Paper-2 Code : Pink

25th NATIONAL EXAMINATION FOR CERTIFICATION
OF
ENERGY MANAGERS & ENERGY AUDITORS - SEPTEMBER, 2025

PAPER - 2 : ENERGY EFFICIENCY IN THERMAL UNTILITIES

Date : 27.09.2025 Timings : 14:00-17:00 HRS Duration : 3 HRS Max. Marks : 150

General instructions :

- *Please check that this question paper contains **8** printed pages*
- *Please check that this question paper contains **64** 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) Please shade the appropriate oval in “SECTION-I” of “MAIN ANSWER BOOKLET” with BLUE/BLACK ball point pen

1.	The flash point of an oil is the: A) Temperature at which the oil ignites spontaneously B) **Lowest temperature at which the oil vapour momentarily ignites on application of a flame** C) Temperature at which the oil starts boiling D) Temperature at which the oil burns continuously
2.	Which type of fuel requires lowest amount of excess air for combustion? A)Furnace oil B) LDO C) **Propane** D) Rice Husk
3.	Which among the following does not release any energy during combustion? A) Carbon B) Sulphur C) **Nitrogen** D) Hydrogen
4.	Which is the best suited pump for pumping viscous liquid fuel? A) Centrifugal pump B) **Gear pump** C) Vertical turbine pump D) None of the above
5.	In a water tube boiler, what is the primary function of the boiler drum? a) To superheat the steam leaving the economizer **b) To separate steam from water and provide storage for steam and water mixture** c) To maintain draft inside the furnace by balancing air and flue gas pressure d) To preheat the feedwater before entering the boiler tubes
6.	Dearation in boilers is primarily carried out to remove: a) Dissolved solids **b) Dissolved gases** c) Suspended particles d) Boiler scale
7.	Which of the following best describes the critical point of steam? A) The point where steam condenses to water at standard atmospheric pressure **B) The highest temperature and pressure at which liquid water and steam can coexist in equilibrium** C) The temperature at which steam becomes superheated D) The point where latent heat of vaporization is maximum
8.	Which of the following is preferable for a heating process? a) Wet steam b) flash steam c) High pressure steam d) **Dry saturated steam**
9.	A float steam trap is an example of which type of steam trap? A) Thermodynamic **B) Mechanical** C) Thermostatic D) Hydraulic

10. Which of the following is commonly used as a low-temperature insulating material?
A) Calcium silicate **B) Polyurethane** C) Magnesia D) Asbestos

11. The economic thickness of insulation is the thickness at which:
A) Heat loss is zero
B) Cost of insulation is minimum
C) Combined cost (heat loss cost and insulation cost) is minimum
D) Heat transfer rate is maximum

12. Which of the following is a key advantage of Fluidized Bed Combustion (FBC) over conventional combustion systems?
a) Lower power requirement for fans
b) Reduced emissions of SO_2 and NO_x
c) Higher excess air requirement
d) Lower combustion efficiency

13. In a fluidized bed combustion system, the fuel is burned in a bed of:
A) Moving metal plates
B) Sand, ash, or other granular material suspended by air flow
C) Rotating drums
D) Water-cooled tubes only

14. In a combined cycle power plant, the waste heat from the gas turbine is used to:
A) Preheat the incoming air to the gas turbine
B) Generate steam for a steam turbine
C) Cool the exhaust gases directly to the atmosphere
D) Operate a diesel generator

15. The effectiveness of a heat exchanger is defined as the ratio of:
A) Actual heat transfer to the maximum possible heat transfer
B) Heat loss to the surroundings to the total heat input
C) Outlet temperature difference to inlet temperature difference
D) Actual heat transfer to the total mass flow rate

16. In pinch analysis, the "pinch point" represents:
A) The location in the heat exchanger where fouling is maximum
B) **The point of minimum temperature difference between hot and cold streams**
C) The point where heat transfer rate is maximum
D) The location where the heat exchanger pressure drop is minimum

17. The presence of high sulphur in fuels mainly contributes to:
A) Reduction in NOx emissions
B) Corrosion and air pollution
C) Decrease in net calorific value
D) Prevention of slag formation

18. Why is viscosity of liquid fuels important in combustion systems?
A) It determines the fuel's sulphur content
B) **It affects atomization and burner performance**
C) It indicates the ash fusion temperature
D) It measures the fuel's calorific value

19. In boilers, natural draft is produced by:
A) A steam ejector
B) The height and temperature difference in the chimney
C) A forced draft fan
D) Vacuum pump

20. As per Indian Boiler Regulations (IBR), a pipe is defined as a steam pipe if it carries steam at a pressure exceeding
1 Mark Awarded to all candidates who attempted this question

21. Which of the following is an example of internal water treatment in boilers?
A) Deaeration
B) Coagulation and filtration
C) **Sodium Phosphate dosing**
D) Clarification

