L-3/T-2/CHE **Date : 06/04/2019**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2017-2018

Sub: **CHE 473** (Biochemical Engineering I)

Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Graph paper will be required to solve question 4(c).

1. (a) Briefly discuss the development of industrial production process of Penicillin. **(15)**

   (b) Write down the functions of the following components of Eukaryotic cell: Nucleus, Chromosomes, and Mitochondria. **(10)**

   (c) Briefly discuss the growth media for microorganisms: defined media and complex media. **(10)**

2. (a) Briefly discuss classifications and growth phases of bacteria. **(15)**

   (b) Briefly discuss reproduction mechanism of Yeast. **(10)**

   (c) Write down the typical population of the following microorganisms in culture: Viruses, Bacteria, Yeast, small unicellular Algae. **(10)**

3. (a) Briefly describe key principle, microbial, and chemical factors affecting food spoilage. **(18)**

   (b) Write a short note on Pasteurization. Briefly discuss process type, effects on shelf and microbes, and typical temperature-time combination of VAT, HTST, and UHT pasteurization techniques. **(17)**

4. (a) Write down the major categories of Enzymes. Briefly explain Enzymatic function based on Activation Energy and Molecular Aspects. **(11)**

   (b) What is Enzyme Inhibition? Write down inhibited enzyme kinetic scheme and rate equation for the Non-competitive Inhibitors with appropriate graphical representation. **(12)**

   (c) An inhibitor (I) is added to an enzymatic reaction at a level of 1.0 g/l. The following data were obtained for K_m = 9.2 g S/l. **(12)**

v	S
0.909	20
0.658	10
0.493	6.67
0.40	5
0.333	4
0.289	3.33
0.227	2.5

   (i) What kind of inhibitor is this? Substantiate the answer.

   (ii) Based on the answer to part (i), what is the value of K_I?

Contd P/2

SECTION - B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) "Different strains of the same organism may have different metabolic pathways"- evaluate this statement. **(5)**

(b) What is dilution rate? Derive the equation of dilution rate for a continuous fermenter. **(10)**

(c) A microorganism is cultured in a 20 L batch bioreactor, which initially contained 200 g/L growth substrate and 0.4 g/L biomass. The doubling time for this culture, t_d = 1.5 hours. It was also found that, at t = 5 h, biomass = 2.5 g/L and substrate concentration = 170 g/L. **(20)**

If half saturation constant, K_s = 5 g/L, determine the following

(i) $Y_{X/S}$ (g biomass/g substrate)

(ii) The cell density at stationary phase

(iii) Time required to reach stationary phase

(iv) Approximate lag time

What would happen if K_s = 50 g/L?

6. (a) How 'stepwise oxidation of sugar in cells' is beneficial over 'direct burning of sugar in chemical reactor'? **(8)**

(b) Vero cell line was isolated from the kidney of an African green monkey. In laboratory, Vero cells are cultured in Dulbecco Modified Eagle Medium. In an experiment, initially 6×10^4 cells per ml was cultured in a 6-ml cell culturing flask. Growth of cells for the subsequent days was monitored with the following results. **(12)**

Time (days)	Number of cells per ml, 10^4
1	3
2	9
3	28
4	59
7	92
8	83
9	8

Determine the specific growth rate constant during the growth phase.

Why number of cells started to fall after 7[th] day?

(c) What are the basic requirements of a clean room? List five major types of sterilization methods used in the industries. **(10)**

(d) Write down few important characteristics of a good filter medium used for sterilization. **(5)**

7. (a) With the help of appropriate reactions, discuss the differences between BOD and COD. Why BOD is not preferable in some cases? **(10)**

(b) Draw a schematic diagram of an activated sludge process. Using the Monod equation for microbial growth and material balance for biomass and substrate, derive an expression to calculate cells' (solids') residence time using volume of sludge tank, effluent flow rate, and the ratio of excess sludge flow to feed flow rate. **(18)**

(c) Which type of bio safety laboratory do you need to use to handle Influenza virus (an air borne pathogen)? Justify your choice. **(7)**

8. (a) What is ELISA and what are the major applications of ELISA? With the help of neat sketch, explain the principles of direct and indirect ELISA techniques. **(18)**

(b) Describe temperature and pressure cycles of an autoclave. **(12)**

(c) What are the disadvantages of Solid State Fermentation (SSF)? **(5)**

L-3/T-2/CHE Date : 06/04/2019

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-II B. Sc. Engineering Examinations 2017-2018

Sub : **CHE 481** (Environmental Science I)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) What are the secondary pollutants? How do they from in the atmosphere? Discuss with proper examples. **(9)**

   (b) How do you control noise pollution in the transmission path? Explain in details. **(7)**

   (c) For a fixed box model, derive the concentration of a pollutant in a city. List all the assumptions. A city has the following description: W = 5 km, L = 15 km, u = 3 m/s, H = 1000m. The emission rate is $q = 4\times10^{-6}$ g/s.m^2. The concentration of CO over the city was calculated to be 25 μg/m^3. During the dry season the background concentration of CO was found twice and the same meteorological conditions occurred only 40 percent of the time. For the remaining 60 percent, the wind blew at right angles to the flow direction at velocity 6 m/s. What is the annual average concentration of carbon monoxide in this city? **(10+9=19)**

2. (a) For a gravity settler, it is known that $\eta_{mixed} = 1 - \exp(-\eta_{block\ flow})$. Symbols have their usual meanings. List the assumptions you make to derive this. Considering that the same approach is applicable for centrifugal separators, derive the equation of the removal efficiency for the block flow in terms of process parameters. **(5+9=14)**

   (b) What are the criteria pollutants and HAPs as per USEPA? Why are they named so? List 3 health impacts of each of the criteria pollutants. **(6+9=15)**

   (c) Explain 'isokinetic sampling' with relevant schematics. **(6)**

3. (a) What are the typical approaches to control the air pollution caused by VOC? Discuss briefly with relevant schematics. **(12)**

   (b) How does air pollution affect ozone layer? Briefly describe ozone cycle and write down the reactions involved in NO_x catalytic cycle. **(3+4+4=11)**

   (c) During Pb measurement in a high volume air sampler, you plan to use 1/4th of the filter paper (8 in × 10 in) for analysis. The 'absorbance vs. μg Pb/ml' data for calibration curve are below. Calibration solution as 50 ml and the extraction solution was 25 ml. 15 ml sample was collected out of the extraction solution for analysis and the absorbance of the sample and blank were 0.381 and 0.003, respectively. Total air flow was 15 m^3. Calculate the Pb concentration in air. **(12)**

Contd. P/2

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Contd ... Q. No. 3(c)

Concentration (μg/m^3)	Absorbance
0.05	0.17
0.2	0.2
0.5	0.25
1	0.35
2	0.58
4	0.95

4. (a) Classify air pollution sources and list appropriate examples of each type of air pollution source. **(9)**

(b) Briefly discuss the four different types of particulate pollutants found in the environment. **(8)**

(c) Write short notes on the following: **(6×3=18)**

(i) Atmospheric removal process

(ii) Impact of noise pollution

(iii) Air Quality Models

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) A continuous wastewater stream is mixing with the flow of Karnaphuli river. The initial ultimate BOD at the mixing point is 15 mg/L and the dissolved oxygen (DO) concentration is at saturation. The river water temperature is 10°C. At 10°C, the deoxygenation rate constant (kd) is 0.30 day^{-1} and the reaeration rate constant (kr) is 0.40 day^{-1}. Using **Sreeter-Phelps Model** determine, **(35)**

(i) the time and distance in downstream at which the oxygen deficit is maximum, and

(ii) the critical DO concentration.

Derive all necessary equations for solving the problem.

Given data: Average flow rate of the river in 0.3 m/s. Average depth of the river is 3.0 m and Width of the river is 500 m. DO table has been attached. Assume a reasonable value for any missing data.

6. (a) State the reasons of performing BOD test for 5 days. Explain BOD and NBOD. Show OD and NBOD on a sketch. **(8)**

(b) Write a short note on aeration system in wastewater treatment process. **(12)**

(c) Explain self purification mechanisms of waste under disposal to surface water. **(5)**

Contd. P/3

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Contd ... Q. No. 6

(d) Draw DO sag curve along with reaeration and deoxygenation curve on a same plot. Explain the DO sag curve in context of reaeration and deoxygenation mechanisms. **(10)**

7. (a) Classify industries based on ECR 1997. How can you get a clearance certificate for a red category industry? **(8)**

(b) Discuss different stages involved in anaerobic biological treatment process with a diagram. **(13)**

(c) Write short notes on the followings: **(7×2=14)**

(i) Impact of sulfur containing compounds in wastewater

(ii) TOC and DOC

(iii) Significance of BOD/COD

(iv) Anoxic process

(v) SVI

(vi) Food to microorganism ratio

(vii) MLVSS

8. (a) Draw a typical wastewater treatment process and label if properly. Describe activated sludge process. What are the advantages and disadvantages of activated sludge process? **(14)**

(b) Explain electrical double layer in respect of coagulation-flocculation with a neat sketch. **(8)**

(c) The design flow for a water treatment plant (WTP) is 3.8×10^3 m^3/d. The rapid mixing tank will have a mechanical mixer and the average alum dosage will be 30 mg/L. The theoretical mean hydraulic detention time of the tank will be 1 minute. Determine the following: **(13)**

(i) the quantity of alum needed on a daily basis in kg/d-

(ii) the dimensions of the tank in meters for a tank with equal length, width, and depth.

