UNIVERSITY OF TECHNOLOGY, JAMAICA

COLLEGE/ FACULTY: Engineering and Computing

SCHOOL/ DEPARTMENT: SOE/Chemical Engineering

Final Examination, Semester 1

Module Name:	**Unit Operations IV**
Module Code:	**ChE3004**
Date:	**DECEMBER 2011**
Theory/ Practical:	**Theory**
Groups:	**BENG. 3C**
Duration:	**TWO (2) HOURS**

Instructions

1. **ANSWER ALL QUESTIONS.**
2. **EACH QUESTION MUST BEGIN ON A NEW PAGE.**
3. **LEAVE TWO LINES BETWEEN PARTS OF A QUESTION.**
4. **SHOW CLEARLY ALL EQUATIONS USED FOR CALCULATIONS.**
5. **ANSWERS MUST BE NUMBERED IDENTICAL TO THE QUESTION BEING ANSWERED.**
6. **THE INTENDED MARK IS INDICATED AT END OF THE QUESTION.**
7. **A FORMULA SHEET AND UNIT CONVERSION ARE ATTACHED.**

DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO DO SO

SECTION A (Short Answers)

Write short answers for the following questions **(2x6=12 marks)**

QUESTION 1:

Define ***thermal conductivity***.

QUESTION 2:

What is the ***critical radius*** of insulation?

QUESTION 3:

What is the relationship between the condensation heat transfer coefficients of ***vertical and inclined plates*** for laminar flow?

QUESTION 4:

Explain ***parallel flow*** and ***counter flow*** arrangements as applied to heat exchangers

QUESTION 5:

What assumptions are made in deriving the expression for the ***Logarithmic Mean Temperature Difference***?

QUESTION 6:

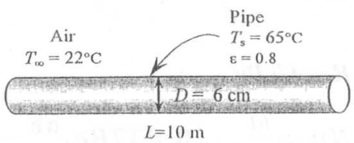
What is meant by a heat exchanger's ***approach temperature***?

SECTION B (Problem Solving)

Show all calculations and use diagrams where necessary for the following questions **(88 marks)**

QUESTION 7 (30 Marks)

A10-m-long section of a 6-cm-diameter horizontal hot water pipe passes through a large room whose temperature is 22°C. If the temperature and the emissivity of the outer surface of the pipe are 65°C and 0.8, respectively, determine the rate of heat loss from the pipe by



(a) natural convection **[25]**

(b) radiation. **[5]**

QUESTION 8 (8 marks)

A person is found dead at 5 PM in a room where the temperature is 20.0°C. The temperature of the body which is 72% water by mass was measured to be 25.0°C at the time of discovery, and the heat transfer coefficient estimated to be $h = 8.0$ Wm^{-2} °C^{-1}. Modeling the body as a 30-cm-diameter, 1.70 m-long cylindrical column of water, show how you would determine whether the lumped system analysis may be used to estimate the time of death. Properties of water at the average temperature are: k =0.617 Wm^{-1} °C, ρ= 996 kg m^{-3}, and C_p =4178 J kg^{-1} °C.

QUESTION 9 (25 marks)

A cross-flow heat exchanger with one fluid mixed and one unmixed is used to heat oil in the tubes (C_{Poil}=1.9 kJ kg^{-1} °C^{-1}) from 15.0 °C to 85.0 °C. Steam entering at 130.0 °C blows at 5.2 kg s^{-1} across the outside of the tubes and exits at 110.0 °C. If the overall heat transfer coefficient of the heat exchanger is 275.0 W m^{-1} °C and C_{Psteam} =1.86 kJ kg^{-1}, Calculate the required surface area.

QUESTION 10 (25 marks)

a) Show that the maximum possible heat transfer in a heat exchanger is given by

$$\dot{Q}_{max} = C_{min}\left(T_{h,in} - T_{c,in}\right)$$

[5 Marks]

b) A counter-flow heat exchanger uses 10.0 °C cold water flowing at 8.0 kg s^{-1}, to cool a hot water stream that enters the tubes at 70.0 °C flowing at 2.0 kg s^{-1}. Assuming the specific heat capacity of water Cp = 4.18 kJ kg^{-1}°C^{-1}, with the aid of a fully labeled diagram calculate the maximum heat transfer rate between the cold and hot water streams.

