PROFESSIONAL ENGINEERS ONTARIO

NATIONAL EXAMS – DECEMBER 2002

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. A batch crystalliser is used to prepare sodium carbonate decahydrate crystals, $Na_2CO_3.10H_2O$. The equipment contains 25000 kg of 30% Na_2CO_3 solution, which is cooled to a temperature of 20°C at which the decahydrate crystals are produced. The solubility of sodium carbonate is 21.5 kg anhydrous Na_2CO_3 per 100 kg of total water.

(a) What will be the yield of $Na_2CO_3.10H_2O$ crystals if it is assumed that no water is evaporated?

(b) If 4% of the total weight of the solution is lost by evaporation of water in cooling, what will be the yield of $Na_2CO_3.10H_2O$ crystals?

Q2.

A flat furnace wall is constructed of a 12 mm layer of Sil-o-cel brick, with a thermal conductivity of 0.14 $W/m^2.K/m$, backed by a 24 mm. layer of common brick, of conductivity 1.4 $W/m^2.K/m$. The temperature of the inner face of the wall is 1035 K, and that of the outer face is 350 K.

(a) Calculate the heat loss through this wall in W/m^2.

(b) What is the temperature of the interface between the refractory brick and the common brick?

Q3.

A dilute NaCl solution at 20°C is added to a well-stirred tank reactor at the rate of 85 kg/hr. A heating coil having an area of 1.0 m^2 is located in the reactor and contains steam at a pressure of 462 $kN.m^2$. The heated liquid leaves at a rate of 55 kg/hr and at the temperature of the salt solution in the reactor, maintained uniform by effective agitation. There is 225 kg of solution at 38°C in the reactor at the start of the operation. Calculate the outlet temperature of the salt solution after 1 hour if the overall heat-transfer coefficient is 400 $W/m^2.K$.

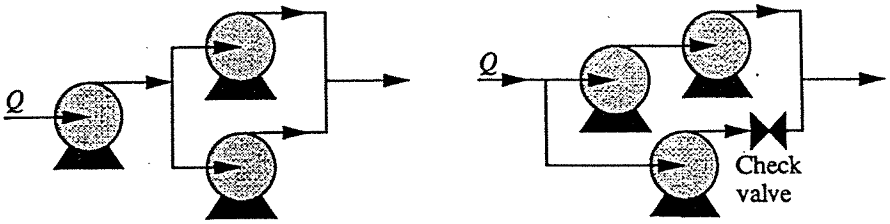
Q4

Two different series/parallel arrangements of three identical centrifugal pumps are shown in Fig. Q4. The head increase Δh across a single such pump varies with the follow rate Q through it according to:

$$\Delta h = c - d.\,Q^2$$

(a) Derive expressions, in terms of *c* and *d* and the total flow rate Q, for the head increases for
  (i) the series arrangement; and
  (ii) the parallel arrangement.

(b) Sketch your results from Q4.(a), also including the performance curve for the single pump.



(i) (ii)

Fig. Q4: Series/Parallel Pump Arrangements

Q5.

A catalytic reactor used for cracking hydrocarbon vapour consists of a randomly packed bed of 5 mm long cubic pellets. The material of which the pellets are made has a specific gravity of 1.6. The bulk density of the packed bed is 0.96 g/cc. The reactor vessel has an internal diameter of 36 cm and a bed depth of 2 m. The density and viscosity of the vapour are 0.642 kg/m^3 and 1.5×10^{-5} Pa.s respectively.

(a) What is the pressure drop through the bed if the superficial fluid velocity is 1.0 m/s and the resistance bed support is neglected?

(b) The reactor is now converted to a fluid catalytic reactor by removing the catalyst-retaining screen at the top of the bed. Calculate the pressure drop at minimum fluidizing conditions with a voidage of $\varepsilon_{mf} = 0.45$.

Q6.

A glass thermometer with emissivity, $\varepsilon = 0.96$, is inserted in a large circular duct at right angles to the wall. The thermometer bulb, 0.65 in diameter, is at the centre of the duct. Air flows through the duct at a rate such that the convective heat-transfer coefficient between the thermometer and the air is 100 $W/m^2.K$.

(a) If the walls of the duct are at $425^{o}C$ and the thermometer reach $150^{o}C$, what is the temperature of the air in the duct?

(b) If a piece of silver foil ($\varepsilon = 0.03$) is wrapped around the thermometer, what will be the new thermometer reading?

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.

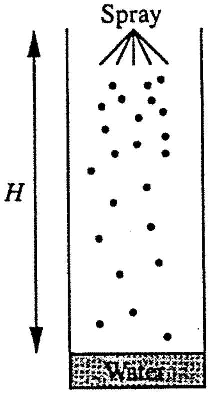


Fig. Q7: Lead Shot Tower

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) Show that the Ergun equation for the pressure drop across a packed bed can be expressed simply as a quadratic function of 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.

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

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?

(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 rat if the pump is still limited to 345 kPas?