Birla Institute of Technology and Science Pilani-K K Birla Goa Campus
SECOND SEMESTER 2022-2023
ME F420 Power Plant Engineering
Comprehensive Examination (Closed Book)

DATE: 10/05/2023 **Time: 2:00 P.M. – 5:00 P.M.** **Maximum Marks: 80**

Instructions:

- Write all steps while answering the problems.
- All the parts of a question must be answered together at a single place.
- Recheck will not be considered where pencil is used while answering.
- All symbols used in the question paper have their standard meaning.

Q.1. Find the diversity factor of power station which supplies loads as motor load of 100 kW working between 10 A.M. and 6 P.M., lighting load of 60 kW between 6 P.M. and 10 A.M., pumping load of 40 kW between 4 P.M. and 10 A.M. **[05]**

Q.2. Determine the height of the chimney to produce a static draught of 22 mm of water if the mean flue gas temperature in the chimney is 290^0C and ambient temperature in a boiler house is 20^0C. The gas constant for the chimney flue gas is 0.257 kJ/kg.K. **[10]**

Q.3. Determine the fluidization velocity for the incipiently fluidized bed by air. Assume voidage is 0.417, average particle size as 427 μm, density of loosely packed bed is 1620 kg/m^3, viscosity is 1.82×10^{-5} kg/m-s, density of air as 1.2 kg/m^3. **[13]**

Q.4. A spray type desuperheater is supplied with water at 60^0C. It is connected in a steam line carrying 200 t/hr of steam at 30 bar. Calculate the amount of water that must be sprayed per hour to maintain the steam at 400^0C when the boiler load causes steam to leave at 450^0C. **[05]**

Q.5. A fluidized bed combustor burn a solid fuel of high volatile matter with calorific value 24 MJ/kg. The combustion conditions are such that 65% of calorific value is released in the upper bed and remainder in the lower bed zone. Products leave at 850^0C from the upper bed. The air inlet temperature is 330^0C and air fuel ratio by mass 13.5:1. The specific heat of the products leaving the bed surface is 1.035 kJ/kg.K. If the burning rate of the coal is 7000 kg/hr. Estimate the amount of net heat available (i) in lower dense portion of the bed (ii) in above bed zone (dilute particles' zone). **[12]**

Q.6. During a boiler trial, a partial analysis of dry flue gas showed 13.2% CO_2 and 3.2% O_2 by volume. Some CO was probably present but its percentage was not measured. The analysis of the coal burnt was 88% carbon, 4.4% hydrogen, and 7.6% ash. The moisture in the fuel was nil. Assuming that all the carbon and hydrogen have been burnt, estimate (i) complete volumetric composition of the dry flue gas, (ii) the actual amount of air supplied per kg coal, (iii) mass of water vapour formed per kg coal, and (iv) dew point temperature of the flue gas. **[15]**

Q.7. Match the parameters of columns A and B. One mark will be deducted for each wrongly answered pair formed after matching.While answering; please don't write only option number but alongwith option number write content of that option number. For example, (9) ABC matches to (X) DEF, where (9) & (X) are option numbers from column **A** and **B** respectively; while ABC and DEF are their content respectively. Answers having only matching option numbers' of column A and B without writing their contents will not be considered for recheck. **[08]**

A	**B**
a. Toluene	i. Lower temperature Rankine cycle solar power plant
b. Efficiency 2.5%	ii. Petrothermal systems
c. 250^0C, 8 bar	iii. OTEC
d. Overall efficiency 10%	iv. Hydrothermal Systems
e. 150^0C to 290^0C	v. High temperature Rankine cycle solar power plant
f. R-11	vi. Medium temperature Rankine cycle solar power plant
g. R-12	vii. Geopressurized system
h. Combustion of methane	viii. Anderson cycle

Q.8. Solve the following questions. One mark will be deducted for each wrongly answered subsquestion.While answering; please don't write only option number but alongwith option number write content of that option number. For example **[Sub Q. NO. 7] -** (v) XYZ, where (v) is option number and XYZ is its content. Answers having only option number will not be considered for recheck. **[12]**

