UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2019

COURSE AND CODE: HEAT TRANSFER ENCH3HE

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER(S): MRS A SINGH
DR S MOODLEY

INTERNAL MODERATOR(S): DR J POCOCK

EXTERNAL MODERATOR: MR CA BAAH

INSTRUCTIONS:

1. **ALL** questions should be attempted. Answer in ink. Graphs may be plotted in pencil.
2. **Two answer books are provided. Label them Book A and Book B respectively. Answer Section A in Book A and Section B in Book B.**
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

Data for a shell and tube heat exchanger is shown in Table 1. The fluids flow counter currently with the hot fluid on the shell side.

Property	Units	Tube Side	Shell Side
Flowrate	kg/s	58.1	20.5
Inlet temperature	^0C	25	146
Outlet temperature	^0C	53.8	72.2
Heat capacity	J/kg.K	1990	2200
Viscosity	kg/s.m	2.04×10^{-4}	5.30×10^{-4}
Thermal conductivity	$W/m^2.K$	0.137	0.114
Density	kg/m^3	825	867

Table 1: Conditions in Heat Exchanger

You have been tasked with investigating the effects of increasing the capacity of the heat exchanger by 20% i.e. increase of 20% in both the shell and tube side flowrates. You may assume that under the changed conditions, the inlet temperatures and physical properties of the streams will not change. In order to ascertain the effect of the change on the heat exchanger, calculate the heat transfer rate when the flowrates have been increased.

The heat exchanger has one shell pass and four tube passes. It consists of 448 tubes arranged in a square pattern. The tubes have an inner diameter of 20 mm and outer diameter of 24 mm. The total length of each tube is 6 m.

Note that the overall heat transfer coefficient needs to take into account fouling as well as the resistance in the tube wall.
Your colleague has very kindly supplied you with the following information:

Convection coefficient	Initial conditions	Changed conditions
h_i ($W/m^2.K$)	1203	1365
h_o ($W/m^2.K$)	1576	1756

Table 2: Convection coefficients

Correction factor charts are provided on page 7.

Effectiveness charts are provided on page 8.

TOTAL /20/

QUESTION 2

A packed cooling tower cools water from 50 ^{0}C to 25 ^{0}C using air that enters the tower at 30 ^{0}C, having a wet bulb temperature of 13 ^{0}C. The air flows counter current to the water at a rate of 4860 kg dry air/m^2.hr. The water flow rate is 4700 kg/ m^2.hr. The ratio of the heat transfer coefficients, $\frac{h_L a}{k_y a}$ is 500 J/mol. ^{0}C. Calculate the height of the cooling tower if it operates at atmospheric pressure, and $k_y a$ is 48 kmol/hr.m^3.
Heat capacity of water = 4.181 kJ/kg. ^{0}C
Molecular mass of water = 18.02 kg/kmol
Molecular mass of air = 28.97 kg/kmol
Psychrometric chart for air-water system at atmospheric pressure is on page 9.
The saturation curve is provided, refer to the figure on page 10. You must do your construction on this page and hand it in with your answer booklet.

$$z = \frac{V'}{sk_y a}\int_{H_{v1}}^{H_{v2}} \frac{dH_v}{H_i - H_v}$$

TOTAL /15/

QUESTION 3

A heat exchanger network is to be designed for the following four streams:

Stream no.	Supply Temperature (^{0}C)	Target Temperature (^{0}C)	Heat Capacity flow rate (kW/^{0}C)
1	160	70	20
2	150	40	12
3	60	140	15
4	100	180	25

The minimum temperature approach is 20 ^{0}C.

3.1 Design a network for maximum energy recovery given that the hot pinch temperature is 120 ^{0}C and the cold pinch temperature is 100 ^{0}C. Show all working, and ensure that the final design presented has all the necessary details.

