2-1. Water at 120 C and a pressure of 250 kPa passes through a pressure-reducing valve and then flows to a separating tank at standard atmospheric pressure of 101.3 kPa, as shown in Fig. 2-14.

(a) What is the state of the water entering the valve (subcooled liquid, saturated liquid, or vapor)?

(b) For each kilogram that enters the pressure-reducing valve, how much leaves the separating tank as vapor?

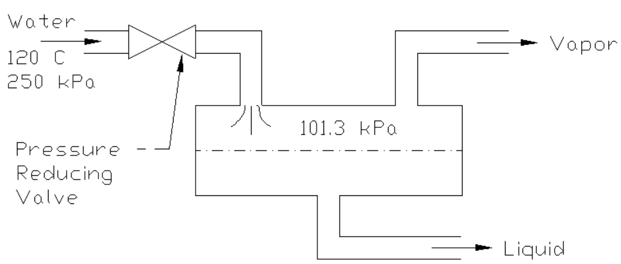

Fig. 2-14. Pressure-reducing valve in Problem 2-1

Solution:

(a) From Fig. 2-2, a temperature of 120 C and pressure of 250 kPa water lies in the sub-cooled regiom. so it is a sub-cooled liquid.

(b) At 120 C, h_1 = 503.72 kJ/kg from Table A-1

For Pressuring Reducing Valve Dh = 0

$h_2 = h_1$

At 101.3 kPa, Table A-1, h_f = 419.06 kJ/kg

h_g = 2676 kJ/kg

Let x be the amount of vapor leaving the separating tank.

$h = h_f + x(h_g - h_f)$

$$x = \frac{h - h_f}{h_g - h_f} = \frac{503.72 - 419.06}{2676 - 419.06}$$

x = 0.0375 kg/kg - - - Ans.

2-2. Air flowing at a rate of 2.5 kg/s is heated in a heat exchanger from -10 to 30 C. What is the rate of heat transfer?

Solution:

$q = mc_p(t_2 - t_1)$

m = 2.5 kg/s

c_p = 1.0 kJ/kg.K

t_2 = 30 C

t_1 = -10 C

Then,

q = (2.5)(1.0)(30 + 10)

q = 100 kw - - - Ans.

2-3. One instrument for measuring the rate of airflow is a venturi, as shown in Fig. 2-15, where the cross-sectional area is reduced and the pressure difference between position A and B measured. The flow rate of air having a density of 1.15 kg/m^3 is to be measured in a venturi where the area of position A is 0.5 m^2 and the area at b is 0.4 m^2. The deflection of water (density = 1000 kg/m3) in a manometer is 20 mm. The flow between A and B can be considered to be frictionless so that Bernoulli's equation applies.
(a) What is the pressure difference between position A and B?
(b) What is the airflow rate?

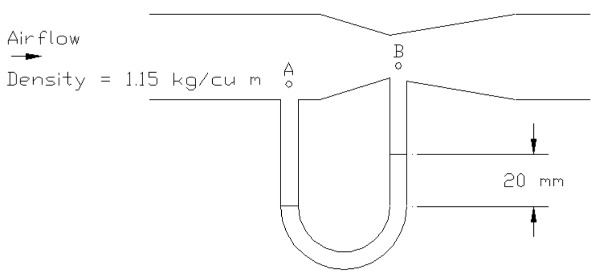

Fig. 2-15. A venturi for measuring air flow.

Solution:

(a) Bernoulli equation for manometer

$$\frac{p_A}{\rho} + gz_A = \frac{p_B}{\rho} + gz_B$$

$p_A - p_B = \rho g(z_B - z_A)$

$z_B - z_A$ = 20 mm = 0.020 m
g = 9.81 m/s^2
ρ = 1000 kg/m^3

$p_A - p_B$ = (1000 kg/m^3)(9.81 m/s^2)(0.020 m)

$p_A - p_B$ = 196.2 Pa - - - Ans.

(b) Bernoulli Equation for Venturi

$$\frac{p}{\rho} + \frac{V^2}{2} = \text{constant}$$

$$\frac{p_A}{\rho}+\frac{V_A{}^2}{2}=\frac{p_B}{\rho}+\frac{V_B{}^2}{2}$$
$$p_A-p_B=\tfrac{1}{2}\rho\left(V_B{}^2-V_A{}^2\right)$$

But $m = \rho A_A V_A = \rho A_B V_B$

$A_A V_A = A_B V_B$

AA = 0.5 m2 ans AB = 0.4 m2

Then

$0.5V_A = 0.4V_B$
$V_A = 0.8V_B$

$$p_A-p_B=196.2\text{ Pa}=\tfrac{1}{2}\left(1.15\text{ kg/m}^3\right)\left[V_B{}^2-\left(0.8V_B\right)^2\right]$$
$V_B = 30.787$ m/s

Air Flow Rate = $A_B V_B$
= $(0.4\text{ m}^2)(30.787\text{ m/s})$
= 12.32 m^3/s - - - Ans.