[20 Marks]

TOTAL MARKS =100

END OF PAPER

Formula Sheet

1. $E = \sigma T^4$
2. $Re_{cr=5\times10^5}$
3. $Gr = \frac{g\beta\Delta T L^3 \rho^2}{\mu^2} = \frac{g\beta \Delta T L^3}{\upsilon^2}$
4. $Ra = Gr Pr$
5. $Nu = \frac{hL}{k} = \left(0.037 Re_L{}^{0.8} - 871\right) Pr^{1/3}$
6. $Bi = hL_c/k$
7. $R = \frac{T_1 - T_2}{t_2 - t_1}$ $\quad P = \frac{t_2 - t_1}{T_1 - t_1}$
8. $q_{conv} = h(T_s - T_\infty) \rightarrow T_s = T_\infty + \frac{q_{conv}}{h}$
9. $q_{max} = C_{cr} h_{fg} [\sigma g \rho_v^2 (\rho_l - \rho_v)]^{1/4}$
10. $q_{film} = 0.62 \left[\frac{g k_v^3 \rho_v (\rho_l - \rho_v)[h_{fg} + 0.4 C_{pv}(T_s - T_{sat})]}{\mu_v D (T_s - T_{sat})}\right]^{1/4} (T_s - T_{sat})$
11. $\alpha = \frac{k}{\rho C_p}$
12. $\dot{q}_{nucleate} = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left(\frac{C_{p,l}(T_s - T_{sat})}{C_{sf} h_{fg} Pr_l^n}\right)^3$
13. $q = k\frac{\Delta T}{L}$
14. $C_h = \dot{m}_h C_{ph}$
15. $C_c = \dot{m}_c C_{pc}$
16. $\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{C_h(T_{h,in} - T_{h,out})}{C_{min}(T_{h,in} - T_{c,in})} = \frac{C_h(T_{h,in} - T_{h,out})}{C_h(T_{h,in} - T_{c,in})}$
17. $C = \frac{C_{min}}{C_{max}}$
18. $\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in})$
19. $NTU = \frac{UA_s}{C_{min}}$
20. $Q = UA\Delta T_{LMTD}$
21. $\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$

FACTORS FOR UNIT CONVERSIONS

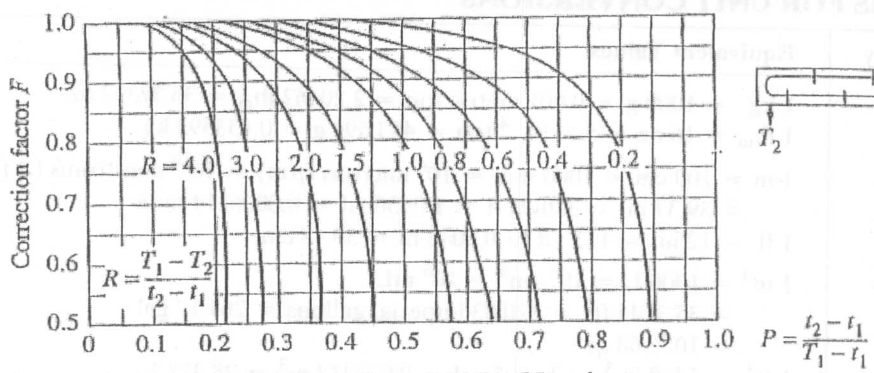
Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