(iii) the power input required for a G of 900 sec^{-1} for water temperature of 10°C. Express the answer in kW. Water viscosity at 10°C is 1 cP.

4

OXYGEN SOLUBILITY TABLE

YSI a xylem brand

Solubility of Oxygen (mg/L) in Water Exposed to Water-Saturated Air at 760 mm Hg Pressure.

Temp °C	Chlorinity 0 Salinity: 0	5.0 ppt 9.0 ppt	10.0 ppt 18.1 ppt	15.0 ppt 27.1 ppt	20.0 ppt 36.1 ppt	25.0 ppt 45.2 ppt
0.0	14.62	13.73	12.89	12.10	11.36	10.66
1.0	14.22	13.36	12.55	11.78	11.07	10.39
2.0	13.83	13.00	12.22	11.48	10.79	10.14
3.0	13.46	12.66	11.91	11.20	10.53	9.90
4.0	13.11	12.34	11.61	10.92	10.27	9.66
5.0	12.77	12.02	11.32	10.66	10.03	9.44
6.0	12.45	11.73	11.05	10.40	9.80	9.23
7.0	12.14	11.44	10.78	10.16	9.58	9.02
8.0	11.84	11.17	10.53	9.93	9.36	8.83
9.0	11.56	10.91	10.29	9.71	9.16	8.64
10.0	11.29	10.66	10.06	9.49	8.96	8.45
11.0	11.03	10.42	9.84	9.29	8.77	8.28
12.0	10.78	10.18	9.62	9.09	8.59	8.11
13.0	10.54	9.96	9.42	8.90	8.41	7.95
14.0	10.31	9.75	9.22	8.72	8.24	7.79
15.0	10.08	9.54	9.03	8.54	8.08	7.64
16.0	9.87	9.34	8.84	8.37	7.92	7.50
17.0	9.67	9.15	8.67	8.21	7.77	7.36
18.0	9.47	8.97	8.50	8.05	7.62	7.22
19.0	9.28	8.79	8.33	7.90	7.48	7.09
20.0	9.09	8.62	8.17	7.75	7.35	6.96
21.0	8.92	8.46	8.02	7.61	7.21	6.84
22.0	8.74	8.30	7.87	7.47	7.09	6.72
23.0	8.58	8.14	7.73	7.34	6.96	6.61
24.0	8.42	7.99	7.59	7.21	6.84	6.50
25.0	8.26	7.85	7.46	7.08	6.72	6.39
26.0	8.11	7.71	7.33	6.96	6.62	6.28
27.0	7.97	7.58	7.20	6.85	6.51	6.18
28.0	7.83	7.44	7.08	6.73	6.40	6.09
29.0	7.69	7.32	6.96	6.62	6.30	5.99
30.0	7.56	7.19	6.85	6.51	6.20	5.90
31.0	7.43	7.07	6.73	6.41	6.10	5.81
32.0	7.31	6.96	6.62	6.31	6.01	5.72
33.0	7.18	6.84	6.52	6.21	5.91	5.63
34.0	7.07	6.73	6.42	6.11	5.82	5.55
35.0	6.95	6.62	6.31	6.02	5.73	5.46
36.0	6.84	3.52	6.22	5.93	5.65	5.38
37.0	6.73	6.42	6.12	5.84	5.56	5.31
38.0	6.62	6.32	6.03	5.75	5.48	5.23
39.0	6.52	6.22	5.98	5.66	5.40	5.15
40.0	6.41	6.12	5.84	5.58	5.32	5.08
41.0	6.31	6.03	5.75	5.49	5.24	5.01
42.0	6.21	5.93	5.67	5.41	5.17	4.93
43.0	6.12	5.84	5.58	5.33	5.09	4.86
44.0	6.02	5.75	5.50	5.25	5.02	4.79
45.0	5.93	5.67	5.41	5.17	4.94	4.72

Table for Q.5.

L-3/T-2/CHE **Date : 10/04/2019**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2017-2018

Sub : **CHE 441** (Fertilizer, Pulp and Paper Technology)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) How does the paper quality vary with the pulping technology and which technology dominates the market at present? Also briefly discuss the world scenario for pulp and paper industries. **(7+6=13)**

   (b) What is Thermo-mechanical pulp (TMP)? What are the differences between mechanical and chemical pulping process? **(4+8=12)**

   (c) What do you understand by the term "pulp bleaching" in the cases of mechanical and chemical pulping? Why does this process differ for these two pulping technologies? **(5+5=10)**

2. (a) Draw a neat sketch of the pulp stock preparation and paper making process (including Fourdrinier machine). Explain the working principle of the Fourdrinier machine. **(13+5=18)**

   (b) Describe the process of continuous digestion for pulping (with a sketch). Also explain the benefit of this process over batch digestion. **(9+4=13)**

   (c) How do fibers bond in paper? Briefly discuss the mechanism. **(4)**

3. (a) In the chemical recovery step for Kraft pulping process, what is the most critical equipment involved? Describe the working principle of that equipment in brief with a sketch. **(3+8=11)**

   (b) How can you quantity the lignin removal from pulp? Explain. **(5)**

   (c) What are the advanced technologies available for utilizing black liquor? Discuss in brief. **(2+8=10)**

   (d) Discuss CEHDP process of lignin removal with a sketch. **(9)**

4. (a) Write short notes on – **(5×3=15)**

   (i) Fiber strength (ii) Pulp viscosity
   (iii) Time to temperature (iv) Time at temperature
   (v) Reduction efficiency

   (b) What is the function of Anthraquinone in pulping process? **(6)**

   (c) What are the building blocks of wood? Among them, which one is the most important for pulp and paper making process? What type of wood produces the best quality pulp and why? **(2+2+4=8)**

   (d) What is Vent gas from Recovery Boiler? Also explain what do you understand by concentrated and dilute non-condensable gases? **(6)**

Contd P/2

CHE 441

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Write short notes on mineral fertilizer industries in Bangladesh. **(10)**

   (b) Apart from natural gas, what might be the other possible alternative raw materials for ammonia production in context of Bangladesh? Give reasons to your answer. **(8)**

   (c) Name the process licensor of ammonia-urea processes used in SFCL, ZFCL, and KAFCO in Bangladesh. **(5)**

   (d) Why the Bangladeshi farmers usually use mineral fertilizer in soil instead of organic fertilizer? What are the distinguishing features between mineral and organic fertilizers? **(2+4)**

   (e) What might be the adverse effect on soil health due to excessive use of mineral fertilizers for agriculture? – State briefly. **(6)**

6. (a) What are the basic types of ammonia converters usually used in fertilizer processing industries? – State briefly. Write the distinguishing features of Kellog and Topsoe ammonia converters. **(5+5)**

   (b) Describe briefly Uhde's ammonia synthesis and refrigeration loop with a neat schematic diagram. **(15)**

   (c) Why is purge gas recovery important in ammonia synthesis? Show ammonia recovery from purge gas in a ammonia synthesis plant with a block diagram. **(2+8)**

7. (a) What are the basic processes you can apply for raw syngas cleaning? Describe their relative advantages and disadvantages. **(2+10)**

   (b) Briefly state the shift conversion processes highlighting operating conditions, reaction involved, catalyst type and CO content at the outlet of the reactor. **(8)**

   (c) What are the adverse effects of biurate in urea? How is biurate formed in urea production process? – Explain with reactions. What are the typical optimum operating conditions in urea production process? **(5+5+5)**

8. (a) What are the factors you need to consider for the quality of phosphate rock? – State briefly. **(10)**

   (b) Why is not rock phosphate directly usable in agricultural application? Why is ammoniate of phosphate a better choice than TSP as a fertilizer? What do you understand by NPK (15-15-15) fertilizer? **(4+4+2)**

   (c) Describe the SSP production process with a block diagram. **(15)**

L-3/T-2/ChE **Date : 31/03/2019**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2017-2018

Sub : **ChE 305** (Mass Transfer II)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) A naphthalene mothball is kept in open air. Can you estimate the time for the naphthalene mothball to dissipate completely? Which additional data would you need for this estimation? Explain your answer with necessary equations. **(15)**

(b) The diffusion coefficient of NO_2 into stagnant water can be measured with the apparatus shown in figure for Q no 1(b). Although the water is initially pure, the mercury drop moves to show that 0.82 cm^3 of NO_2 is absorbed in 3 minutes. The gas-liquid interface has an area of 36.3 cm^2, the pressure is 0.93 atm, the temperature is 16°C, and the Henry's law constant is 37,000 cm^3 atm/mol. The coefficient is found to be 5×10^{-6} cm^2/sec. How deep should be the water be to ensure that the answer is accurate? **(20)**

(Note: You may use the flux equation for equimolar counter diffusion)

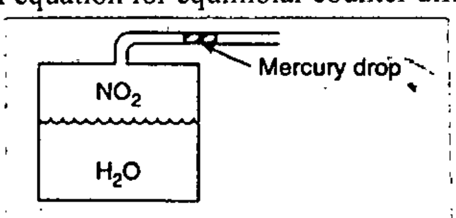

Figure for Q no 1 ~~a~~ b

2. (a) The objective of Packing Design is to attain high mass transfer with maximum capacity and minimum pressure drop. Write down the engineering features to be considered in order to achieve the objective. **(10)**

(b) A tower packed with 25.4 mm ceramic rings is to be designed to absorb SO_2 from air by using pure water at 293K and 101.3 kPa abs pressure. The inlet gas contains 1 mol% SO_2 and the outlet gas contains 0.2 mol% SO_2. The inert air flow is 6.53×10^{-4} kg mol air/s and the inert water flow is 4.2×10^{-2} kg mol water/s. The tower cross sectional area is 0.0929 m^2. For dilute SO_2 the film mass transfer coefficient for 25.4 mm rings are: **(25)**

$$k'_y a = 0.0594 G_y^{0.2} G_x^{0.23} \qquad k'_x a = 0.152 G_x^{0.02}$$

where $k'_y a$ is kgmol/s.m^3.mol frac, $k'_x a$ is kg mol/s.m^3.mol frac, and G_x and G_y are kg total liquid or gas, respectively, per sec per m^2 tower cross section. Calculate the tower height.

