PROFESSIONAL ENGINEERS ONTARIO

NATIONAL EXAMS – DECEMBER 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

An insulated, perfectly mixed tank contains a heating coil. Water flows in and out of the tank at 0.283 m^3/min. The volume of water in the tank is 2.83 m^3 with initial temperature of 21°C. The temperature of the water flowing out is 66°C. The heater adds 88 kW and the horsepower added by the mixer is 5 hp.

a) Using mass and energy balances derive an expression for determining the tank temperature as a function of time. *(15 marks)*

b) What is the tank temperature as time t approaches infinity, i.e. $t \rightarrow \infty$? *(5 marks)*

Q2.

Liquid ammonia is heated from 5 to 35°C in a counter-flow double-pipe heat exchanger with hot water that enters the exchanger at 60°C. The flow rate of the hot water is 4.0 kg/s. The overall heat-transfer coefficient is 900 W/m^2 °C and the total area of the heat exchanger is 30 m^3. Calculate the flow rate of ammonia. *(20 marks)*

Q3

Figure Q3 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 $A >> a$ *(12 marks)*

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? *(8 marks)*

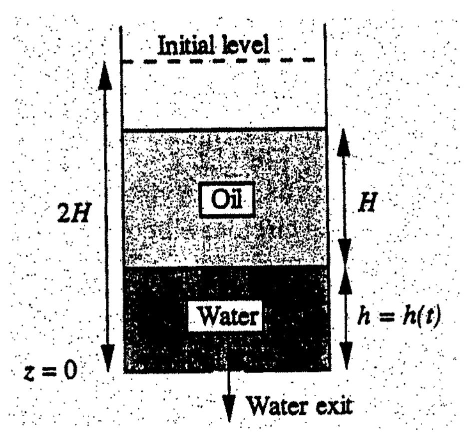

Figure Q3: Draining tank with oil and water

Q4

A spherical copper container of liquid oxygen at 87°K has an outside diameter 0.3 m and wall thickness 20 mm. The container is insulated with 5 cm of material whose thermal conductivity is $k = 0.002\ W.m^{-1}.K^{-1}$ and the external heat transfer coefficient may be taken as $18\ W.m^{-2}.K^{-1}$. The thermal conductivity of copper is $400\ W.m^{-1}.k^{-1}$.

Estimate the leakage of heat into the container if the conduction of heat through any fittings passing through the insulation can be neglected. The container is in ambient air at 298°K. *(20 marks)*

Q5

Two different series/parallel arrangements of three identical centrifugal pumps are shown in Fig. Q5. The head increase Δh across a single such pump for incompressible fluids varies with the flow rate Q through it according to:

$$\Delta h = k_1 - k_2.Q^2$$

where k_1 and k_2 are constants.

a) Derive expressions, in terms of k_1 and k_2 and the total flow rate Q, for the head increases for

(i) the series arrangement; *(6 marks)*

(ii) the parallel arrangement. *(6 marks)*

b) Sketch your results from Q5 (a). Your sketch must include the performance curve for the single pump. *(8 marks)*

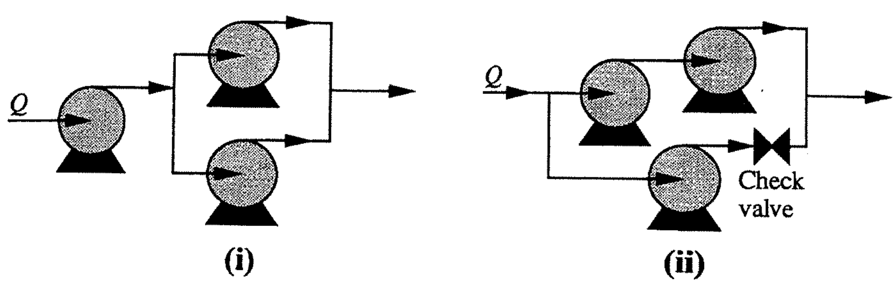

Fig. Q5: Series and Parallel Pump Arrangements

Q6

(a) Show that the Ergun equation for the pressure drop across a packed bed can be expressed simply as a quadratic function of volumetric flow rate, Q and inversely proportional to the square of particle diameter, D_P, for constant μ, L, ε, and ρ and noting that the superficial velocity, U_o, is proportional to Q the flow rate. *(6 marks)*

(b) A liquid reactant is pumped through a horizontal and cylindrical catalytic reactor packed with spherical catalyst of diameter $d_1 = 2.0$ mm. Test data summarized in the table below show pressure drops $-\Delta p$ across the reactor at two different volumetric flow rates:

Q, m^3 / hr	$-\Delta p$, kPa
0.34	66.2
0.68	166.2

If the maximum pressure drop is limited to 345 kPa by the pump, what is the upper limit on the flow rate? *(8 marks)*

(c) After the existing catalyst is spent, a similar batch is unfortunately unavailable, and the reactor has to be packed with a second batch whose diameter is now $d_2 = 1.0$ mm. What is the new maximum allowable flow rate if the pump is still limited to 345 kPas? *(6 marks)*

Q7

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°C has a specific heat of 0.93 cal/g °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 °C, determine the heat transfer surface area required for this operation? *(10 marks)*
b) Calculate the steam consumption in kg/h. *(10 marks)*

Q8

In a batch preparation of an aqueous solution 5.0 tones of water at 15°C is heated to 80°C in a jacketed agitated vessel. The jacket area available for heat transfer is 27.9 m^2 and the overall heat transfer coefficient can be taken as 285 $W.m^{-2}.K^{-1}$. If steam is available at 2.7 bar, estimate the heating time required. *(20 marks)*