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NUMERICALS FROM BOE EXAMS

PROPERTIES OF STEAM

Problem (Maharashtra BOE 2014, 2024, 6 marks)

Find the volume of 1 kg of steam at pressure of 14 kg/cm^2 (g) in each of the following case:

(i) When steam is dry saturated?

(ii) When steam is wet having dryness fraction 0.9?

(iii) When steam is superheated, the degree of superheat being 40^{0}C?

Solution

$$P_{abs} = P_g + P_{atm}$$

$$= 14 + 1.033 = 15.033 \text{ kg/cm}^2 \text{ say } 15 \text{ kg/cm}^2$$

From steam tables at $P_{abs} = 15$ kg/cm^2

Specific volume of dry saturated steam

$$v_g = 0.1317 \text{ m}^3/\text{kg}$$

Volume of dry saturated steam

$$V_{dry} = mv_g = 1 \text{ kg} \times 0.1317 \text{ m}^3/\text{kg} = 0.1317 \text{ m}^3$$

Specific volume of wet steam

$$v_{wet} = xv_g$$

$$v_{wet} = 0.9 \times 0.1317 \text{ m}^3/\text{kg} = 0.1153 \text{ m}^3/\text{kg}$$

Volume of wet steam

$$V_{wet} = mv_{wet} = 1 \text{ kg} \times 0.1153 \text{ m}^3/\text{kg} = 0.11853 \text{ m}^3$$

From steam tables for $P_{abs} = 15$ kg/cm^2, the saturation temperature is $T_{sat} = 198.3^0$C

Superheated temperature

$$T_{sup} = T_{sat} + \Delta T_{sup}$$

$$= 198.3^0\text{C} + 40^0\text{C} = 238.3^0\text{C}$$

From superheated steam tables at $P_{abs} = 15$ kg/cm^2 and $T_{sup} = 283.3^0$C,

specific volume, $v_{sup} = 0.153 \text{ m}^3/\text{kg}$

Volume of superheated steam

$$V_{sup} = mv_{sup} = 1 \text{ kg} \times 0.153 \text{ m}^3/\text{kg} = 0.153 \text{ m}^3$$

Problem (Gujarat BOE 2023, 5 marks)

Calculate amount of heat required to produce 5 Kg of steam at pressure 5 Bar. Feed water temperature is 20^0C & steam is dry saturated. (Gujarat BOE 2023, 5 marks)

Solution

Given data

$p = 5$ bar

$t_w = 25^0C$

From steam tables, corresponding to pressure of 5 bar

Abs. Pressure bar	**Temp. ^0C**	**Sp. enthalpy (kJ/kg)**		
p	t_s	h_f	h_{fg}	h_g
5.0	151.8	640.1	2107.4	2747.5
5.2	153.3	646.5	2102.7	2749.3

$h_f = 640.1$ kJ/kg

$h_{fg} = 2107.4$ kj/kg

$t = 151.8\ ^0C$

Water temperature = 20^0C

Heat already in water = $4.2 \times 20 = 84$ kJ

When the steam is dry saturated

We know that enthalpy or total heat of 1 kg of dry saturated steam

$$h_g = h_f + h_{fg} = 640.1 + 2107.4 = 2747.5 \text{ kJ}$$

Hence, heat actually required = 2747.5 - 84 = 2663.5 kJ

Problem (Gujarat BOE 2021, 2024, 5 marks)

Steam is generated in a boiler at 110 kg/cm^2 at 520^0C. Assume drum pressure is 118 kg/cm^2. Using steam table, find:

1. Saturated steam temperature.

2. Degree of superheat.

3. Enthalpy of steam.

Solution

(i) From the steam table, saturated temperature corresponding to 118 kg/cm^2 (=118/1.02 = 116 bar) (drum pressure) is 322 °C.

