CHAPTER 7

EVAPORATOR CALCULATION

7.1 EVAPORATOR CALCULATION

7.1.1 Introduce about evaporator

A. Functional:

The evaporator is the one of the main components of a refrigeration system, use to cool the coolant (water or NaC_l, $CaCL_2$). The coolant has led to cooler and cooling the air in the cooled space.

In the evaporator, heat exchange between the liquid coolant and cooling agent from the cooler return. Coolant move in the pipe and cooling agents moving outside. As a result of the heat transfer is cooling agent into steam, coolant cooled temperature required.

B. Type of evaporator

Classify about displacement of coolant in evaporator, partition 3 kind:

+ Liquid flooded evaporator.
+ Half liquid flooded evaporator.
+ Direct evaporator.

7.1.2 Evaporator analysis selection

Liquid flooded evaporation: liquid coolant to cover the entire surface of the heat exchange, liquid coolant from the bottom. With this kind, cold water motion in the pipe, and liquid cooling agent moves outside of the pipe. High heat transfer coefficient.

Half liquid flooded evaporator: liquid coolant to cover only entire surface of the heat exchange, the rest of the surface heat exchangers used to superheat steam return compressor. In this type, liquid coolant supplied from the top of the evaporator and moving outside the pipe, while cold water moving in the pipe. High heat transfer coefficient.

Direct evaporation: liquid coolant moves in the pipe, while cold water move outside the pipe. With this kind, pressure losses in water is small, cooling agent intake systems are relatively few. But the heat transfer coefficient don't high.

From the above analysis we choose the evaporator is flooded liquid, because the high coefficient device's size smaller response large refrigerating capacity. Due building need air conditioning have a heat loss Q_o = 1170,82 kW, the choice of this system is reasonable. With this evaporation, water inside motion can be considered as confidential should the few air enters the system, therefore reducing corrosion of equipment.

7.1.3 Evaporator calculation and design

A. Primary parameters

In the air conditioning system of the building used 01 evaporator for cold water supply to the entire system. With the cooling load for the evaporator of the entire is **Q_o = 1170,82 kW**.

In the system we use coolant evaporator with the water moving in the pipe, and cold agent R134a moving outside of the pipe. In evaporator uses copper pipe with external fin.

Input Temperature water evaporator: $t_{s1} = 14^oC$

Output Temperature water evaporator: $t_{s2} = 9^oC$

Parameters copper pipe:

+ Inside diameter: d_{tr} = 0,016 m

+ Outer diameter: d_{ng} = 0,019 m

+ Fin diameter: D_c = 0,022 m

+ Fin pitch: S_c = 0,00118 m

+ Bottom Fin thickness: δ_o = 0,0003 m

+ Head Fin thickness: δ_d = 0,0002 m

+ Tube steps: S = 0,027 m

Inner face of 1m pipe area: $F_{tr} = \pi.d_{tr} = 3{,}14.0{,}016 = 0{,}05024\, m^2/m$

Facade of 1m pipe area

$$F_d = \frac{\pi(D_c^2 - d_{ng}^2)}{2.S_c} = \frac{3{,}14.(0{,}022^2 - 0{,}019^2)}{2.0{,}00118} = 0{,}16365\, m^2/m$$

Outside face of 1m pipe area

$$F_{ng} = \pi.d_{ng}.\left(1 - \frac{\delta_o}{S_c}\right) + \frac{\pi.D_c.\delta_d}{S_c}$$

$$F_{\text{ng}} = 3{,}14.0{,}019.\left(1 - \frac{0{,}0003}{0{,}00118}\right) + \frac{3{,}14.0{,}022.0{,}0002}{0{,}00118}$$

$$F_{\text{ng}} = 0{,}05620 \quad \text{m}^2/m$$

Sum outside of 1m pipe area:

$$F = F_d + F_{\text{ng}} = 0{,}16365 + 0{,}05620 = 0{,}21985 \ \ m^2/m$$

Make fin factor:

$$\beta = \frac{F}{F_{\text{tr}}} = \frac{0{,}21985}{0{,}05024} = 4{,}376$$

B. Evaporator calculation:

B.1 Calculate about water:

The water average temperature:

$$\bar{t}_s = \frac{1}{2}(t_{s1} + t_{s2}) = \frac{1}{2}(14 + 9) = 11{,}5^oC$$

Check Reference 25 pages 413 document [3], water thermophysical properties:

+ Heat capacity: $C_{\rho n} = 4{,}1897$ kJ/kg.K

+ Gravity: $\rho_n = 999{,}475$ kg/m^3

+ Kinematic viscosity: $\nu_n = 1{,}261.10^{-6}$ m^2/s

+ Conduction factor: $\lambda_n = 57{,}82.10^{-2}$ W/m.K

+ Prandtl factor: $Pr_n = 9{,}145$

Cold water traffic into evaporator:

$$G_n = \frac{Q_0}{C_n.\ \Delta t_n} = \frac{1170{,}82}{4.1898 \text{ x } 5} = 55{,}89 \text{ kg/s}$$

With the don't high quality of water in our country, to make appropriate turbulent water in the condenser, to reduce energy losses to the pump, reduce the likelihood of corrosion speed pipe, water should not be chosen too large. Water speed is selected in the range (1÷2,5 m/s).

