Indian Forest Service (Main) Examination, 2024

JBNV-U-CHME

CHEMICAL ENGINEERING

Paper – I

Time Allowed : **Three Hours**

Maximum Marks : **200**

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

There are ***EIGHT*** *questions in all, out of which* ***FIVE*** *are to be attempted.*

Questions no. ***1*** *and* ***5*** *are* ***compulsory****. Out of the remaining* ***SIX*** *questions,* ***THREE*** *are to be attempted selecting at least* ***ONE*** *question from each of the two Sections* ***A*** *and* ***B****.*

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary, and indicate the same clearly.

Neat sketches may be drawn, wherever required.

Answers must be written in ***ENGLISH*** *only.*

SECTION A

Q1. (a) Briefly describe the working principle of a steam jet ejector, along with its performance. *8*

(b) Discuss the dependency of temperature on the viscosities of gases and liquids. *8*

(c) Describe various types of dryers with sketches and applications. *8*

(d) In liquid-liquid extraction, describe the selection criteria of good solvents. *8*

(e) A grey body of 20 m^2 area, radiates 10^6 W at 1227°C. Calculate the emissivity of grey body. If the temperature is increased to 1327°C, what would be the percentage change in emissive power ? *8*

Q2. (a) Countercurrent stripping of ammonia from a dilute solution by air is carried out in a sieve tray column having 6 trays. The equilibrium relationship is given by $y_e = 0{\cdot}85\ x_e$.

90 percent of ammonia is removed when the molar flow of air is 1·5 times that of the solution. *15*

(i) Calculate the ideal stages of the column and stage efficiency.

(ii) Find the percentage removal, if the air rate of flow is increased to 2 times the solution rate.

(b) Rivers are the source of water supply for factories. Water at the rate of 2×10^5 kg/hr has to be pumped from a river to a factory overhead tank, placed at a height of 25 metres from the river bed, the total length of pipeline being 1500 metres. The iron pipe having an inside diameter of 30 cm has been used for this pumping. The viscosity of river water is 0·764 cP and friction factor is given by $f = 0{\cdot}0014 + \dfrac{0{\cdot}125}{Re^{0{\cdot}32}}$. *15*

Calculate :

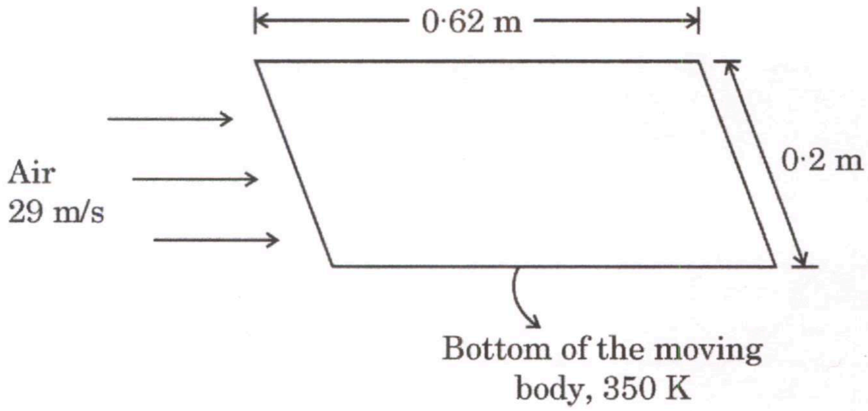
(i) The Reynolds number (Re), if $\rho = 1$ gm/cc

(ii) The head loss due to friction.