(17)

3.2 How many heat exchangers does the network have?

(1)

3.3. State the minimum hot and cold utility requirements of the network.

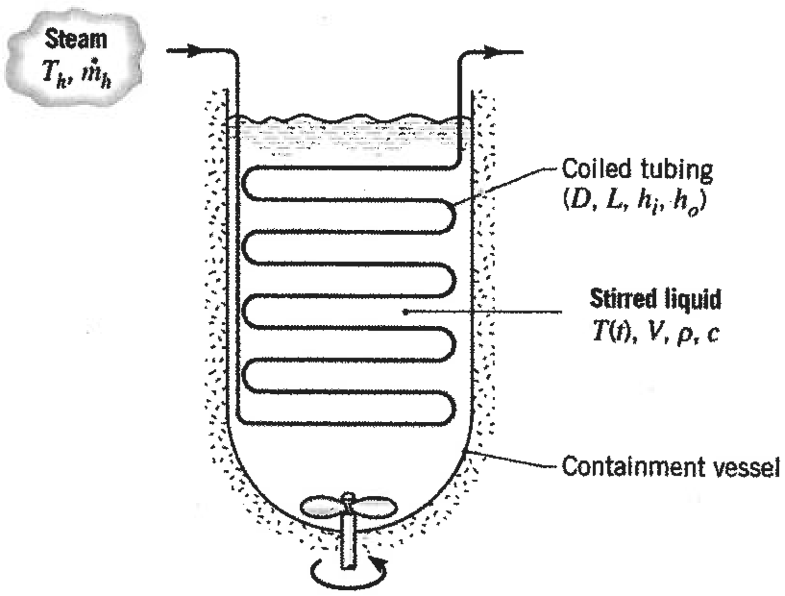
(2)

TOTAL /20/

SECTION B

QUESTION 4

A chemical of density $\rho = 1200$ kg/m^3 and specific heat capacity $c = 2200$ J/kg·K occupies a volume $V = 2.25$ m^3 in an insulated vessel. The chemical is to be heated from 300 K to a temperature of 450 K by passing saturated steam at 500 K through a coiled, *thin*-walled, 20-mm-diameter tube in the vessel. Steam condensation within the tube maintains an interior convection coefficient of 1×10^4 W/m^2·K, while the well-mixed liquid in the stirred vessel maintains an outside convection coefficient of 2000 W/m^2·K.



If the chemical is to be heated from 300 to 450 K in 60 minutes, what is the required length L (in metres) of the submerged tubing?

Hints: Apply the lumped capacitance method in your analysis, by noting that T_∞ may be replaced by the temperature of the steam, while the heat transfer coefficient h may be replaced by the overall heat transfer coefficient U. The thermal resistance of the tube may be neglected.

Equations:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

TOTAL /13/

QUESTION 5

An air-cooled steam condenser is operated with air in cross flow over an in-line (i.e. aligned) array of 400 tubes ($N_T = N_L$), with an outside tube diameter of 20 mm and longitudinal and transverse pitches of 60 mm and 45 mm, respectively. Saturated steam at a pressure of 2.5 bars enters the tubes, and a uniform tube outer surface temperature of $T_s = 390$ K may be assumed to be maintained as condensation occurs within the tubes. The temperature and velocity of the air upstream of the tube array are $T_s = 300$ K and $V = 4$ m/s, respectively. The tubes are 2 m long. What is the rate at which steam is condensed, in kg/s?

Properties:

Air ($T_i = 300$ K): $\rho = 1.16$ kg/m^3, $c_p = 1007$ J/kg·K, $\nu = 15.89\times10^{-6}$ m^2/s, $k = 0.0263$ W/m·K, Pr = 0.707. ($T_s = 390$ K): Pr = 0.692.