See Table for Question no 2b for equilibrium data.

Contd. P/2

ChE 305

3. (a) 'Sometimes mass transfer in the top section of an absorption column is liquid phase controlled and in the bottom section it is gas phase controlled'- do you agree with this statement? Justify your answer with necessary plots and equations. **(15)**

   (b) Spheres of benzoic acid are being dissolved in water in a large tank at a rate of 1.8×10^{-4} lbmol/h at 77°F. The diffusivity and solubility of benzoic acid in water are 9.88×10^{-9} ft^2/s and 0.00184 lbmol/ft^3 of solution, respectively. **(20)**

   i. Calculate the mass transfer coefficient

   ii. Calculate the fractional rate of surface renewal

4. Explain the following statement:

   (a) Overall mass transfer coefficient is more frequently used instead of gas phase or liquid phase mass transfer coefficient. **(9)**

   (b) The HTU or HETP value represents the efficiency of a packing. **(9)**

   (c) Diffusivity in liquids can be approximated from viscosity. **(9)**

   (d) Mass flux in porous membrane is calculated using $1/4$ th of diffusivity i.e. $\frac{1}{4}D_A$. **(8)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Write a short note on analogy among heat, mass and momentum transfer. **(7)**

   (b) It is planned to cool water from 110°F to 85°F in a packed counter current water-cooling tower using air entering at 85°F with a wet bulb temperature of 75°F and a humidity of 0.0165 lb water/lb dry air. The water flow is 2000 lb_m/h-ft^2 and the air flow is 1400 lb_m air/h-ft^2. The overall mass-transfer coefficient is K_Ga = 6.90 lb mol/h-ft^3.atm. See table for question no. 5(b) for required data. **(28)**

   i) Calculate the minimum air rate that can be used.

   ii) Calculate the tower height needed if the air flow of 1400 lb_mair/h-ft^2 is used.

6. (a) "Size reduction nitrogen of absorbent particles does not change adsorption capacity"- Justify the above statement. **(10)**

   (b) Data for drying nitrogen with molecular sieve type 4A are given below. **(25)**

   T = 79°F L_T = 1.44 ft P = 86 psia ρ_b = 44.5 lb/ft^3

   N_2 feed = 29.2 mol/h-ft^2 c_a = 1490 ppm

Contd. P/3

ChE 305

Contd ... Q. No. 6(b)

t, h	0	10	15	15.4	15.6	15.8	16	16.2
C, ppm	<1	<1	<1	5	26	74	145	260
t, h	16.4	16.6	16.8	17	17.2	17.6	18	18.5
C, ppm	430	610	798	978	1125	1355	1465	1490

Calculate the saturation capacity from the breakthrough curve, and determine the length of unused bed based on a break-point concentration c/c_0 of 0.05.

7. (a) A distillation column with total condenser and partial reboiler is used to separate acetone-water mixture. The feed rate is 200 kg moles/hr with composition of 60 mol% acetone. The feed is mixture of 60% liquid and 40% vapor by mole and is fed on the optimum plate which is $N_p = 10$. The distillate composition is 0.95 and bottom is 0.08 mole fraction of acetone. The optimum feed stage at total reflux, $N_{p.min} = 4$. You have to calculate Relative volatility (α) and external reflux ratio (L/D) of the distillation column. **(18)**

Given: The Gilliland correlation:

$$\frac{N - N_{min}}{N+1} = 1.0 - 18.571x$$

Where, $x = \dfrac{L/D - (L/D)_{min}}{1 + L/D}$

(b) Under what circumstances you will select pervaporation as a separation technique? In pervaporation the VLE is quite different from the VLE in distillation - justify this statement with the help of mass flux equation. **(17)**

8. (a) Identify the type of mass transport involved in Reverse osmosis. Write down the mass transfer equations for both water and salt at steady state and explain each term. **(9)**

(b) Describe the working principle of a Pressure Swing Adsorber (PSA). **(10)**

(c) Write short notes on i) Asymmetric membrane and **(16)**

ii) Membrane selectivity

Table for Question no 2b)
Equilibrium data for SO_2-water system

Mole Fraction SO_2 in Liquid, x_A	Partial Pressure of SO_2 in Vapor, p_A (mm Hg)		Mole Fraction SO_2 in Vapor, y'_A; P = 1 Atm	
	20°C (293 K)	30°C (303 K)	20°C	30°C
0	0	0	0	0
0.0000562	0.5	0.6	0.000658	0.000790
0.0001403	1.2	1.7	0.00158	0.00223
0.000280	3.2	4.7	0.00421	0.00619
0.000422	5.8	8.1	0.00763	0.01065
0.000564	8.5	11.8	0.01120	0.0155
0.000842	14.1	19.7	0.01855	0.0259
0.001403	26.0	36	0.0342	0.0473
0.001965	39.0	52	0.0513	0.0685
0.00279	59	79	0.0775	0.1040
0.00420	92	125	0.121	0.1645
0.00698	161	216	0.212	0.284
0.01385	336	452	0.443	0.594
0.0206	517	688	0.682	0.905
0.0273	698		0.917	

Source: T. K. Sherwood, *Ind. Eng. Chem.*, 17, 745 (1925).

TABLE 10.5-1. *Enthalpies of Saturated Air–Water Vapor Mixtures (0°C Base Temperature)*

T_L		H_y		T_L		H_y	
		btu/lb$_m$ dry air	J/kg dry air			btu/lb$_m$ dry air	J/kg dry air
°F	°C			°F	°C		
60	15.6	18.78	43.68×10^3	100	37.8	63.7	148.2×10^3
80	26.7	36.1	84.0×10^3	105	40.6	74.0	172.1×10^3
85	29.4	41.8	97.2×10^3	110	43.3	84.8	197.2×10^3
90	32.2	48.2	112.1×10^3	115	46.1	96.5	224.5×10^3
95	35.0	55.4	128.9×10^3	140	60.0	198.4	461.5×10^3

Table for Question 5(b)

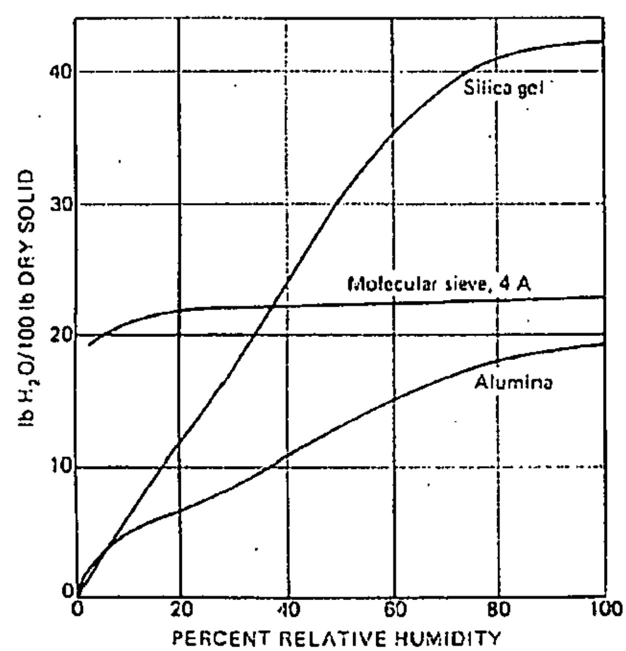

FIGURE 25.3
Adsorption isotherms for water in air at 20 to 50°C.

Figure for Question 6(c)

L-3/T-2/CHE — Date : 25/03/2019

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2017-2018

Sub : **CHE 311** (Special Topics in Unit Operations)

Full Marks : 280 — Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Assume reasonably if additional data/information is required. Notations indicate their usual meaning.

Use figure for the question 1(a), 2(a), 3(b) and attach with answer scripts

---

1. (a) A basket type of double effect evaporator connected for backward feed is to be used to concentrate a NaOH solution. Each evaporator body has a 2000 ft^2 heating area. The caustic solution enters at 80°F and is 5 weight percent NaOH. It is to be concentrated to 50 weight percent. Previous operation indicates that overall coefficients of 400 Btu/hr ft^2°F and 550 Btu/hr ft^2°F may be obtained in the first and second effects, respectively. Saturated steam at 150 psia is available, and a vacuum of 2 in. Hg absolute may be obtained with existing ejectors. What is the maximum production rate obtainable? **(30)**

   (b) Discuss the effects of liquid head and boiling point elevation on the capacity of the evaporator. **($8\frac{2}{3}$)**

   (c) Discuss the working principle of Entrainment separator. **(8)**

2. (a) A 32.5 percent solution of $MgSO_4$, at 120F (48.9°C) is cooled, without appreciable evaporation to 70°F (21.1°C) in a batch water cooled crystallizer. How much heat must be removed from the solution per ton of crystals? **(10)**

   (b) What is the difference between homogeneous and heterogeneous nucleation? **(10)**

   (c) Draw a schematic diagram of Draft tube-baffle crystallizer and discuss the salient features. **($10\frac{2}{3}$)**

   (d) Write the values of shape factor standard turbine. Prove that Power Number is proportional to the Reynolds Number for an adequately baffled, geometrically similar systems. **(16)**

3. (a) For two stages of compression, what should be the pressure across the cylinders if the intercooler and piping pressure drop is 3 psi? Given Suction to the first stage is 0 psig and discharge from the second stage is 150 psig. **(12)**

   (b) It is necessary to pump a liquid with properties similar to the water at a rate of 300 gal/min against a head of 70ft. Recommend the type of pump and select the appropriate size of the impeller. **($20\frac{2}{3}$)**

   (c) Write a short note on **(7+7)**

      i. Multistage Centrifugal pump

      ii. Characteristics Curves of Centrifugal pump.