(c) The wall of a furnace is constructed from an inner layer of 0·6 cm thick steel (k = 40 W/mK) and an outer layer of 10 cm brick (k = 2·5 W/mK). The inner surface temperature is 900 K and the outside surface temperature is 480 K. Calculate the heat loss from the furnace per unit area and also the temperature at the interface. Assume steady state exists and effects at the corners and edges of the wall are negligible. The temperatures at the surface are uniform. *10*

Q3. (a) A hot moving body is 0·62 m long, 0·2 m wide and 0·1 m deep. The surface temperature of the hot body is 350 K. Find the rate of heat flow (heat loss) from the hot body to the atmosphere at 276 K at a speed of 29 m/s. The conditions are such that boundary layer may be assumed turbulent over the entire surface. The radiation from the hot body may be neglected. The same average convection heat transfer coefficient, as for the bottom and sides, may be used for the front and rear surfaces. The properties of air at the average temperature are given as :

Density = 1·092 kg/m^3; Viscosity = $19{\cdot}123 \times 10^{-6}$ $N.s/m^2$.
Thermal conductivity = 0·0265 W/m.K,
Specific heat = 1014 J/kg.K, Prandtl Number = 0·71.



15

(b) Crushing is an important method for size reduction of solid particles. Estimate the energy required to crush 1×10^5 kg/hr of sodium silicate, if 80% of the feed passes through a screen 3·75 cm aperture and 80% of the product passes through a screen with 0·03 cm aperture. The work index (W_i) for sodium silicate is 13·1. *15*

(c) A spherical naphthalene ball of 10 gm is kept suspended in a large volume of air at 45°C and one atm pressure. Diffusivity of naphthalene in air $D_{AB} = 6{\cdot}92 \times 10^{-6}$ m^2/s, and density $\rho = 1{\cdot}14$ gm/cc. The sublimation pressure at 45°C is 0·8654 mm Hg. Calculate the time required for sublimation of 7 gm of naphthalene. Molecular weight of naphthalene is 128. *10*

Q4. (a) A 20% NaOH solution is concentrated in an evaporator. 4500 kg/h of this solution enters the evaporator at 333 K and the product contains 50% solids. The pressure of saturated steam used is 172·4 kPa and the pressure in the vapour space of evaporator is 11·7 kPa. The overall heat transfer coefficient is 1565 W/m^2 K. Calculate the heating surface area required and the steam economy of the evaporator.

The heat capacity of superheated steam may be taken as 1·884 kJ/kg.K.

