

PROFESSIONAL ENGINEERS ONTARIO

NATIONAL EXAMS – MAY 2010

04-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 $\rho_o = 0.80 \text{ g/cc}$), 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,

- 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 $A \gg a$. *15marks*
- 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? *(5marks)*

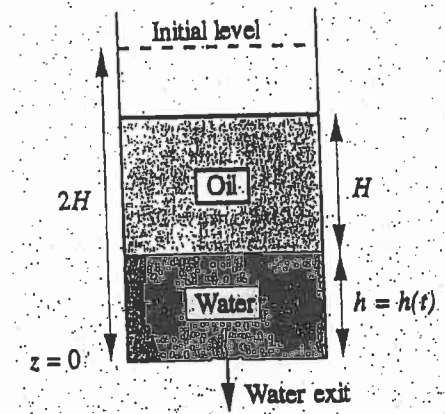


Figure Q1: Draining tank with oil and water

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. *(10 marks)*

- Calculate the losses by friction in the conduit if the efficiency of the turbine is known to be 90%.
- How much would the water be heated in flowing through the conduit and the turbine if there were no heat transfer to the surroundings? *(10 marks)*

Q3. A pump draws a solution, sp. gr. 1.84, from a storage tank of large cross section through a 3-in. pipe as shown in the sketch below. The velocity in the suction line is 3 fps. The pump discharges through a 2-in. pipe to an overhead tank. Friction losses in the entire system are 10 ft of solution. What pressure must the pump develop in pounds per square inch? What is the theoretical horsepower of the pump?

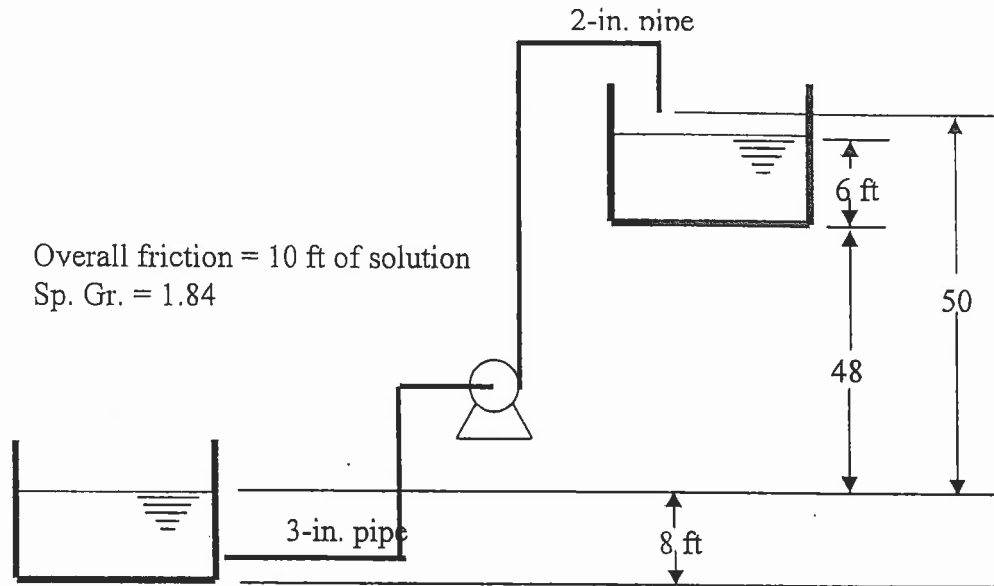


Figure Q3 Sketch of Problem Q3

Q4 A tank of very large surface area contains water that is open to the atmosphere. The water level in the tank is 4 m. A plastic tube with a diameter of 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 assumed that the tube is frictionless. (10 marks)
- b) What would be the effect on the value of h if friction in the tube could not be assumed negligible? (10 marks)

Q5 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 conductivity is $k = 0.002 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ and the external heat transfer coefficient may be taken as $18 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$. The thermal conductivity of copper is $400 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$.

- a) 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. (15 marks)
- b) How big a role does radiation play in the heat leakage? (5 marks)

Q6 A lubricating oil of density $\rho = 950 \text{ kg/m}^3$ is flowing turbulently at a mean velocity of $u_m = 3.05 \text{ m/s}$ in a horizontal pipe 25.4 mm internal diameter. The Fanning friction factor is $f = 0.0070$. The viscosity of the oil is 0.85 cp.

- a. What error in the frictional pressure drop would ensue if the assumption were erroneously made that the flow was laminar, and the previous value of the friction factor, $f = 0.0070$, was abandoned? (14 marks)
- b. Estimate the roughness, ϵ/D , of the pipe. (6 marks)

Q7 A hydrocarbon oil with specific heat $c_p = 2.09 \text{ kJ/kg} \cdot \text{K}^\circ$ and flowing at a rate of 5.04 kg/s is cooled in a 1-2 shell-and-tube heat exchanger from 366.5 °K to 344.3 °K by 2.02 kg/s of water entering at 283.2 °K. The overall heat transfer coefficient U_o is 340 $\text{W/m}^2 \cdot \text{K}^\circ$.

- a. Determine the outlet water temperature. (5 marks)
- b. What is the value of F_T , the correction factor for LMTD, the log mean temperature difference? (5 marks)
- c. Calculate heat transfer area required. (10 marks)

Q8 A horizontal oxidized steel pipe carrying steam and having an OD of 0.1683 m has a surface temperature of 374.9°K and is exposed to air at 297.1°K in a large enclosure. Calculate the heat loss per meter of pipe.

For this steel pipe, emissivity ϵ , is 0.79. Assume that the convective heat transfer coefficient is may be estimated. by

$$h_{\text{convective}} = (\Delta T/D)^{1/4}$$

Calculate the heat loss from the pipe by convection and radiation. (20marks)