22.	In boiler water treatment, Reverse Osmosis (RO) is primarily used to: A) Remove only suspended solids from water **B) Remove dissolved salts and impurities** C) Increase the alkalinity of feedwater D) Convert hard water into soft water
23.	Which of the following is not a benefit of condensate recovery in a steam system? **1 Mark Awarded to all candidates who attempted this question**
24.	When steam passes through a pressure reducing valve (PRV), its enthalpy: A) Increases B) Decreases **C) Remains the same** D) Becomes zero
25.	A thermocompressor in a steam system is primarily used to: A) Convert wet steam into dry saturated steam B) **Recompress low-pressure steam with high-pressure steam to obtain medium-pressure steam** C) Increase boiler steam generation rate D) Reduce steam temperature without affecting pressure
26.	Higher excess air in an oil-fired furnace leads to: A) Higher efficiency B) Lower flue gas heat loss C) Zero stack losses D) **None of the above**
27.	The main benefit of using preheated air for combustion is: A) Reduced furnace temperature B) **Increased fuel savings** C) Increased excess air requirement D) Higher flue gas temperature
28.	Choose the correct statement about insulating materials: A) Insulating materials have high thermal conductivity B) **Insulating materials reduce heat loss** C) Insulating materials increase heat transfer rate D) All of the above
29.	Choose the incorrect statement about refractories: A) Refractories are used to withstand high temperatures in furnaces B) Refractories should have low thermal conductivity for insulation purposes **C) Refractories should have low melting points for easy shaping** D) Refractories must be resistant to thermal shock
30.	Which of the following defines the *Gross Calorific Value (GCV)* of a fuel? **a) Heat liberated after complete combustion including latent heat of water vapor** b) Heat available after combustion excluding latent heat of water vapor c) Heat required to raise 1 kg of fuel by 1°C d) Ratio of heat released to air-fuel ratio
31.	Which of the following statements about a fluidized bed boiler is correct? **A) It can efficiently burn low-grade fuels with high ash content** B) It requires very high combustion temperatures (above 1600 °C) C) It operates without any bed material D) It cannot be used for biomass fuels

32. An extraction condensing turbine is designed to:
A) Exhaust all steam to the process at high pressure
B) **Extract some steam for process use and balance steam for power generation**
C) Operate only as a back pressure turbine
D) Exhaust steam directly to atmosphere

33. The main advantages of a cogeneration system include:
A) Higher overall efficiency
B) Simultaneous production of power and heat
C) Reduced fuel consumption
D) All of the above

34. The relationship between heat rate and plant efficiency is such that:
A) Higher heat rate means higher efficiency
B) Lower heat rate means higher efficiency
C) Heat rate and efficiency are unrelated
D) Both increases together

35. A metallic radiation recuperator is primarily used to:
A) Recover heat from flue gases to preheat combustion air
B) Convert radiant heat into electricity
C) Cool furnace walls to prevent overheating
D) Measure furnace temperature using radiation

36. Select the correct statement about the benefits of waste heat recovery:
A) It increases fuel consumption
B) It reduces overall plant efficiency
C) **It saves energy and reduces operating costs**
D) It always requires high-grade heat sources

37. Terminal temperature difference (TTD) in a steam to water heat exchanger is:
A) Inlet temp. difference
B) Outlet temp. difference
C) **Difference of Steam Saturation temperature and outlet water temperature.**
D) Avg. temperature difference

38. Select the correct statement about flash steam:
A) It is produced by cooling steam below saturation temperature
B) It is produced by cooling steam above saturation temperature
C) It forms when hot condensate is released to a lower pressure
D) It forms when hot condensate is released to a higher pressure

39. The specific gravity of a fuel is the ratio of:
A) Weight of fuel to its volume
B) Density of fuel to the density of water
C) Volume of fuel to volume of water
D) Mass of fuel to its calorific value

40. Select the correct statement about volatile matter in coal:
A) It reduces flame stability in combustion
B) It consists of gases released when coal is heated
C) It is the same as fixed carbon
D) It increases the ash content of coal

41. The Net Calorific Value (NCV) of a fuel is obtained by:
A) **Subtracting the heat of vaporization of water from the Gross Calorific Value**
B) Adding the heat of vaporization of water to the Gross Calorific Value
C) Measuring only the sensible heat of combustion products
D) Ignoring latent heat losses in the fuel

