pressurized bed
44.	Which of the following fuel requires maximum air for stochiometric combustion? a) Butane b) Propane **c) Hydrogen** d) Coal
45.	Stochiometric air required for combustion of Bagasse is about a) 13.7 **b) 3.2** c) 6 d) 18
46.	Which fuel releases the most energy per kg on complete combustion a) Carbon b) Sulphur c) Nitrogen **d) Hydrogen**
47.	How many kg of CO_2 are produced in complete combustion of 16 kg of Methane? a) 42 **b) 44** c) 16 d) none of the above
48.	Theoretical CO_2 of a fuel in % is 15.5. The measured CO_2 in the stack gas is 11% by volume. The percentage of excess air will be **a) 40.9%** b) 38.7 % c) 240.9 % d) 140.9 %
49.	Evaporation ratio (steam to fuel ratio) of an oil fired efficient boiler is in the range of a) 5 - 6 **b) 13 – 14** c) 1 - 3 d) 7 – 9
50.	A rise in conductivity of boiler feed water indicates a) drop in the total dissolved solids in boiler water b) more steam generation c) greater purity of feed water **d) rise in the total dissolved solids in boiler water**

-------- End of Section - I ---------

Section - II: SHORT DESCRIPTIVE QUESTIONS **Marks: 10 x 5 = 50**

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

S-1 (i) State the stochiometric combustion equation for Hydrogen and Carbon.
(ii) How many kg of water are generated by complete combustion of 1 kg of Hydrogen?
(iii) How many kg of Carbon Dioxide are generated by complete combustion of 1 kg of Carbon?

(i) $2H_2 + O_2 = 2H_2O$ **or** $H_2 + ½ O_2 = H_20$
4 + 32 = 36 (only for reference and further calculation)

$C + O_2 = CO_2$
12 + 32 = 44 (only for reference and further calculation)

(ii) **36/4 = 9 kg of water are generated for each kg of Hydrogen (**
(iii) **44/12 = 3.67 kg of Carbon Dioxide are generated for each kg of Carbon.**

S-2 Assume the stochiometric (theoretical) air to fuel ratio of furnace oil is 13.8. The burner operates at 15% excess air. Calculate the mass of stack gas generated from combustion of one kg of oil.

(i) Mass of air + mass of fuel = mass of stack gas
1.15 x 13.8 + 1 = 16.87 kg

S-3 (i) Explain the difference between the indirect and direct method of boiler efficiency evaluation
(ii) State both equations.

(i) The difference is that in the direct method two major flows (steam and fuel flow) must be measured to calculate the energy streams for steam as useful output and energy input from the fuel. The direct method does not identify or measure energy losses. In the indirect method no flow measurements are necessary and this method identifies and measures major losses and estimates not so major losses.

$$\eta \text{ (direct)} = \frac{\text{Heat output x 100}}{\text{Heat input}} \text{ in \%}$$

A more precise formulation is to replace heat output by "useful heat output" or "absorbed heat".

In the indirect method the losses are either measured or estimated and subtracted from 100.

η (indirect) = 100 – sum of losses in %.

S-4 Explain why group trapping is not recommended with steam traps.

a) **group trapping normally causes water logging**
b) **group trapping causes loss of output**
c) **pressure in the various steam spaces will be different, i.e. pressure at the drain outlet of a heavily loaded unit will be less than in the case of one that is lightly loaded. Since the traps discharge condensate due to differential pressure, the condensate from the heavily loaded one finds it difficult to reach the trap.**

S-5 A reheating furnace output is 5 tons/hour. Thermal efficiency is claimed to be 20%. Specific heat of billet is 0.12 kcal/kg^{o} C. Billets enter the furnace at 50^{o}C and leave at 1200^{o}C. Calculate the hourly oil consumption in liter if GCV of oil is 9,000 kCal/liter.

$$\text{Efficiency} = \frac{\text{heat absorbed in the stock}}{\text{heat in the fuel}} = 0.20 = \frac{5000 \times 0.12\,(1200-50)}{\text{liter} \times 9{,}000}$$

it follows, oil consumption is 383.3 liter/hour

S-6 How does high emissivity coating in a furnace chamber helps in reducing energy consumption?