The required charts and steam tables are enclosed. *15*

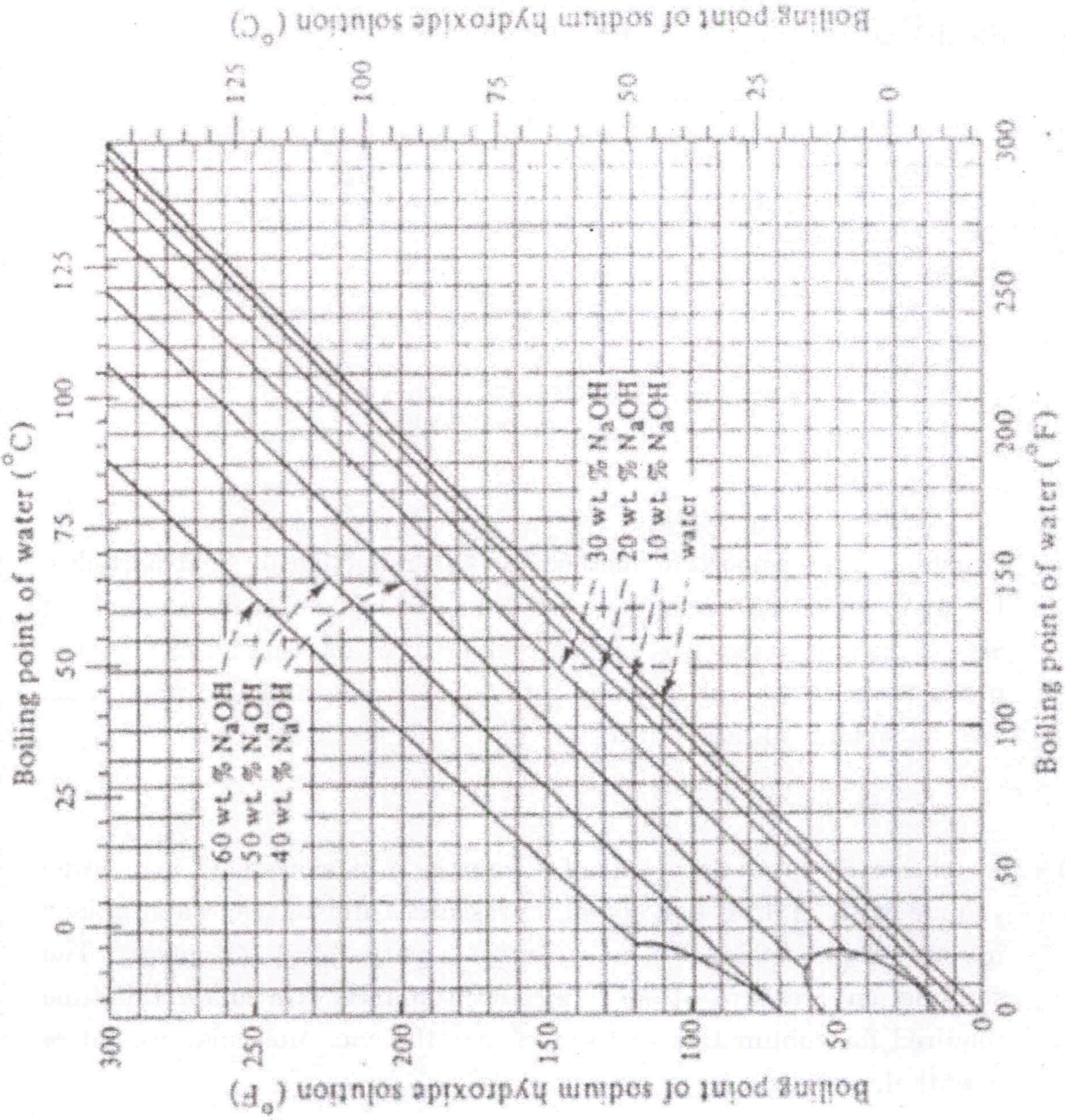


Fig. 1 : Dühring lines for aqueous solutions of Sodium hydroxide

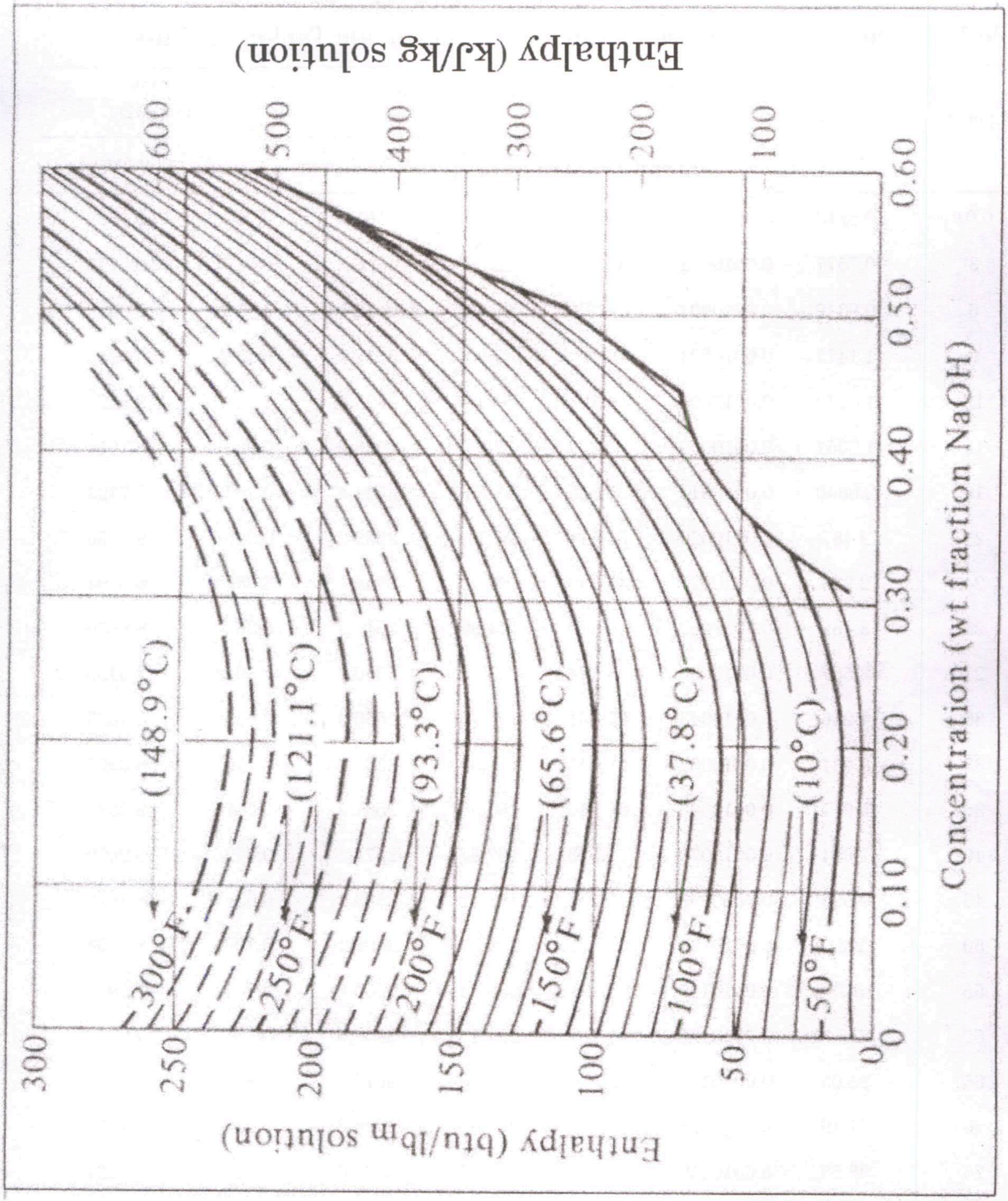


FIGURE 2 Enthalpy concentration chart for the system NaOH-water

Table 1 : Properties of saturated Steam and Water (Steam Table), SI Units

Temperature (°C)	Vapour Pressure (kPa)	Specific Volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy (kJ/kg.K)	
		Liquid	Sat'd Vapour	Liquid	Sat'd Vapour	Liquid	Sat'd Vapour
0.01	0.6113	0.0010002	206.136	0.00	2501.4	0.0000	9.1562
3	0.7577	0.0010001	168.132	12.57	2506.9	0.0457	9.0773
6	0.9349	0.0010001	137.734	25.20	2512.4	0.0912	9.0003
9	1.1477	0.0010003	113.386	37.80	2517.9	0.1362	8.9253
12	1.4022	0.0010005	93.784	50.41	2523.4	0.1806	8.8524
15	1.7051	0.0010009	77.926	62.99	2528.9	0.2245	8.7814
18	2.0640	0.0010014	65.038	75.58	2534.4	0.2679	8.7123
21	2.487	0.0010020	54.514	88.14	2539.9	0.3109	8.6450
24	2.985	0.0010027	45.883	100.70	2545.4	0.3534	8.5794