Saturated water at 2.5 bars: $h_{fg} = 2.183\times10^6$ J/kg

Equations and supporting information:

Zukauskas correlation for a tube bank:

$$\overline{\mathrm{Nu}}_D = C_1 \mathrm{Re}_{D,\max}^m \mathrm{Pr}^{0.36}\left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s}\right)^{1/4}$$

$$\begin{bmatrix} N_L \geq 20 \\ 0.7 \leq \mathrm{Pr} \leq 500 \\ 10 \leq \mathrm{Re}_{D,\max} \leq 2\times10^6 \end{bmatrix}$$

Configuration	$\mathrm{Re}_{D,\max}$	C_1	m
Aligned	10–10^2	0.80	0.40
Staggered	10–10^2	0.90	0.40
Aligned	10^2–10^3	Approximate as a single (isolated) cylinder	
Staggered	10^2–10^3	Approximate as a single (isolated) cylinder	
Aligned ($S_T/S_L > 0.7$)	10^3–2×10^5	0.27	0.63
Staggered ($S_T/S_L < 2$)	10^3–2×10^5	$0.35\times(S_T/S_L)^{1/5}$	0.60
Staggered ($S_T/S_L > 2$)	10^3–2×10^5	0.40	0.60
Aligned	2×10^5–2×10^6	0.021	0.84
Staggered	2×10^5–2×10^6	0.022	0.84

Table 3. Constants C_1 and m for the *Zukauskas* correlation

Continued on next page ...

QUESTION 5 continued ...

If $N_L < 20$, then
$\overline{\mathrm{Nu}}_D|_{(N_L<20)} = C_2\overline{\mathrm{Nu}}_D|_{(N_L\geq 20)}$
where C_2 is obtained from the following table:

N_L	1	2	3	4	5	7	10	13	16
Aligned	0.70	0.80	0.86	0.90	0.92	0.95	0.97	0.98	0.99
Staggered	0.64	0.76	0.84	0.89	0.92	0.95	0.97	0.98	0.99

$$\Delta T_{\mathrm{lm}} = \frac{(T_s - T_i) - (T_s - T_o)}{\ln\left(\frac{T_s - T_i}{T_s - T_o}\right)}$$

$$\frac{T_s - T_o}{T_s - T_i} = \exp\left(-\frac{\pi D N \bar{h}}{\rho V N_T S_T c_p}\right)$$

$$q' = \pi D N \bar{h} \Delta T_{\mathrm{lm}}$$

For a staggered configuration, if $S_D = \left[S_L^2 + \left(\frac{S_T}{2}\right)^2\right]^{1/2} < \frac{S_T+D}{2}$, then $V_{\max} = \frac{S_T}{2(S_D-D)}V$;
otherwise, $V_{\max} = \frac{S_T}{S_T-D}V$

TOTAL /15/

QUESTION 6

A circular stove plate of diameter 0.25 m and emissivity 0.9 is maintained at a constant surface temperature T_s. The electrical power that is supplied to the plate when the room air and surroundings are at 24°C is 90 Watts. With the exception of β (i.e. volumetric expansion coefficient), assume that the properties of air do not vary significantly with the film temperature. The Rayleigh number is anticipated to fall within the range $10^4 \leq \text{Ra}_L \leq 10^9$. Calculate the surface temperature of the plate by noting that heat losses from the plate to the surroundings are due to convection *and* radiation. If your solution requires an iterative computation, then perform a maximum of one iteration.

Hint: Formulate an expression in terms of T_s by performing an energy balance on the stove plate.

Properties: *Air*: $\nu = 20.93 \times 10^{-6}$ m²/s, $k = 0.030$ W/m·K, $\alpha = 29.9 \times 10^{-6}$ m²/s

Equations and supporting information:

Lower Surface of Hot Plate or Upper Surface of Cold Plate:

$\overline{\text{Nu}}_L = 0.52\text{Ra}_L^{1/5}$ $(10^4 \leq \text{Ra}_L \leq 10^9, \text{Pr} \geq 0.7)$

Upper Surface of Hot Plate or Lower Surface of Cold Plate:

$\overline{\text{Nu}}_L = 0.54\text{Ra}_L^{1/4}$ $(10^4 \leq \text{Ra}_L \leq 10^7, \text{Pr} \geq 0.7)$