(i) **promotes rapid and efficient transfer of heat**
(ii) **more uniform heating**
(iii) **extended life of refractory**
(iv) **for intermitted furnaces or where rapid heating is required such coating has reduced energy consumption by 8% to 20%.**

S-7 (i) Which sources of heat can be recovered from a 2 MW reciprocating engine cogeneration system? and
(ii) What is roughly the temperature level of these waste streams?

(i) **There are essentially two work streams such as a) exhaust gas b) coolers for water, air and oil**
(ii) **The temperature level of the exhaust gas streams are about 350^{0} C - 450^{0} C from exhaust gas and above 100^{0} C from cooling water.**

S-8 (i) list prime movers for cogeneration, and
(ii) state the one with the highest efficiency.

(i) list of prime movers

a) **steam turbine – back pressure**
b) **steam turbine – extracting and condensing**
c) **gas turbine**
d) **reciprocating engine**

(ii) the back pressure steam turbine cogeneration system is the most efficient if 100% of the back pressure exhaust steam is used.

S-9 Calculate the blow down rate in kg/hr from a boiler with an evaporation rate of 5 tons/hr, if the maximum permissible TDS in the boiler water is 4000 ppm and with 15% make up water addition. The feed water TDS is 300 ppm

$$\text{Blowdown (\%)} = \frac{\text{(feedwater TDS in \%)} \times \text{(\% Makeup)}}{\text{Permissible TDS in Boiler} - \text{Feedwater TDS}}$$

= 300 x 15/(4000-300) = <u>1.22%</u> or 5000 x 1.22/100 = <u>60.8 kg/hr</u>

(OR)

$$\textbf{Blowdown (\%)} = \frac{\textbf{feedwater TDS x \% Makeup}}{\textbf{Maximum Permissible TDS in Boiler water}}$$

$$\textbf{Blowdown (\%)} = \frac{\textbf{300 x 15}}{\textbf{4000}} \textbf{ = 1.13\% or 5000 x 1.13/100 = 56.5 kg/hr}$$

(Marks are to be awarded if the candidates have worked out the solution based on any one of the above formula.)

S-10 A firm wants to recover waste heat in a flue gas stream of 1800 kg/hour from a furnace. Specific heat of flue gas is 0.23 kCal/kg^{0}C.

(i) calculate the heat recovered if the heat exchanger has an efficiency of 97% and temperature of flue gas drops from 900^{0}C to 220^{0}C across the heat exchanger.

(ii) How many liters of water per hour can be heated by 40^{0}C from this waste stream?

(i) Heat transferred to water = 1,800 x 0.97 x 0.23 x (900 – 220)
= 273,074.4 kCal/hour

(ii) Solve for 273,074.4 = litres x 1 x 40

It follows <u>6827 litres per hour.</u>

-------- End of Section - II ---------

Section - III: LONG DESCRIPTIVE QUESTIONS Marks: 5 x 10 = 50

(i) Answer all **<u>Five</u>** questions
(ii) Each question carries **<u>Ten</u>** marks

L-1 It is proposed to replace an oil-fired boiler of 10 tons per hour with a coal fired boiler of equivalent capacity. With the help of the data provided find out the following:

(i) the annual oil consumption in tons per year?
(ii) the annual coal consumption in tons per year?
(iii) estimate annual fuel cost savings in Crore rupees
(iv) simple pay back period of the project, assuming the coal fired boiler costs Rs.1.5 Crore and annual repair and maintenance costs of the coal fired boiler are 25% of capital cost.
(v) Comment about accuracy of the calculated payback period.

