Refrigeration

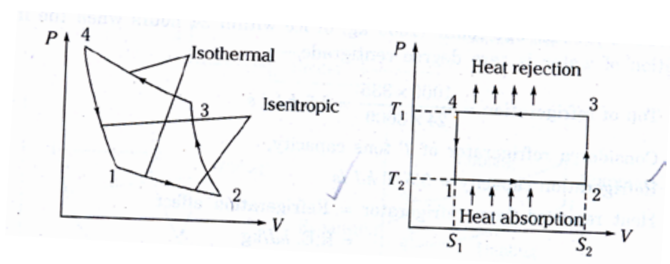
Definition

Refrigeration is the process of providing and maintaining temperature of the system below that of the surrounding atmosphere.

Carnot Cycle

The reversed carnot cycle can be considered in refrigeration system.

$$C.O.P = \frac{T_2}{T_2 - T_1} \quad \text{where } T_2 < T_1$$



Unit of Refrigeration

The common unit used in the field of refrigeration is known as Ton of refrigeration.

A ton of refrigeration is defined as the quantity of heat required to be removed to produce one ton (1000kg) of ice within 24 hours when the initial condition of water is 0ºC

$$Ton \text{ of refrigeration} = \frac{1000x335}{24x3600} = 3.5 \text{ kJ/s}$$

Consider a refrigerator of T tons capacity,
Refrigeration capacity = 3.5 kJ/s
Heat removed from
refrigerator = Refrigeration effect =R.E. kJ/s
Power of the compressor =work/kg of refrigerant x mass flow rate

Air Refrigeration system working on
Bell-coleman cycle

In air refrigeration system, air is used as the refrigerant which always remains in the gaseous phase. The heat removed consists only of sensible heat and as a result, the coefficient of performance (C.O.P) is low.

The various processes are:

Process 1-2:

The air leaving the evaporator enters a compressor. Where it is compressed isentropically to higher pressure and temperature.

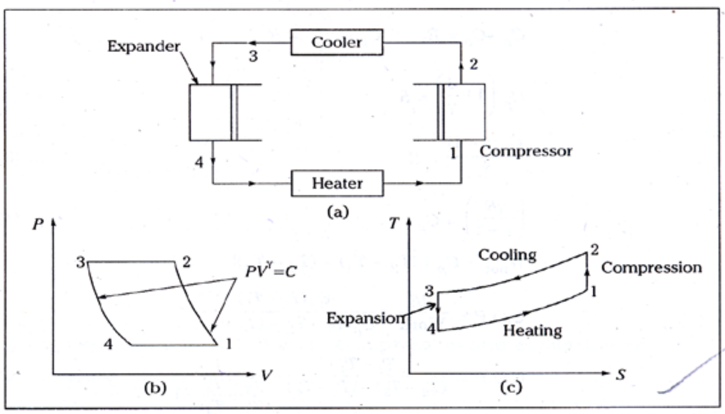
Process 2-3:

This high pressure, high temperature air, then enters a cooler where it is cooled at constant pressure to a low temperature.

Process 3-4: This high pressure, low temperature air is then expanded in an expander to lower pressure and temperature in a isentropic manner.At point 4, the temperature of the air will be lowest.

Process 4-1: This low temperature air is then passed through the heater coils where it absorbs heat from the space to be cooled namely the refrigerator and the air gets heated back to the initial temperature, but in the process, it cools the refrigerator. And the cycle repeats.

Air refrigeration system



Expression C.O.P when compression and expansion are Isentropic

Refrigeration Effect = Heat removed from the refrigerator

$$= C_p(T_1 - T_4) kJ/kg$$

$$Work \text{ input} = W_C - W_E = \gamma\left(\frac{P_2V_2 - P_1V_1}{\gamma - 1}\right) - \gamma\left(\frac{P_3V_3 - P_4V_4}{\gamma - 1}\right)$$

$$Work \text{ input} = W_C - W_E = \left(\frac{\gamma}{\gamma - 1}\right)\left[R(T_2 - T_1) - R(T_3 - T_4)\right]$$

$$W_{net} = \left(\frac{\gamma R}{\gamma - 1}\right)\left[(T_2 - T_1) - (T_3 - T_4)\right]$$

$$But \qquad C_p = \frac{\gamma R}{\gamma - 1}$$

$$W_{net} = C_p\left[(T_2 - T_1) - (T_3 - T_4)\right]$$

Pr*ocess* 1 - 2 is isentropic

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad ----(2)$$

Pr*ocess* 3 - 4 is isentropic

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad ----(3)$$

From (2) and (3)

