04-CHEM-A2, MECHANICAL and THERMAL OPERATIONS

May 2016

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.** One textbook of your choice with notations listed on the margins etc., but no loose notes are permitted into the exam.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. At least **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. A test-model pump delivers, at its best efficiency, 108 m^3/hr at a 107-meter head with a required net positive suction head (NPSH) of 3.05 meters and a power input of 41 kW at 3500 revolutions per minute, when using a 10.5-inch diameter impeller.

(a) **[18 points]** What is the performance of a full-scale prototype pump with a 20-inch impeller operating at 1170 revolutions per minute?

(b) **[7 points]** What are the specific needs and the suction specific needs of the test-model and full-model prototype pumps?

A2. Spherical glass particles (12 mm diameter and 2500 kg/m^3 density) and spherical metal particles (1.5 mm diameter and 7500 kg/m^3) are falling in water (density = 1000 kg/m^3).

(a) **[12.5 points]** Calculate the terminal falling velocities of glass and metal particles in water for a constant friction factor of 0.22.

(b) **[12.5 points]** At what water velocity will fluidized beds of glass particles and metal particles have the same bed densities? The relation between fluidization velocity (u_c), terminal velocity (u_0) and bed voidage (e) for a spherical particle is given by the equation $(u_c/u_0) = e^{2.3}$

A3. The following laboratory data on filtering calcium silicate with an average particle size of 6.5 μm in a 4.287 x 10^{-2} m^2 plate-and-frame filter press operating at a pressure of 68.9 kPa and a slurry-solid mass fraction of 0.00495 was obtained:

Elapsed Time (in seconds)	**Filtrate Volume** (in m^3)
0	0
9	1 x 10^{-3}
19	2 x 10^{-3}
31.5	3 x 10^{-3}
49.5	4 x 10^{-3}
70	5 x 10^{-3}
93	6 x 10^{-3}
120	7 x 10^{-3}
152	8 x 10^{-3}
187	9 x 10^{-3}
227	1 x 10^{-2}
270	1.1 x 10^{-2}

The cake has an average moisture content corresponding to a cake mass fraction of solids of 0.2937. Calculate the medium resistance and average specific filtration resistance.

DATA:

Viscosity of water = 1 x 10^{-3} Pa.s
Density of liquid = 1000 kg/m^3
Density of solid = 1950 kg/m^3

Section B: Thermal Operations

B1. A solution containing 500 kg of Na_2SO_4 in 2500 kg of water is cooled from 333 K to 283 K in an agitated mild steel vessel of mass 750 kg. At 283 K, the solubility of the anhydrous salt is 8.9 kg per 100 kg of water and the stable crystalline phase is $Na_2SO_4.10H_2O$. If 2% of the water initially present is lost by evaporation during cooling, estimate the heat that must be removed.

DATA:
Heat of solution at 291 K = -78.5 MJ/kmol
Specific heat capacity of Na_2SO_4 solution = 3.6 kJ/kg K
Specific heat capacity of mild steel = 0.5 kJ/kg K

B2. A single-effect evaporator operates at 13 kPa. Calculate the heating surface area required to concentrate 4500 kg/hr of 10% caustic soda solution to 41% using steam at 390 K. The overall heat transfer coefficient is 1.25 kW/m^2 K and the heating surface is 1.2 meters below the liquid level. The boiling-point rise of the solution is 30 K and the feed temperature is 291 K.

DATA:
Specific heat capacity of 10% caustic soda feed solution = 4.0 kJ/kg K
Specific heat capacity of 41% caustic soda product solution = 3.26 kJ/kg K
Density of the boiling liquid = 1390 kg/m^3

B3. A pipe of outer diameter 50 mm, maintained at 1100 K, is covered with 50 mm of insulation. The thermal conductivity of the insulation is 0.17 W/m K and the surrounding air is at 280 K. We would like to use an additional insulation layer of magnesia, which has a thermal conductivity of 0.09 W/m K and it will not stand temperatures above 615 K. Given this information, calculate the thickness of the additional magnesia insulation layer needed to reduce the outer surface temperature to 370 K. The surface coefficient of heat transfer by radiation and convection can be taken as 10 W/m^2 K.