Operation data

Heat content of steam	760 kCal/kg.
Feed water inlet temperature	70^0 C
Daily operating hours	24
Number of days / year	280
Efficiency of oil fired boiler	80%
Efficiency of coal fired	74%
Cost of oil	Rs.14/- kg.
Cost of coal	Rs.1.4 kg.
GCV of oil	10,000 kCal/kg
GCV of coal	4,400 kCal/kg.

(i) the hourly oil consumption is $\frac{10{,}000 \text{ kg} \times (760-70)}{10{,}000 \text{ kCal} \times 0.80}$ = 862.5 kg/h

it follows 862.5 x 24 x 280/1000 = <u>5796 tons per year</u>

(ii) the hourly coal consumption is $\frac{10{,}000 \text{ kg} \times (760-70)}{4{,}400 \times 0.74}$ = 2,119 kg/h

it follows 2,119 x 24 x280/1000 = <u>14240 tons/year</u>

(iii) Savings (5796 x14,000 – 14240 x 1,400)/10,000,000 = <u>Rs 6.12 Cr</u>

(iv) Simple pay back period 1.5/(6.12-0.25 x 1.5) = 0.26 years

(v) The dynamic payback period in fact cannot be calculated with these few simplistic assumptions because when switching from oil to coal there are additional labor and coal processing cost, which do not exist for oil. In addition the avoided repair and maintenance costs of the oil operation should be added. Note, that arguing the simple payback period method is inaccurate because of the time value of money is a wrong statement in this context where payback is in any case shorter than 1 year.

L-2 (i) Explain why dry saturated steam is preferred over wet or super heated steam for industrial process heating

(ii) Complete the enthalpy equation h_g = ? for wet steam and name the variables.
(iii) Why should one use dry steam at the lowest possible pressure for indirect steam heating.

(i) (a) Superheated steam gives up heat at a slower rate then saturated steam.
(b) wet steam has a lower heat content than dry steam.
(c) dry steam condenses quickly and provides a faster heat transfer (3 marks)

(ii) $h_g = h_f + X.h_{fg}$
h_f = enthalpy of saturated water at a given pressure
h_{fg} = enthalpy of evaporation of saturated water to saturated steam
h_g = enthalpy of saturated steam
X= dryness fraction of wet steam

(iii) The latent heat of steam increase with reduction of steam pressure and only latent heat takes part in the indirect heating process.

L-3 Explain incomplete combustion with reference to

(i) causes of incomplete combustion
(ii) the products of incomplete combustion

(i) In general the three T apply: Temperature in the combustion chamber should be high enough to ignite and maintain combustion, Turbulence helps for good mixing of fuel and oxygen and enough Time should be given to the fuel in the combustion chamber

The causes of incomplete combustion may be either of a chemical/kinetic or a physical nature.

Major causes of physical nature are insufficient atomization of oils, wrong sizing of coal, wrong pressure of oil, combustion flame coming too close to a "colder" surface and therefore freezing the chemical reaction, worn out burner nozzles, insufficient preheating of oil. In general bad mixing of fuel and combustion air and not enough turbulence.

The major chemical cause for incomplete combustion is insufficient amount of combustion air and therefore implicitly not enough oxygen to burn Carbon and Hydrogen to CO_2 and $H2_O$. The amount of combustion air must be more then the stochiometric or theoretical air for Carbon and Hydrogen.

(ii) The products of incomplete combustion are Carbon Monoxide (CO), as well as fine Carbon or soot, and liquid Higher Hydrocarbons.

L-4 (i) State the general equation for heat loss from a hot wall or pipe surface.
(ii) Name each variable and state SI - units of these variables

(ii) Where does the thermal conductivity of the wall or pipe structure enter in this equation?