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W·m⁻²·K⁻⁴

$$q''_{\text{rad}} = \varepsilon\sigma(T_s^4 - T_{\text{surr}}^4)$$

$$\text{Ra}_L = \text{Gr}_L \times \text{Pr} = g\beta\,(T_s - T_\infty)L^3/(\nu\alpha)$$

$L = \frac{A_s}{P}$ where A_s is the surface area of <u>one</u> side of the object

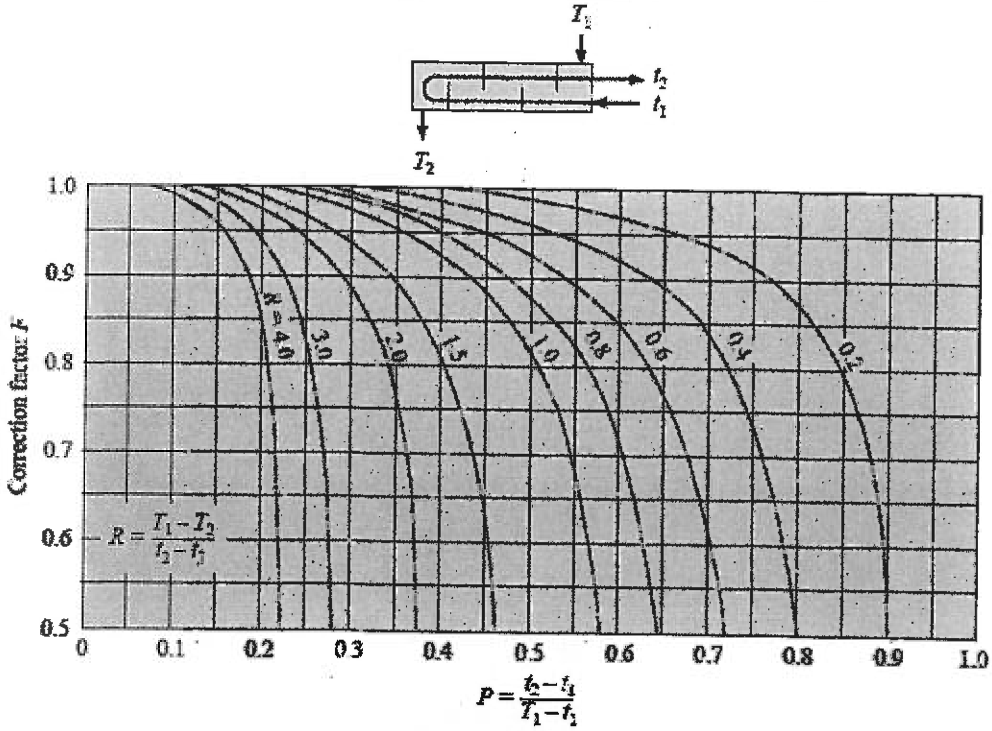
$\beta = (-1/\rho) \times (\partial\rho/\partial T)|_p$; for an ideal gas, $\beta = 1/T_f$