42. Which of the following agro fuels typically has the highest moisture content?
A) Saw dust
B) Paddy husk

	C) De-oiled bran D) Coconut shells
43.	Select the correct statement about excess air in combustion: A) Excess air always increases boiler efficiency B) **Excess air is needed to ensure complete combustion of fuel** C) Excess air reduces flue gas losses D) Excess air is less than the theoretical air
44.	In a pulverised fuel boiler, the fuel is burned in : A) lump form B) fluidised bed form **C) fine powder form** D) None of the above
45.	Select the correct statement about a supercritical boiler: **A) It generates steam at pressures above the critical point** B) It always requires a steam drum for separation of steam and water C) It operates only with natural circulation D) It produces steam with high moisture content
46.	A thermic fluid heater is primarily used to: A) Generate steam at high pressure B) **Heat a mineral oil** C) Produce hot water D) Produce hot air
47.	A cupola furnace is primarily used for: A) **Producing cast iron** B) Producing steel ingots C) Heating non-ferrous metals D) Producing coke
48.	Select the correct statement about flue gas losses in a reheating furnace: A) Flue gas losses decrease with higher flue gas temperature B) **Flue gas losses increase with excess air and higher exhaust temperature** C) Flue gas losses are unaffected by excess air D) All of the above
49.	The principle of cogeneration is based on: A) Using separate systems to produce heat and power B) **Sequential use of energy to produce both electricity and useful heat from the same fuel** C) Converting all heat into electricity D) Using waste heat only for cooling
50.	Trigeneration refers to the simultaneous production of: A) **Power, heat, and cold** B) Power, heat, and steam C) Power, steam, and compressed air D) Heat, cold, and compressed air

.... End of Section I ....

Section – II: SHORT DESCRIPTIVE QUESTIONS

Marks: 8 x 5 = 40

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

S-1

A 10-TPH forced-draft boiler is tested at a load of 8 TPH. Fuel flow is 0.53 TPH and the fuel GCV is 10,000 kcal/kg. Feedwater temperature is 70 °C. The boiler delivers saturated steam at 10 bar(g) at 186 °C. Take the specific enthalpy of saturated steam has 664 kcal/kg.

a) Calculate the direct efficiency assuming dry saturated steam. 3 Marks

b) The indirect method efficiency is 87%, which does not match with the direct method. The auditor claims this difference is due to the wetness of steam. Establish the auditor's claim by calculating the dryness fraction. 2 Marks

S-1 Ans

Fuel flow to boiler = 0.53 TPH
Steam flow = 8TPH
Fuel GCV = 10000 kcal/kg
Steam enthalpy = 664 kcal/kg
Feed water enthalpy = 70 kcal/kg
Direct efficiency =

$$\frac{8\ x\ (664-70)}{.53\ x\ 10000} = 89.7\%$$

Indirect efficiency = 87%

Moisture content/ Steam quality: If the steam is slightly wet, the actual enthalpy is lower, reducing the direct efficiency closer to the indirect efficiency.

Total heat content of wet steam = sensible heat + (dryness fraction * latent heat)
= 186 + (x* (664-186))
= 186+478x

$$Boiler\ Efficiency = \frac{8 * [(186 + 478x) - 70]}{.53\ x\ 10000} = .87$$

X= 96.3%. Hence steam is not fully dry in nature. This is the reason for difference in efficiency

S-2

A boiler has an air preheater whose design and actual conditions are given below:

	Design (^0C)	Actual (^0C)
Flue gas Inlet temperature to APH	330	330
Flue gas outlet temperature from APH	180	210
Air inlet temperature to APH	40	40
Air outlet temperature from APH	190	190

Assume the following: specific heats of flue gas and air are equal, there is no heat loss to the surroundings, and as per design the mass of flue gas is approximately to the mass of air.

Analyze and discuss the deviations between actual operating condition and design condition in air mass flow, flue-gas mass flow and APH heat transfer.

S-2 Ans

Cp FG = Cp Air
m FG = m Air

Design

(TFGout – TFG in) = (330-180) = 150
(Tair out – Tair in) = (190-40) = 150
Heat balance exists

Actual

(TFGout – TFG in) = (330-210) = 120
(Tair out – Tair in) = (190-40) = 150
Heat is not balanced.

Implications:

a) Air mass flow: Likely lower than design (or part of the air is bypassing the APH). When less air is heated, temperature of outlet air can still reach 190 °C, but the gas won't cool as per design.

b) Flue-gas mass flow: Effectively higher than air by ~25% at the APH (or flue-gas ingress/leakage upstream of APH inflates the gas stream). This drives the exit flue-gas hotter than the design (210 °C vs 180 °C).

c) APH heat transfer: Heat recovery is less than the design as evidenced by the higher gas outlet temperature (less gas-side cooling).

S-3

If the insulation thickness on a steam pipe is increased from 50 mm to 100 mm, calculate the percentage reduction in heat loss. The surface temperature of the insulation is 70 °C for 50 mm thickness and 60 °C for 100 mm thickness. Ambient temperature is 35 °C.