25	3.169	0.0010029	43.360	104.89	2547.2	0.3674	8.5580
27	3.567	0.0010035	38.774	113.25	2550.8	0.3954	8.5156
30	4.246	0.0010043	32.894	125.79	2556.3	0.4369	8.4533
33	5.034	0.0010053	28.011	138.33	2561.7	0.4781	8.3927
36	5.947	0.0010063	23.940	150.86	2567.1	0.5188	8.3336
40	7.384	0.0010078	19.523	167.57	2574.3	0.5725	8.2570
45	9.593	0.0010099	15.258	188.45	2583.2	0.6387	8.1648
50	12.349	0.0010121	12.032	209.33	2592.1	0.7038	8.0763
55	15.758	0.0010146	9.568	230.23	2600.9	0.7679	7.9913
60	19.940	0.0010172	7.671	251.13	2609.6	0.8312	7.9096
65	25.03	0.0010199	6.197	272.06	2618.3	0.8935	7.8310
70	31.19	0.0010228	5.042	292.98	2626.8	0.9549	7.7553
75	38.58	0.0010259	4.131	313.93	2635.3	1.0155	7.6824
80	47.39	0.0010291	3.407	334.91	2643.7	1.0753	7.6122
85	57.83	0.0010325	2.828	355.90	2651.9	1.1343	7.5445
90	70.14	0.0010360	2.361	376.92	2660.1	1.1925	7.4791
95	84.55	0.0010397	1.9819	397.96	2668.1	1.2500	7.4159
100	101.35	0.0010435	1.6729	419.04	2676.1	1.3069	7.3549

