PROFESSIONAL ENGINEERS ONTARIO

NATIONAL EXAMS – DECEMBER 2009

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 work book, 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.

(MARKING SCHEME)

Q1. (a) 3  (b) 2  (c) 15.
Q2. 20
Q3. (a) 5  (b) 5  (c) 10
Q4. 20
Q5. (a) 16  (b) 4
Q6. (a) 10,  (b) 10
Q7. 20.
Q8. 20.
Q1 In a calibration exercise of a thermocouple probe, the probe is used to measure the temperature of hot air flowing in a pipe whose walls are at $T_w = 400 \, \text{K}$. The true gas temperature $T_G = 465 \, \text{K}$.

a. Sketch a PFD (Process Flow Diagram) showing heat transfers (source to sink),

b. Discuss the role of radiation in the calibration.

c. Determine the temperature of the probe.

Q2 The tank and pipe shown Fig Q2 is initially filled with liquid of viscosity, $\mu$ and density, $\rho$. Assuming laminar flow and taking friction to be the only resistance and ignoring exit kinetic-energy effects. Show that the efflux time is? Where

$$T_{\text{efflux}} = \frac{(8L R^2)}{(\rho g r^4)} \ln(1 + H/L)$$

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**Fig. Q2:** Tank draining in laminar flow

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Q3 A hydrocarbon oil with specific heat $c_p = 2.09 \, \text{kJ/kg.K}$ and flowing at a rate of $5.04 \, \text{kg/s}$ is cooled in a 1-2 shell-and-tube heat exchanger from 366.5 K to 344.3 K by $2.02 \, \text{kg/s}$ of water entering at $283.2 \, \text{oK}$. The overall heat transfer coefficient $U_o$ is $340 \, \text{W/m}^2 \cdot \text{K}$.

a. Determine the outlet water temperature.  

b. What is the value of $F_T$, the correction factor for LMTD, the log mean temperature difference?  

c. Calculate heat transfer area required.
Q4 Water stored in large, well-insulated storage tank at 21.0 °C and the atmospheric pressure is being pumped at steady state from this tank by a pump at the rate of 8.5 kW. The water is used as a cooling medium and passes through a heat exchanger where 255 kW of heat is added to the water. The heated water then flows to a second, large vented tank, which is 25 m above the first tank. Determine the final temperature of the water delivered to the second tank.

Q5 Figure Q5 shows a centrifugal pump installation that is used for pumping high performance lubricating oil with specific gravity, s = 0.92, from one tank into a process under a pressure p3 through to another tank at an elevation of 25 m of 4-in I.D. The installation consists of another 20 m of equivalent of pipe length (including for fittings, etc.) of nominal 4-in I.D. pipeline. Is it to another tank at that height, or into a pressurized tank, or a pressurized process? Is p3 the pressure at what point on the diagram? As it is the problem is underdefined.

Figure Q5: Pumping Installation

a) Show that by doing an energy balance for the pumping installation, the pressure drop in the pipeline between points 2 and 3 is given closely in terms of the volumetric flow rate Q m³/s by:

\[ \Delta p = p_2 - p_3 = C_1 + C_2 f Q^2 \]

Where C₁ and C₂ are constants and f is the Fanning friction factor. What are the values of C₁ and C₂?

b) Calculate the Reynolds number Re in the pipeline.
Q6. A single-effect evaporator is used in concentrating an aqueous feed solution of organic colloids and water from 5 to 50 wt %. The mean heat capacity of the feed is \( C_{pm} = 4.06 \text{kJ/kg.K} \) and the feed enters at 15.6\(^\circ\)C. Saturated steam at 101.32 kPa is available for heating, and the pressure in the vapour space of the evaporator is 15.3 kPa. A total of 4536 kg/hr of water is to be evaporated. Assuming that no colloid gets evaporated in the process,

a) Calculate the feed rate of the organic solution;

b) What is the required heat transfer surface area if the overall heat transfer coefficient is 1988 W/m\(^2\).K?

![Figure Q7](image)

Q7. An insulated and perfectly mixed tank contains a heating coil. Water flows in and out of the tank at 0.283 m\(^3\)/min. The volume of in the tank is 2.83 m\(^3\) with initial temperature of 21\(^\circ\)C. The temperature of the water flowing out is 66\(^\circ\)C. The heater adds 88 kW and the horsepower added by the mixer is 5 hp. Using mass and energy balances, derive an expression for determining the tank temperature as a function of time.  

20 marks)

Q8. A food cold storage room is to be constructed of an inner layer of 19.1 mm pine wood, a middle layer of cork board and an outer layer 50.8 mm of concrete. The inside wall is at -17.8\(^\circ\)C and the outside surface temperature at the outer concrete surface 29.4\(^\circ\)C. The mean conductivities for pine =wood = 0.151, for cork board = 0.0433, and for concrete = 0.0762 W/m.\(^\circ\)K. The total inside surface area is approximately 40 m\(^2\) (neglecting corners and end effects). Determine the thickness of the cork board needed to keep the heat loss to 586 W.

20 marks)