National Exams December 2013

04-Chem-A3 Mass Transfer Operations

Three Hour Duration

NOTES:

1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.

3) This is an open-book exam.

4) Any non-communicating calculator is permitted.

5) The examination is in two parts – Part A (Questions 1, 2, and 3), Part B (Questions 3, 4, and 5). Answer **TWO** questions from Part A, and **TWO** questions from Part B. **FOUR** questions constitute a complete paper.

6) Each question is of equal value.

PART A: ANSWER ONE OF QUESTIONS 1-3

Note: Four questions constitute a complete paper (with two from Part A, and two from Part B)

1) A service attendant accidently spills 50 L of gasoline, which spreads quickly over a level surface having an area of 8.0 m^2. Estimate the time required for the gasoline to evaporate into the stagnant air above the surface of the liquid. The diffusivity of gasoline into air is 0.65 m^2/h. The temperature of the air and gasoline is 298 K. Evaporation may be assumed to take place through a film of still air 2.0 m thickness, i.e. assume take the concentration of gasoline to be zero at 2.0 meters above the surface of the gasoline. The vapour pressure of gasoline at 298 K is 76 mm of Hg. The density of gasoline is 720 kg/m^3 and the average molecular weight of gasoline is 200. The total pressure is constant at 1.0 atm.

2) Water vapour is diffusing at steady-state through stagnant air in a conical stack (Figure 1) at 54°C and 1.0 bar. The height of the stack is 10 m, and its diameter changes from 80 cm at the bottom to 40 cm at the top. The partial pressure of water vapour at the bottom of the stack is 2500 Pa, and the partial pressure of water vapour at the top of the stack is 500 Pa. The diffusivity of water in air at this temperature is 3 x 10^{-5} m^2/s.

Calculate

a) The molar rate of transfer of water vapour in kg/h.
b) The molar fluxes of water vapour at the top of the stack and at the bottom.

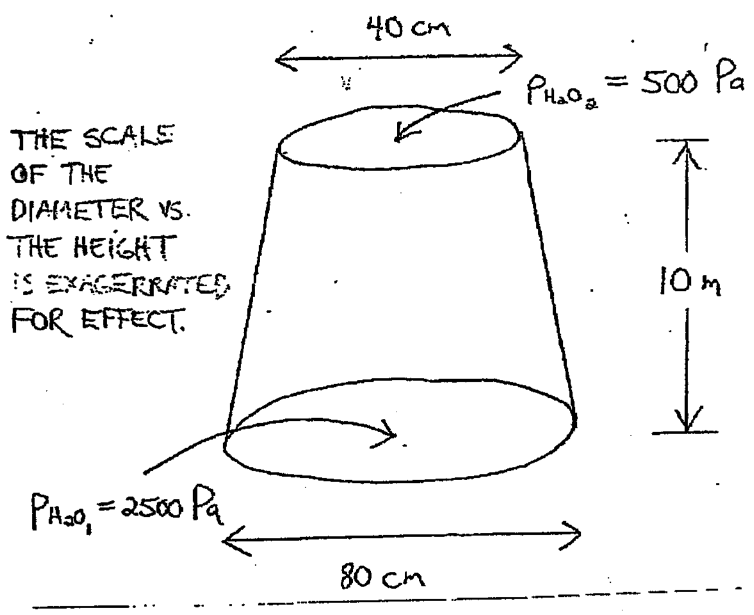


Figure 1

3) A 25 mm-thick porous slab initially containing 0.5 kg of solute A/kg of solid is placed in a well-agitated tank of liquid B (Figure 2), so that the slab is exposed to the liquid on both faces (neglect end effects). If the effective diffusivity of A through the porous slab is 5.0×10^{-10} m^2/s, determine the time required for the solute content at the center of the slab to decrease to 0.005 kg of A/kg of solid. Neglect any counter-diffusion of B into the solid.