CHE 311

4. (a) "In a fixed capacity ejector, increase in steam pressure do not increase vapor handling capacity"-explain the statement. Why Ejector is attractive for industrial application? State 8 reasons. **(16)**

   (b) Discuss the merits of Spray died product. **($12\frac{2}{3}$)**

   (c) Write a short note on **(9+9)**

      i. Tunnel Kiln Dryer

      ii. Principle of Drying

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Discuss the merits and demerits of steam Turbine. **(10)**

   (b) Make comparison between Impulse turbine and Reaction Turbine. **(11)**

   (c) If the friction over blade surface is neglected for impulse turbine, Show that the maximum value of blade efficiency **($25\frac{2}{3}$)**

   $$(n_b)_{max} = cos^2 \alpha$$

   where the blades are symmetrical

6. (a) With neat sketch, discuss the major types of relief devices. **(15)**

   (b) Why do you think that relief sizing is important in petrochemical industry. **(8)**

   (c) Discuss different types of relief containment system. **($11\frac{2}{3}$)**

   (d) A positive displacement pump can pump water at 400 gpm at a pressure of 400 psig. Because a dead headed Pump can be easily damaged, compute the area required to relieve the Pump. Assume a backpressure of 20 psig and 10% overpressure (kp = 0.6). Make appropriate assumption if necessary. **(12)**

7. (a) Discuss the factors that influencing the size of the product of a Ball mill. **(12)**

   (b) For fine grinding, the energy required for size reduction is directly proportional to the increase in surface. True/False - Explain your answer. **(8)**

   (c) How could you avoid particles re-entrainment problem in electrostatic precipitation? **(10)**

   (d) Discuss the classification of gas cleaning fabric filters. **($16\frac{2}{3}$)**

8. Write short notes on

   a) Deflagration venting for dust and vapor explosions **($10\frac{2}{3}$)**

   b) Extraction turbine **(9)**

   c) Runway reaction relief **(9)**

   d) Wet Scrubbers **(9)**

   e) Screw conveyor **(9)**

Properties of Saturated Steam and Water†

Temperature T, °F	Vapor pressure p_A, $lb_f/in.^2$	Specific volume, ft^3/lb Liquid v_x	Specific volume, ft^3/lb Saturated vapor v_y	Enthalpy, Btu/lb Liquid H_x	Enthalpy, Btu/lb Vaporization λ	Enthalpy, Btu/lb Saturated vapor H_y
32	0.08859	0.016022	3,305	0	1,075.4	1,075.4
35	0.09992	0.016021	2,948	3.00	1,073.7	1,076.7
40	0.12166	0.016020	2,445	8.02	1,070.9	1,078.9
45	0.14748	0.016021	2,037	13.04	1,068.1	1,081.1
50	0.17803	0.016024	1,704.2	18.06	1,065.2	1,083.3
55	0.2140	0.016029	1,431.4	23.07	1,062.4	1,085.5
60	0.2563	0.016035	1,206.9	28.08	1,059.6	1,087.7
65	0.3057	0.016042	1,021.5	33.09	1,056.8	1,089.9
70	0.3632	0.016051	867.7	38.09	1,054.0	1,092.0
75	0.4300	0.016061	739.7	43.09	1,051.1	1,094.2
80	0.5073	0.016073	632.8	48.09	1,048.3	1,096.4
85	0.5964	0.016085	543.1	53.08	1,045.5	1,098.6
90	0.6988	0.016099	467.7	58.07	1,042.7	1,100.7
95	0.8162	0.016114	404.0	63.06	1,039.8	1,102.9
100	0.9503	0.016130	350.0	68.05	1,037.0	1,105.0
110	1.2763	0.016166	265.1	78.02	1,031.4	1,109.3
120	1.6945	0.016205	203.0	88.00	1,025.5	1,113.5
130	2.225	0.016247	157.17	97.98	1,019.8	1,117.8
140	2.892	0.016293	122.88	107.96	1,014.0	1,121.9
150	3.722	0.016343	96.99	117.96	1,008.1	1,126.1
160	4.745	0.016395	77.23	127.96	1,002.2	1,130.1
170	5.996	0.016450	62.02	137.97	996.2	1,134.2
180	7.515	0.016509	50.20	147.99	990.2	1,138.2
190	9.343	0.016570	40.95	158.03	984.1	1,142.1
200	11.529	0.016634	33.63	168.07	977.9	1,145.9
210	14.125	0.016702	27.82	178.14	971.6	1,149.7
212	14.698	0.016716	26.80	180.16	970.3	1,150.5

Temperature T, °F	Vapor pressure p_A, $lb_f/in.^2$	Specific volume, ft^3/lb Liquid v_x	Specific volume, ft^3/lb Saturated vapor v_y	Enthalpy, Btu/lb Liquid H_x	Enthalpy, Btu/lb Vaporization λ	Enthalpy, Btu/lb Saturated vapor H_y
220	17.188	0.016772	23.15	188.22	965.3	1,153.5
230	20.78	0.016845	19.386	198.32	958.8	1,157.1
240	24.97	0.016922	16.327	208.44	952.3	1,160.7
250	29.82	0.017001	13.826	218.59	945.6	1,164.2
260	35.42	0.017084	11.768	228.76	938.8	1,167.6
270	41.85	0.017170	10.066	238.95	932.0	1,170.9
280	49.18	0.017259	8.650	249.18	924.9	1,174.1
290	57.53	0.017352	7.467	259.44	917.8	1,177.2
300	66.98	0.017448	6.472	269.73	910.4	1,180.2
310	77.64	0.017548	5.632	280.06	903.0	1,183.0
320	89.60	0.017652	4.919	290.43	895.3	1,185.8
340	117.93	0.017872	3.792	311.30	879.5	1,190.8
350	134.53	0.017988	3.346	321.80	871.3	1,193.1
360	152.92	0.018108	2.961	332.35	862.9	1,195.2
370	173.23	0.018233	2.628	342.96	854.2	1,197.2
380	195.60	0.018363	2.339	353.62	845.4	1,199.0
390	220.2	0.018498	2.087	364.34	836.2	1,200.6
400	247.1	0.018638	1.8661	375.12	826.8	1,202.0
410	276.5	0.018784	1.6726	385.97	817.2	1,203.1
420	308.5	0.018936	1.5024	396.89	807.2	1,204.1
430	343.3	0.019094	1.3521	407.89	796.9	1,204.8
440	381.2	0.019260	1.2192	418.98	786.3	1,205.3
450	422.1	0.019433	1.1011	430.2	775.4	1,205.6

†Abstracted from *Steam Tables*, by Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, John Wiley & Sons, New York, 1969, with the permission of the publisher.

4

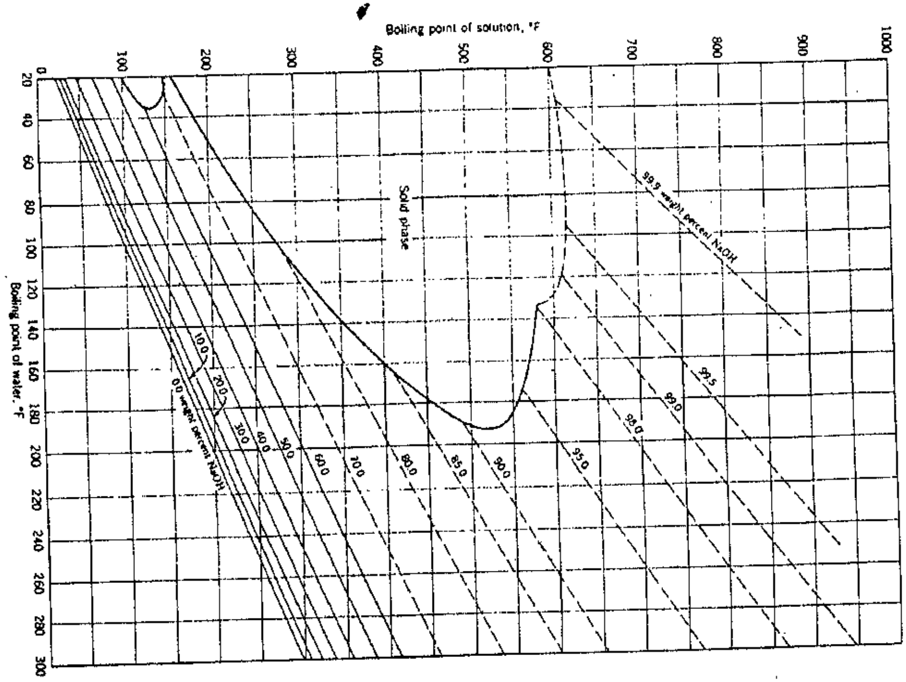

Figure 19.11. Dühring lines for the NaOH–H_2O system.