[1] Amount of heat absorbed in KJ/kg when limestone decomposes
(i) 90 (ii) 180 (iii) 45 (iv) 360

[2] Temperature range at which CFB Boiler works is
(i) 1100 K – 1150 K (ii) 550 K – 575 K (iii) 800 K – 900 K (iv) none of these

[3] Natural circulation occur at following value of pressure difference per unit length in a evaporator
(i) 9.81 kN/m^3 (ii) more than 9.81 kN/m^3 (iii) less than 9.81 kN/m^3 (iv) none of these.

[4] If pressure is greater than ….. bar, downcomers are placed inside the furnace
(i) 30 (ii) 40 (iii) 180 (iv) none of these.

[5] At x = 0.5 in a heat exchanger, natural circulation may
(i) occur (ii) not occur (iii) both i.e may occur, may not occur (iv) none of these.

[6] The gas temperature below the dew point temperature causes
(i)Formation of water vapour (ii) acid formation (iii) high plume (iv) none of these

Q.1.

Q:1

$$\text{Diversity factor} = \frac{\text{Sum of Individually connected maximum demand}}{\text{Peak ~~demand~~ load}}$$

$$= \frac{(100 + 60 + 40)\text{ kW}}{\text{peak load}}$$

$$\text{Diversity factor} = \frac{200}{\text{peak load}}$$ → 1 Marks

Now, peak load will not be 100 kW because ^lighter^ Motor works from 10 AM to 6 PM with 100 kW and Pump works from 4 PM to 10 AM with 40 kW i.e Motor and pump work simultaneously at a time from 4 PM to 6 PM, so for this time interval (4 PM to 6 PM), the total load will be:→ 100 kW(^from^ motor) + 40 kW(pump) + 0 kW(Lighting :- 6 PM to 10 AM) = 140 kW

∴ peak load = 140 kW → 3 Mark

$$\therefore \text{Diversity Factor} = \frac{200}{140} = 1.428$$ → 1 Mark

(NOTE :- ^While calculating peak load,^ Lighting load is not coming betⁿ 4 PM to 6 PM, so it is considered as lighting load is 0 kW from 4 PM to 6 PM)

Q.2

=

$$\Delta P = H g (\rho_{air} - \rho_{g}) \rightarrow (I)$$

$\Delta P = ?$

Now, ΔP = 22 mm of water = 212.97 N/m^2 → (2) mark

∴ Eqn. (I), $212.97 = H \times 9.81 (\rho_a - \rho_g)$ → (II)

∴ Now, $\rho_{air} = \frac{1}{v} = \frac{P}{RT}$

$$= \frac{101.325}{0.287(273+20)}$$

and $\rho_a = 1.20\ kg/m^2$ → (2) mark

$$\rho_g = \frac{1}{v_g} = \frac{P}{R_g \cdot T_g}$$

$$= \frac{101.325}{0.287 \times (273+290)}$$

$\rho_g = 0.70\ kg/m^2$ → (2) mark

Using (II)

$$H = \frac{212.97}{9.81(1.20 - 0.70)}$$

$$\boxed{H = 43.41\ m}$$ → (4) mark

Q.3

Q. (3)

$$Re = \frac{\rho_g U d_p}{\mu_g}$$

$$\therefore U_{mf} = \frac{\mu_g Re_{mf}}{\rho_g \cdot d_p}$$

where $Re_{mf} = \left[C_1^2 + C_2 A_r \right]^{0.5} - C_1$

where $A_r = \dfrac{\rho_g (\rho_s - \rho_g) \cdot g \cdot d_p^3}{\mu_g^2}$

where $\rho_s = \dfrac{\rho_b}{1 - \varepsilon_{mf}}$

$$= \frac{1620}{1 - 0.417}$$

(3) marks → $\boxed{\rho_s = 2778.73 \ kg/m^3}$

$$\therefore A_r = \frac{1.21 (2778.73 - 1.21) \cdot 9.81 \times (427 \times 10^{-6})^3}{(1.82 \times 10^{-5})^2}$$