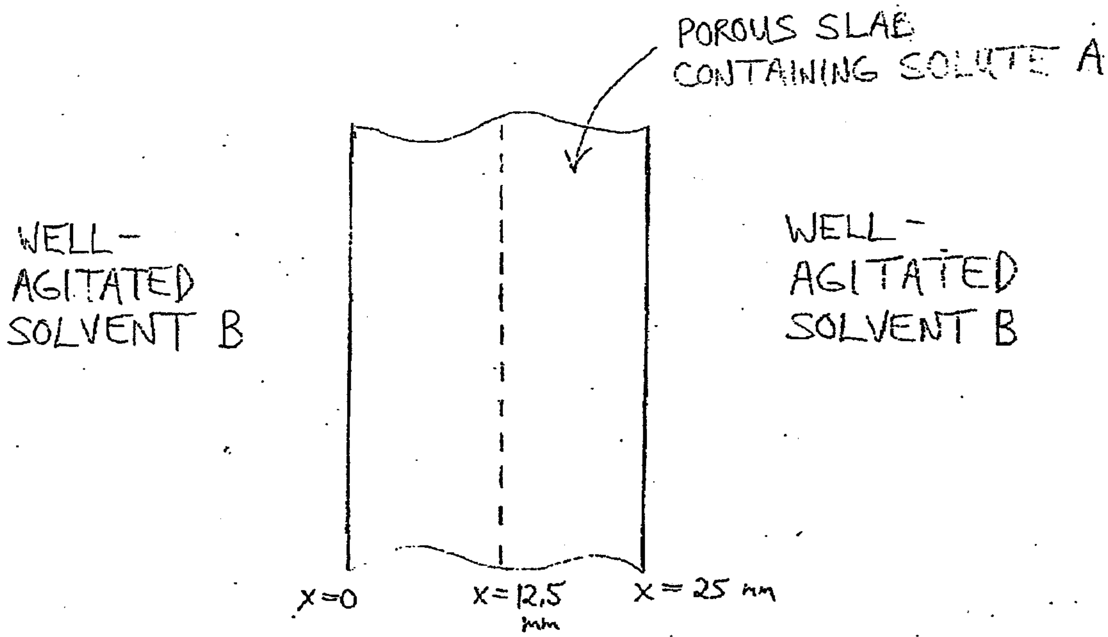


Figure 2

PART B: ANSWER TWO OF QUESTIONS 4-6

Note: Four questions constitute a complete paper
(with two from Part A, two from Part B)

4) An absorption column is set up to perform an absorption of Gas A from an inert gas into an absorbing Liquid B. The following data are available:

Equilibrium curve:	$y_A^* = 12.0x_A^*$
Inlet concentration of A in the gas stream:	$y_{A1} = 0.04$
Inlet concentration of A in the liquid stream:	$x_{A2} = 0.0002$
Outlet concentration of A in the gas stream:	$y_{A2} = 0.0065$
Inlet Gas Flux:	$G_s = 25$ kmol/m²·h
Inlet Liquid Flux:	$L_s = 398$ kmol/m²·h
Column height:	2.0 m

Calculate the values of both the overall mass transfer coefficients, K_ya and K_xa.

5) A natural-draft cooling tower is to be designed to cool a stream of 2000 kg/h of water from 50°C to 30°C. Air is available at a dry-bulb temperature of 30°C and a wet-bulb temperature of 24°C. The gas-phase interfacial mass transfer coefficient, k_ya, is 2400 kg/m³·h. You are instructed to use 20% excess air. Assuming the cross-sectional area of the tower is 1.0 m², estimate the height of the tower.

Show all your work on the chart(s). **Do not forget to hand in your chart with the exam booklet, and write your name on the chart.**

6) The mass transfer coefficient for the laminar boundary layer formed over a flat plate has been correlated in terms of the local Sherwood number by