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

$$C.O.P = \frac{RE}{Work} = \frac{C_p(T_1 - T_4)}{C_p[(T_2 - T_1) - (T_3 - T_4)]}$$

$$C.O.P = \frac{(T_1 - T_4)}{[(T_2 - T_1) - (T_3 - T_4)]} = \frac{1}{\frac{T_2 - T_3}{T_1 - T_4} - 1} \quad --(1)$$

$$\frac{T_2}{T_3} = \frac{T_1}{T_4}$$

$$\frac{T_2}{T_3} - 1 = \frac{T_1}{T_4} - 1$$

$$\frac{T_2 - T_3}{T_3} = \frac{T_1 - T_4}{T_4}$$

$$\frac{T_2 - T_3}{T_1 - T_4} = \frac{T_3}{T_4} \qquad -----(4)$$

From (1) and (4)

$$C.O.P = \frac{1}{\frac{T_3}{T_4} - 1}$$

$$C.O.P = \frac{T_4}{T_3 - T_4}$$

For Polytropic process

Net work

$$W_{net} = \left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)C_p\left[(T_2 - T_1) - (T_3 - T_4)\right]$$

$$COP = \frac{T_4}{(T_3 - T_4)\left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)}$$

Advantages of air refrigeration system

1. Air is cheap, easily available.
2. It is not flammable.
3. For a given capacity, weight of air refrigeration system is less compared to other system and hence it is widely used for aircraft cooling.

Disadvantages

1. Since heat removed by air consists only of sensible heat, weight of air required is high.
2. C.O.P of the system is low compared to other systems.

Problem 1

A cold storage is to be maintained at -5°C (268k) while the surroundings are at 35°C. the heat leakage from the surroundings into the cold storage is estimated to be 29kW. The actual C.O.P of the refrigeration plant is one third of an ideal plant working between the same temperatures. Find the power required to drive the plant. (VTU Jan 2007)

Solution :-

$T_1 = 35°C = 308k \qquad T_2 = 5°C = 268k$

C.O.P of the ideal plant is nothing but

C.O.P based on carnot cycle.

$$\therefore \text{C.O.P ideal} = \frac{T_2}{T_1 - T_2}$$

$$= \frac{268}{308 - 268} = 6.7$$

$$Actual\ C.O.P = \frac{1}{3} ideal C.O.P$$

$$= \frac{1}{3} x 6.7 = 2.233$$

Q2 = The heat removed from low temperature reservoir (cold storage) must be equal to heat leakage from surroundings to the cold storage(which is 29kw)

$$Q_2 = 29kW$$

$$Actual\ C.O.P = \frac{Q_2}{W}$$

$$\text{W} = \frac{Q_2}{Actual\ C.O.P} = \frac{29}{2.233}$$

$$Power\ \text{required} = 12.98\ \text{kW}$$

Problem 2

A refrigeration machine of 6 tones capacity working on Bell coleman cycle has an upper limit pressure of 5.2 bar. The pressure and temperature at the start of the compression are I bar and 18°C respectively. The cooled compressed air enters the expander at 41°C. assuming both expansion and compression to be adiabatic with an index of 1.4. Calculate:-

(i) Co-efficient of performance.

(ii) Quantity of air circulated per minute.

(iii) Piston displacement of compressor and expander

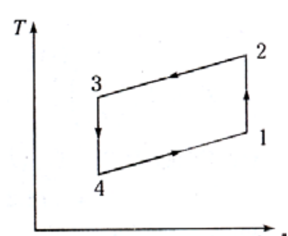
(iv) Bore of compression and expansion cylinder when the unit runs at 240 rpm and is double acting with stroke length =200 mm

(v) Power required to drive the unit

Solution : -

$\text{T}_1 = 18°C \quad \text{P}_1 = 1\text{bar}$

$\text{T}_3 = 41°C\ \text{P}_2 = 5.2\text{bar}$



$$Work\ \text{input} = \mathrm{C_p}\left[(T_2 - T_1) - (T_3 - T_4)\right]$$
$$= 1.005\left[(466 - 291) - (314 - 196)\right] = 57kJ / kg$$

$$C.O.P = \frac{\text{Re}\,griferation\ effect}{\text{Work input}}$$
$$= \frac{95.42}{57} = 1.67$$

$$\text{Re}\ frigeration\ \text{capacity} = 6\ \text{tons} = 6\text{x}3.5 = 21\text{kJ/s}$$

$$Mass\ \text{of air/sec} = \frac{\text{Re}\,griferation\ c\text{apacity}}{\text{R.E}}$$
$$= \frac{21}{95.42} = 0.22kg / s$$

$$Power\ \text{required} = workdone\text{/kg of air x Mass of air/sec}$$
$$= 57\ \text{x}\ 0.22 = 12.54\text{kW}$$

