

NAME: _____

STUDENT NUMBER: _____

LAKEHEAD UNIVERSITY
FINAL EXAMINATION

ENGI 3453/3454 WA

MECHANICAL ENGINEERING

SUBJECT | COURSE NO. | SECTION

DEPARTMENT

Heat Transfer design/Applied Heat Transfer

Dr. B. Singh

COURSE TITLE

INSTRUCTOR

April 9, 2011

1:00 – 4:00 pm {3 hours}

EXAM DATE

EXAM TIME & DURATION

TYPE OF EXAMINATION

FINAL EXAMINATION

- < Closed book.
- < Non-programmable calculator allowed.
- < No explanation/clarification will be provided during the examination.
- < Each question is worth 15 marks.

This examination question paper **MAY NOT** be taken from the examination room.

STUDENT PLEASE NOTE:

YOU MUST count the number of pages in this examination question paper **BEFORE** beginning to write, and report any discrepancy immediately to a proctor.

Note: No explanation/clarification will be provided during the examination. Each question is worth 15 marks. All formulas and data you may need to answer the questions are provided in the pages following the questions.

1. A copper plate 2.5 m long, 2.5 m tall, and 0.1 cm thick, initially at 90°C is suddenly placed in a room with still air at 30°C . The plate is held in vertical position. Calculate the initial heat transfer coefficient, initial rate of heat transfer by convection, and the initial rate of temperature change for the plate.
2. The temperature of air flowing through a 25-cm-diameter duct whose inner walls are at 320°C is to be measured using a thermocouple soldered in a cylindrical well of 1.2-cm OD with an oxidized exterior (emissivity = 0.94). The air flows normal to the cylinder at a mass velocity of $17,600 \text{ kg/hr.m}^2$. If the temperature indicated by the thermocouple is 200°C , estimate the actual temperature of the air.
3. A counter-flow heat exchanger is stated to have an overall heat transfer coefficient of $280 \text{ W/m}^2.\text{K}$ when operating at design and clean conditions. Hot fluid enters the tube side at 95°C and exits at 75°C , while the cold fluid enters the shell side at 25°C and exits at 35°C . After a period of use, built-up scale in the heat exchanger gives a fouling factor of $0.0004 \text{ m}^2.\text{K/W}$. If the surface area is 93 m^2 , determine (a) the rate of heat transfer in the heat exchanger and (b) the mass flow rate of both hot and cold fluids. Assume both hot and cold fluids have a specific heat of 4.2 kJ/kg.K .
4. Consider the flow of oil at 20°C in a 50-cm-diameter pipeline at average velocity of 0.5 m/s . A 2500-m-long section of the pipeline passes through icy waters of a lake at 5°C . Measurements indicate that the surface temperature of the pipe is very nearly 5°C . Disregarding the thermal resistance of the pipe material, determine (a) the temperature of the oil when the pipe leaves the lake, (b) the rate of heat transfer from the oil, and (c) the pumping power required to overcome the pressure losses and to maintain the flow of oil in the pipe.

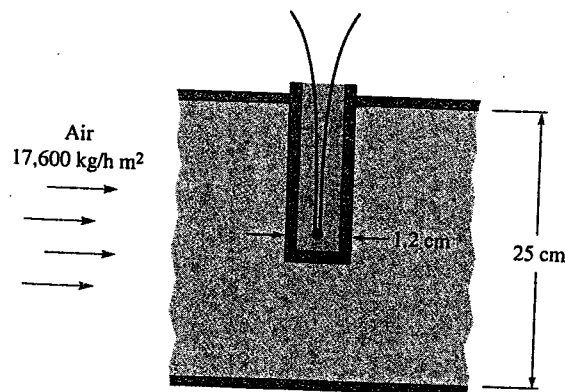


Fig. 1. sketch for question 2.

Formulas and Data :- Not necessarily in the same order as questions. Correlations may not be the same as in the text book.

$$\dot{Q} = \dot{m} c_p \Delta T; \quad \dot{Q}_{\text{cond}} = -kA \frac{dT}{dx}; \quad \dot{Q}_{\text{conv}} = hA\Delta T;$$

$$\dot{Q}_{\text{rad}} = \epsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4); \quad \sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$$

For flow of gases or liquids across cylinders at uniform temperature:

$$Nu_{\text{cyl}} = \frac{hD}{k} = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{283000}\right)^{5/8}\right]^{4/5}$$

Fluid properties at $T_f = \frac{1}{2}(T_\infty + T_s)$.

For Copper :- $k = 400 \text{ W/m}\cdot\text{K}$; $\rho = 8933 \frac{\text{kg}}{\text{m}^3}$; $c_p = 385 \frac{\text{J}}{\text{kg}\cdot\text{K}}$

For Air:	$\rho \text{ kg/m}^3$	$c_p \text{ J/kg}\cdot\text{K}$	$k \text{ W/m}\cdot\text{K}$	$\mu \text{ kg/m}\cdot\text{s}$
at 30°C	1.164	1007	0.02588	1.872×10^{-5}
at 50°C	1.092	1007	0.02735	1.963×10^{-5}
at 100°C	0.9458	1009	0.03095	2.181×10^{-5}
at 200°C	0.7459	1023	0.03779	2.577×10^{-5}

$$Gr = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2}; \quad Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}; \quad Pr = \frac{\mu c_p}{k}$$

$Ra = Gr \cdot Pr$; $\beta = \frac{1}{T}$ for ideal gases; $L_c = \text{Plate height (natural convection)}$.

$$\frac{1}{UA_s} = \frac{1}{U_c A_c} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi KL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

$$\Delta T_{\text{lm}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Thermal entry length: $L_t \approx 0.05 Re \cdot Pr \cdot D$, for laminar flow

$L_{h, \text{laminar}} \approx 0.05 Re \cdot D$; $L_{h, \text{turbulent}} \approx L_{t, \text{turbulent}} \approx 10D$

Constant surface temperature: Flow in tubes

$$T_e = T_s - (T_s - T_i) \exp(-hA_s / \dot{m}c_p)$$

constant surface heat flux; $T_e = T_i + \frac{\dot{q}_s A_s}{\dot{m}c_p}$

$$f = \frac{64}{Re} \text{ for laminar flow}$$

$$\Delta P = f \frac{L}{D} \frac{\rho V_{avg}^2}{2}$$

For oil:

	Density ρ , kg/m ³	c_p J/kg.K	k W/m.°C	μ kg/m.s
at 20°C	888	1881	0.1450	0.8374
at 0°C	899	1797	0.1469	3.814
at 10°C	893	1839	0.1460	2.326

For internal forced convection:

Entry region, laminar
(Hydrodynamically developed,
Thermally not fully developed)

$$Nu = 3.66 + \frac{0.065 (D/L) Re \cdot Pr}{1 + 0.04 \left[\frac{D}{L} Re \cdot Pr \right]^{2/3}}$$

Natural convection from vertical plate:

$$Nu = \left\{ 0.825 + \frac{0.387 Ra_L^{1/4}}{\left[1 + \left(\frac{0.492}{Pr} \right)^{9/16} \right]^{4/27}} \right\}^2 \text{ valid for all } Ra_L$$

Lumped System Analysis: $Bi < 0.1$; $Bi = \frac{hL_c}{k}$; $L_c = \frac{V}{A_s}$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = \exp\left(-\frac{hA_s}{\rho V c_p} t\right)$$

If you think any data are missing, make justifiable assumptions. Explain your work clearly.