S-3 Ans

S = [10 + (Ts − Ta)/20] × (Ts − Ta)

Calculations

1) Heat loss for 50 mm insulation:

ΔT1 = Ts1 − Ta = 70 − 35 = 35 °C

S_{50} = [10 + (35/20)] × 35 = (10 + 1.75) × 35 = 11.75 × 35 = 411.25 kcal/hr/m^2

2) Heat loss for 100 mm insulation:

ΔT2 = Ts2 − Ta = 60 − 35 = 25 °C

S_{100} = [10 + (25/20)] × 25 = (10 + 1.25) × 25 = 11.25 × 25 = 281.25 kcal/hr/m^2

Note : Since the diameter of the pipe is not mentioned in the question paper. If the candidate has calculated the rate of heat loss for 50 mm and 100 mm insulation full marks may be awarded.

S-4

In a food processing industry, steam at 15 kg/cm^2 was used to heat 10 TPH of milk from 40 °C to 80 °C. An energy auditor suggests installing a PRV to reduce steam pressure from 15 kg/cm^2 to 3 kg/cm^2. Specific heat of milk is 1.0 kcal/kg/°C.

Steam Parameters	Present Condition (Steam Pressure 15 kg/cm^2)	Proposed Condition (Steam Pressure 3 kg/cm^2)
Sensible heat	200.6 kcal/kg	133.287 kcal/kg
Latent Heat	465.72 kcal/kg	517.17 kcal/kg
Dryness Fraction	0.9	?

a) Determine the outlet moisture percentage when steam passes through the PRV. 3 Marks

b) Calculate the steam savings per hour due to this measure. 2 Marks

S-4 Ans

a) Total heat content before PRV = Total heat content after PRV

200.6 + (0.9*465.72) =133.287 +(x *517.17)

x = 0.94

b)

Heat required for water = (10*1000)*1*(80-40) = 400000 kcal/hr

Steam requirement at present condition= 400000/ (465.72*0.9) = 954.3 kg/hr

Steam requirement at proposed condition = 400000/ (517.17*.94) = 822.8 kg/hr

Savings = 131.5 kg/hr of steam

S-5

In an oil-to-water counterflow heat exchanger, hot oil enters at 150 °C and leaves at 90 °C. Cold water enters at 30 °C and leaves at an unknown temperature Tc,o. The log mean temperature difference (LMTD) for the exchanger is 60 °C. Calculate the exit temperature of the water.

S-5 Ans

Given:

Hot oil inlet temperature, Th,i = 150 °C

Hot oil outlet temperature, Th,o = 90 °C

Cold water inlet temperature, Tc,i = 30 °C

Cold water outlet temperature, Tc,o = ?

LMTD = 60 °C

For counterflow heat exchangers:

ΔT1 = Th,i − Tc,o = 150 − Tc,o

ΔT2 = Th,o − Tc,i = 90 − 30 = 60

LMTD is given by:

LMTD = (ΔT1 − ΔT2) / ln(ΔT1 / ΔT2) = 60

Let ΔT1 = A. Then:

(A − 60) / ln(A / 60) = 60

This equation holds true when A = 60 (equal terminal differences case).
Therefore: 150 − Tc,o = 60 ⇒ Tc,o = 90 °C

Answer
The exit temperature of the cold water is Tc,o = 90 °C.

S-6 A batch furnace uses LPG and draws combustion air at 30 °C from the ambient condition. An energy auditor proposes fitting a recuperator to use hot flue gas (950 °C) to preheat this air to 400 °C.

Parameter	Value
Gross Calorific Value (GCV)	11,500 kCal/kg
Baseline fuel consumption	50 kg/h
Excess air	20 %
Stoichiometric air requirement	15.5 kg air / kg LPG
Specific heat of air & flue gas	0.24 kCal/kg°C

a) Find the % fuel savings from preheating the air to 400 °C. 2 Marks
b) Find the new LPG consumption after retrofit. 2 Marks
c) Calculate the flue-gas exit temperature from the recuperator using an energy balance. 1 Mark

S-6 Ans

Given:
EA = 20%, Stoichiometric air = 15.5 kg air/kg LPG, cp (air & flue gas) = 0.24 kcal/kg·°C.
Actual air (AAS) = (1 + EA) × 15.5 = 1.2 × 15.5 = 18.6 kg/kg fuel.
Flue gas per kg fuel: mfg = 1 + AAS = 1 + 18.6 = 19.6 kg/kg fuel.