$$\text{Mass of air/min} = 0.22\text{x}60 = 13.2\text{kg/min}$$

$$V_1 = \frac{mRT_1}{P_1} = \frac{13.2x0.287x291}{1x10^2} = 11m^3 / \min$$

$$Piston\ \text{displacement of compressor V}_1 = 11m^3 / \min$$

$$V_4 = \frac{mRT_4}{P_4} = \frac{13.2x0.287x196}{1x10^2} = 7.42m^3 / \min$$

$$Piston\ \text{displacement of expander V}_4 = 7.42m^3 / \min$$

$$But \quad V_1 = 2\frac{\pi}{4}d_1^2LN$$

$$11 = 2\frac{\pi}{4}d_1^2x0.2x240$$

$$d_1 = diameter\ \text{of compressor cylinder} = 0.38\text{m} = 38\text{cm}$$

$$V_4 = 2\frac{\pi}{4}d_2^2LN$$

$$7.42 = 2\frac{\pi}{4}d_1^2x0.2x240$$

$$d_1 = diameter\ \text{of expander cylinder} = 0.313\text{m} = 31.3\text{cm}$$

Problem3 An air refrigerator system operating on Bell Coleman cycle, takes in air from cold room at 268 K and compresses it from 1 bar to 5.5 bar the index of compression being 1.25. the compressed air is cooled to 300 K. the ambient temperature is 20ºC. Air expands in expander where the index of expansion is 1.35.

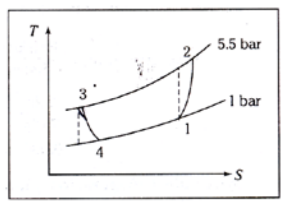
Calculate:

- ***i) C.O.P of the system***
- ***ii) Quantity of air circulated per minute for production of 1500 kg of ice per day at 0°C from water at 20ºC.***
- ***iii) Capacity of the plant.***

Solution

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 268(5.5)^{\frac{1.25-1}{1.25}}$$

$$= 376.8\text{K}$$



$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} = 300\left(\frac{1}{5.5}\right)^{\frac{1.35-1}{1.35}} = 192.83\text{K}$$

$$\text{W}_\text{C} = \left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)C_p(T_2 - T_1)$$

$$= \left(\frac{1.25}{1.25-1}\right)\left(\frac{1.4-1}{1.4}\right)1.005(376.8-268) = 156.2kJ/kg$$

$$\text{W}_\text{E} = \left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)C_p(T_3 - T_4)$$

$$= \left(\frac{1.35}{1.35-1}\right)\left(\frac{1.4-1}{1.4}\right)1.005(300-192.83) = 118.69kJ/kg$$

$$Network = W_C - W_E = 156.2 - 118.69 = 37.5kJ/kg$$

$$R.E = C_p(T_1 - T_4) = 1.005(268-192.83) = 75.54kJ/s$$

$$C.O.P = \frac{RE}{work} = \frac{75.54}{37.5} = 2$$

$Heat \text{ extracted/kg of ice} = C_{pw}(20-0) + L$

$= 4.187(20) + 335 = 418.74 \text{kJ/kg}$

$\text{Mass of ice produced/sec} = \frac{1500}{24 \text{x} 3600} = 0.0173 kg/s$

$Actual\ heat \text{ extracted/sec} = 418.74 \text{x} 0.0173$

$\text{or Refrigeration capacity} = 7.26 \text{kJ/s} = \frac{7.26}{3.5} = 2.02 tons$

$Mass \text{ flow rate} = \frac{\text{Refrigeration Capacity}}{\text{Refrigeration efect}} = \frac{7.26}{75.54}$

$= 0.096 kg/s$

Problem 4

An air refrigeration system is to be designed according to the following specifications

Pressure of air at compressor inlet=101kPa

Pressure of work at compressor outlet=404kPa

Pressure loss in the inter cooler=12kPa

Pressure loss in the cold chamber=3kPa

Temperature of air at compressor inlet=7°

Temperature of air at turbine inlet=27°

Isentropic efficiency of compressor =85%

Isentropic efficiency of turbine =85%

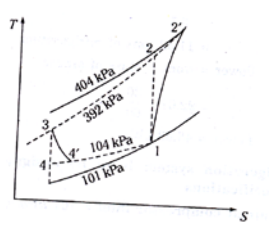
Determine

i) C.O.P of cycle
ii) Power required to produce 1 ton of refrigeration
iii) Mass flow rate of air required for 1 ton of refrigeration