(3) marks → $\boxed{A_r = 7645 [illegible]}$ [illegible]

$$\therefore Re_{mf} = \left[(27.2)^2 + (0.0408 \times 7749.12) \right]^{0.5} - 27.2$$

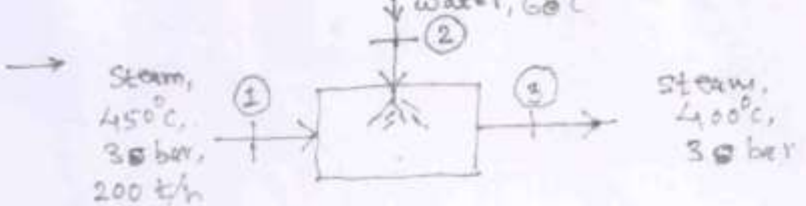
(3) marks → $\boxed{Re_{mf} = 5.25}$ [illegible]

$$\therefore U_{mf} = \frac{1.82 \times 10^{-5} \times 5.296}{1.21 \times 427 \times 10^{-6}}$$

(4) marks → $\boxed{U_{mf} = 0.186 \ m/s}$

Q.4

Q.: 4 A spray type desuperheater is supplied with water at 60°C. It is connected in a steam line carrying 200 t/h of steam at 30 bar. Calculate the amount of water that must be sprayed per hr to maintain steam at 400°C, when boiler load causes steam to leave at 450°C.



Energy balance for desuperheater,

$$W_s \cdot h_1 + W \cdot h_2 = (W_s + W)\, h_3$$

$$\therefore \quad W = \frac{W_s (h_1 - h_3)}{h_3 - h_2}$$

→ (2) marks

Table B.1.3

$h_1 = 3344 \ \frac{kJ}{kg}$, $h_3 = 3230.82 \ \frac{kJ}{kg}$

Table B.1.1, $h_2 = 251.11 \ \frac{kJ}{kg}$

(1) marks

$$\therefore \quad W = \frac{200\,(3344 - 3230.82)}{3230.82 - 251.11}$$

$W = 7.596$ t/h

$W = 2.110$ kg/sec → (2) marks

Q.5 All steps carry 2 marks each except steps 6 and 7 which carry 1 mark each

Q.5

1) Total heat released in CFB riser = $\dot{Q}$ =

$= [0.65+0.35] \times 24000 \times \frac{7000}{3600} = 46666\ kW$ —→ (1)

2) Heat Added by air into the riser per kg-cal = Q_{air} =

$= [13.5\ \frac{kg}{kg\text{-}coal}] \times 1.032\ \frac{kJ}{kg\text{-}K} \times (330+273)K$

$= 7828.32\ \frac{kJ}{kg\text{-}coal}$

(NOTE) (Refer page 8 of steam Table for h air at 600K)

3) $\dot{Q}_{air\ total} = 7828.32 \times \frac{7000}{3600}\ \frac{kg\text{-}coal}{sec} = 15221\ kW$ —→ (2)

4) Heat carried away by flue gas per kg of coal = Q_{gas}

$= [13.5+1] \times 1.035 \times (550+273)K$

$= 16853.42\ \frac{kJ}{kg\text{-}coal}$

5) $\dot{Q}_{gas\ total} = 16853.42 \times \frac{7000}{3600}\ \frac{kg\text{-}coal}{sec} = 32770\ kW$ —→ (3)

6) Hence Total heat available in riser

= eqn. (1) + eqn. (2) − eqn. (3)

= 46666 + 15221 − 32770

= 29116 kW

7) (a) 0.65 × 29116 = 18925 kW } upper bed

(b) 0.35 × 29116 = 10190 kW } Lower bed regime

Q.6.