(a) % Fuel savings:
Recovered heat to air per kg fuel: $P = m_{air} \times cp \times (T_{air,out} - T_{air,in})$
= 18.6 × 0.24 × (400 − 30) = 1651.68 kcal/kg fuel
Savings = P / GCV = 1651.68 / 11,500 = 0.1436 ⇒ **14.36 %**

(b) New LPG consumption:
$m_{new} = m_{old} \times (1 - \text{Savings}) = 50 \times (1 - 0.1436) \approx$ **42.8 kg/h**

(c) Flue-gas exit temperature from recuperator (energy balance):
$m_{fg} \text{ x } cp \text{ x } (T_{fg,in} - T_{fg,out}) = m_{air} \text{ x } cp \text{ x } (T_{air,out} - T_{air,in})$
$19.6\,(950 - T_{fg,out}) = 18.6 \times 370 = 6882$
$950 - T_{fg,out} = 6882 / 19.6 \approx 351.12 \Rightarrow T_{fg,out} \approx 950 - 351.12 =$ **599 °C**

S-7 Match the Following:

Term	Description
1. Topping Cycle	a. Produces power first, then recovers heat for process use
2. Bottoming Cycle	b. Produces power, heat, and cooling from the same energy source
3. Heat-to-Power Ratio	c. Produces heat first, then uses waste heat to generate power
4. Combined Cycle Plant	d. Useful thermal energy to electrical energy output
5. Trigeneration	e. Uses gas turbine and steam turbine in series

S-7 Ans

1 – a
2 – c
3 – d
4 – e
5 – b

S-8 **Fill in the Blanks:**

1. A furnace oil consumption of 250 liters/day, with density 0.96 kg/l and GCV 10,200 kcal/kg, provides a total heat input of _________ kcal/day.
2. If the NCV of a fuel is 9,500 kcal/kg and the mass of fuel burned is 500 kg, the total heat energy released is _________ MWh
3. For complete combustion of 1 kg of carbon, the theoretical air requirement is _________ kg.
4. Calculate % of nitrogen in dry flue gas if 1 kg of hydrogen is completely burned in presence of 34.8 kg of air.
5. A coal sample with a GCV of 4,500 kcal/kg and moisture content of 10% has an approximate NCV of _________ kcal/kg, assuming latent heat of vaporization of water = 587 kcal/kg.

S-8 Ans

1. 250 L/day × 0.96 kg/L = 240 kg/day, Heat input = 240 × 10,200 = 2,448,000 kcal/day
2. Energy = 9,500 × 500 /(860 *1000) = 5.52 MWh
3. 11.6 kg of theoretical air per kg of carbon
4. 100%
5. NCV = GCV − (Moisture fraction × 587) = 4,500 − (0.10 × 587) = 4,441 kcal/kg

.... End of Section II ....

Section – III: LONG DESCRIPTIVE QUESTIONS **Marks: 6 x 10 = 60**

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

L-1

A small-scale industry with an old 2-pass gas fired boiler, operating at 65% efficiency is considering replacing it with a new 3-pass boiler that has an efficiency of 80%. The industry has an average steam load of 8 TPH at 10 kg/cm^2 with steam enthalpy of 665 kcal/kg, and the new boiler is also equipped with an economizer to preheat the feedwater from 35°C to 75°C. The flue gas exit temperature of the old boiler is 160°C, and the new boiler's flue gas exit temperature will be 85°C. The total operating hours for the year are 6,000. The GCV of natural gas is 9,500 $kcal/m^3$.

Given the above conditions, calculate the following:
1.The annual fuel savings from replacing the old boiler with the new 3-pass boiler **6 Marks**
2. Fuel saving due to preheating the feed water. **2 Marks**
3. Evaluate the % improvement in boiler evaporation ratio if Natural gas density is 0.68 kg/m^3 **2 Marks**

L-1 Ans

1.Annual fuel savings from replacing the old boiler with the new 3-pass boiler:

Fuel Consumption Calculation for the Old Boiler

Useful Heat Output (Old Boiler):
The useful heat output can be calculated using steam flow rate and enthalpy difference:
Useful Heat Output = Steam Load × (Enthalpy of Steam - Enthalpy of Feed Water)
Useful Heat Output = 8,000 kg/h × (665 kcal/kg - 35 kcal/kg) = 5,040,000 kcal/h.

Heat Input to Old Boiler:
The heat input required by the old boiler is given by:
Heat Input (Old Boiler) = Useful Heat Output / Efficiency (Old Boiler)
Heat Input (Old Boiler) = 5,040,000 / 0.65 = 7,746,153.85 kcal/h.

Fuel Consumption (Old Boiler):
To calculate the fuel consumption, we use the GCV of natural gas:
Fuel Consumption (Old Boiler) = Heat Input (Old Boiler) / GCV of Natural Gas
Fuel Consumption (Old Boiler) = 7,746,153.85 / 9,500 = 815.3 m^3/h.

Fuel Consumption Calculation for the New Boiler

Heat Input to New Boiler:
The new boiler operates at 80% efficiency,
Heat Input (New Boiler) = Useful Heat Output / Efficiency (New Boiler)
Useful Heat Output = Steam Load × (Enthalpy of Steam - Enthalpy of Feed Water)
Useful Heat Output = 8,000 kg/h × (665 kcal/kg - 75 kcal/kg) = 4,720,000 kcal/h
Heat Input (New Boiler) = 4,720,000 / 0.80 = 5,900,000 kcal/h.