Solution :-

$T_1 = -7°C \quad P_1 = 101 \text{kPa}$

$T_3 = 27°C \ \eta_T = 0.85; \eta_C = 0.85$



$\text{Process 1-2 is isentropic, Hence } T'_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$= 266 \left(\frac{404}{101}\right)^{\frac{1.4-1}{1.4}} = 395.4 \text{K}$

$$\eta_C = \frac{T_2 - T_1}{T'_2 - T_1} \quad \text{or} T'_2 - T_1 = \frac{395.4 - 266}{0.88}$$

$$T'_2 = 418.2k$$

$$P_4 - P_1 = 0.03P_1 \quad \therefore P_4 = 1.03P_1 = 1.03x101 = 104kPa$$

$$P_2 - P_3 = 0.03P_2 \quad \therefore P_3 = 0.97P_2 = 0.97x404 = 392kPa$$

$$\text{Pr}\,ocess\ \text{3 - 4 is isentropic,} \quad \therefore T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 300\left(\frac{104}{392}\right)^{\frac{1.4-1}{1.4}} = 202.3\text{K}$$

$$\eta_E = \frac{T_3 - T'_4}{T_3 - T_4} \quad \therefore T'_4 = T_3 - \eta_T\left(T_3 - T_4\right)$$

$$T'_4 = 300 - 0.85x[300 - 205.3] = 216.53k$$

$$\text{Re}\ frigeration\ \text{effect/kg of air} = \text{C}_\text{p}\left(T_1 - T_4\right)$$

$$= 1.005\text{x}[266 - 216.53] = 50.47\text{kJ/kg}$$

$$C\text{ompressor work/kg of air} = \text{C}_\text{p}\left(T'_2 - T_1\right)$$

$$= 1.005\text{x}[418.2 - 266] = 152.96\text{kJ/kg}$$

$$T\text{urbine work/kg of air} \quad \text{W}_\text{T} = \text{C}_\text{p}\left(T_3 - T_4'\right)$$

$$= 1.005\text{x}[300 - 216.53] = 84.9\text{kJ/kg}$$

$$\text{Net work Input/kg of air } \text{W}_\text{net} = \text{W}_\text{C} - \text{W}_\text{T}$$

$$= 152.96 - 80.9 = 72.06kJ / kg$$

$$C.O.P = \frac{RE}{Work} = \frac{46.73}{72.06} = 0.73$$

$$Power\ \text{required per tons of refergeration}$$

$$= \frac{\text{Refrigeration capacity}}{\text{C.O.P}}$$

$$\text{Refrigeration capacity} = 1\ \text{ton} = 3.5\text{kJ/s}$$

$$\text{Mass of air} = \frac{\text{Refrigeration capacity}}{\text{RE}}$$

$$= \frac{3.5}{50.47} = 0.075kg / s$$

$$Power = W_{net}xmassofair / \sec = 72.06x0.075 = 5.42kW$$

Pscychrometrics and Air-conditioning Systems

Problem 1

Moist air at 30°C,1.01325 bar has a relative humidity of 80%. Determine without using the psychrometry chart

1) Partial pressures of water vapour and air
2) Specific humidity
3) Specific Volume and
4) Dew point temperature (V.T.U. July2004)

Solution: At 30°C from table $p_{\upsilon s} = 4.2461 kPa$

$$\phi = \frac{p_\upsilon}{p_{\upsilon s}}$$

$$p_\upsilon = 0.8x4.2461 = 3.397 kPa$$

$$\omega = \frac{0.622\, p_\upsilon}{p - p_\upsilon} = 0.622x\frac{3.397}{101.325 - 3.397}$$

$$= 0.213 \text{ kg/kg of dry air.}$$

Corresponding to Pv =3.397 kPa from tables, we get dew point temperature = 28.9°C

Problem 2:

Atmospheric air at 101.325 kPa ha 30°C DBT and 15°C DPT. Without using the pschrometric chart, using the property values from the table, Calculate

1. Partial pressure of air and water vapour
2. Specific humidity
3. Relative humidity
4. Vapour density and
5. Enthalpy of moist air

Solution:

$$p = 101.325 kpa = 1.01325 bar$$

$$DBT = 30°C,$$

$$\text{DPT} = 15°\text{C}$$

From table

Corresponding to DBT = 30°C, we have $p_{\upsilon s} = 0.042461 bar$

Corresponding to DPT = 15°C, we have $p_\upsilon = 0.017051 bar$

Partial pressure of air $= p - p_\upsilon = 1.01325 - 0.017051$

$$= 0.984274 \text{ bar}$$

$$Specific\ humidity = 0.622\frac{p_\upsilon}{p_a} = \frac{0.622x0.017051}{0.984274}$$

$$= 0.01077 \text{kJ/kg of dry air}$$

$$\text{Re}\,lative\ humidity = \frac{p_\upsilon}{p_{\upsilon s}} = \frac{0.017051}{0.042461} = 0.4015$$

$$= 40.15\%$$

$$\text{Enthalphy} = 1.005\text{t}_{\text{db}} + \omega(2500 + 1088 t_{db})$$

$$= 1.005\text{x}30 + 0.010775(2500 + 1.88\text{x}30)$$

$$= 57.69 \text{kj/kg of dry air}$$

$$Specific \text{ volume of dry air}, \upsilon_a = \frac{RT}{P}$$

$$= \frac{0.2872\text{x}303}{0.98425x100} = 0.874 m^3 / kg$$

$$Vapour \text{ density } \rho_w = \frac{\omega}{\upsilon_a} = \frac{0.010775}{0.847} = 0.12 kg / m^3$$