$$T^{[k]} = T^{[k-1]} - \frac{f(T^{[k-1]})}{f'(T^{[k-1]})}$$

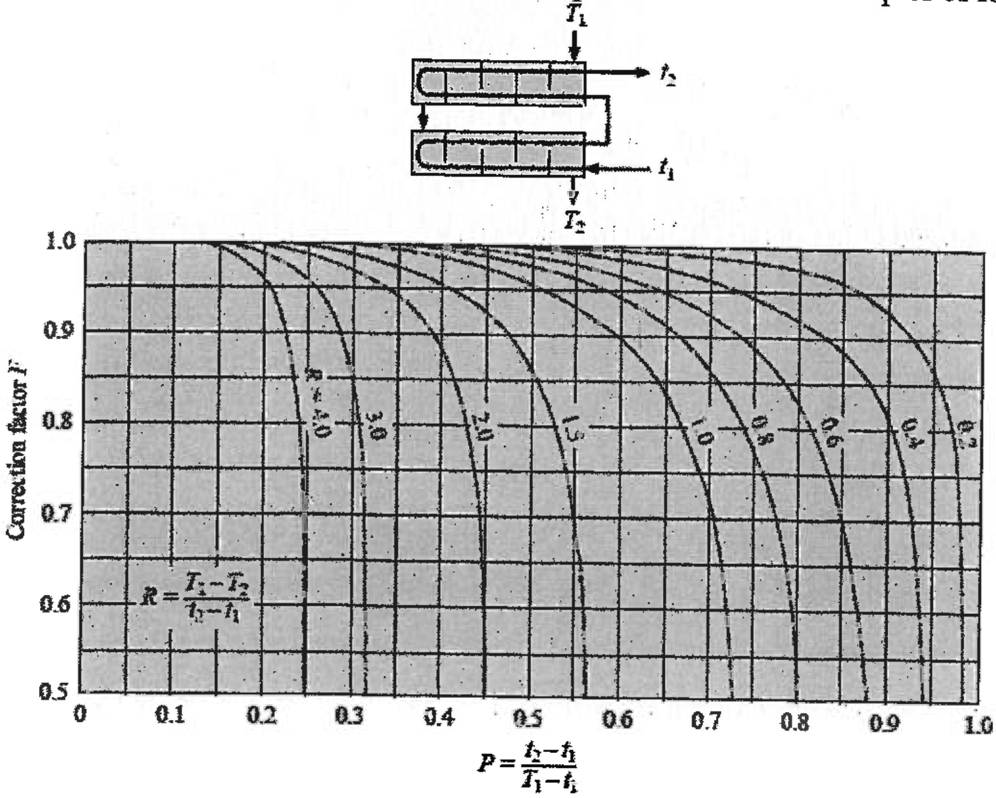
TOTAL /17/

CORRECTION FACTORS

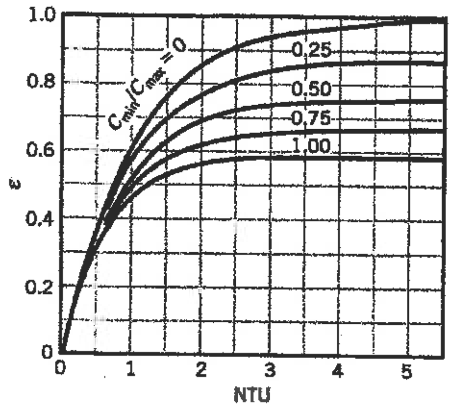
Correction factor plot for heat exchanger with one shell pass and two or more even tube passes



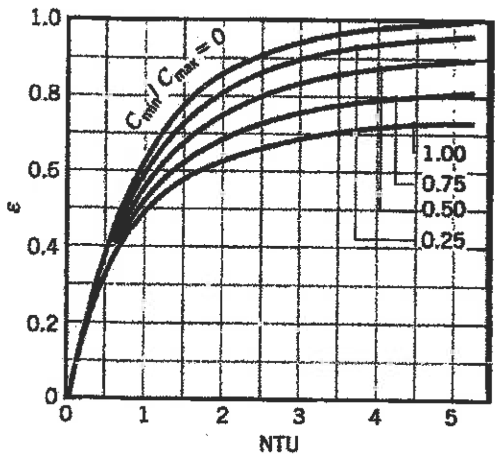
Correction factor for heat exchanger with two shell passes and four or multiples of four tube passes