2-4. Use the perfect-gas equation with R = 462 J/kg.K to compute the specific volume of saturated vapor at 20 C. Compare with data of Table A-1.

Solution:

Perfect-Gas Equation:
$$p\nu = RT$$
$$\nu=\frac{RT}{p}$$
At 20 C, Table A-1, Saturation Pressure = 2.337 kPa = 2337 Pa.
Specific volume of saturated vapor = 57.84 m^3/kg
T = 20 C + 273 = 293 K
$$\nu=\frac{\left(462\text{ J/kg.K}\right)\left(293\text{ K}\right)}{2337\text{ Pa}}$$
$$\nu = 57.923\text{ m}^3/\text{kg}$$

$$\text{Deviation}=\frac{57.923-57.84}{57.84}\left(100\%\right)$$
Deviation = 0.1435 %

2-5. Using the relationship shown on Fig. 2-6 for heat transfer when a fluid flows inside tube, what is the percentage increase or decrease in the convection heat-transfer coefficient h_c if the viscosity of the fluid is decreased 10 percent.

Solution:

Figure 2-6.

$$Nu = 0.023Re^{0.8}Pr^{0.4}$$

where:

$$Re = \frac{\rho VD}{\mu}$$

$$Pr = \frac{\mu c_p}{k}$$

$$Nu = \frac{h_c D}{k}$$

Then,

$$\frac{\left(\frac{h_{c1}D}{k}\right)}{\left(\frac{h_{c2}D}{k}\right)} = \frac{0.023\left(\frac{\rho VD}{\mu_1}\right)^{0.8}\left(\frac{\mu_1 c_p}{k}\right)^{0.4}}{0.023\left(\frac{\rho VD}{\mu_2}\right)^{0.8}\left(\frac{\mu_2 c_p}{k}\right)^{0.4}}$$

$$\frac{h_{c1}}{h_{c2}} = \left(\frac{\mu_2}{\mu_1}\right)^{0.4}$$

If viscosity is decreased by 10 %

$$\frac{\mu_2}{\mu_1} = 0.9$$

Then,

$$\frac{h_{c1}}{h_{c2}} = (0.9)^{0.4}$$

$h_{c2} = 1.043h_{c1}$

$$Increase = \frac{h_{c2} - h_{c1}}{h_{c1}}(100\%)$$

Increase = (1.043 - 1)(100 %)

Increase = 4.3 % - - - Ans.

2-6. What is the order of magnitude of heat release by convection from a human body when the air velocity is 0.25 m/s and its temperature is 24 C?

Solution:

Using Eq. (2-12) and Eq. (2-18)

$C = h_c A(t_s - t_a)$

$h_c = 13.5V^{0.6}$

V = 0.25 m/s

$h_c = 13.5(0.25)^{0.6} = 5.8762\ W/m^2.K$

Human Body: $A = 1.5$ to $2.5\ m^2$ use $1.5\ m^2$
$t_s = 31$ to 33 C use 31 C

$C = (5.8762\ W/m^2.K)(1.5\ m^2)(31\ C - 24\ C)$
$C = 61.7\ W$

Order of Magnitude ~ 60 W - - - Ans.

2-7 What is the order of magnitude of radiant heat transfer from a human body in a comfort air-conditioning situation?

Solution:

Eq. 2-10.

$$q_{1-2} = \sigma A F \varepsilon F_A \left(T_1^{\ 4} - T_2^{\ 4}\right)$$

Surface area of human body = 1.5 to 2.5 m^2 use 1.5 m^2

$AF_\varepsilon F_A = (1.0)(0.70)(1.5\ m^2) - 1.05\ m^2$

$s = 5.669x10^{-8}\ W/m^2.K^4$

T_1=31 C + 273 = 304 K

T_2 = 24 C + 273 = 297 K

$q_{1-2} = (5.669x10^{-8})(1.05)(304^4 - 297^4)$

$q_{1-2} = 45\ W$

Order of Magnitude ~ 40 W - - - Ans.

2-8. What is the approximate rate of heat loss due to insensible evaporation if the skin temperature is 32 C, the vapor pressure is 4750 Pa, and the vapor pressure of air is 1700 Pa? The latent heat of water is 2.43 MJ/kg; $C_{diff} = 1.2x10^{-9}$ kg/Pa.s.m^2.

Solution:

Equation 2-19.