Absolute pressure (bar) p	Temp. (°C) t_s	Specific enthalpy (kJ/kg) h_f	h_{fg}	h_g	Specific entropy (kJ/kg K) s_f	s_{fg}	s_g	Specific volume (m^3/kg) v_f	v_g
110.0	318.0	1 450.6	1 258.7	2 709.3	3.430 4	2.129 1	5.559 5	0.001488	0.0160
112.0	319.4	1 458.9	1 246.5	2 705.4	3.444 0	2.103 6	5.547 6	0.001496	0.0157
114.0	320.7	1 467.2	1 234.3	2 701.5	3.457 4	2.078 3	5.535 7	0.001504	0.0153
116.0	322.1	1 475.4	1 222.0	2 697.4	3.470 8	2.053 1	5.523 9	0.001511	0.0149
118.0	323.4	1 483.6	1 209.7	2 693.3	3.484 0	2.028 0	5.512 1	0.001519	0.0146

(ii) Degree of super heat = Superheated steam temperature – Saturated temperature

= 520 – 322 = 198 °C.

(iii) Enthalpy of the superheated steam as found from steam table corresponding to 110 kg/cm^2 (=110/1.02 = 108 bar) and 520 °C is 815.8 kcal/kg.

↓p (bar) (t_s)	t (°C) →	350	375	400	450	500	550	600	700
80	v	0.02995	0.03222	0.03432	0.03817	0.04175	0.04516	0.04845	0.05481
(294.9)	h	2987.3	3066.1	3138.3	3272.0	3398.3	3521.0	3642.0	3882.4
	s	6.130	6.254	6.363	6.555	6.724	6.878	7.021	7.281
90	v	0.0258	0.02796	0.02993	0.03350	0.03677	0.03987	0.04285	0.04857
(303.3)	h	2956.6	3041.3	3117.8	3256.6	3386.1	3511.0	3633.7	3876.5
	s	6.036	6.169	6.285	6.484	6.658	6.814	6.959	7.222
100	v	0.02242	0.02453	0.02641	0.02975	0.03279	0.03564	0.03837	0.04358
(311.0)	h	2923.4	3015.4	3096.5	3240.9	3373.7	3500.9	3625.3	3870.5
	s	5.944	6.089	6.212	6.419	6.597	6.756	6.903	7.169
110	v	0.01961	0.02169	0.02351	0.02668	0.02952	0.03217	0.03470	0.03950
(318.0)	h	2887.3	2988.2	3074.3	3224.7	3361.0	3490.7	3616.9	3864.5
	s	5.853	6.011	6.142	6.358	6.540	6.703	6.851	7.120

Problem (Gujarat BOE 2023, 5 marks)

Steam at 100^{0}C is added to ice at 0^{0}C. Find the amount of ice melted and the final temperature when mass of steam is 10.0 grams and the mass of ice is 50.0 grams.

Solution

$$m_{ice} = \frac{m_{steam}L_{steam} + m_w C_w \Delta T}{L_{ice}}$$

$$= \frac{10(540) + (1)(1)(100-0)}{80} = 68.75\,g$$

68.75 g > 50 g

Hence, entire ice will melt.

Hence, final temperature will be 0^0C.

Problem (Gujarat BOE 2021, 5 marks0

Calculate the heat required to be added to 1000 kg of steam at 15 kg/cm^2 in order to superheat to 400 centigrade.

Solution

m_{steam} = 1000 kg

P_{steam} = 15 kg/cm^2

Final temperature of superheated steam, $T_2 = 400^0$C

Saturation temperature of steam at 15 kg/cm^2 = 198.3^0C

15.0	198.3	844.7	1945.2	2789.9

Specific heat capacity of superheated steam, C_p = 2.09 kJ/kg^{0}C

$\Delta T = 400 - 198.3 = 201.7^0$C

Now using $Q = mC_p\Delta T$ = 1000 x 2.09 x 201.7 = 421543 kJ

Problem (Maharashtra BOE 2023, 6 marks)

What quantity of heat is required to raise the temperature of 450 grams of water from 15°C to 85°C? The specific heat capacity of water is 4.18 J/g/°C.