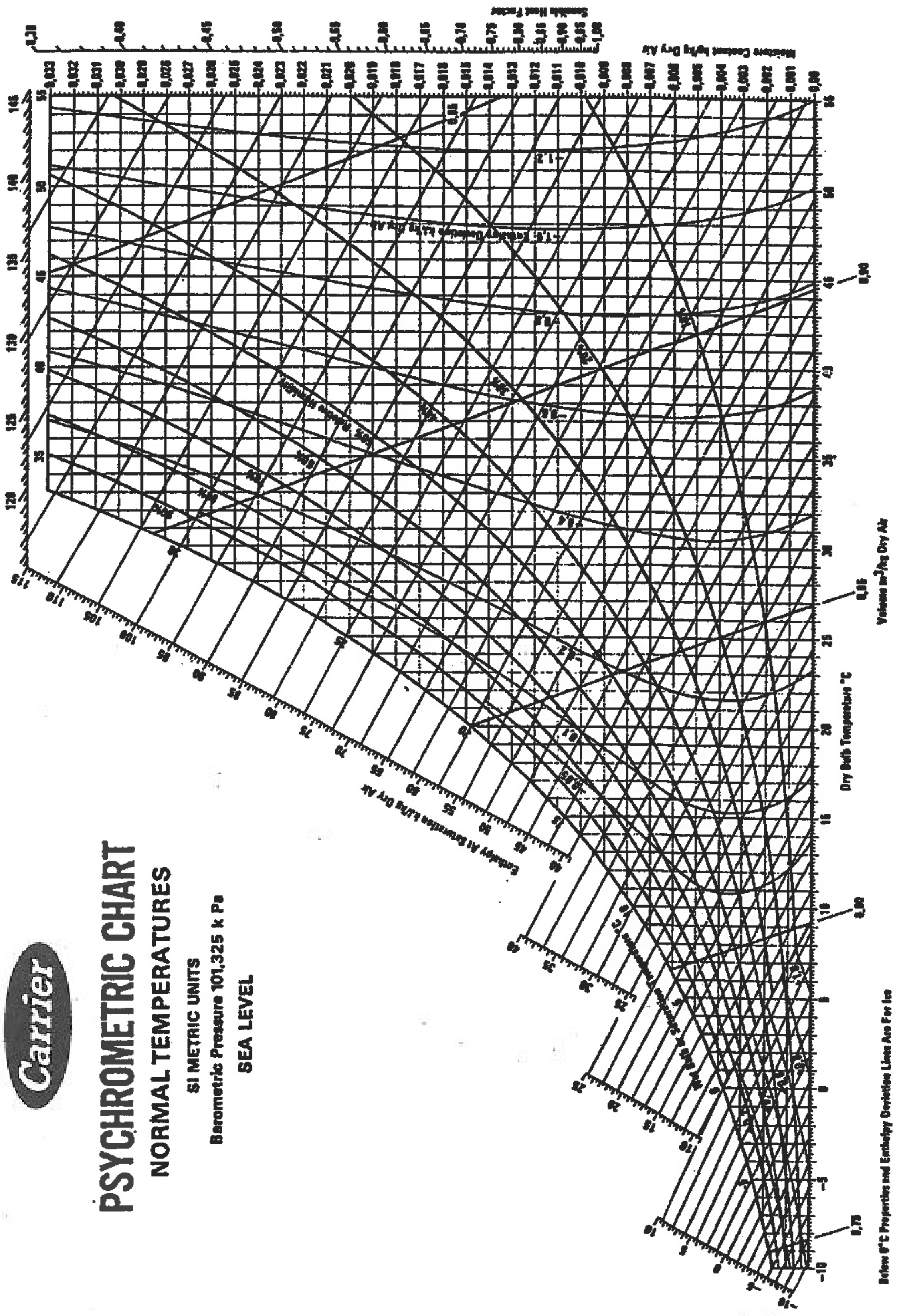
EFFECTIVENESS CHARTS



Effectiveness of a shell-and-tube heat exchanger with one shell and any multiple of two tube passes (two, four, etc. tube passes)



Effectiveness of a shell-and-tube heat exchanger with two shell passes and any multiple of four tube passes (four, eight, etc. tube passes)


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101,325 k Pa
SEA LEVEL

DETACH THIS PAGE AND SUBMIT WITH ANSWER BOOK A

NAME: ______________________ **STUDENT NUMBER:** ______________________