PROFESSIONAL ENGINEERS ONTARIO

NATIONAL EXAMS – MAY 2003

98-CHEM-A2
Mechanical & Thermal Operations

(3 hours duration)

Notes:

1. Whether doubt exists or not 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. Any non-communicating calculator will be permitted. This is an Open Book examination. Candidates should identify the calculator used on the inside left-hand sheet of examination workbook, i.e. name and model designation.

3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

4. All questions are of equal value.

Q1 Figure Q1 shows a tank of cross-sectional area A that initially at time t = 0, contains two layers, each of depth H: oil (density ρ_o = 0.80 g/cc), and water (ρ_w). A sharp-edged orifice of cross-sectional area a with a coefficient of contraction 0.62 in the base of the tank is then opened. Neglecting friction,

a) Derive an expression for the time t taken for the water to drain completely from the tank in terms of H, g, A, a, ρ_o, and ρ_w, assuming that $A >> a$.
b) How long would it take if the orifice was well rounded with diameter 2.0 cm, the tank diameter is 1.0 m, and H is 2.0 m?

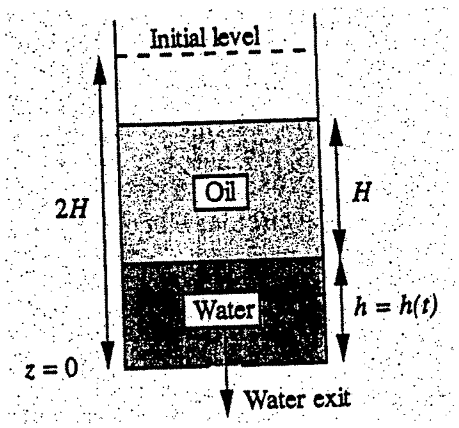

Figure Q1: Draining tank with oil and water

Q2 Water is flowing from an elevated reservoir through a conduit to a turbine at a lower level and out of the turbine through a similar conduit. The pressure at a point in the conduit 100 m above the turbine is 200 kPa absolute and 120 kPa absolute at a point in the conduit 3 m below the turbine. The water is flowing at 1000 kg/s, and the output at the shaft of the turbine is 800 kW.

(a) Calculate the losses by friction in the conduit if the efficiency of the turbine is known to be 90%.
(b) How much would the water be heated in flowing through the conduit and the turbine if there were no heat transfer to the surroundings?

Q3 A well-stirred tank reactor of volume V = 2.0 m^3, shown in Figure Q3, is filled with brine, in which the initial concentration of sodium chloride (NaCl) at time t = 0 is c_o = 1.0 kg/m^3. Subsequently, a flow rate of v = 0.01 m3/s of pure water is fed steadily to the tank, and the *same* flow rate of brine leaves the tank through a drain. Additionally, there is an ample supply of NaCl crystals in the bottom of the tank, which dissolves at a uniform rate of m = 0.02 kg/s.

a) Derive an expression for the subsequent concentration c of NaCl in terms of c_o, m, t, v, and V.
b) Make a sketch of c versus t and label the main features.

c) Assuming an inexhaustible supply of NaCl crystals, what will the c of NaCl in the tank be at $t = 0$, 100, and ∞ s?

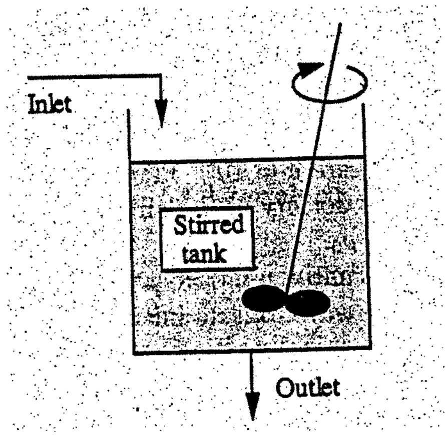

Figure Q3: Stirred tank reactor with continuous flow

Q4. A counter-flow double-pipe heat exchanger is used to heat liquid ammonia from 10 to 30°C with hot water that enters the exchanger at 60°C. The flow rate of the water is 5.0 kg/s and the overall heat-transfer coefficient is 800 W/m^2 °C. The total area of the heat exchanger is 30 m^3. Calculate the flow rate of ammonia.

Q5 A long-tube vertical evaporator is used to concentrate an organic solution from 15 to 50 percent solids. The solution has a negligible elevation in boiling point. The feed entering at 15^{O}C has a specific heat of 0.93 cal/g ^{O}C. Steam is available saturated at 0.8 atm absolute, and the pressure of the condenser is 100 mm Hg absolute. The evaporator must evaporate 25,000 kg of water per hour.

a) If the overall coefficient of the evaporator is 1700 W/m^2 ^{O}C, determine the heat transfer surface area required for this operation?

b) Calculate the steam consumption in kg/h

Q6 Natural gas is being delivered to a petrochemical plant through a 1.016 m ID pipeline of commercial steel from a gas reservoir located 161 km from the plant at a rate of 2.08 kgmol/s. It may be assumed that the pipeline is isothermal at 16^{O}C. The pressure at the discharge end of the line is 170.3 kPa absolute. Calculate the pressure at the inlet end of the pipeline if it assumed that natural gas is essentially methane with a viscosity of 1.04 x 10^{-5} Pa.s at 16^{O}C.

Q7 The manufacture of lead shot presents an interesting situation of simultaneous transport of mass, momentum and heat. Lead shot are formed by spraying molten lead from a shot tower and letting it cool and solidify as it falls through the surrounding air, as shown in Fig. Q7.

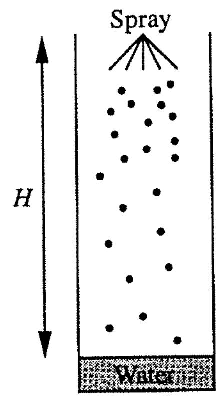

Fig. Q7: Lead Shot Tower

The hot lead spheres have a diameter of d = 0.30 mm and a density $\rho = 11.4$ g/cm^3. They enter the tower at $T_i = 620$ K, fall through a height H metres in air at 294 K, and solidify by the time they reach the cushioning pool of water at the base of the tower. State clearly any simplifying assumptions and the necessary boundary conditions required for answering the following questions:

(a) Set up the differential equation to be solved for determining the time of fall, t, of the shot as a function of its diameter, d.

(b) Derive the heat balance equation to be solved for estimating the temperature of the shot just before hitting the pool of water. The heat transfer coefficient between the shot and air is h = 370 W/m^2.K

Q8 A tank of very large surface area contains water that is open to the atmosphere. The water level in the tank is $H = 4$ m. A plastic tube with a diameter of $a = 50$ mm is inserted into the tank to siphon water from the tank. The bottom of the tube where the water will drain out to the atmosphere is at a level of h m above the bottom of the tank. If the pressure outside the tube is 30 kPa greater than the pressure inside the tube, then the tube will collapse and the siphon will stop functioning.

(a) Determine the minimum value of h if it can be assume that the tube is frictionless.

(b) What would be the effect on the value of h if friction in the tube could not be assumed negligible?

(c) If the tank is now being filled with water at a steady volumetric rate Q m^3/s as it is drained through the siphon, derive the expression for the steady-state water level H in terms of a, g, h, and Q.