Solution

$Q = mc\Delta T = (450\ g)(4.18\ J/g/^0C)(85 - 15) = 131670$ J

Problem (Gujarat BOE 2021, 5 marks)

Find suitable size of pipe to carry 320 tons of steam per hour with specific volume of 0.22 m^3/kg at approximately 40 m/sec velocity. (Gujarat BOE 2021, 5 marks)

Solution

Mass flow rate of steam = 320 t/hr = 88.89 kg/s

Sp. volume of steam = 0.22 m^3/kg

Velocity of steam = 40 m/s

Now, Q = mass flow rate x specific volume

= 88.89 x 0.22 = 19.556 m^3/s

Now area A = Q/velocity = 19.556/40 = 0.4889 m^2

$$A = \frac{\pi D^2}{4}$$

Hence $$0.4889 = \frac{\pi D^2}{4}$$

Giving D = 0.788 m

FUELS, COMBUSTION AND FLUE GASES

Problem (Karnataka BOE 2023, 5 marks)

If one ball of coal of 250 c.c. volume breaks in to small 250 pcs. of ball having a volume of 1 cc of each ball, calculate how many times the surface area exposed to heat for combustion will increase?

Solution

Volume $$V_L = \frac{4}{3}\pi r_L^{\,3} \Rightarrow 250 = \frac{4}{3} r_L^{\,3} \Rightarrow r_L = \left(\frac{750}{4\pi}\right)^{1/3} cm$$

$$1 = \frac{4}{3}\pi r_S^{\,3} \Rightarrow r_s = \left(\frac{3}{4\pi}\right)^{1/3} cm \quad [\text{ Volume of one ball} = 250/250 = 1 \text{ cc}]$$

Now **area** $$A_L = 4\pi\left[\left(\frac{750}{4\pi}\right)^{1/3}\right]^2 = 4\pi\left(\frac{750}{4\pi}\right)^{2/3} cm^2$$

$$A_S = 4\pi\left[\left(\frac{3}{4\pi}\right)^{1/3}\right]^2 = 4\pi\left(\frac{3}{4\pi}\right)^{2/3} cm^2$$

Ratio

$$\frac{A_{S,total}}{A_L} = \frac{250(4\pi)\left(\frac{3}{4\pi}\right)^{2/3}}{4\pi\left(\frac{750}{4\pi}\right)^{2/3}} = 6.3$$

Problem (Assam BOE 2023, 2 marks)

Fuel oil-fired boiler's steam rate averages 114 lb of steam/gal. of fuel oil. The boiler operates 24 hr/day, 350 days/yr. The fuel oil costs ₹1.75/gal. and the load is 50 Klb/hr. What is the annual fuel cost?

Solution

FC= (Fuel oil cost x 24 x 350 x load)/Steam rate

= (1.75 x 24 x 350 x 50,000)/1.75

= ₹ 42,00,00,000

Problem (Gujarat BOE 2023, 5 marks)

Following parameters are noted from the ultimate analysis of coal sample:

Carbon: 40%

Sulphur: 2%

Hydrogen: 4%

Calculate the theoretical quantity of air required in kilograms. If the boiler is operated at 4% excess oxygen, then calculate the actual air quantity in kilograms.

Solution

Theoretical air

Method 1

Constituent	**Mass fraction**	**Mass of O_2 required for complete combustion**	**Mass of products (kg)**		
			N_2	**CO_2**	**SO_2**
C	0.4	0.4 x (8/3) = 1.07		0.4 x (11/3) = 1.47	
H_2	0.04	0.04 x 8 = 0.32			
S	0.02	0.02 x 1= 0.02			0.02 x 2 = 0.04
Total		Σ = 1.41		Σ = 1.47	Σ = 0.02
O_2	0	0			

N_2	0		0		

Total O_2 required for complete combustion = 1.41 - 0 = 1.41 kg/kg of fuel

Air required = 1.41 x (100/23) = 6.12 kg/kg of fuel

Method 2

Quantity of theoretical air required (by weight) per kilogramme of fuel is given by

$$4.35\left[\left(\frac{8}{3}C+8H_2+S\right)-O_2\right]kg$$

$$= 4.35\left(\frac{8}{3}x0.4+8x0.04+0.02\right)=6.12\,kg$$

Actual air quantity

Excess air percentage = $\frac{Oxygen\ percentage\ in\ flue\ gas}{21-Oxygen\ percentage}x100$

Boiler is operated at 4% excess oxygen.

