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.
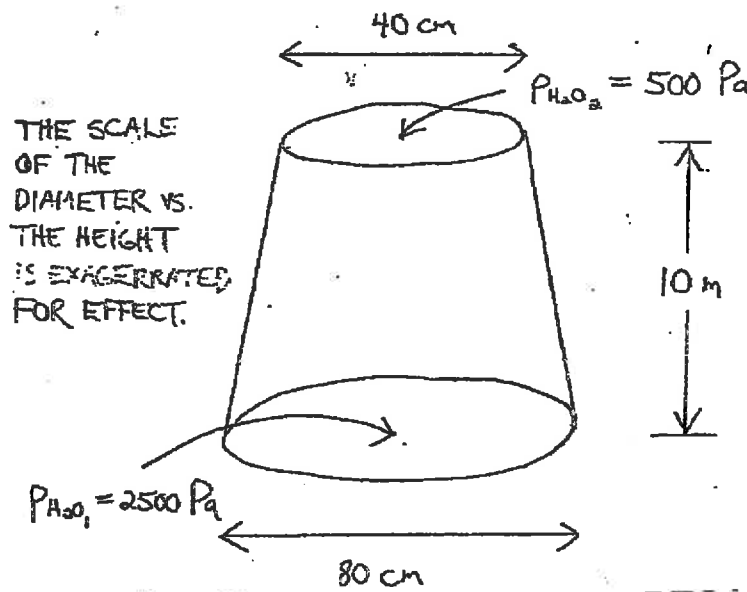

Figure 1

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 x 10^{-10} m²/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.
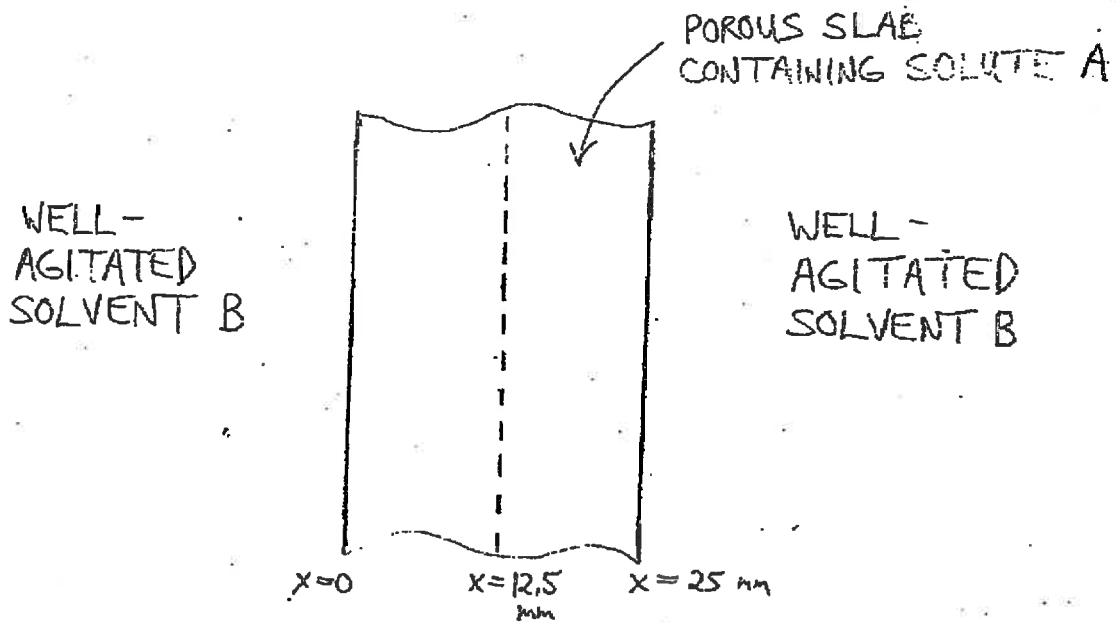

Paneltext:
POROUS SLAB
CONTAINING SOLUTE A

WELL-
AGITATED
SOLVENT B

WELL-
AGITATED
SOLVENT B

$X=0$ $X=12.5$ mm $X=25$ mm

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:	$y_A^* = 12.0 x_A^*$
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, $K_y a$ and $K_x a$.