$$Sh_x = 0.332Re_x^{1/2}Sc^{1/3}$$

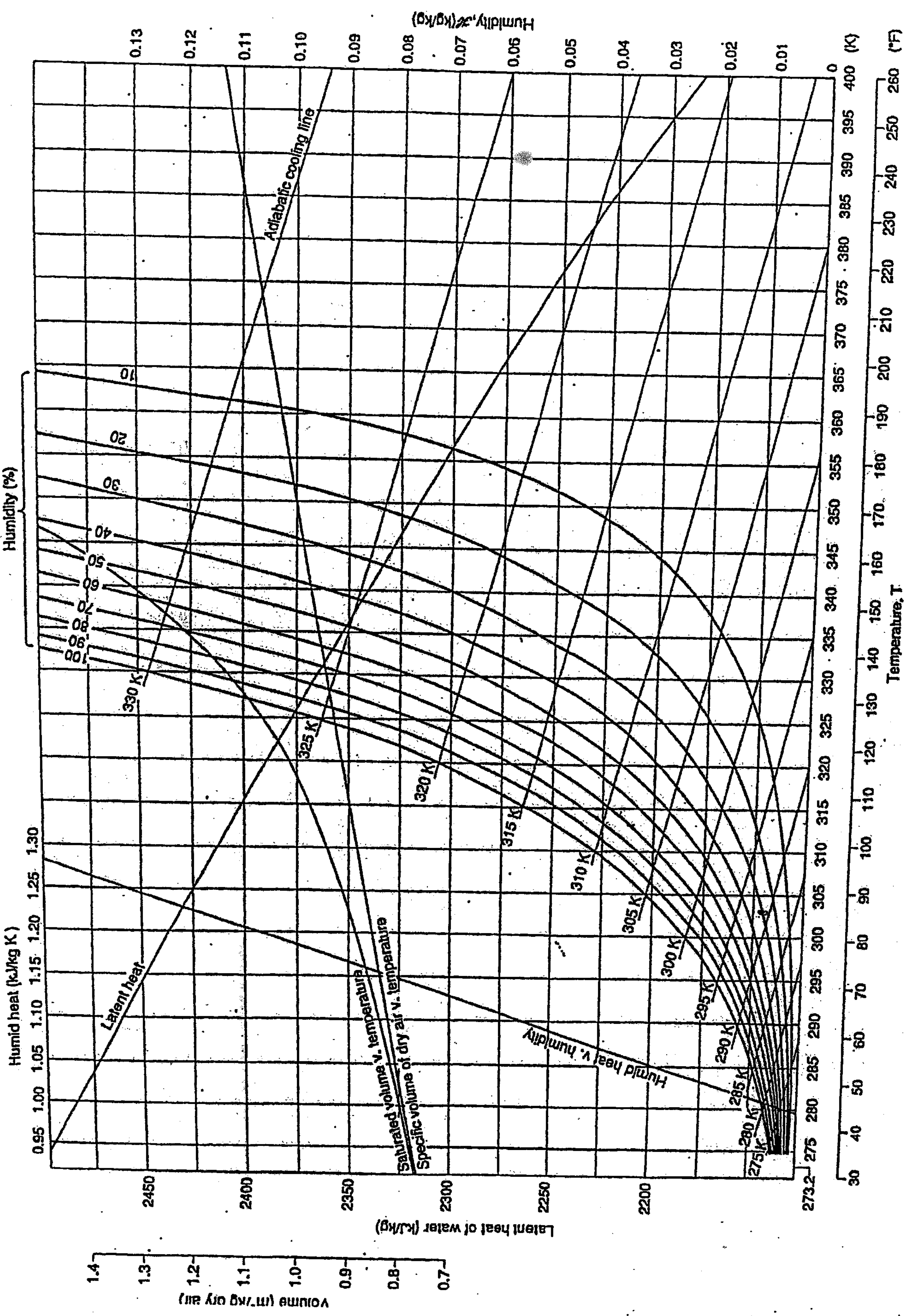
Likewise, the mass transfer coefficient for the turbulent boundary layer is given by

