National Exams December 2014

04-CHEM-A2, Mechanical and Thermal Operations

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an OPEN BOOK EXAM.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. **Two problems** from **each** of sections **A** and **B** must be attempted.
5. **Only the first two** questions as they appear in the answer book from each section will be marked.
6. State all assumptions clearly.

Section A: Mechanical Operations

A1. Water is pumped at 1.4 m^3/s from a tank at a treatment plant to a tank at a local works through two parallel pipes, 0.3 m and 0.6 m diameter, respectively. Assume there are no elevation changes, negligible entrance and exit effects, and turbulent flow with the friction factor inversely proportional to the one-quarter power of the Reynolds number.

a) **[15 points]** What is the velocity in each pipe?

b) **[10 points]** If a single pipe is used and the pressure drop remains the same, what diameter will be needed if this flow of water is to be transported?

A2. A single-frame laboratory plate and frame filter press is used to filter water containing 7.23% mass fraction of calcium carbonate. The density of solid calcium carbonate is 2830 kg/m^3. Tests at a temperature of 19 °C and $\Delta P = 2.76 \times 10^5$ Pa gave the following results:

Filtrate Volume (in liters)	Time (in seconds)
0.2	1.8
0.4	4.2
0.6	7.5
0.8	11.2
1.0	15.4
1.2	20.5
1.4	26.7
1.6	33.4
1.8	41.0
2.0	48.8
2.2	57.7
2.4	67.2
2.6	77.3
2.8	88.7

The unit was 3 cm thick and had a filtering area of 0.0263 m^2. Density of the dried cake was 1603 kg/m^3. Determine the following:

a) **[12 points]** Filtrate volume equivalent in resistance to the filter medium and piping

b) **[9 points]** Specific cake resistance and cake porosity

c) **[4 points]** Specific surface area of the cake

A3. Solid particles (diameter = 1.5 x 10^{-4} m, average density = 2800 kg/m^3) are settling in water at 30 °C. The properties of water at this temperature are viscosity (μ) = 8 x 10^{-4} kg/m.s and density (ρ) = 996 kg/m^3.

a) **[13 points]** What is the terminal velocity for the particles?

b) **[12 points]** What would be the velocity of the system in a separator with an acceleration of 390 m/s^2?