Fuel Consumption (New Boiler):
Fuel Consumption (New Boiler) = Heat Input (New Boiler) / GCV of Natural Gas
Fuel Consumption (New Boiler) = 5,900,000 / 9,500 = 621.1 m^3/h

	Fuel Savings from Replacing the Old Boiler Fuel Savings: Fuel Savings = Fuel Consumption (Old Boiler) - Fuel Consumption (New Boiler) Fuel Savings = 815.3 - 621.1 m^3/h= 195.1 m^3/h. Annual Fuel Savings: Annual Fuel Savings = Fuel Savings × Operating Hours Annual Fuel Savings = 195.1 × 6,000 = 1,170,600 m^3/year. **2. Fuel saving due to preheating the feed water.** Temperature difference = 75-35 = 40^oC Heat recovery = 8000*1*40 = 3,20,000 kcal/hr Equivalent fuel savings = 3,20,000 /9500 = 33.68 m^3/hr **3. % improvement in boiler evaporation ratio if Natural gas density is 0.68 kg/m^3** Evaporation ratio of the old boiler = 8000 / (815.3*0.68) = 14.43 Evaporation ratio of the new boiler = 8000 / (621.1*0.68) = 18.94 % improvement = {(18.94-14.43) / 14.43} *100 = 31.25 %
L-2	A chemical plant is considering the following two schemes: **Scheme 1:** A boiler supplies steam for a condensing turbine as well as for the process heat requirement. The condensing turbine produces 1 MW of electric power with an overall efficiency of 33%. The process requires 3 MW of heat, and the boiler efficiency is 80%. **Scheme 2:** A boiler supplies steam for a back-pressure turbine, which produces 1 MW of electric power with an overall efficiency of 90%. The process heat requirement of 3 MW is met by the back-pressure steam and the boiler efficiency is 75%. Calculate the following: 1.Determine the heat input to the boiler (in MW) and energy utilization factor for both the schemes. **6 Marks** 2. The percentage fuel savings achieved by the energy-efficient scheme compared to the other. **4 Marks**
L-2 Ans	**Scheme 1:** Power produced by condensing power plant = 1MW Heat input to thermal power plant = 1/.33 = 3 MW Process heat requirement = 3 MW Both the thermal requirements come from boiler running at 80% efficiency Hence to produce 6MW of heat, the fuel input to boiler should be 6/.80 = 7.5 MW Energy Utilization factor = (3 + 1)/7.5 = 0.53 **Scheme 2:** Cogeneration plant power production 1 MW BP overall efficiency is 90%, output of BP turbine is 3 MW Let the boiler output be x, So(x-3)*0.9 = 1MW x= 4.1 MW Boiler runs at 75% efficiency Fuel input = 4.1/ 0.75 = 5.5 MW Energy Utilization factor = (3 + 1)/5.5 = 0.73 Therefore, scheme -2, would be the efficient scheme. % reduction = (7.5-5.5)/7.5 x100 = 26.66% improvement

L-3

The operating parameters of the re-heating furnace in a hot rolling mill, both before and after the improvements, are presented below:

Parameter	**Value**
Fuel consumption	2300 litres/hour
Furnace oil density	0.92
Furnace oil is pre-heated from 30 °C to 105 °C	30°C → 105 °C
GCV of furnace oil	10200 kcal/kg
Cost of fuel per ton	Rs.49,000/-
Exit flue gas temperature after recuperator	400 °C
Specific heat of flue gas	0.24 kcal/kg·°C
Specific heat of steel	0.12 kcal/kg·°C
Billet temperature	1250 °C
Present combustion air preheat temperature	290 °C
Average production	650 tonnes/day
Average operating hours per day	12 hours
Annual operation days	300
Ambient temperature	30 °C
Oxygen in flue gas	11 %
Theoretical air requirement	14 kg/kg fuel
Improved Condition:	
Oxygen in flue gas	5 %
Combustion air preheat temperature	390 °C
Flue gas temperature after improving recuperator performance	340 °C

Calculate the following:

a) Present Specific Energy Consumption (SEC) in litres/ton – ***1 Mark***

b) Fuel savings achieved after improvements in recuperator in per tonne of metal- **6 Marks**

c) New Specific Energy Consumption (SEC) in litres/ton – ***1 Mark***

*d)*Annual savings in Rs. Lakhs ***2 Marks***

L-3 Ans

Production in TPH	54.17	
SEC (lts/ton)	42.46	
SEC (kg of fuel / ton of metal)	39.06	
Fuel Savings = Equivalent Heat Recovery from recouperator		
Before Improvements		
Excess air in Present Condition = 11/(21-11)*100	110	%
AAS= 14*(1+1.11)	29.54	kg /kg fuel
Mass of Flue Gas = AAS+1	30.54	kg /kg fuel
Heat Loss= 30.54*0.24*(400-30)	2711.952	kCal/kg Fuel
After Improvements		
Excess air in Present Condition = {5/(21-5)}*100	31.25	%
AAS= 14*(1+0.3125)	18.375	kg /kg fuel
Mass of Flue Gas = AAS+1	19.375	kg /kg fuel
Heat Loss = 19.375*0.24*(340-30)	1441.5	kCal/kg Fuel
Heat Loss Reduction/Heat Recovery	1270.452	kCal/kg Fuel
% heat recovery = 1270.45/10200	12.46	%
Equivalent Fuel Quantity Savings = 2300*0.92*0.1246	263.56	kg/Hr
Fuel Savings per Tonne of Metal	4.87	kg/ Ton of Metal