We choose water speed: $\omega_n = 2$ m/s.

Number of tubes in a journey (1 pass water):

$$n_1 = \frac{4\ .\ G_n}{\pi\ .\ d_{tr}^{2}.\ \rho_n.\ \omega_n} = \frac{4\ .\ 55{,}89}{3{,}14\ .\ 0{,}016^2\ .\ 999{,}475\ .\ 2} = 139{,}13$$

we choose number of tubes: n_1 = 139 pipes

We defined rate of water in pipe again:

$$\omega_n = \frac{4.\ G_n}{\pi\ .\ d_{tr}^{2.}.\ \rho_n.\ n_1} = \frac{4\ .\ 55{,}89}{3{,}14\ .\ 0{,}016^2.\ 999{,}475\ .\ 139} = 2\ m/s$$

Reynold factor of water:

$$Re = \frac{\omega_n.\ d_{tr}}{v_n} = \frac{2.\ 0{,}016}{1{,}261.\ 10^{-6}} = 25376{,}68 > 10000$$

So, Regime of water in pipe is turbulent regime.

Nusselt factor of water:

$$\mathrm{Nu} = 0{,}021.\ \mathrm{Re}^{0,8}.\ \mathrm{Pr}^{0,43}.\ \left(\frac{\mathrm{Pr}_f}{\mathrm{Pr}_w}\right)^{0,25}.\ \varepsilon_l\ .\ \varepsilon_R$$

Temperature between surface of the pipe wall and water in pipe don't high, choose $\left(\frac{\mathrm{Pr}_f}{\mathrm{Pr}_w}\right) = 1$. In condenser, pipe diameter $\frac{l}{d} > 50$, $\varepsilon_l = 1$, with pipe using is straight so $\varepsilon_R = 1$.

Therefore:

$$\mathrm{Nu} = 0{,}021\ .\ 25376{,}68^{0,8}\ .\ 9{,}145^{0,43}.\ 1\ .\ 1\ .\ 1 = 181{,}58$$

Heat transfer coefficient on the cooling water side:

$$\alpha_w = \frac{\mathrm{Nu}\ .\ \lambda}{d_{tr}} = \frac{181{,}58.\ 57{,}82.10^{-2}}{0{,}016} = 6561{,}84\ W/m^2.\mathrm{K}$$

B.2 Calculate of the condition agent R134a:

With the boiling temperature of the agent: $t_o = 5^oC$, the average temperature of the logarithm of the average evaporation is defined as follows:

$$\theta_m = \frac{t_{s1} - t_{s2}}{\ln\frac{t_{s1} - t_o}{t_{s2} - t_o}} = \frac{14 - 9}{\ln\frac{14 - 5}{9 - 5}} = 6{,}17^oC$$

Impedance heat irritated class: $\sum\frac{\delta_i}{\lambda_i} = (\ 0{,}12 \div 0{,}15\ ).\ 10^{-3}\ m^2.\mathrm{K}/W$

Total thermal resistance was chosen to calculate: $\sum\frac{\delta_i}{\lambda_i} =\ 0{,}13.\ 10^{-3}\ m^2.\mathrm{K}/W$

Current density required of the cooling water temperature:

$$q_w = \frac{t_v - \bar{t}_w}{\frac{1}{\alpha_w} + \sum\frac{\delta_i}{\lambda_i}} = \frac{\theta_m - \theta}{\frac{1}{\alpha_w} + \sum\frac{\delta_i}{\lambda_i}}$$

$$q_w = \frac{6,17 - \theta}{\frac{1}{6561,84} + 0,00013}$$

$$q_w = 3541,01.\,(6,17 - \theta)$$

Heat flow density of the agent R134a boiling on the surface of the wings are ascribed to the water (surface) as follows:

$q_{\text{atr}} = 564 \,.\, p_o^{0,45} \,.\, \theta^{1,82} \,.\, \varepsilon_n \,.\, \varepsilon_d \,.\, \beta$ (formula pages 256 Reference [3])

In which:

p_o – the boiling pressure of the agent $t_o = 5^oC$; $p_o = 349,70$ kPa

ε_n – coefficient taking into account the effect of beam tube with wings, in average evaporation cooling water we get: $\varepsilon_n = 1$.