Temperature (°C)	Vapour Pressure (kPa)	Specific Volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy (kJ/kg.K)	
		Liquid	Sat'd Vapour	Liquid	Sat'd Vapour	Liquid	Sat'd Vapour
105	120.82	0.0010475	1.4194	440.15	2683.8	1.3630	7.2958
110	143.27	0.0010516	1.2102	461.30	2691.5	1.4185	7.2387
115	169.06	0.0010559	1.0366	482.48	2699.0	1.4734	7.1833
120	198.53	0.0010603	0.8919	503.71	2706.3	1.5276	7.1296
125	232.1	0.0010649	0.7706	524.99	2713.5	1.5813	7.0775
130	270.1	0.0010697	0.6685	546.31	2720.5	1.6344	7.0269
135	313.0	0.0010746	0.5822	567.69	2727.3	1.6870	6.9777
140	316.3	0.0010797	0.5089	589.13	2733.9	1.7391	6.9299
145	415.4	0.0010850	0.4463	610.63	2740.3	1.7907	6.8833
150	475.8	0.0010905	0.3928	632.20	2746.5	1.8418	6.8379
155	543.1	0.0010961	0.3468	653.84	2752.4	1.8925	6.7935
160	617.8	0.0011020	0.3071	675.55	2758.1	1.9427	6.7502
165	700.5	0.0011080	0.2727	697.34	2763.5	1.9925	6.7078
170	791.7	0.0011143	0.2428	719.21	2768.7	2.0419	6.6663
175	892.0	0.0011207	0.2168	741.17	2773.6	2.0909	6.6256
180	1002.1	0.0011274	0.19405	763.22	2778.2	2.1396	6.5857
190	1254.4	0.0011414	0.15654	807.62	2786.4	2.2359	6.5079
200	1553.8	0.0011565	0.12736	852.45	2793.2	2.3309	6.4323
225	2548	0.0011992	0.07849	966.78	2803.3	2.5639	6.2503
250	3973	0.0012512	0.05013	1085.36	2801.5	2.7927	6.0730
275	5942	0.0013168	0.03279	1210.07	2785.0	3.0208	5.8938
300	8581	0.0010436	0.02167	1344.0	2749.0	3.2534	5.7045

Table 2 : Properties of Superheated Steam (Steam Table), SI Units (v, specific volume, m^3/kg; H, enthalpy, kJ/kg; s, entropy, kJ/kg.K)