New Fuel Consumption	1852.44	kg/Hr
New SEC (lts/Hr) = 1852.44/0.92/54.17	37.17	lts/ton
Annual Savings		
Difference in fuel consumption	5.29	lts/ton
Density of furnace oil	0.92	
Furnace oil cost	49000.00	Rs/ton
Cost per liter	45.08	Rs/liter
Average production	650	tonnes/day
Average operating hours per day	12	hours
Daily fuel savings	1.55	Rs.Lakh/Day
Annual Savings	465	Lakhs

L-4

A hot liquid waste stream with a flow rate of 4.0 kg/s, an inlet temperature of 80°C, and a specific heat capacity of 4200 J/kg K is utilized in a heat exchanger to recover heat for preheating boiler make-up water. The make-up water enters at 35°C with a flow rate of 3.0 kg/s and the same specific heat capacity of 4200 J/kg K and it is required to leave at 55°C. The heat exchanger has an overall heat transfer coefficient of 850 W/m^2 K and heat losses to the surroundings are assumed negligible. Based on these conditions, determine:

a)	The rate of heat transfer	**2 Marks**
b)	The exit temperature of the waste stream	**6 Marks**
c)	The required area of the heat exchanger	**2 Marks**

L-4 Ans

1) Heat Transfer Rate (Q):
The heat transfer rate can be calculated using the formula:
Q = ṁ_m * c_m * (T_m,out - T_m,in)
Substituting the values:
Q = 3 kg/s * 4200 J/kg·K * (55 - 35) K
Q = 3 * 4200 * 20 = 252,000 J/s = 252 kW
Thus, the heat transfer rate is 252 kW.
2) Exit Temperature of the Effluent (Waste Stream):
The heat lost by the waste stream is equal to the heat gained by the make-up water. Therefore, we can calculate the exit temperature of the waste stream using the formula:
Q = ṁ_w * c_w * (T_w,in - T_w,out)
Rearranging for T_w,out:
T_w,out = T_w,in - (Q / (ṁ_w * c_w))
Substituting the values:
T_w,out = 80°C - (252,000 J/s / (4.0 kg/s * 4200 J/kg·K))
T_w,out = 80°C - (252,000 / 16,800)
T_w,out = 80°C - 15°C
T_w,out = 65°C
Thus, the exit temperature of the effluent (waste stream) is 65°C.
3) Area of the Heat Exchanger (A):
We can use the heat exchanger equation to calculate the area required:
Q = U * A * ΔT_m
Where ΔT_m is the log mean temperature difference (LMTD). To calculate ΔT_m, we use:
ΔT_m = ((T_w,in - T_m,out) - (T_w,out - T_m,in)) / ln((T_w,in - T_m,out) / (T_w,out - T_m,in))
Substitute the values:
ΔT_m = ((80 - 55) - (65 - 35)) / ln((80 - 55) / (65 - 35))
ΔT_m = (25 - 30) / ln(25 / 30)
ΔT_m = -5 / ln(0.83)
ΔT_m = -5 / -0.186 ≈ 26.88 K
Now, we can solve for A:
A = Q / (U * ΔT_m)
Substituting the values:
A = 252,000 / (850 * 26.88)
A = 252,000 / 22,848 ≈ 11.03 m^2
Thus, the area of the heat exchanger required is approximately 11.03 m^2.
(Any value between 10.81 m^2 to 11.05 m^2 full marks shall be awarded)

L-5

a)
An oil-fired boiler is generating 80 TPH of steam at 88% efficiency, operating 300 days in a year. Management has installed a water treatment plant at an investment of Rs. 1.5 crore to reduce the TDS in boiler feed water from 600 ppm to 200 ppm. The maximum permissible limit of TDS in the boiler is 3000 ppm, and the make-up water is 12%. The temperature of blowdown water is 180°C, and the boiler feed water temperature is 50°C. The calorific value of fuel oil is 10,500 Kcal/kg, and the cost of fuel is Rs. 40,000 per ton. Calculate the payback period for the investment in the water treatment plant. **6 Marks**

b) True or False **4 Marks**

1. Saturated steam and dry steam mean the same thing in practical usage.
2. Installing a steam trap upside down has no effect on its operation because condensate is removed due to pressure difference only.
3. If a boiler operates with 8% blowdown at full load, reducing it to 4% will proportionally increase steam generation without additional fuel consumption.
4. A pressure reducing valve (PRV) saves energy by converting high-pressure steam to low-pressure steam with lower enthalpy.