Q 1(a)

(5)

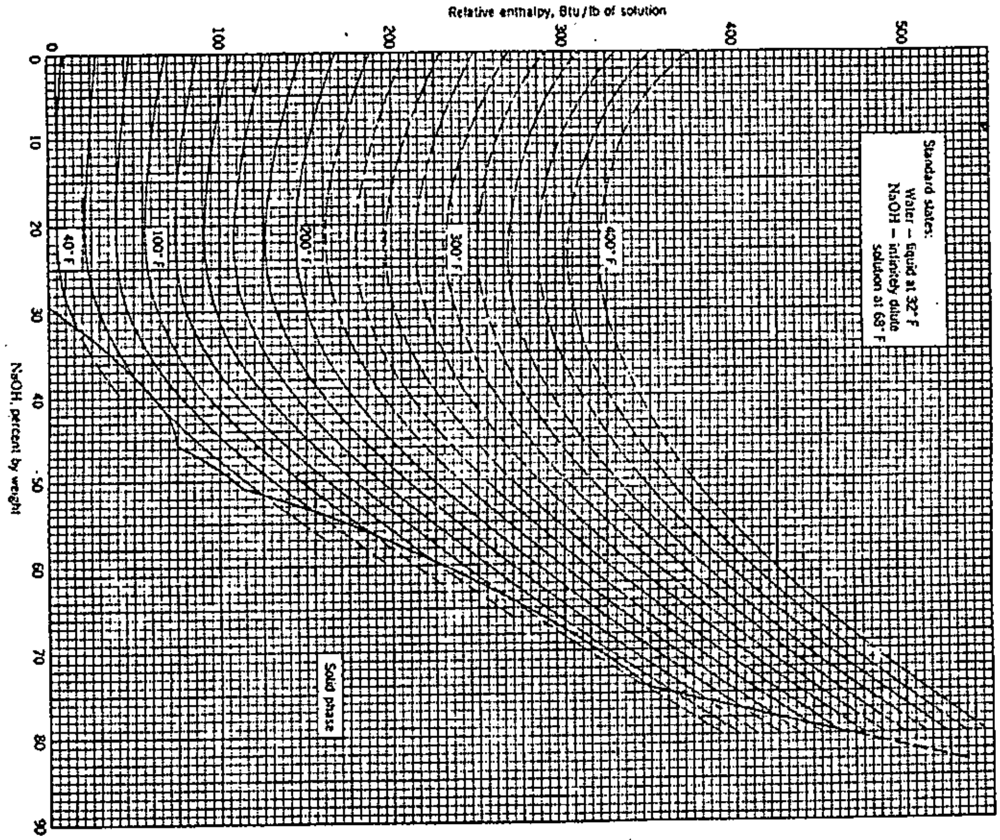

Figure 19.13. Enthalpy-concentration diagram for aqueous solutions of NaOH under a total pressure of one atmosphere. The reference state for water is taken as liquid water at 32°F under its own vapor pressure. This reference state is identical with the one used in most steam tables (8). For sodium hydroxide, the reference state is that of an infinitely dilute solution at 68°F. [From McCabe, W. L., *Trans. A.I.Ch.E.*, *31*, p. 129 (1935), by permission of A.I.Ch.E., copyright © 1935.]

Q 1(a)

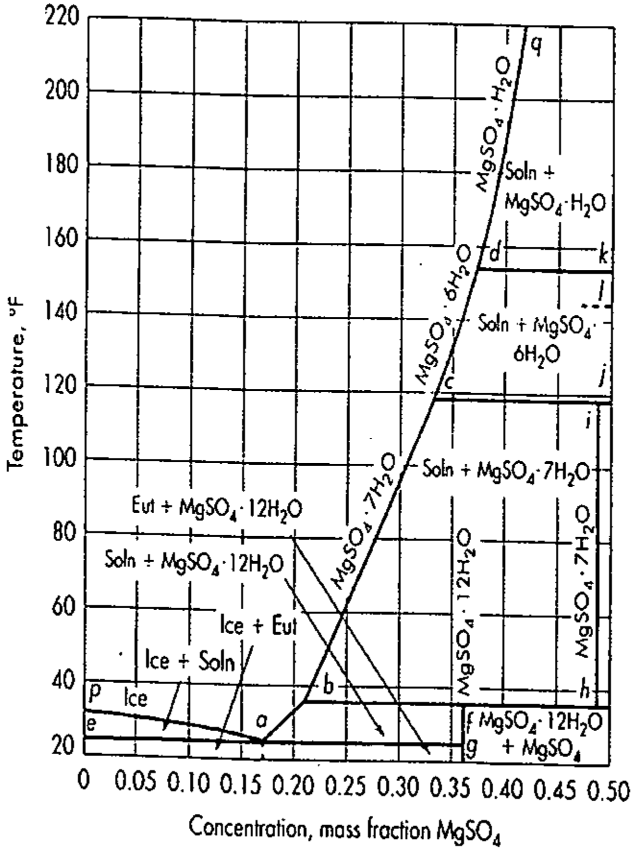

FIGURE 27.3

Phase diagram, system $MgSO_4 \cdot H_2O$. [*By permission, from J. H. Perry (ed.), Chemical Engineers' Handbook, 4th ed. Copyright, 1963, McGraw-Hill Book Company.*]

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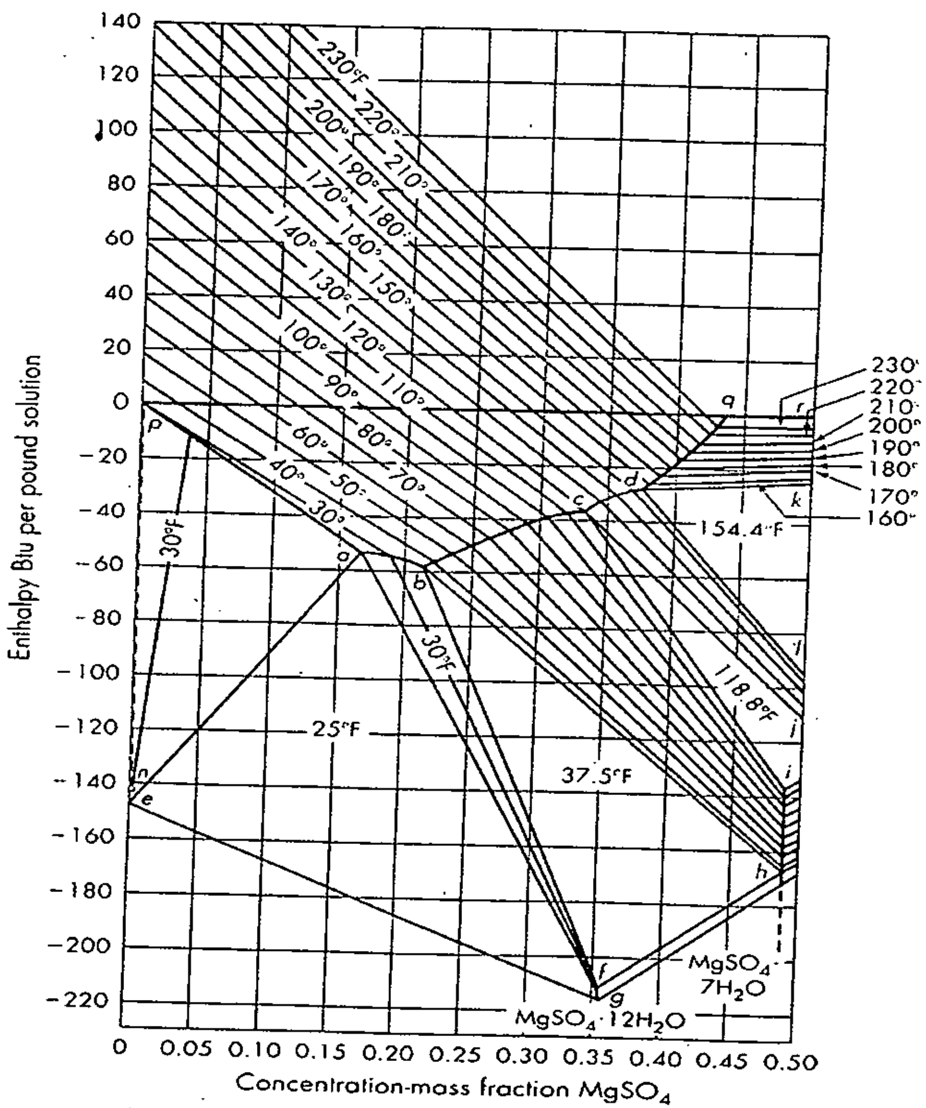

FIGURE 27.4
Enthalpy-concentration diagram, system $MgSO_4 \cdot H_2O$. Datum is liquid water at 32°F (0°C). [*By permission, from J. H. Perry (ed.)*

Q2(a)

8

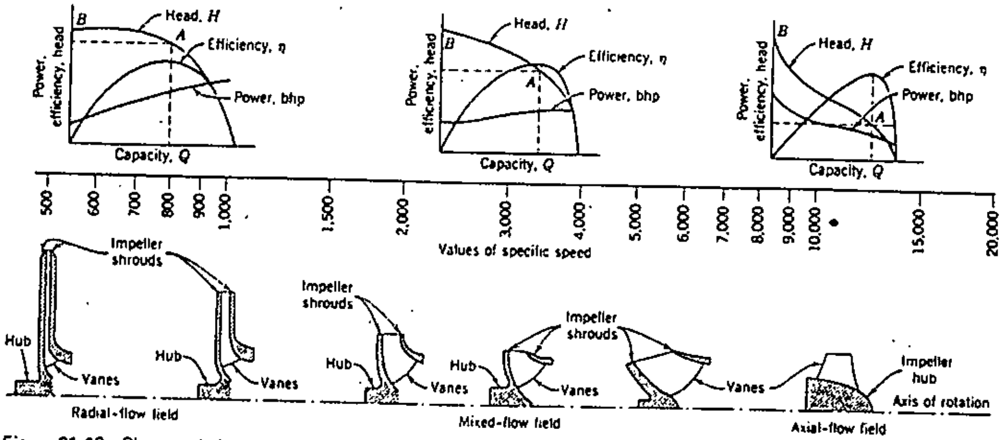

Figure 21.19. Characteristic curves and specific speeds for various impellers. Impellers that tend to promote radial flow, as in a standard centrifugal pump, operate at the lowest specific speed (up to 4200). Mixed-flow impellers, which produce both axial and radial flow, operate at higher specific speeds (4200 to 9000). Axial flow impellers operate at the highest specific speeds (above 9000). (Courtesy Worhtington Pumps, Inc.)