Problem 3:

Air at 30°C DBT and 25°C WBT is heated to 40°C. if the air is 300 m3/min, find the amount of heat added/min and RH and WBT of air. Take air pressure to be 1 bar

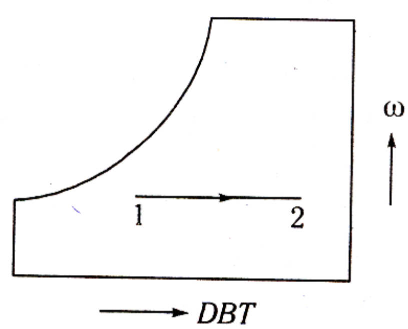
Solution:

At 25°C WBT from tables pwswbt=0.03166 bar

$$\therefore\ \text{p}_\upsilon = (P_{VS})_{wbt} - \frac{(p - p_{\upsilon swbt})(t_{db} - t_{wb})}{1547 - 1.44 t_{wb}}$$

$$= 0.03166 - \frac{(1 - 0.03166)(30 - 25)}{1547 - 1.44x25}$$

$$= 0.0284 \text{ bar}$$



$$\omega_1 = 0.622\frac{p_\upsilon}{p - p_\upsilon}$$

$$= 0.622\left(\frac{0.0284}{1 - 0.0284}\right)$$

$$= 0.0179 kJ / kg \text{ of dry air}$$

$At\ 40°C\ DBT$

$P_{VS} = 0.07375 bar$

$During\ sensible\ heating\ \omega$ and p_{υ} $remain$ constant

$p_{\upsilon} = 0.0284 bar$

$$RH = \phi = \frac{p_{\upsilon}}{p_{\upsilon s}} = \frac{0.0284}{0.07375}$$

$$= 0.385 = 38.5\%$$

$$H_2 = 1.005x40 + 0.0179(2500 + 1.88x40)$$

$$= 86.29 \text{kJ/kg of dry air}$$

$$Weight \text{ of } 300m^3/\min of air = \frac{(p - p_{\upsilon})V}{RT}$$

$$= \frac{(1 - 0.0284)x300x10^2}{0.287x303} = 335.18 kg/\min$$

$$\therefore Heat \text{ added/min} = 335.18(86.29 - 76) = 3449 \text{kJ/min}$$

From chart WBT = 27.2°C

Problem 4:

One stream of air at 5.5m3/min at 15°C and 60% RH flows into another stream of air at 35m3/min at 25°C and 70%RH, calculate for the mixture

1) Dry bulb temperature, 2) Wet bulb temperature 3) Specific Humidity and 4) Enthalpy

Solution:

For air at 15°C and 60%RH, V=5.5m3/min

$$\therefore\ p_{\upsilon s} = 0.017051 bar$$

$$RH = \phi = \frac{p_{\upsilon}}{p_{\upsilon s}}$$

$$\therefore\ p_{\upsilon} = 0.6x0.017051 = 0.01023 bar$$

$$Mass \text{ of air} = \frac{(p - p_{\upsilon})V}{RT} = \frac{(1.01325 - 0.01023)x10^2x5.5}{0.287x288}$$

$$m_1 = 6.672 kg/\min$$

$$\omega_1 = \frac{0.622 p_{\upsilon}}{(p - p_{\upsilon})} = \frac{0.622x0.01023}{(1.01325 - 0.01023)}$$

$$= 0.006343 kg/kg \text{ of dry air}$$

$$H_1 = 1.005t_{db} + \omega_1(2500 + 1.88t_{db})$$
$$= 1.008x18 + 0.006343(2500 + 1.88x15)$$
$$= 34.12\text{J/kg of dry air}$$

For air at 25°C and 70% RH, $V = 35m^3 / \min$

$$P_{\upsilon s} = 0.03169 bar$$
$$\phi = RH = \frac{p_\upsilon}{p_{\upsilon s}}$$
$$p_\upsilon = 0.03169x0.7 = 0.02218 bar$$

$$H_1 = 1.005t_{db} + \omega_1(2500 + 1.88t_{db})$$
$$= 1.008x18 + 0.006343(2500 + 1.88x15)$$
$$= 34.12\text{J/kg of dry air}$$

For air at 25°C and 70% RH, $V = 35m^3 / \min$

$$P_{\upsilon s} = 0.03169 bar$$
$$\phi = RH = \frac{p_\upsilon}{p_{\upsilon s}}$$
$$p_\upsilon = 0.03169x0.7 = 0.02218 bar$$

$$Mass \text{ of air} = \frac{(1.01325 - 0.02218x10^2 x35)}{0.287x298}$$
$$m_2 = 40.55 kg.\min$$
$$\omega_2 = \frac{0.622x0.02218}{(1.01325 - 0.02218)} = 0.01392 kg / kg \text{ of dry air}$$
$$H_2 = (1.005x25) + 0.01392(2500 + 1.88x25)$$
$$H_2 = 60.59 kJ / kg \text{ of dry air}$$