Absolute Pressure kPa (Sat. Temp., °C)		*Temperature (°C)* 100	150	200	250	300	360	420	500
	v	17.196	19.512	21.825	24.136	26.445	29.216	31.986	35.679
10	H	2687.5	2783.0	2879.55	2977.3	3076.5	3197.6	3320.9	3489.1
(45.81)	s	8.4479	8.6882	8.9038	9.1002	9.2813	9.4821	9.6682	9.8978
	v	3.418	3.889	4.356	4.820	5.284	5.839	6.394	7.134
50	H	2682.5	2780.1	2877.7	2976.0	3075.5	3196.8	3320.4	3488.7
(81.33)	s	7.6947	7.9401	8.1580	8.3556	8.5373	8.7385	8.9249	9.1546
	v	2.270	2.587	2.900	3.211	3.520	3.891	4.262	4.755
75	H	2679.4	2778.2	2876.5	2975.2	3074.9	3196.4	3320.0	3488.4
(91.78)	s	7.5009	7.7496	7.9690	8.1673	8.3493	8.5508	8.7374	8.9672
	v	1.6958	1.9364	2.172	2.406	2.639	2.917	3.195	3.565
100	H	2672.2	2776.4	2875.3	2974.3	3074.3	3195.9	3319.6	3488.1
(99.63)	s	7.3614	7.6134	7.8343	8.0333	8.2158	8.4175	8.6042	8.8342
	v		1.2853	1.4443	1.6012	1.7570	1.9432	2.129	2.376
150	H		2772.6	2872.9	2972.7	3073.1	3195.0	3318.9	3487.6
(111.37)	s		7.4193	7.6433	7.8438	8.0720	8.2293	8.4163	8.6466
	v		0.4708	0.5342	0.5951	0.6548	0.7257	0.7960	0.8893
400	H		2752.8	2860.5	2964.2	3066.8	3190.3	3315.3	3484.9
(143.63)	s		6.9299	7.1706	7.3789	7.5662	7.7712	7.9598	8.1913
	v			0.2999	0.3363	0.3714	0.4126	0.4533	0.5070
700	H			2844.8	2953.6	3059.1	3184.7	3310.9	3481.7
(164.97)	s			6.8865	7.1053	7.2979	7.5063	7.6968	7.9299
	v			0.2060	0.2327	0.2579	0.2873	0.3162	0.3541
1000	H			2827.9	2942.6	3051.2	3178.9	3306.5	3478.5
(179.91)	s			6.6940	6.9247	7.1229	7.3349	7.5275	7.7622
	v			0.13248	0.15195	0.16966	0.18988	0.2095	0.2352
1500	H			2796.8	2923.3	3037.6	3.1692	3299.1	3473.1
(198.32)	s			6.4546	6.7090	6.9179	7.1363	7.3323	7.5698
	v				0.11144	0.12547	0.14113	0.15616	0.17568
2000	H				2902.5	3023.5	3159.3	3291.6	3467.6
(212.42)	s				6.5453	6.7664	6.9917	7.1915	7.4317
	v				0.08700	0.09890	0.11186	0.12414	0.13998
2500	H				2880.1	3008.8	3149.1	3284.0	3462.1
(223.99)	s				6.4085	6.6438	6.8767	7.0803	7.3234
	v				0.07058	0.08114	0.09233	0.10279	0.11619
3000	H				2855.8	2993.5	3138.7	3276.3	3456.5
(233.90)	s				6.2872	6.5390	6.7801	6.9878	7.2338

(b) Write explanatory notes on the following : *5×2=10*

(i) Minimum fluidization velocity

(ii) Navier-Stokes equation

(c) An oil is being cooled in a heat exchanger from 372 K to 350 K and flows inside the tube at a rate of 3600 kg/h. A flow of 1450 kg water per hour enters at 289 K for cooling and flows outside the tube. Mean heat capacity of the oil, $C_{pm} = 2 \cdot 30$ kJ/kg.K and for water, $C_{pm} = 4 \cdot 187$ kJ/kg.K.

(i) Calculate the outlet temperature of water and heat transfer area if the overall heat transfer coefficient $U_i = 340$ W/m^2.K and the streams are countercurrent.

(ii) Find the above two values for parallel flow streams as mentioned in part (i). *15*