$q_{ins} = h_{fg} A C_{dif} f(\ p_s - p_a\ )$

Where:

$A = 2.0\ m^2$ average for human body area

h_{fg} = 2.43 MJ/kg = 2,430,000 J/kg

p_s = 4750 Pa

p_a = 1700 Pa

$C_{diff} = 1.2x10^{-9}$ kg/Pa.s.m^2

$q_{ins} = (2,430,000)(2.0)(1.2x10^{-9})(4750 - 1700)$

q_{ins} = 18 W - - - Ans.

- 0 0 0 -

3-1 Calculate the specific volume of an air-vapor mixture in cubic meters per kilogram of dry air when the following conditions prevail: t = 30 C, W = 0.015 kg/kg, and p_t = 90 kPa.

Solution:

Equation 3-4.

$$\nu = \frac{R_a T}{p_a} = \frac{R_a T}{p_t - p_s}$$

T = 30 C + 273 = 303 K

R_a = 287 J/kg.K

P_t = 90 kPa = 90,000 Pa

Equation 3-2

$$W = \frac{0.622 p_s}{p_t - p_s}$$

$$0.015 = \frac{0.622 p_s}{90 - p_s}$$

1.35 - 0.15p_s = 0.622p_s

p_s = 2.1193 kPa

$$\nu = \frac{R_a T}{p_t - p_s} = \frac{(287)(303)}{90000 - 2119.3}$$

ν = 0.99 m^3/kg - - - Ans.

3-2. A sample of air has a dry-bulb temperature of 30 C and a wet-bulb temperature of 25 C. The barometric pressure is 101 kPa. Using steam tables and Eqs. (3-2), (303), and (3-5), calculate (a) the humidity ration if this air is adiabatically saturated, (b) the enthalpy of air if it is adiabatically saturated, (c) the humidity ratio of the sample using Eq. (3-5), (d) the partial pressure of water vapor in the sample, and (e) the relative humidity.

Solution:

Eq. 3-2.

$$W = \frac{0.622 p_s}{p_t - p_s}$$

Eq. 3-3.

$h = c_p t + W h_g$

Eq. 3-5

$h_1 = h_2 - (W_2 - W_1) h_f$

$h_1 = c_p t_1 + W h_{g1}$

h_{g1} at 30 C = 2556.4 kJ/kg

t1 = 30 C

cp = 1.0 kJ/kg.K

h_1 = (1)(30) + 2556.4W_1

h_1 = 30 + 2556.4W_1

$h_2 = c_p t_2 + Wh_{g2}$

hg_2 at 25 C = 2547.3 kJ/kg
t_2 = 25 C
c_p = 1.0 kJ/kg.K

$h_2 = (1)(25) + 2547.3W_2$
$h_2 = 25 + 2547.3W_2$

h_f at 25 C = 125.66 kJ/kg

Then:

$h_1 = h_2 - (W_2 - W_1)h_f$
$30 + 2556.4W_1 = 25 + 2547.3W_2 - (W_2 - W_1)(125.66)$
$5 = 2421.64W_2 - 2430.74W_1$

But,

$$W_2 = \frac{0.622p_s}{p_t - p_s}$$

ps at 25 C = 3.171 kPa

$$W_2 = \frac{0.622(3.171)}{101 - 3.171}$$

W_2 = 0.0201 kg/kg

$5 = 2421.64(0.0201) - 2430.74W_1$
W_1 = 0.018 kg/kg

(a) Humidity Ratio
W_2 = 0.0201 kg/kg - - - Ans.

(b) $h_2 = c_p t_2 + W_2 hg_2$
$h_2 = (1)(25) + (0.0201)(2547.3)$
h_2 = 76.2 kJ/kg - - - Ans.

(c) Humidity Ratio
W_1 = 0.018 kg/kg - - - Ans.

(d) p_{s1}

$$W_1 = \frac{0.622p_s}{p_t - p_s}$$

$$0.018 = \frac{0.622p_s}{101 - p_s}$$

p_{s1} = 2.84 kPa
p_{s1} = 2840 kPa - - - Ans.

(e) At 30 C, p_s = 4.241 kPa

Relative Humidity = (2.84 kPa / 4.241 kPa)(100%)

Relative Humidity = 67 % - - - Ans.

3-3 Using humidity ratios from the psychrometric chart, calculate the error in considering the wet-bulb line to be the line of constant enthalpy at the point of 35 C dry-bulb temperature and 50 percent relative humidity.

Solution:

Dry-bulb Temperature = 35 C
Relative Humidity = 50 %

Fig. 3-1, Psychrometric Chart.
At constant enthalpy line: Wet-bulb = 26.04 C
At wet-bulb line = Wet-bulb = 26.17 C

Error = 26.17 C - 26.04 C
Error = 0.13 C

3-4. An air-vapor mixture has a dry-bulb temperature pf 30 C and a humidity ratio of 0.015. Calculate at two different barometric pressures, 85 and 101 kPa, (a) the enthalpy and (b) the dew-point temperature.