Mass of dry air/Unit mass of moist air

$$m_{a1} = \frac{m_1}{1 + \omega_1} = \frac{6.672}{1 + 0.006343} = 6.6299$$

Since $m_{a2} = \frac{m_2}{1 + \omega_2} = \frac{40.55}{1 + 0.01392} = 39.993$

Then enthalpy of the mixed air,

$$H_{mix} = \frac{m_{a1}(H_1) + m_{a2}(H_2)}{m_1 + m_2}$$
$$= \frac{6.6299(34.12) + 39.993(60.56)}{6.672 + 40.55)}$$
$$= 55.96 \text{ kJ/kg of dry air}$$

Specific Humidity of the mixed air,

$$\omega_{\text{mix}} = \frac{m_{a1}(\omega_1) + m_{a2}(\omega_2)}{m_1 + m_2}$$

$$= \frac{(6.6299\text{x}0.006343) + (39.993\text{x}0.01932)}{6.672 + 40.55}$$

$$= 0.01268\text{kg/kg of dry air}$$

But $\text{H}_{\text{mix}} = 1.005 t_{db} + \omega_{mix}(2500 + 1.88 t_{db})$

$55.96 = 1.005 x t_{db} + 0.01234(2500 + 1.88 t_{db})$

$t_{db} = 24.42°C$

DBT of the mixture $= 24.42°\text{C}$

From chart WBT $= 19°\text{C}$

RH $= 67\%$

Problem 5:

An air conditioning system is designed under the following conditions

Outdoor conditions: 30°CDBT, 75% RH

Required indoor conditions: 22°CDBT,70% RH

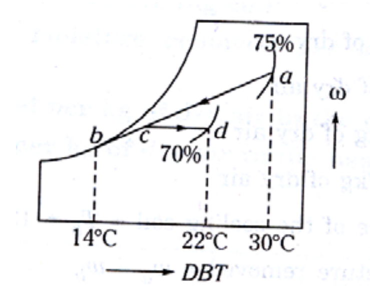
Amount of Free air circulated 3.33 m3/s

Coil dew point temperature DPT=14°

The required condition is achieved first by cooling and dehumidification and then by heating. Estimate

1) The capacity of the cooling coil in tons of refrigeration
2) *Capacity of the heating coil in kW*
3) *The amount of water vapour removed in kg/hr*

Solution:



Locate point 'a' 30°C DBT, 75%RH out door condition

Locate point 'd' 22°C DBT, 70%RH required condition

Locate point 'b' 14°C DPT, coil surface temperature

Join ab

at d, draw a horizontal line to cut the

line ab at point c.

ac $\rightarrow$ cooling and dehumidification

cd $\rightarrow$ heating

From chart

$H_a = 83kJ/kg$ of air

$H_b = 40kJ/kg$ of air

$H_d = 53kJ/kg$ of air

$H_c = 48kJ/kg$ of air

$W_a = 0.0202kg/kg$ of dry air

$W_c = W_d = 0.0118kg/kg$ of dry air

$V_{sa} = 0.88m^3/kg$

$$\textit{Mass} \text{ of air} = \frac{V}{V_a} = \frac{3.33}{0.88} = 3.78kg/s$$

$$\text{Capacity of cooling coil} = \frac{m_a(H_a - H_c)}{3.5}$$

$$= \frac{3.78(83-48)}{3.5} = 37.84\textit{tons} \text{ of refrigeration}$$

$$\text{Capacity of heating coil} = m_a(H_d - H_c)$$

$$= 3.78(53-48) = 18.92\text{kW}$$

$$\textit{Amount} \text{ of water vapour removed} = m_a(\omega_a - \omega_d)3600$$

$$= 3.78(0.0202-0.0118)3600$$

$$= 114.3\text{kg/hr}$$

Problem 6:

A summer air conditioning system for hot and humid weather (DBT=32°Cand 70% RH)

Consists in passing the atmosphere air over a cooling coil where the air is cooled and dehumidified. The air leaving the cooling coil is saturated at the coil temperature. It is then sensibly heated to the required comfort condition of 24°C and 50%RH by passing it over an electric heater then delivered to the room.