L-5 Ans

A)
Initial Blowdown:
Blowdown % = (Feed water TDS * Make-up water % * 100) / (Max permissible TDS in boiler - Feed water TDS)
= (600 * 0.12 * 100) / (3000 - 600) = 72 / 2400 = 3%
Improved Blowdown:
= (Improved Feed water TDS * Make-up water % * 100) / (Max permissible TDS in boiler - Improved Feed water TDS)
= (200 * 0.12 * 100) / (3000 - 200) = 24 / 2800 = 0.86%
Reduction in Blowdown = Initial Blowdown % - Improved Blowdown % = 3% - 0.86% = 2.14%
Reduction in Blowdown = 2.14 * 80 * 1000 / 100 = 1712 kg/hr
Heat Savings Calculation:
Heat Savings = m * Cp * (T1 - T2)
Heat Savings = 1712 * 1 * (180 - 50) = 1712 * 130 = 222,560 kcal/hr
Fuel Oil Savings Calculation:
Fuel Oil Savings = Heat Savings / (Calorific value of fuel * Boiler Efficiency)
Fuel Oil Savings = 222,560 / (10,500 * 0.88) = 222,560 / 9,240 = 24.0866= 24.09 kg/hr
Annual Fuel Oil Savings:
Annual Fuel Oil Savings = Fuel Oil Savings * 24 * 300 / 1000
Annual Fuel Oil Savings = 24.09 * 24 * 300 / 1000 = 173.44 MT/year
Cost Savings Calculation:
Fuel Oil Cost Savings = Annual Fuel Oil Savings * Cost per ton of fuel
Fuel Oil Cost Savings = 173.44 * 40,000 = Rs.69,37,600= Rs. 69.37 lakh/year
Payback Period Calculation:
Payback Period = Investment on water treatment plant / Fuel Oil Cost Savings
Payback Period = 1,50,00,000 / 69,37,600 = 2.16 years (or 25.9 months)

b)True or False

1. Saturated steam and dry steam mean the same thing in practical usage.
   Answer: False
2. Installing a steam trap upside down has no effect on its operation because condensate is removed due to pressure difference only.
   Answer: False
3. If a boiler operates with 8% blowdown at full load, reducing it to 4% will proportionally increase steam generation without additional fuel consumption.
   Answer: False
4. A pressure reducing valve (PRV) saves energy by converting high-pressure steam to low-pressure steam.
   Answer: False

L-6

Fill in the Blanks **Each 1 mark**

1. In a ______________, heat exchange takes place between the flue gases and the incoming air through metallic or ceramic walls.
2. The ______________stores heat in brickwork during one part of the cycle and releases it to the incoming cold air during the other part of the cycle.
3. A ___________________is a rotating porous disk that transfers heat between two separate air streams.
4. In a __________, heat transfer occurs via evaporation and condensation of a working fluid inside a sealed

	container. 5. ____________ in a boiler recovers waste heat from flue gases to preheat the boiler feedwater. 6. A ___________________ uses a series of thin corrugated plates to separate and transfer heat between two fluids. 7. In high-temperature applications where metallic recuperators are unsuitable, _________ tube recuperators can be used to handle gas inlet temperatures up to around 1550°C. 8. The equipment with a direct contact heat exchange principle in a high pressure boiler system is _________________ 9. A _____________ upgrades low-temperature waste heat to a higher temperature using mechanical work. 10. Steam generation from gas turbine waste heat is typically carried out through a _________________
L-6 Ans	1. In a **recuperator**, heat exchange takes place between the flue gases and the incoming air through metallic or ceramic walls. 2. The **regenerator** stores heat in brickwork during one part of the cycle and releases it to the incoming cold air during the other part of the cycle. 3. A **heat wheel** is a rotating porous disk that transfers heat between two separate air streams. 4. In a **heat pipe**, heat transfer occurs via evaporation and condensation of a working fluid inside a sealed container. 5. **Economiser** in a boiler recovers waste heat from flue gases to preheat the boiler feedwater. 6. A **plate heat exchanger** uses a series of thin corrugated plates to separate and transfer heat between two fluids. 7. In high-temperature applications where metallic recuperators are unsuitable, **ceramic** tube recuperators can be used to handle gas inlet temperatures up to around 1550°C. 8. The equipment with a direct contact heat exchange principle in a high pressure boiler system is **de-aerator** 9. A **heat pump** upgrades low-temperature waste heat to a higher temperature using mechanical work. 10. Steam generation from gas turbine waste heat is typically carried out through a **Heat Recovery Steam Generator (HRSG)**

.... End of Section III ....