Solution:

At 30 C, p_s = 4.241 kPa, h_g = 2556.4 kJ/kg

(a) $h = c_p t + W h_g$

For 85 and 101 kPa
c_p = 1.0
t = 30 C
W = 0.015 kg/kg
h_g = 2556.4 kJ/kg

h = (1.0)(30) + (0.015)(2556.4)
h = 68.3 kJ/kg

(b) For dew-point:

$$W = \frac{0.622 p_s}{p_t - p_s}$$

at 85 kPa

$$0.015 = \frac{0.622 p_s}{p_t - p_s}$$

p_s = 2.0016 kPa

Dew-Point = 17.5 C - - - Ans.

at 101 kPa

$$0.015 = \frac{0.622p_s}{p_t - p_s}$$

p_s = 2.3783 kPa

Dew-Point = 20.3 C - - - Ans.

3-5. A cooling tower is a device that cools a spray of water by passing it through a stream of air. If 15 m^3/s of air is at 35 C dry-bulb and 24 C wet-bulb temperature and an atmospheric pressure of 101 kPa enters the tower and the air leaves saturated at 31 C, (a) to what temperature can this airstream cool a spray of water entering at 38 C with a flow rate of 20 kg/s and (b) how many kilograms per second of make-up water must be added to compensate for the water that is evaporated?

Solution:

At 35 C dry-bulb, 24 C wet-bulb.

Fig. 3-1, Psychrometric Chart
h_1 = 71.524 kJ/kg,
ν_1 = 0.89274 m^3/kg
W_1 = 0.0143 kg/kg
At 31 C saturated, Table A-2.
h_2 = 105 kJ/kg
W_2 = 0.0290 kg/kg

Then;
m = (15 m^3/s) / (0.89274 m^3/kg) = 16.8022 kg/s

(a) t_{w1} = 38 C
m_w = 20 kg/s
c_{pw} = 4.19 kJ/kg.K

$m_w c_{pw}(t_{w1} - t_{w2}) = m(h_2 - h_1)$

$(20)(4.19)(38 - t_{w2}) = (16.8022)(105 - 71.524)$

t_{w2} = 31.3 C - - - Ans.

(b) Make-Up Water = m_m

$m_m = m(W_2 - W_1)$
$m_m = (16.8022)(0.0290 - 0.0143)$

m_m = 0.247 kg/s - - - Ans.

3-6. In an air-conditioning unit 3.5 m^3/s of air at 27 C dry-bulb temperature, 50 percent relative humidity, and standard atmospheric pressure enters the unit. The leaving condition of the air is 13 C dry-bulb temperature and 90 percent relative humdity. Using properties from the psychrometric chart, (a) calculate the refrigerating capacity inkilowatts and (b) determine the rate of water removal from the air.

Solution:

At 27 C dry-buld, 5 Percent Relative Humidity
h_1 = 55.311 kJ/kg,
ν_1 = 0.86527 m^3/kg
W_1 = 0.0112 kg/kg

At 13 C Dry-Bulb, 90 Percent Relative Humidity
h_2 = 33.956 kJ/kg
W_2 = 0.0084 kg/kg

m = (3.5 m^3/s)/(0.86526 m^3/kg) = 4.04498 kg/s

(a) Refrigerating Capacity
= $m(h_1 - h_2)$
= (4.04498)(55.311 - 33.956)
= 86.38 kW - - - Ans.

(b) Rate of Water Removal
= $m(W_1 - W_2)$
= (4.04498)(0.0112 - 0.0084)
= 0.0113 kg/s - - - Ans.

3-7. A stream of outdoor air is mixed with a stream of return air in an air-conditioning system that operates at 101 kPa pressure. The flow rate of outdoor air is 2 kg/s, and its condition is 35 C dry-bulb temperature and 25 C wet-bulb temperature. The flow rate of return air is 3 kg/s, and its condition is 24 C and 50 percent relative humidity. Determine (a) the enthalpy of the mixture, (b) the humidity ratio of the mixture, (c) the dry-bulb temperature of the mixture from the properties determined in parts (a) and (b) and (d) the dry-bulb temperature by weighted average of the dry-bulb temperatures of the entering streams.

Solutions:

Use Fig. 3-1, Psychrometric Chart
At 35 C Dry-Bulb, 24 C Wet-Bulb
h_1 = 75.666 kJ/kg, m_1 = 2 kg/s
W_1 = 0.0159 kg/kg

At 24 C Dry-Bulb, 50 Percent Relative Humidity
h_2 = 47.518 kJ/kg, m_2 = 3 kg/s
W_2 = 0.0093 kg/kg

(a)

$$h_m = \frac{(2)(75.666)+(3)(47.518)}{2+3}$$

h_m = 58.777 kJ/kg - - - Ans.