Sketch the flow diagram of the arrangement and represent the process undergone by the air on a skeleton psychometric chart and determine

1) *The temperature of the cooling coil*
2) *The amount of moisture removed per kg of dry air in the cooling coil.*
3) *The heat removed per kg of dry air in the cooling coil and*
4) *The heat added per kg of dry air in the heating coil*

From chart

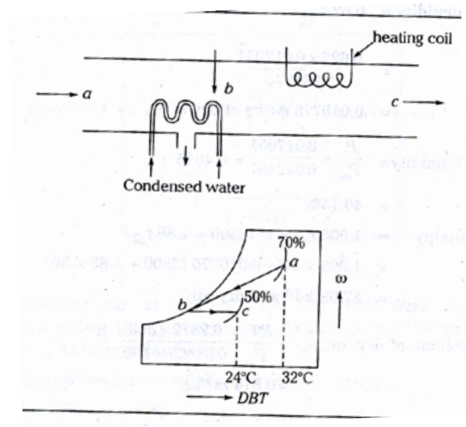
$H_a = 86kJ/kg$ of air

$H_b = 38kJ/kg$ of air

$H_c = 48.5kJ/kg$ of air

$\omega_a = 0.021kg/kg$ of dry air

$\omega_b = 0.0092kg/kg$ of dry air



The temperature of the cooling

$$\text{coil} = T_b = 13°C$$

Amount of moisture removed $= \omega_a - \omega_b$

$= 0.021 - 0.0092 = 0.0108$ kg/kg of dry air

Heat removed $= H_a - H_b = 86 - 38$

$= 48$ kJ/kg of dry air

Heat added $= H_c - H_b = 48.5 - 38$

$= 10.5$ kJ/kg of dry air

Locate point 'a' 32°C , 70%RH out door condition

Locate point 'c' 24°C DBT, 50%RH required condition

At c draw a horizontal line to cut the saturation line at point 'b'

Join ab

ab $\rightarrow$ cooling and dehumidification

b*c* $\rightarrow$ heating

Problem 7

It is required to design an air conditioning plant for an office room with the following conditions.
Outdoor conditions: 14°CDBT, 10°CWBT
Required conditions: 20°CDBT,60% RH
Amount of air circulated 0.3m3/min/person
Starting capacity of the office= 60

The required condition is achieved first by heating and then by adiabatic humidifying.
Determine the following.
Heating capacity of the coil in kW and the surface temperature required, if the by pass factor of the coil is 0.4
Capacity of the humidifier.

Locate point 'a' 14°C , and 10°CWBT (out door condition)

Locate point 'c' 20°C DBT, 60%RH required condition

At a draw a horizontal line

At 'c' draw a constant enthalpy line to cut the horozontal line at point 'b'

Join ab

ab $\rightarrow$ heating

b*c* $\rightarrow$ *adiabatic* humidification

From chart

$H_a = 30 kJ/kg$ of air

$H_b = H_c = 43 kJ/kg$ of air

$\omega_a = \omega_b = 0.006 kg/kg$ of dry air

$\omega_c = 0.00875$ kg/kg of dry air

Specific volome $V_{sa} = 0.8175 m^3/kg$

Volume of air supplied $= V = \frac{0.3x60}{60} = 0.3 m^3/\sec$

Weight of air supplied $m_a = \frac{V}{V_a} = \frac{0.3}{0.8175}$

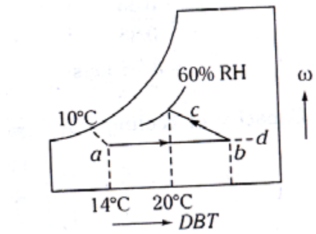
$= 0.3669$ kg/sec

Capacity of the heating coil $= m_a(H_b - H_a)$

$= 0.3669(43-30) = 4.77$ kW

From chart $T_b = 26.5°C$

Let coil surface temperature be T_d



By passing factor $= \frac{T_d - T_b}{T_d - T_a} = 0.4T_d - 5.6 = T_d - 26kJ$

$$0.4 = \frac{T_d - 26.5}{T_d - 1.4}$$

$$T_d = 34.8°C$$

Capacity of the humidifier $= m_a(\omega_c - \omega_b)x3600$

$= 0.3669(0.00875 - 0.006)3600$

$= 3.63$ kg/hour

Problem 8

An air conditioned system is to be designed for a hall of 200 seating capacity when the following conditions are given:

Atmospheric condition = 30^0C DBT and 50% RH

Indoor condition = 22^0C DBT and 60% RH

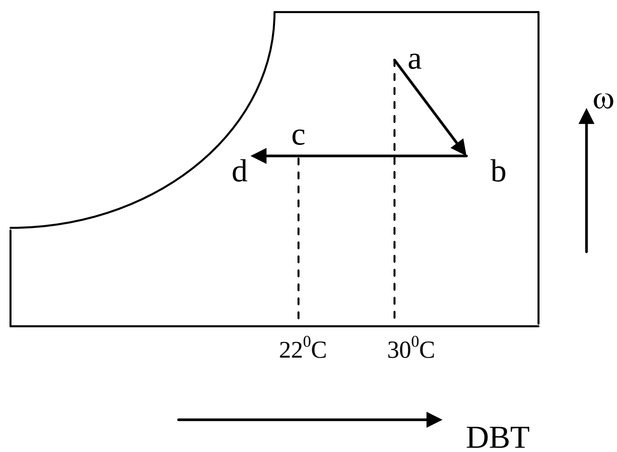
Volume of air required = $0.4m^3$/min/person

The required condition is achieved first by chemical dehumidification and after that by sensible cooling.