ε_d – coefficient taking into account the influence of lubricating oil soluble in Freon agent, we get: $\varepsilon_n = 0,82$.

So: $q_{\text{atr}} = 564 \,.\, p_o^{0,45} \,.\, \theta^{1,82} \,.\, 1 \,.\, 0,82 \,.\, 4,376$

$$q_{\text{atr}} = 564 \,.\, 3,4970^{0,45} \,.\, \theta^{1,82} \,.\, 1 \,.\, 0,82 \,.\, 4,376$$

$$q_{\text{atr}} = 3554,95.\theta^{1,82}$$

We have a system of equations: $\begin{cases} q_{\text{str}} = 3541,01 \,.\, (6,17 - \theta) \\ q_{\text{atr}} = 3554,95.\, \theta^{1,82} \end{cases}$

$$3554,95.\, \theta^{1,82} = 3541,01.\,(6,17 - \theta) \quad \Rightarrow \quad \theta = 2,14^oC$$

$$q_{\text{tr}} = 14196,67\, W/m^2$$

The total heat transfer area provided on the surface of:

$$F_{\Sigma\text{tr}} = \frac{Q_o}{q_{\text{tr}}} = \frac{1170,82 \,.10^{.3}}{14196,67} = 82,47 \text{ m}^2$$

The total length of the average evaporation tube:

$$L_\Sigma = \frac{F_{\Sigma\text{tr}}}{\pi \,.\, \text{d}_{\text{tr}}} = \frac{82,47}{3,14 \,.\, 0,016} = 1641,52 \text{ m}$$

Select the waterline in average evaporation z = 2.

Therefore, the total number of tubes in the average evaporation is:

$$n = n_1.\, z = 139 \,.\, 2 = 278 \text{ pipes.}$$

Select m = 22 (Chapter 6) then the number of tubes that are physically filled will be:

Total number of tubes in the average evaporation is:

$$n' = 0{,}75.(m^2 - 1) + 1 = 0{,}75.(22^2 - 1) + 1 = 363\ pipes$$

The number of discarded tubes to prevent the upper part of the steam tank from being flooded is: n" = n' – n = 363 – 278 = 85.

The length of a pipe in the tank evaporates:

$$l = \frac{L}{n} = \frac{1641{,}52}{278} = 5{,}9\ \text{m}$$

Sieve diameter:

$D = \text{m . S} = 22\ .\ 0{,}027 = 0{,}594$ m

Ratio:

$$k = \frac{l}{D_{ms}} = \frac{5{,}9}{0{,}594} = 9{,}9$$

We see the ratio k is the acceptable range (3,5 ÷ 10).

7.1.4 Hydrodynamic evaporator calculation:

In addition to calculating the average evaporation heat transfer, it is also the resistance of the water when cold through evaporation. According to formula 9.25 pages 358 Reference [1]:

Hindrance to the water through the condenser:

$$\Delta P = \left(\lambda \frac{L}{d_{tr}} + \xi_v + 1 + \frac{\xi_v + 1}{z}\right) . \frac{\omega^2 . \rho}{2} . z$$

In which:

ξ_v - coefficient of local resistance when water in tube: $\xi_v = 0{,}5$.

L - length of average between the two manifestations: L = 4.2 m

d_{tr} - diameter of pipe: $d_{tr} = 0{,}016$ m

z - number of lines water in equipment: z = 2

ω - the velocity of water flow in pipes: ω = 2 m/s

ρ - the density of cold water: ρ = 999,475 kg/m^3

λ - coefficient of friction.

Because the water in the tube in a turbulent state, so for copper pipe friction coefficient is calculated as follows: (Formula 9.6 pages 349 Reference [1])

$$\lambda = \frac{0{,}3164}{Re^{0,25}} = \frac{0{,}3164}{25376{,}68^{0,25}} = 0{,}0251$$

So pressure drop water through the evaporator:

$$\Delta P = \left(0{,}0251.\frac{4{,}2}{0{,}016} + 0{,}5 + 1 + \frac{0{,}5+1}{4}\right).\frac{2^2.999{,}475}{2}.4$$

$$\Delta P = 67674{,}45\,N/m^2 = 67674{,}45 \text{ Pa}$$

7.1.5 Strength evaporator calculation

A. Strength case evaporator calculation:

Evaporator in the air conditioning system is the low pressures side pressure device. Therefore, we have to calculate reliable equipment to ensure the safety of the device when operating …

Due to the structure of the average evaporation cylindrical geometry, so under pressure. The thickness of the cylindrical body S is chosen to satisfy the following conditions:

$$S \geq \frac{P_R \,.\, D_{tr}}{2\,.\,[\sigma]\,.\,\phi_d - P_R} + C$$ (Formula 10.1page 364 Reference [3])

In which:

P_R - Calculation of the pressure equipment, MPa. According to table 10.1page 360 Reference [3] was chosen: $P_R = 12$ bar $= 1{,}2$ MPa.