Hence, excess air percentage = $\frac{4}{21-4}x100=23.5\%$

$$Actual\ air\ qty = Theoretical\ air\left(1+\frac{excess\ air\%}{100}\right)$$

= 6.12 x 1.235 = 7.35 kg/kg of fuel

Problem (Chhattisgarh BOE 2021, 5 marks)

The following is the percentage composition of coal on mass basis:

C - 90%

H_2 = 3.3%

O_2 - 3%

S - 0.9%

and remaining is ash.

Calculate

(i) The theoretical air required to burn 1 kg of coal completely.

(ii) The percentage composition of dry flue gases on mass basis if 50% excess air is supplied. Assume air has 23% oxygen on mass basis.

Solution

Constituent	Mass fraction	Mass of O_2 required for complete combustion	Mass of products (kg)		
			N_2	CO_2	SO_2
C	0.9	0.9 x (8/3) = 2.4		0.9 x (11/3) = 3.3	
H_2	0.033	0.033 x 8 = 0.264			
S	0.009	0.009 x 1= 0.009			0.009 x 2 = 0.018
Total		Σ = 2.673		Σ = 3.3	Σ = 0.08
O_2	0.03	0.03			
N_2	0		0		

Total O_2 required for complete combustion = 2.673 - 0.03 = 2.643 kg/kg of fuel

Air required = 2.643 x (100/23) = 11.49 kg/kg of fuel

For 50% air

N_2 = 11.49 x 1.5 x 0.77 + 0 = 13.27 kg

O_2 = 11.49 x 0.5 x 0.23 = 1.32 kg

Constituent	Mass (kg)	% by mass
CO_2	3.3	3.3 x (100/17.908) = 18.43
SO_2	0.018	0.018 x (100/17.908) = 0.10
N_2	13.27	13.27 x (100/17.908) = 74.10
O_2	1.32	1.32 x (100/17.908) = 7.37
	Σ = 17.908	

Problem (Jharkhand BOE 2022, 4 marks)

Estimate SO_2 emission through chimney in tons/annum.

Data:

Days considered = 340

Fuel used = furnace oil

Specific gravity = 0.94

Sulphur content = 3.8%

Quantity of FO (Fuel Oil) consumption = 3.5 kl/hr

and if measured O_2 in flue gas is 2.5%, find excess air level.

Solution

Quantity of sulphur/annum

= 3500 x 0.94 x 24 x 340 x 0.038

= 1020163.2 kg/annum

Now $S + O_2 \rightarrow SO_2$

We conclude that 1 kg of sulphur produces 2 kg of SO_2.

Quantity of SO_2 generated per annum

= 2 x 1020163.2

= 20403264.4 kg/annum

= 2041 tonnes/annum

For 2.5% O_2 in flue gas, excess air

$$= \frac{O_2}{21 - O_2} = \frac{2.5}{21 - 2.5} = 0.1351 = 13.51\%$$

Problem (Punjab BOE 2021, 10 marks)

A sample of fuel has the following percentage composition by weight:

Carbon = 84%

Hydrogen = 10 %

Oxygen = 3.5%

Nitrogen = 1.5%

Ash = 3.5%

(i) Determine the stoichiometric air-fuel ratio by mass

(ii) If 20% excess air is supplied, find the percentage composition of dry flue gases by volume.

Solution

Stoichiometric air fuel ratio

On the basis of 100 kg of fuel let us assume an equivalent formula $C_aH_bO_cN_d$.

From the given analysis by weight, we can write

$12a = 84 \Rightarrow a = 7$

$1b = 10 \Rightarrow b = 10$