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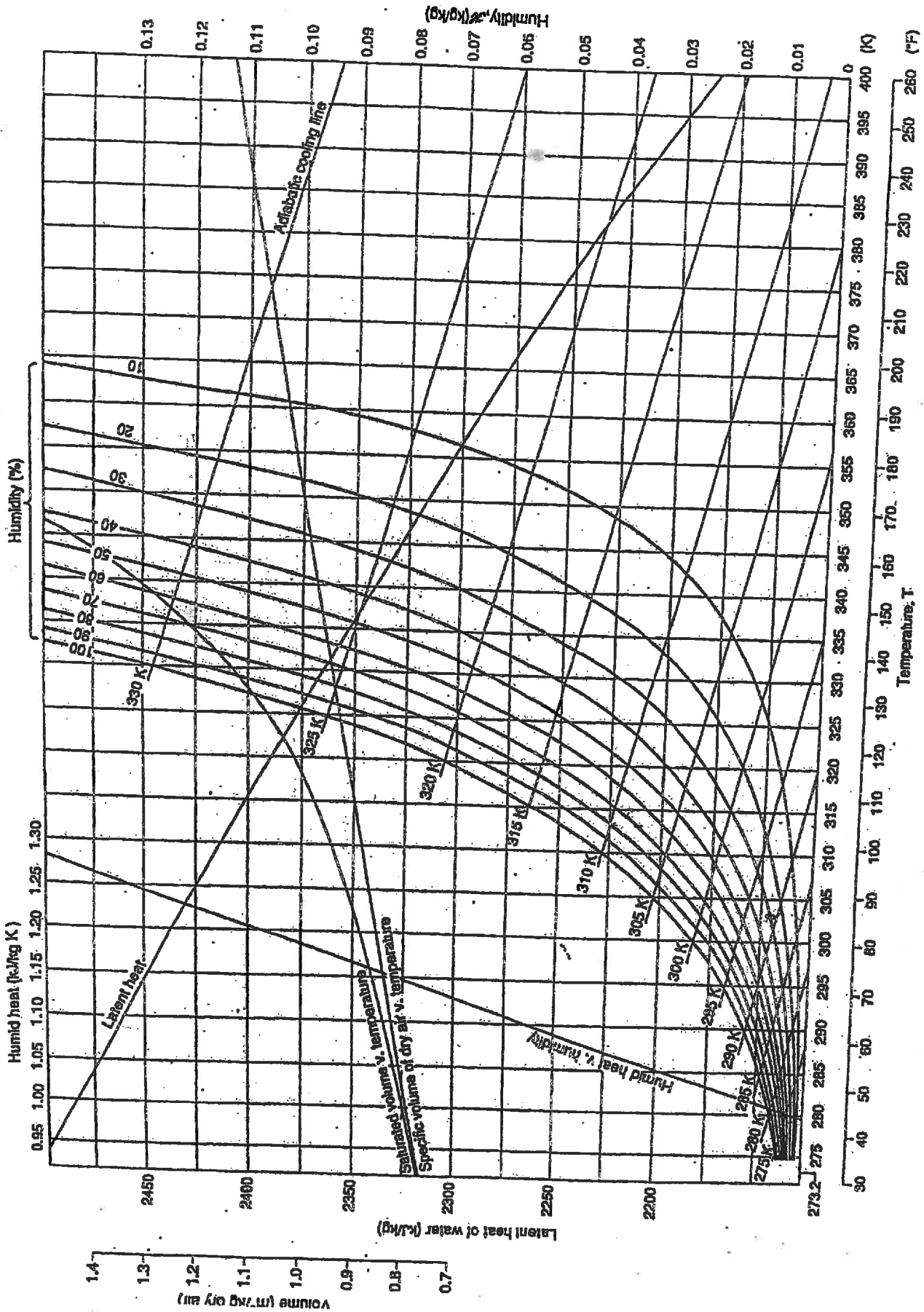
$$Sh_x = 0.332 Re_x^{1/2} Sc^{1/3}$$

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

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

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:

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

in which u is the fluid velocity, ν 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.