(i) H = h x A x (T_h – T_a)

(ii) variables and units

H = heat loss in Watt (=Joules/s and therefore a heat loss rate)
h = heat (or film heat) transfer coefficient in W/m^2 °K (same as W / m^2 °C)
A = outer surface in m^2
T_h = hot surface temperature in degree Centigrade
T_a = ambient (surroundings) temperature in degree Centigrade

(iii) Thermal conductivity of the wall does enter this equation through T_h the hot surface temperature but not through h.

(OR)

S = [10 + (Ts-Ta)/20] x (Ts-Ta)

Where

S	=	Surface heat loss in kCal/hr m^2
Ts	=	Hot surface temperature in K
Ta	=	Ambient temperature in K

(OR)

$$Q = a\,x\,(t_1 - t_2)^{5/4} + 4.88\,E\,x\left(\left(\frac{t_1+273}{100}\right)^4 - \left(\frac{t_2+273}{100}\right)^4\right)$$

where Q: Quantity of heat released (kCal/hr)
a : factor regarding direction of the surface of natural convection ceiling = 2.8, side walls = 2.2, hearth = 1.5
t_l : temperature of external wall surface of the furnace (°C)
t_2 : temperature of air around the furnace (°C)
E: emissivity of external wall surface of the furnace

L-5 (i) Draw the schematic for a 2 MW internal combustion engine used as cogeneration system to generate power and hot water by cold water.

(ii) How many cubic meters of water can be heated from 30^0 C to 60^0 C per hour if the power generation unit has an efficiency of 40% for the generation of electricity without the waste heat recovery components and 82% with the waste heat recovery component. Assume a fuel oil consumption of 220 gram/kWh electricity at an output of 1.8 MW and GCV of oil 10,000 kCal/kg

(i)

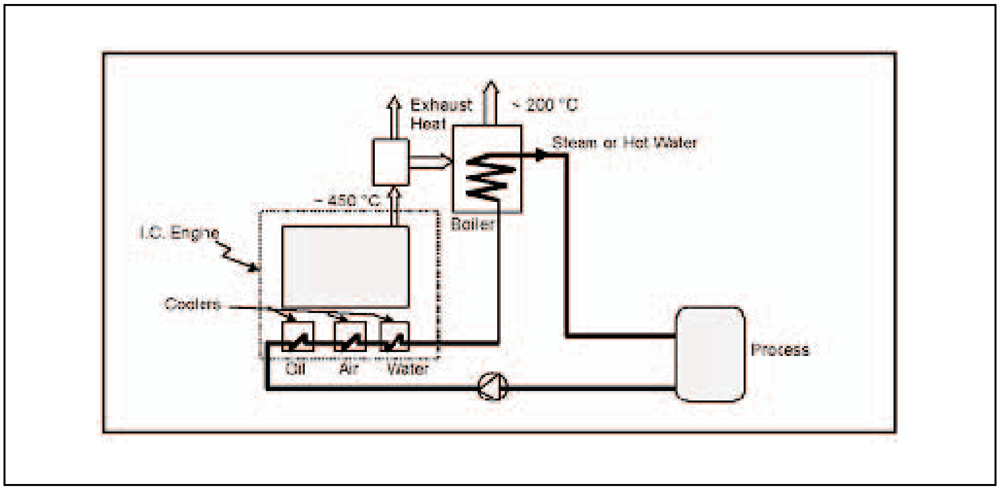

Figure 7.5 Schematic Diagram of Reciprocating Engine Cogeneration

(ii) Total fuel energy available is 0.22 x 10,000 x 1,800 = 3,960,000 kCal/h

Fuel energy per hour converted to electricity is 0.4 x 0.22 x 10,000 x 1800 = 1,584,000 kCal/h.

Fuel energy loss neither converted to electricity nor warm water 0.18 x 0.22 x10,000 x1,800 = 712,800 kCal/h

Fuel energy available to heat water 3,960,000–1,584,000–712,800= 1,663,200 kCal/h
Consequently 1,663,200 / [(60-30)x1000] = 55 cubic meters of water per hour

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