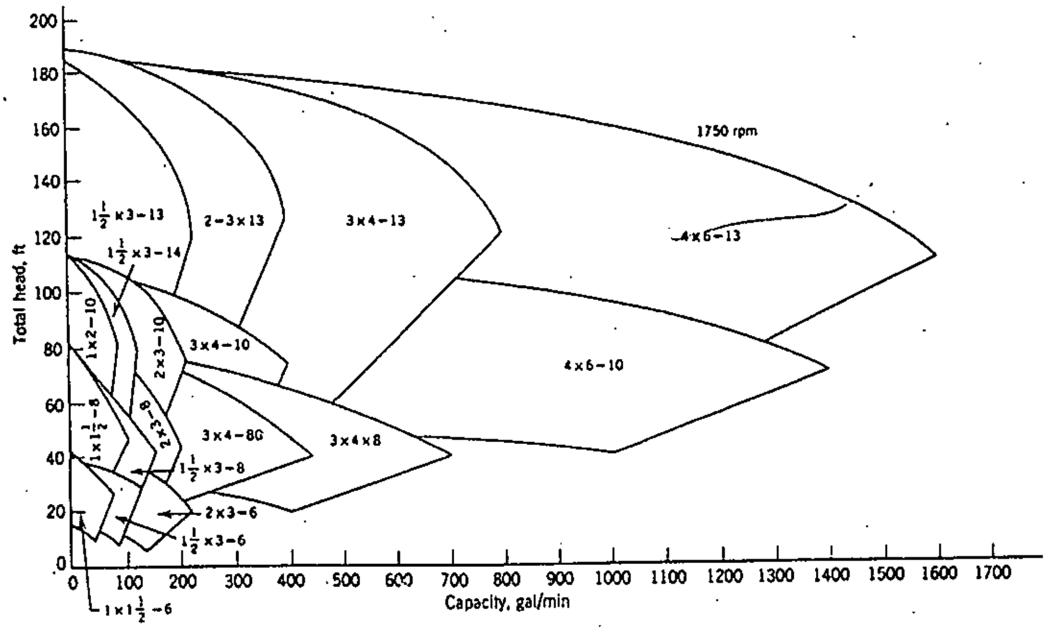

Figure 21.23. Operating ranges of a series of centrifugal pumps. Each labeled area represents the head/capacity region in which a specific size pump can operate. The model number is given for each size, where the first number is the diameter of the discharge line, the second is the diameter of the suction line, and the third is the maximum diameter of impeller that will fit in the pump casing. All diameters are in inches. Figure 21.17a gives detailed operating characteristics of one size pump in this series. This pump's range overlaps the ranges of several smaller-size pumps in this series, as can be seen by comparing the figures. (Courtesy Goulds Pumps, Inc.)

Q 3(b)

L-3/T-2/CHE Date : 14/03/2019

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2017-2018

Sub : **CHE 309** (Particle Technology)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Wastewater from a de-inking plant is to be clarified by continuous sedimentation. Feed to the thickener is one million gal/day containing 1.20% by weight solids. The underflow from the unit analyzes 8% solids. Specify the depth and diameter of the thickener. One US liquid gallon equals to 3.79 L. **(30)**

A single batch settling test on the feed material gave the following information:

SG of solids = 2.00

SG of solution = 1.00

Concentration of solids in test = 0.12%

Time (min)	0	5	10	20	40	60	180	240	∞
Height of solid-liquid interface (cm)	31	21	10	3.2	2.2	2.12	2.0	1.96	1.94

(b) Derive the formula of 'operating line' for thickener design. **(5)**

2. (a) A tubular bowl centrifuge is to be used to separate water from a fish oil. This centrifuge has a bowl 4.2 in. in diameter by 35 in. long and rotates at 17000 rpm. The oil has a density of 0.94 g/cm^3 and a viscosity of 50 cp at 25 degree Celsius. The radii of the inner and outer overflow dams are 1.25 in. and 1.26 in. respectively. Determine the critical diameter of droplets of oil suspended in water and of droplets of water suspended in oil if the feed rate is 400 gal/hr of a suspension containing 25% fish oil. **(18)**

(b) Determine outlet dam heights and throughput that would permit the tubular bowl centrifuge of 2(a) to separate droplets down to a critical diameter of 1 micron from both oil and water phases. **(12)**

(c) Write a short note on 'flocculation by polyelectrolyte'. **(5)**

3. (a) Calculate the terminal radial velocity of a soluble coffee particle 120 microns in diameter in air at 250°C entering a cyclone 0.5 m in diameter. The tangential velocity of the particle is 200 cm/sec and the SG of the solid is 1.09. **(10)**

(b) A spray-dried detergent has the following screen analysis – **(10)**

Tyler Mesh	–10+14	–14+20	–20+28	–28+35	–35+48	–48+65	–65
Weight fraction	0.02	0.05	0.1	0.18	0.25	0.25	0.15

Determine the volume mean diameter of this material.

Contd P/2

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Contd ... Q. No. 3

(c) Derive the "Buoyant Force" on a spherical particle by solving the provided equations for "Creeping Flow Around a Sphere". The symbols have their usual meanings. **(15)**

$$v_r = v_\alpha \left[1 - \frac{3}{2}\left(\frac{R}{r}\right) + \frac{1}{2}\left(\frac{R}{r}\right)^3\right] \cos\theta$$

$$v_0 = v_\alpha \left[-1 + \frac{3}{4}\left(\frac{R}{r}\right) + \frac{1}{4}\left(\frac{R}{r}\right)^3\right] \sin\theta$$

$$p = p_0 - pgz - \frac{3}{2}\frac{\mu v_\alpha}{R}\left(\frac{R}{r}\right)^2 \cos\theta$$

$$\tau_{r\theta} = \tau_{\theta r} = \frac{3}{2}\frac{\mu v_\alpha}{R}\left(\frac{R}{r}\right)^4 \sin\theta$$

$$F_n = \int_0^{2\pi}\int_0^{\pi} \left(-P|_{r=R} \cos\theta\right) R^2 \sin\theta \, d\theta \, d\varphi$$

$$F_t = \int_0^{2\pi}\int_0^{\pi} \left(+\tau_{r\theta|r=R} \sin\theta\right) R^2 \sin\theta \, d\theta \, d\varphi$$

4. (a) Quarts (SG 2.65) and pyrites (SG 5.1) are separated by continuous hydraulic classifications. The feed to the classifier ranges in size between 10 microns and 300 microns. The fractions are obtained: a pure quartz product, a pure pyrites product, and a mixture of quartz and pyrites. What is the size range of the two materials in the mixed fraction for each of the following cases: **(25)**

(i) The bottoms product to contain the maximum amount of pure pyrites.

(ii) The overhead product to contain the maximum amount of quartz.

(b) With reference to the "Normal Distribution", explain the terms – Mean, Median and Mode. What is skewness and what does it indicate? **(10)**

Additional information:

$$C_D = \frac{24}{N_{Rep}}, N_{Rep} > 1$$

$$C_D = \frac{24}{N_{Rep}}\left[1 + 0.14 N_{Rep}^{0.7}\right] 1 \le N_{Rep} \le 1000$$

$$C_D = 0.44, N_{Rep} > 1000$$

Contd P/3

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SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

Graph papers are to be supplied with this question paper.

Symbols have their usual meanings if not mentioned.

5. (a) What do you understand by "Screen Analysis"? There are different ways to represent the screen analysis data – histogram, cumulative distribution, fractional distribution and semi-log/log-log of fractional distribution. Discuss the type of information you can obtain from these representations with neat sketches of the graphs. **(2+16=18)**

   (b) What is shape factor? Give examples of two shape factors with their possible uses and significance. **(2+8=10)**

   (c) "If a sample (of particles) is sorted, it has a lower porosity" – true or, false? Explain. **(7)**

6. (a) $\Delta P = \frac{150\mu\mu_0 L_b}{D_p{}^2}\frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{1.75\,\rho\mu_0^2 L_b}{D_p}\frac{(1-\varepsilon)}{\varepsilon^3}$ **(7)**

   Write down the description each parameter used in this equation.