SECTION B

Q5. (a) Find the solution to the following Laplace equation : *8*

$$F(s) = \frac{s}{(s+1)(s+4)}$$

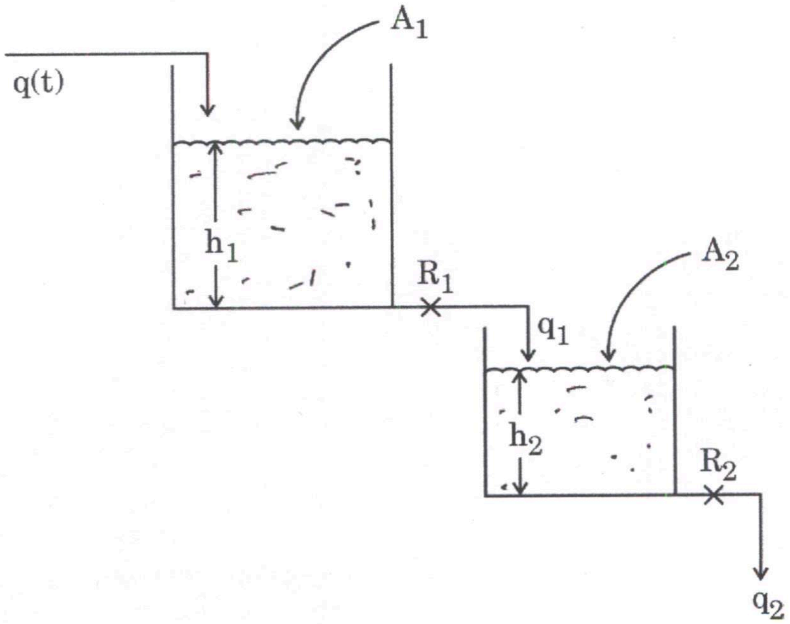
(b) What do you understand by the term "steady state temperature" ? Steady state temperature of a thermometer (time constant 0·2 min) is 30°C. At time t = 0, the thermometer is placed in a bath maintained at 40°C. What will be the temperature read by the thermometer after 9·0 seconds ? *8*

(c) What are the types of heads used for vertical tall vessels ? Explain each type with neat diagram. *8*

(d) Explain the applications of supercritical fluid in separation processes. *8*

(e) Explain mechanism of separation by dialysis with a neat concentration profile diagram. *8*

Q6. (a) Two tanks are connected in series (non-interacting mode) as shown in the figure. The time constants are $\tau_2 = 1$ and $\tau_1 = 0{\cdot}5$; $R_2 = 1$. Plot the response of the level in tank 2 if a unit-step change is made in the inlet flow rate to tank 1. (Graph paper is enclosed) *10*



(b) It is proposed to remove Ca^{+2} from water which contains 0·15 gm/litre by using Na-resin. The percentage removal of Ca^{+2} ions is to be 90%. The resin has ion exchange capacity of 3 eq/litre. Find out the quantity of resin needed to remove Ca^{+2} ion of 40,000 litres water. Selectivity is given as $K'_{Ca}/K'_{Na} = 2{\cdot}5$. *15*

(c) Explain the following with neat sketch :

(i) Ultimate stress

(ii) Proof stress

(iii) Yield stress

(iv) Resilience *15*

Q7. (a) A vessel is to be designed for maximum operating pressure of 450 kN/m^2. The vessel has a nominal diameter of 1·4 m and tangent to tangent length 2·5 m. The maximum allowable design stress of the material is 120 MN/m^2 at working temperature. Corrosion allowance is 1·5 mm. The weld joint efficiency of vessel material is 0·80.

Calculate the thickness of standard plate to fabricate this vessel. *15*

(b) Define the term "Final value theorem". Also find an analytical expression for n unit impulse response of a system whose transfer function is given by *10*

$$\frac{Y(s)}{X(s)} = \frac{23}{(s^2 + 3s + 2)}$$

(c) In an industrial township it is required to supply drinking water of 2×10^7 litres/day from raw water containing 3·3% salt concentration. It is decided to use RO unit, so that it can supply drinking water with < 300 ppm of salt. Membrane used was of thickness 0·8 micrometer and having water permeability of 70 $L/m^2.h$ MPa and salt rejection 98%. The pressure applied in feed side is 75 atm and on the permeate side is 1·0 atm. Assume polarization modulus is 1·2.

Calculate area of membrane needed if only 30% of the feed water permeates through the membrane. *15*

Q8. (a) Explain the general categories of chemical attacks for handling corrosive liquids in vessel.

For handling and storage of 98% sulphuric acid and phosphoric acid, what materials do you recommend for storage economically ? *15*

(b) An organic solution in 0·05 molar NaCl needs to be separated by ultrafiltration. The filtration is gel layer controlled. The feed concentration is 0.01 gm/mL and gel concentration is 0.4 gm/mL. The charge number of organic molecule is 10e and radius 0·005 micrometer. Calculate the permeate flux.

Data : Mass transfer coefficient 5×10^{-5} m/s. *10*

(c) Express the transfer function (C/R), for the following block diagram. *15*