Find the following .

a) DBT of the air leaving the dehumidifier.
b) The quantity of water vapour removed in the duhumidifier per hour.
c) The capacity of cooling coil in tons of refrigeration.
d) Surface temperature of the coil if the by pass factor of the coil is 0.25.

Solution:



Locate point ‘a’, 30^0C DBT, 50% RH, the atmospheric condition.
Locate point ‘c’, 22^0C DBT, 60% RH, the required indoor condition.
“Since chemical dehumidification process follows constant enthalpy line”
at a draw a line parallel to constant enthalpy line.
At ‘c’ draw a constant ω line to cut the previous line at point b.

a) DBT of air leaving the dehumidifier $T_b = 40.5^0C$

From chart

Hb = Ha = 65kJ/kg, $\omega_a = 0.013$ kg/kg of dry air

Hc = 45 kJ/kg, $\omega_b = 0.009$ kg/kg of dry air

$V_{sa} = 0.875\ m^3/min$

Volume of air = 200 X 0.4 = 80 m^3/min

W_a = Weight of air = V/Vsa = 80/0.875 = 91.42 kg/min

b) Quantity of water vapour removed/hour = $W_a(\omega_a-\omega_b)60$

= 91.42(0.13-0.009)60 = 21.94 kg/hr

c) Capacity of cooling coil = $W_a(H_a-H_b)/ (60 X 3.5)$ = 91.42(65-45)/(60 X 3.5)

= 8.7 tons

d) By pass factor = $(T_c-T_d)/(T_b-T_d) = 0.25$

T_d = Temperature of cooling coil = 15.83^0C

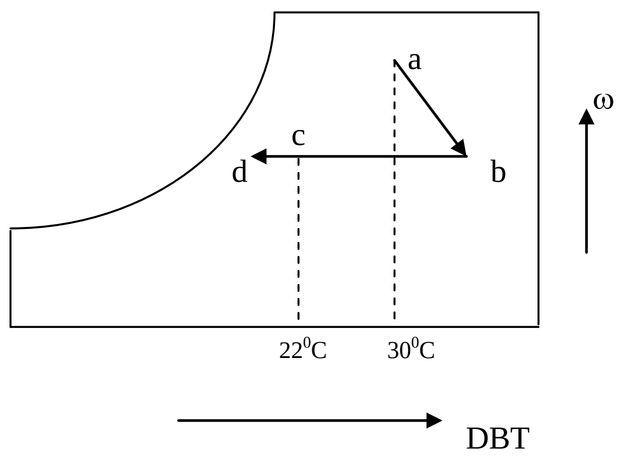
Problem 9

An air conditioned system is to be designed for a cinema hall of 1000 seating capacity when the following conditions are given:
Outdoor condition = 11^0C DBT and 70% RH
Required indoor condition = 20^0C DBT and 60% RH

Amount of air required = $0.3m^3$/min/person
The required condition is achieved first by heating, then by humidifuing and finaly by heating. The condition of air coming out of the humidifier is 75% RH.
Find the following .

a) Heating capacity of the first heater in kW and condition of the air coming out of the first heater in kW and condition of the air

Solution:



Locate point 'a', 30^0C DBT, 50% RH, the atmospheric condition.
Locate point 'c', 22^0C DBT, 60% RH, the required indoor condition.
"Since chemical dehumidification process follows constant enthalpy line"
at a draw a line parallel to constant enthalpy line.
At 'c' draw a constant ω line to cut the previous line at point b.

e) DBT of air leaving the dehumidifier $T_b = 40.5^0C$

From chart

Hb = Ha = 65kJ/kg, ω_a = 0.013 kg/kg of dry air
Hc = 45 kJ/kg, ω_b = 0.009 kg/kg of dry air
V_{sa} = 0.875 m^3/min
Volume of air = 200 X 0.4 = 80 m^3/min
W_a = Weight of air = V/Vsa = 80/0.875 = 91.42 kg/min

f) Quantity of water vapour removed/hour = $W_a(\omega_a-\omega_b)60$
= 91.42(0.13-0.009)60 = 21.94 kg/hr

g) Capacity of cooling coil = $W_a(H_a-H_b)$/ (60 X 3.5) = 91.42(65-45)/(60 X 3.5)
= 8.7 tons

h) By pass factor = $(T_c-T_d)/(T_b-T_d)$ = 0.25

T_d = Temperature of cooling coil = 15.83^0C