   (b) When do you consider a bed of particles as "fluidized"? **(5)**

   (c) A bed of $\frac{1}{4}$ inch cubes is to be used as packing for a regenerative heater. The cubes are poured into the cylindrical shell of the regenerator to depth of 10 ft. If air flows through this bed, entering at 100°F and 100 psia, leaving at 400°F, and flowing at a mass rate of 1200 lb/ft^3 of free cross section, determine the pressure drop across bed. Clearly state any assumption you make during solution. (Given : $\Psi = \frac{\pi D_0^2}{A_P}$, see also the attached figures). Assume viscosity of air, 0.023 cP. **(20)**

   (d) What is fixed bed "friction factor"? **(3)**

7. (a) A solute that forms cubic crystals is to be precipitated from solution at a rate of 10,000 lb of solid (dry basis) per hour using 1000 lb/hr of seed crystals. If no nucleation occurs and the seed crystals have the size distribution as in Table 3a, determine the product size distribution. (Graph paper is to be supplied for this question). **(24)**

   (b) What is mixed-suspension mixed product removal (MSMPR) crystallizer? Describe its salient features. **(2+6=8)**

   (c) What do you understand by nucleation rate? **(3)**

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8. (a) What is optimum filtration time for constant pressure filtration? **(4)**

(b) A 30 by 30 inch plate and frame filter press with twenty frames (2.50 inch thick) is to be used to filter the $CaCO_3$ slurry. The slurry has 0.0723 weight fraction of $CaCO_3$. The density of the solid dried cake is 100 lb/ft^3. The area of filtration is 4.7 ft^2 with a Ve of 0.327 *l*. Filtration is carried out at a constant pressure of 40 psia ($-\Delta p$). Determine the volume of slurry that will be handled until the frames are full, and the time required for this filtration. (Given: $\varepsilon = 0.453$, $S_0 = 1.83 \times 10^6$ ft^2/ft^3, $\alpha = 2.41 \times 10^{11}$ ft/lbs, $\rho_{CaCO_3} = 183$ lb/ft^3, $\mu_\omega = 1.1$ cP. **(18)**

Equations: $\theta = \dfrac{\mu \alpha w}{g_c A^2 (-\Delta P_t)}\left(\dfrac{V^2}{2} + V_e V\right)$ and,

$$LA(1-\varepsilon)\rho_s = w(v + \varepsilon LA)$$

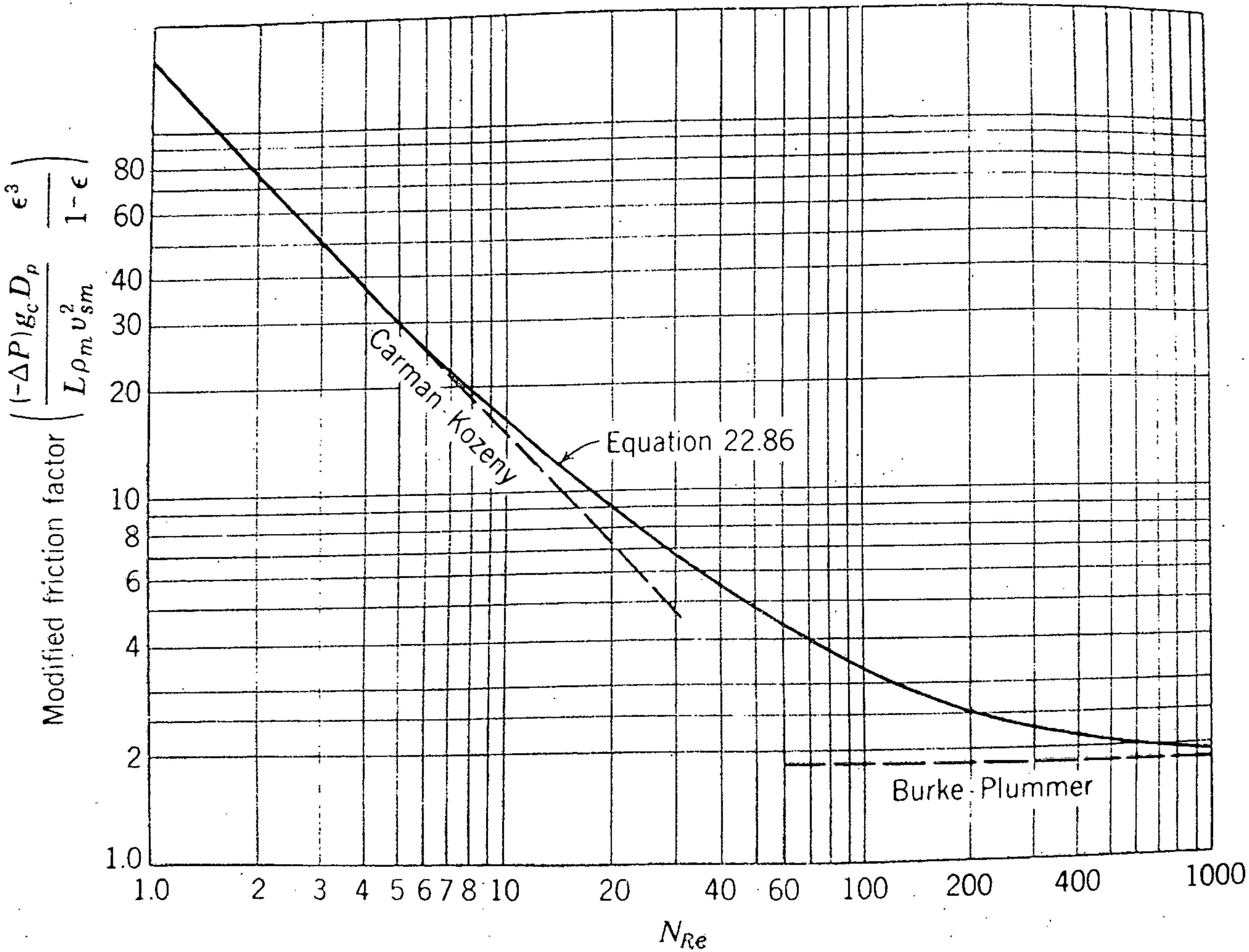
(c) An open sand filter uses a 2.5 feet deep bed of –20+28 mesh sand as primary filter bed. The sand particles used have an estimated sphericity of 0.9. If the slurry being filtered is essentially water and stands 2 ft deep over the top of the sand, determine the maximum flow rate through the bed that occurs immediately after backwashing. (See figure 4c attached). **(13)**

Equations: $\dfrac{-(\Delta P)_f \, g_c}{L} = k_c \dfrac{(1-\varepsilon)^2 \mu v_s}{\varepsilon^3 D_p^2}$

$$\frac{-(\Delta P) g_c}{L} \frac{D_p}{\rho v_{sm}^2} \frac{\varepsilon^3}{(1-\varepsilon)} = 150 \frac{(1-\varepsilon)}{N_{Re}} + 1.75$$

---

(5)



For Question 2(c)

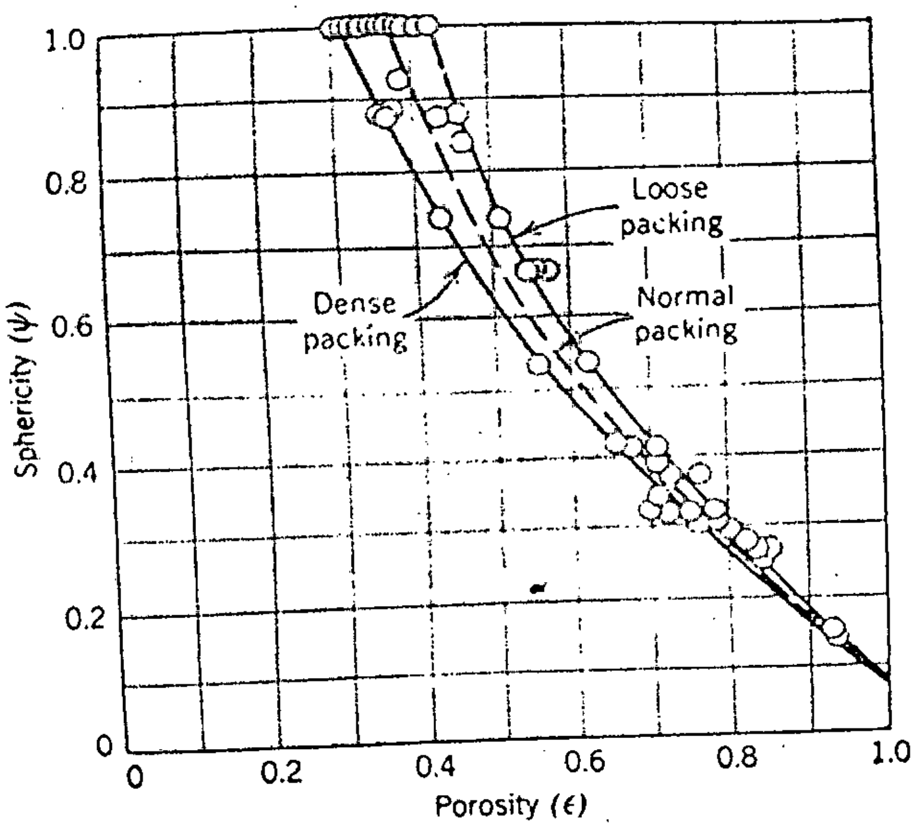


Figure B-12. Sphericity as a function of porosity for random-packed beds of uniformly sized particles (2). (By permission of John Wiley & Sons, copyright © 1950.)