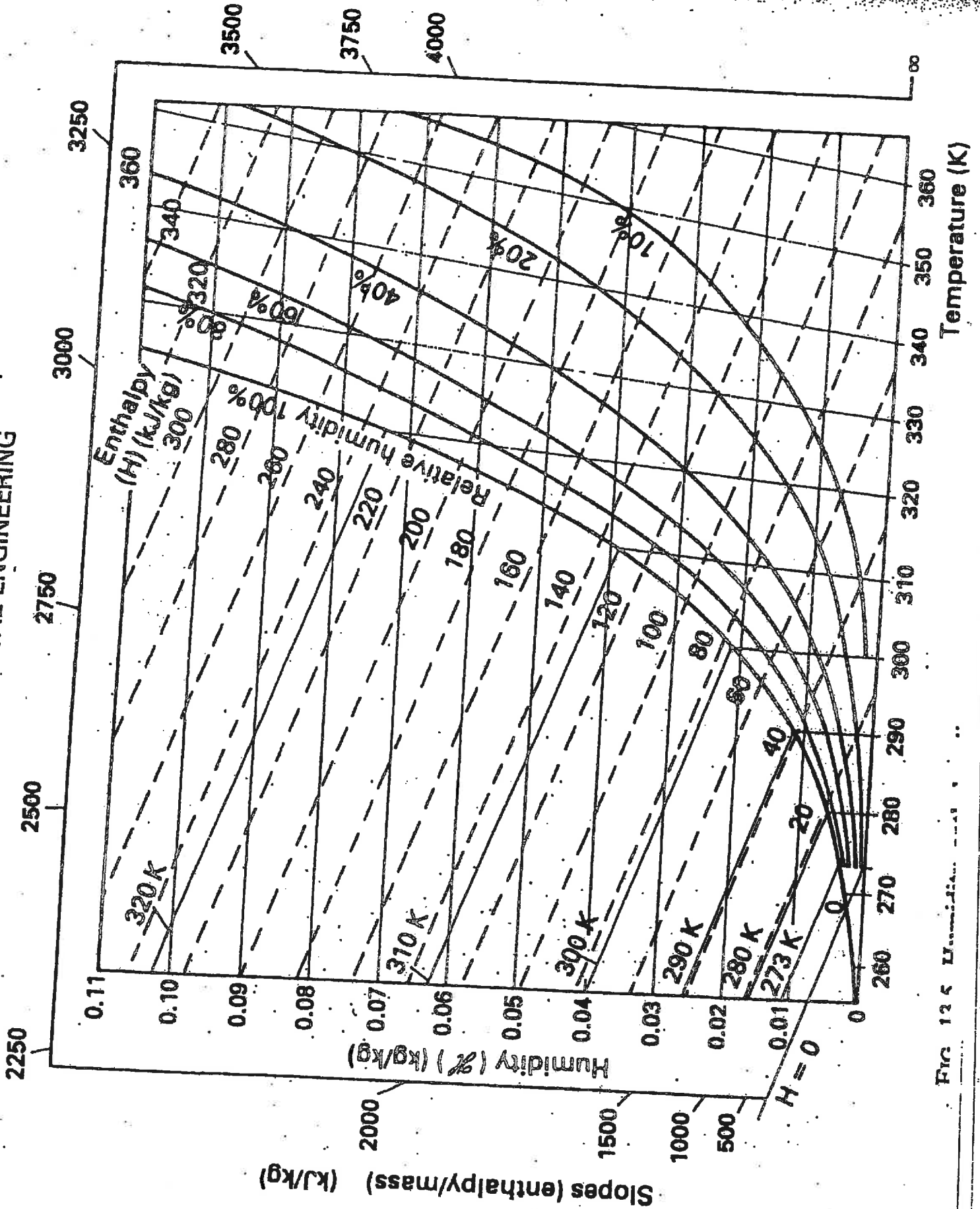Humidity chart (psychrometric chart): Humidity $\mathscr{H}$ (kg/kg) versus Temperature, T (K and °F), showing Humidity (%) lines, Adiabatic cooling line, Latent heat, Saturated volume v. temperature, Specific volume of dry air v. temperature, Humid heat v. humidity, Humid heat (kJ/kg K), Latent heat of water (kJ/kg), and Volume (m³/kg dry air).

CHEMICAL ENGINEERING

Fig. 12.5 Humidity and ...

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PSYCHROMETRIC CHART
NORMAL TEMPERATURE
SI Units
SEA LEVEL
BAROMETRIC PRESSURE: 101,325 kPa

Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com