$$Sh_x = 0.0292Re_x^{4/5}Sc^{1/3}$$

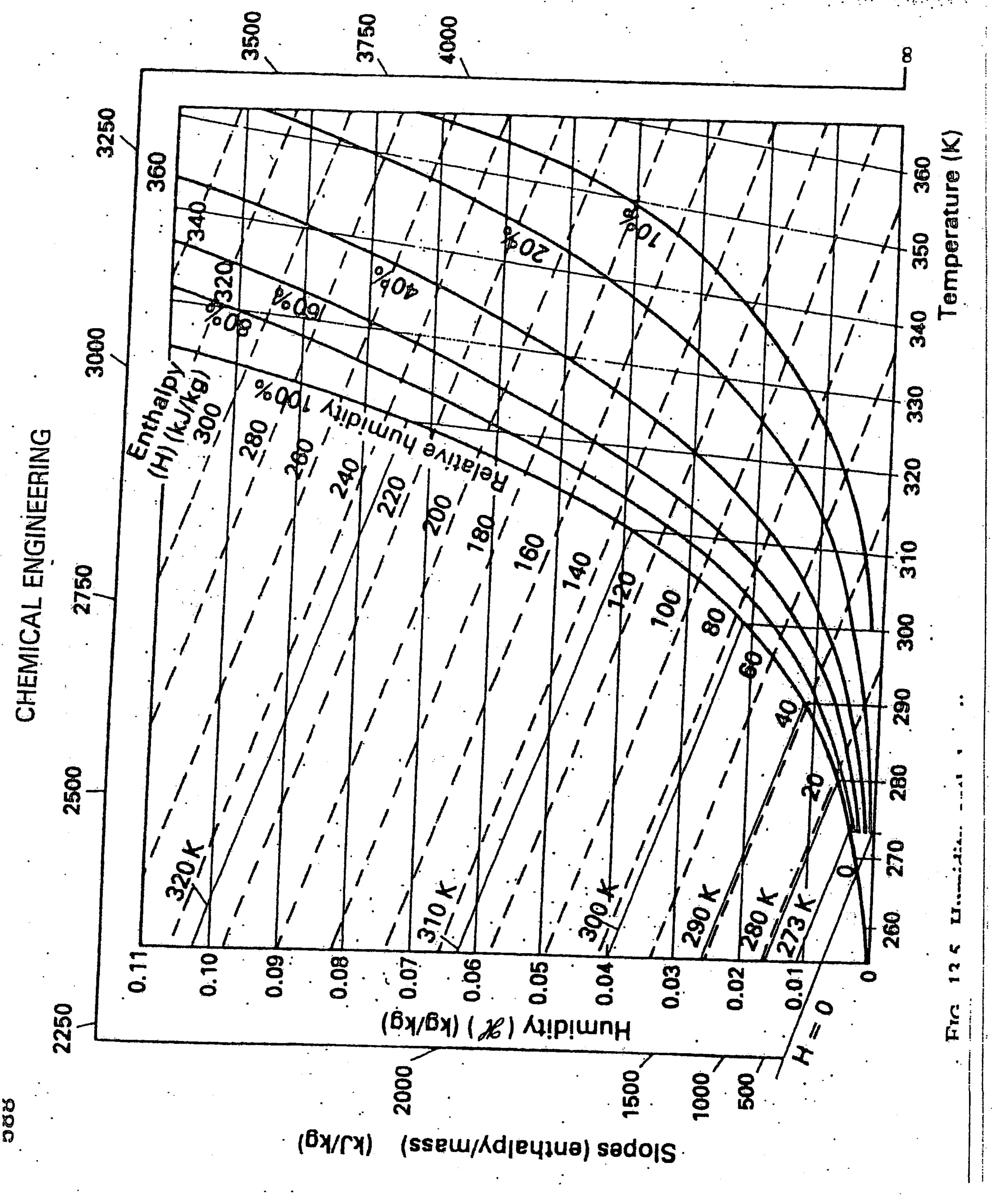
in which x is the distance along the plate from the leading edge. Show that for a flat plate of length L, the mean mass transfer coefficient, $\overline{k_c}$, is given by the following relationship:

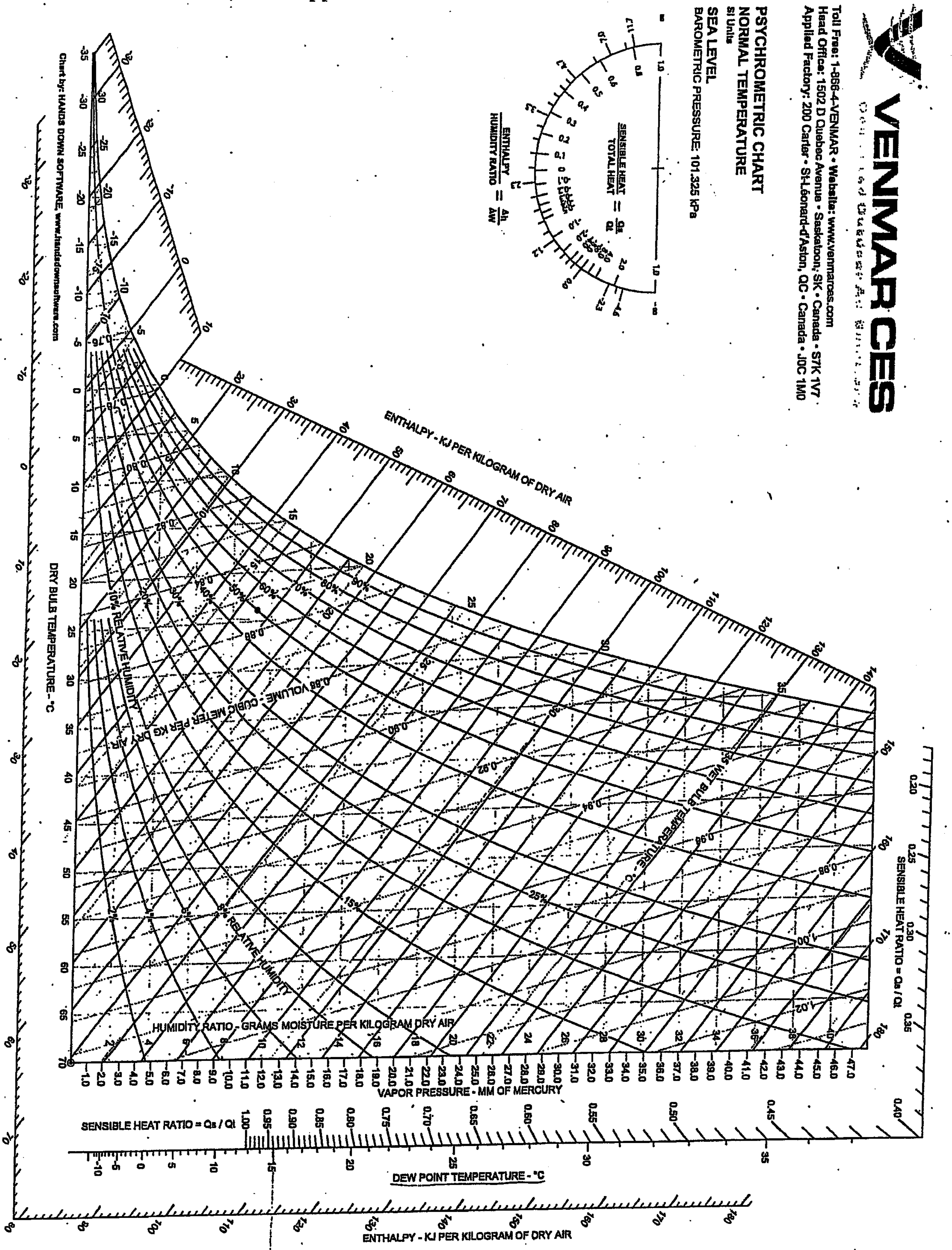
$$\overline{k_c} = \frac{0.664 D_{AB} \left(\frac{u}{v}\right)^{1/2} Sc^{1/3} L_t^{1/2} + 0.0365 D_{AB} \left(\frac{u}{v}\right)^{1/2} Sc^{1/3} \left[L^{4/5} - L_t^{4/5}\right]}{L}$$

in which u is the fluid velocity, v is the kinematic viscosity of the fluid, and L_t is the distance from the leading edge of the plate to where the transition from laminar flow to turbulent flow occurs.



Humidity, ℋ(kg/kg)
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
(K)
(°F)
Adiabatic cooling line
Humidity (%)
10
20
30
40
50
60
70
80
90
100
330 K
325 K
320 K
315 K
310 K
305 K
300 K
295 K
290 K
285 K
280 K
275 K
Latent heat
Saturated volume v. temperature
Specific volume of dry air v. temperature
Humid heat v. humidity
Humid heat (kJ/kg K)
0.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
Temperature, T
273.2
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
Latent heat of water (kJ/kg)
2450
2400
2350
2300
2250
2200
Volume (m³/kg dry air)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7


CHEMICAL ENGINEERING
Enthalpy (H) (kJ/kg)
Relative humidity 100%
80%
60%
40%
20%
10%
Temperature (K)
Humidity (ℋ) (kg/kg)
Slopes (enthalpy/mass) (kJ/kg)
H = 0
320 K
310 K
300 K
290 K
280 K
273 K
260
270
280
290
300
310
320
330
340
350
360
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
2250
2500
2750
3000
3250
3500
3750
4000
∞
2000
1500
1000
500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PSYCHROMETRIC CHART
NORMAL TEMPERATURE
SI Units
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - KJ PER KILOGRAM OF DRY AIR
DRY BULB TEMPERATURE - °C
10% RELATIVE HUMIDITY
VOLUME - CUBIC METER PER KG DRY AIR
WET BULB TEMPERATURE - °C
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAMS MOISTURE PER KILOGRAM DRY AIR
VAPOR PRESSURE - MM OF MERCURY
SENSIBLE HEAT RATIO = Qs / Qt
DEW POINT TEMPERATURE - °C
Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com