For Question 2 (c)

Table 3a

Tyler Sieve Mesh	Weight Fraction Retained
-48+65	0.15
-65+100	0.30
-100+150	0.45
-150+200	0.05
-200+270	0.05

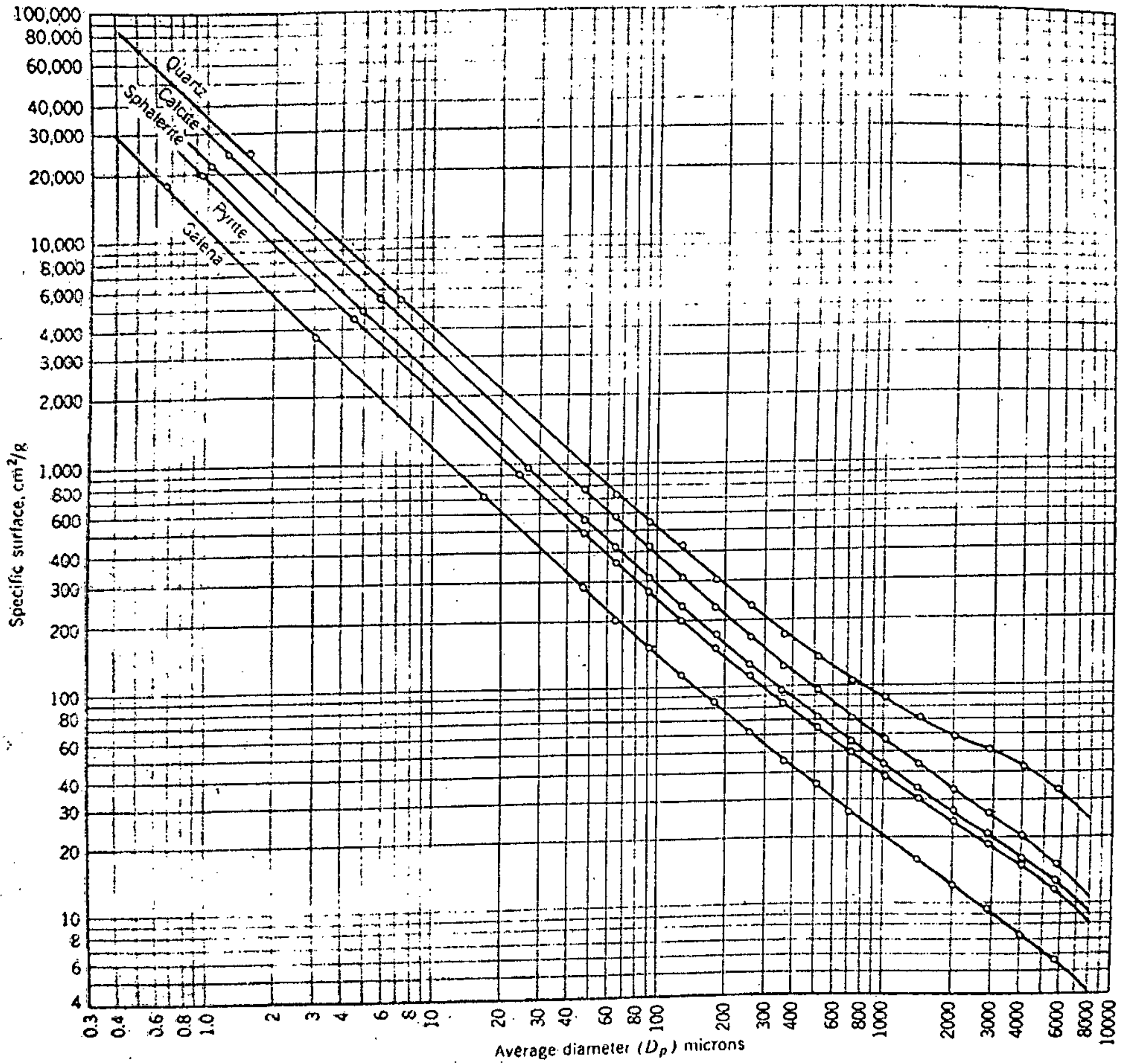
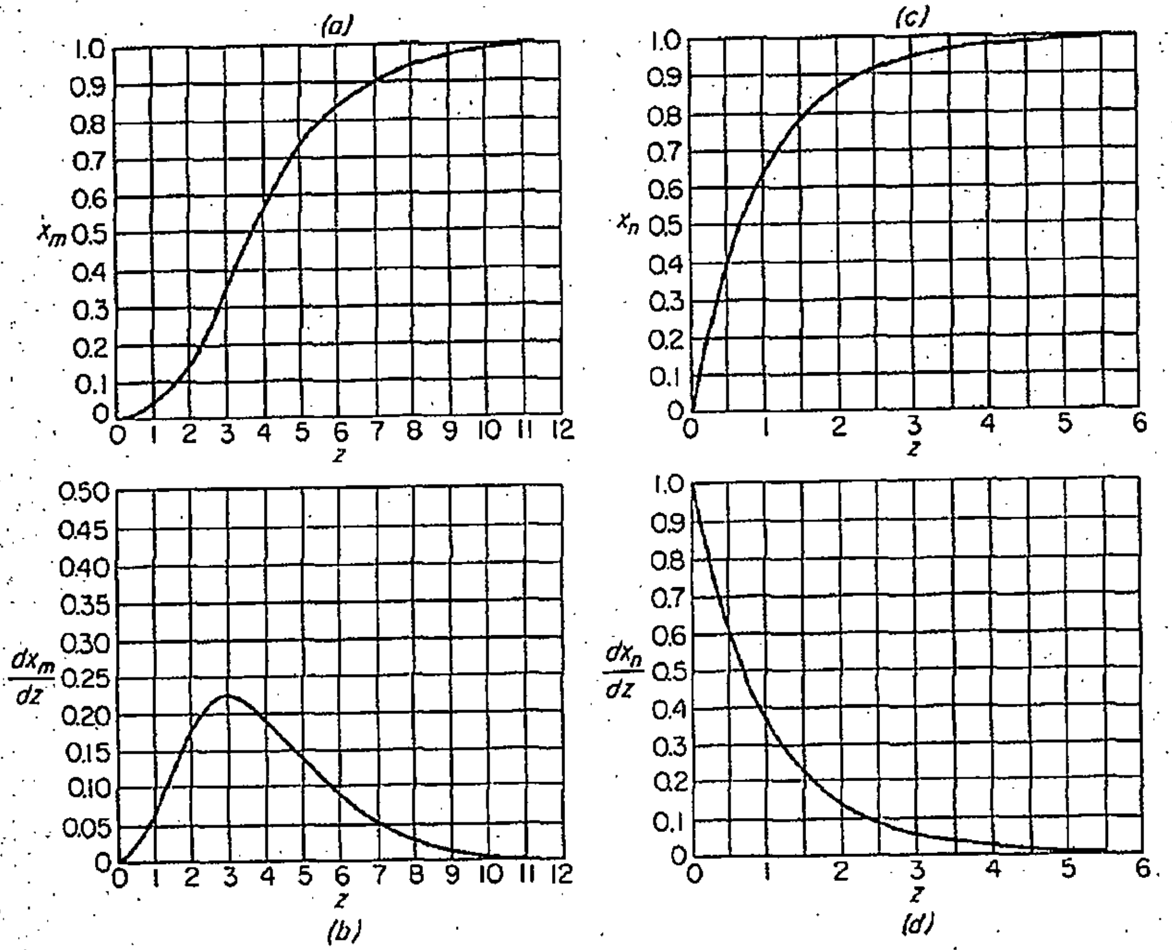


Figure B-10. Measured specific surface of five common minerals (5). (U.S. Bureau of Mines Bull. No. 402, by courtesy of publisher.)

Figure 4c

TYLER STANDARD SCREEN SIZES

Standard Interval = $\sqrt{2}$, Aperture, in.	Interval = $\sqrt[4]{2}$			
	Aperture, in.	Aperture, mm	Mesh Number	Wire Diameter,
1.050	1.050	26.67	...	0.148
	0.883	22.43	...	0.135
0.742	0.742	18.85	...	0.135
	0.624	15.85	...	0.120
0.525	0.525	13.33	...	0.105
	0.441	11.20		0.105
0.371	0.371	9.423	...	0.092
	0.312	7.925	2½	0.088
0.263	0.263	6.680	3	0.070
	0.221	5.613	3½	0.065
0.185	0.185	4.699	4	0.065
	0.156	3.962	5	0.044
0.131	0.131	3.327	6	0.036
	0.110	2.794	7	0.0326
0.093	0.093	2.362	8	0.032
	0.078	1.981	9	0.033
0.065	0.065	1.651	10	0.035
	0.055	1.397	12	0.028
0.046	0.046	1.168	14	0.025
	0.0390	0.991	16	0.0235
0.0328	0.0328	0.833	20	0.0172
	0.0276	0.701	24	0.0141
0.0232	0.0232	0.589	28	0.0125
	0.0195	0.495	32	0.0118
0.0164	0.0164	0.417	35	0.0122
	0.0138	0.351	42	0.0100
0.0116	0.0116	0.295	48	0.0092
	0.0097	0.248	60	0.0070
0.0082	0.0082	0.208	65	0.0072
	0.0069	0.175	80	0.0056
0.0058	0.0058	0.147	100	0.0042
	0.0049	0.124	115	0.0038
0.0041	0.0041	0.104	150	0.0026
	0.0035	0.088	170	0.0024
0.0029	0.0029	0.074	200	0.0021
	0.0024	0.061	230	0.0016
0.0021	0.0021	0.053	270	0.0016
	0.0017	0.043	325	0.0014
0.0015	0.0015	0.038	400	0.0010



[redacted]

Size-distribution relations in mixed suspension:

(a) cumulative mass distribution; (b) differential mass distribution; (c) cumulative population distribution; (d) differential population distribution.