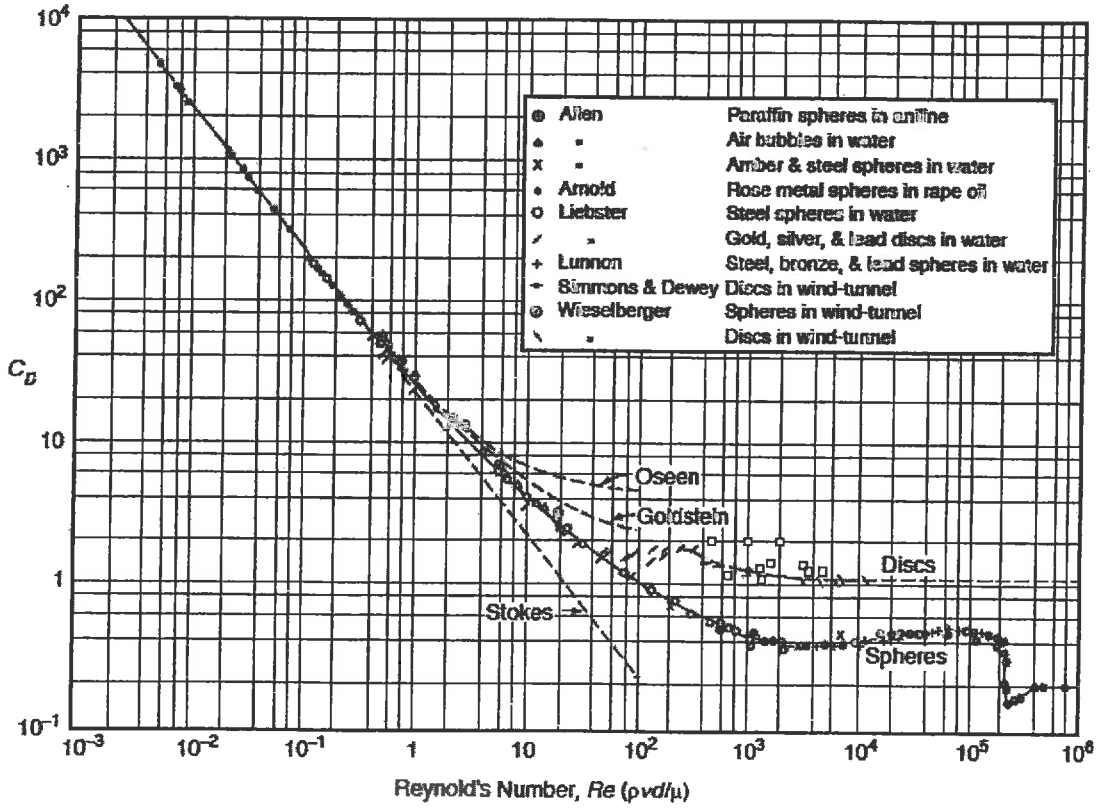

Figure A3 Drag Coefficients (C_D) for Sedimentation
Rouse H. 1937. Nomogram for the Settling Velocity of Spheres. *Report of the Committee on Sedimentation*, p.57, P.D.Trask, chm., National Research Council, Division of Geology and Geography

Section B: Thermal Operations

B1. The walls of a furnace are built with 150 mm thick refractory material of thermal conductivity 1.5 W/m K. The surface temperatures of the inner and outer faces of the refractory material are 1400 K and 540 K, respectively.

a) **[20 points]** If a layer of insulating material 25 mm thick with a thermal conductivity of 0.3 W/m K is added, what temperatures will its surfaces (inner and outer) attain assuming the inner surface of the furnace is to remain at 1400 K? The heat transfer coefficient from the outer surface of the insulation to the surroundings, which are at 290 K, is given below at different temperatures:

Heat Transfer Coefficient (in W/m^2 K)	Temperature (in K)
4.2	370
5.0	420
6.1	470
7.1	520

b) **[5 points]** What will be the reduction in heat loss compared with no insulation?

B2. Glauber's salt ($Na_2SO_4.10H_2O$) is to be produced in a Swenson-Walker crystallizer by cooling to 290 K a solution of anhydrous Na_2SO_4 that saturates between 300 K and 290 K. The solubilities of anhydrous Na_2SO_4 in water are 40 kg/100 kg of water at 300 K and 14 kg/100 kg water at 290 K. The mean heat capacity of the liquor is 3.8 kJ/kg K and the heat of crystallization is 230 kJ/kg. For the crystallizer running in countercurrent flow mode, the available heat transfer area is 3 m^2/m length, the overall heat transfer coefficient is 0.15 kW/m^2 K, and the molecular masses of $Na_2SO_4.10H_2O$ = 322 g/mol and Na_2SO_4 = 142 g/mol. If the cooling water enters the crystallizer at 280 K and leaves at 290 K with negligible evaporation, how many sections of the crystallizer will be required to process 0.25 kg/s of the product? Assume each section to be 3 m long.

B3. A shell-and-tube heat exchanger consists of 120 tubes of 22-mm internal diameter and length of 2.5 m. It is operated as a single-pass condenser with benzene condensing at a temperature of 350 K on the outside of the tubes and water at inlet temperature of 290 K passing through the tubes. Initially there is no scale on the walls, and a rate of condensation of 4 kg/s is obtained with a water velocity of 70 cm/s through the tubes. After prolonged operation, a scale resistance of 2×10^{-4} m^2 K/W is formed on the inner surface of the tubes. Assuming the heat transfer coefficient on the water side is proportional to 0.8 power of velocity and the heat transfer coefficient for condensing vapor is 2.25 kW/m^2 K based on the inside area, to what value must the water velocity be changed in order to maintain the same rate of condensation? The latent heat of vaporization of benzene is 400 kJ/kg.