TABLE A–1

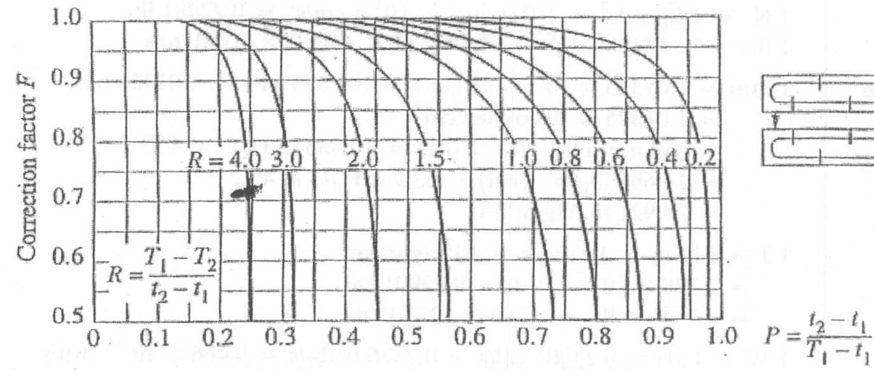
Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, *M* kg/kmol	Gas constant, *R* kJ/kg · K*	Critical-point properties: Temperature, K	Pressure, MPa	Volume, m^3/kmol
Air	—	28.97	0.2870	132.5	3.77	0.0883
Nitrogen	N_2	28.013	0.2968	126.2	3.39	0.0899
Oxygen	O_2	31.999	0.2598	154.8	5.08	0.0780
Water	H_2O	18.015	0.4615	647.1	22.06	0.0560

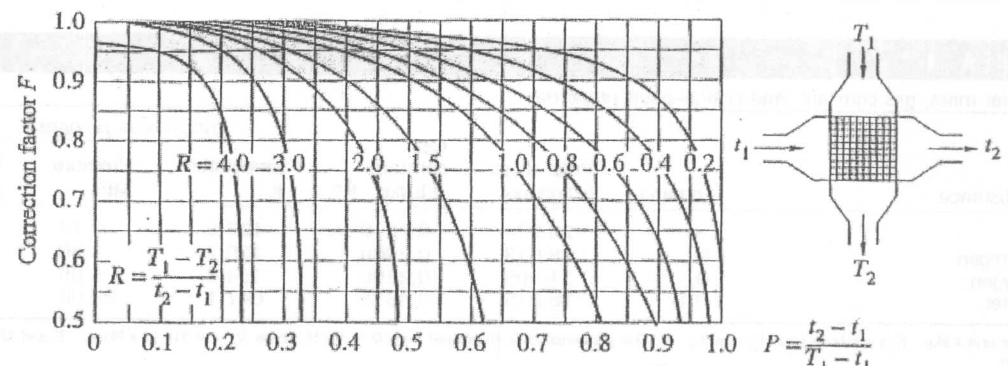
*The unit kJ/kg · K is equivalent to kPa · m^3/kg · K. The gas constant is calculated from $R = R_u/M$, where R_u = 8.31447 kJ/kmol · K and *M* is the molar mass.



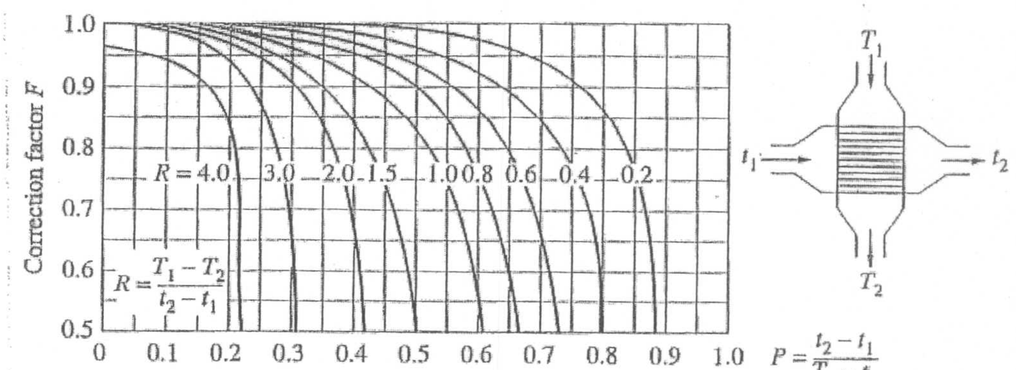
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes



(*c*) Single-pass cross-flow with both fluids *unmixed*



(*d*) Single-pass cross-flow with one fluid *mixed* and the other *unmixed*