Solution For 100 kg of coal, let a moles of oxygen are supplied.

$$\frac{88}{12}C + \frac{4.4}{2}H_2 + aO_2 + 3.76aN_2 \longrightarrow bCO_2 + dCO + eO_2 + fN_2 + gH_2O$$

Carbon balance: $\frac{88}{12} = 7.333 = b + d$

Hydrogen balance: $2.2 = g$

Oxygen balance: $a = b + \frac{d}{2} + e + \frac{g}{2} = b + \frac{d}{2} + e + 1.1$

Nitrogen balance: $3.76a = f$

From dfg analysis, $0.132 = \frac{b}{b+d+e+f}$

From steam table DPT = 32.9

$$0.032 = \frac{e}{b+d+e+f} \quad (5)$$

Dividing (4) by (5), $\frac{b}{e} = 4.125$ (6)

From Eqs (1), (2) and (6),

$$a = 7.333 - d + \frac{d}{2} + \frac{7.333-d}{4.125} + 1.1 = 10.21 - 0.742\,d$$

$$f = 38.39 - 2.79\,d$$

From Eq. (4),

$$0.132 = \frac{7.333-d}{7.333 - d + d + \frac{7.333-d}{4.125} + 38.39 - 2.79d} = \frac{7.333-d}{47.5 - 3.032d}$$

$$d = 1.772$$

$$a = 10.21 - 0.742 \times 1.772 = 8.895$$

$$b = 7.333 - 1.772 = 5.561$$

$$e = \frac{5.561}{4.125} = 1.348$$

$$f = 3.76 \times 8.895 = 33.45$$

Mass of air supplied for 100 kg coal $= \dfrac{8.895 \times 32}{0.232} = 1227$ kg

Mass of air supplied per kg coal = 12.27 kg *Ans.*(b)

Total number of moles of dfg $= b + d + e + f = 42.131$

$$\% \; CO_2 \text{ by volume} = \frac{5.561}{42.131} \times 100 = 13.20\%$$

$$\% \; O_2 \text{ by volume} = \frac{1.348}{42.131} \times 100 = 3.20\%$$

$$\% \; CO \text{ by volume} = \frac{1.772}{42.131} \times 100 = 4.20\%$$

$$\% \; N_2 \text{ by volume} = \frac{33.45}{42.131} \times 100 = 79.40\%$$

Ans(a)

Value of a to f, carries 6 marks, Ans (i/a) carries 4 Marks, Ans (ii/b) carries 1 mark

Mass of water vapour formed per kg coal $= \dfrac{2.2 \times 18}{100} = 0.396$ kg *Ans.*(b)

Mole fraction of water vapour in flue gas $s = \dfrac{g}{b+d+e+f+g} = \dfrac{2.2}{42.131+2.2} = 0.0496$

Partial Pressure of water vapour

Partial pressure of water vapour = X_{H2O} * P_{atm} = 0.0496 * 101.325 = 4.96 kPa

and corresponding temperature from steam table B.1.1 is 32.09 deg Cel.

Ans (iii) 1 marks, and , Ans (iv) carries (1+1+1) mark = (s value + partial pressure + dew point temperature)

Q.7 & Q.8

Q.7

1. Tolune → (I) Lower Temp. Rankine cycle-solar
2. Efficiency 2.5% → (III) OTEC, (VIII) Anderson cycle
3. 250°C, 8 bar → (IV) Hydrothermal systems
4. η_{overal} 10% → (VI) medium Temp. Rankine cycle-solar
5. 150°C to 290°C → (II) Petrothermal system
6. R-11 → (I) Lower Temp. Rankine cycle-solar
7. R-12 → (III) OTEC, (VIII) Anderson cycle
8. Combustion of CH_4 → (VII) Geopressurized system

Q-8.

[1] → (ii) 180

[2] → (i) 1100 K - 1150 K

[3] → (iii) Less than 9.81 KN/m^2

[4] → (iv) None of these

[5] → (iii) both i.e may occur, may not occur.

[6] --> (ii) Acid formation