$[\sigma]$ - Allowing stress of metal fabrication body average, MPa. According to table 10.2 pages 361 Reference [3], choose body building materials per evaporation is steel CCT38, with the calculation of the wall temperature is: $t = 36^0C$ we have: $[\sigma] = 138{,}8$ MPa.

D_{tr} - Diameter of the body evaporation comment: $D_{tr} = 729$ mm

φ_d - Vertical weld strength coefficient, $\varphi_d = 0{,}9$ (1, page 364, table 10-3)

C - Additional thickness, mm ; $C = C_1 + C_2 + C_3$

C_1 - the additional thickness to compensate for corrosion when exposed to hazardous substances: $C_1 = 0{,}001$ m

C_2 - additional thickness to compensate for the negative thickness tolerance: $C_2 = 0{,}001$ m

C_3 - the additional thickness due to the relative thickness of Votes thinning during pulling, stamping, bending, etc. ...: $C_3 = 0{,}001$ m

So:

$$S \geq \frac{1{,}2\ .\ 0{,}729}{2\ .\ 138{,}8\ .\ 0{,}9\ - 1{,}2} + 0{,}003 = 0{,}0065 \text{ m}$$

Choose the standard TEMA: $S = 0{,}0079$ m (Table CB 3.13, pages 5.3-1 ,Reference [4]).

Condenser has the following dimensions:

$D_{\text{tr}} = 0{,}729$ m

$$D_{\text{ng}} = D_{\text{tr}} + 2.\text{S} = 0{,}729 + 2.0{,}0079 = 0{,}7448 \text{ m}$$

B. Calculate the thickness of floating tube sheet:

In the condenser the ground is soldered to the cylindrical body of the condenser. The copper tube is tight on the floor, so that the thickness of the floor to ensure tight tube and must meet the following conditions:

$$S_m \geq 0{,}5\ .\ \text{D}_E\sqrt{\frac{|\ \text{P}_o - P_R|}{[\ \sigma]}} + C$$

In which:

P_R - Calculate the pressure outside the tube, is the calculation of the pressure equipment. According to table 10.1 pages 360 Reference [3] was chosen: $P_R = 12$ bar $=$ 1,2 MPa.

P_o - Calculate the pressure inside the pipe: $P_o = 1{,}5$ bar $= 0{,}15$ MPa

$[\sigma]$ - Allowing stress of metal fabrication place, MPa. According to the table 10.2 pages 367 Reference [3], select the material is steel CCT38, to calculate the temperature of the wall is: $t = 36^0 C$ was chosen: $[\sigma] = 138{,}8$ MPa..

D_E - The diameter of the circle can accommodate the largest in the area do not have the tube on the floor: $D_E = 85$ mm

C - Additional section thickness: $C = 0{,}003$ m

So: $S_m \geq 0{,}5\ .\ \text{D}_E\sqrt{\frac{|\ \text{P}_o - P_R|}{[\ \sigma]}} + C = 0{,}5.0{,}085.\sqrt{\frac{|\ 0{,}15-1{,}2|}{138{,}8}} + 0{,}003 = 0{,}0066$ m

We choose the thickness of floating tube sheet: $S_m = 0{,}0066$ m $= 6{,}6$ mm

C. Strength for the lid calculation:

With condenser cylindrical geometry, we use a curved lid can be removed to open the assembly with two top flange cylindrical body. I choose the bottom of the device is curved circular curved bottom edge boards (Figure 10-4 c, pages 370 Reference [3]).

Round cap thickness is determined as follows: (Formula pages 370 Reference [3])

$$S_n \geq \frac{\mathrm{P}_R\ .\ \mathrm{R}}{2\ .\ \phi_d\ .\ [\sigma] - 0{,}5\ .\ \mathrm{P}_R} + C$$

In which:

R - radius of the curved lid, m ; $R = D_{\mathrm{tr}} = 0{,}729$ m

$H_{\mathrm{tr}} = 0{,}25\ .\ \mathrm{D}_{\mathrm{tr}} = 0{,}25\ .\ 0{,}729 = 0{,}18225$ m - The height of the inside of the lid.

ϕ_d - Weld strength coefficient along, $\phi_d = 0{,}9$

P_R - Calculation of pressure equipment: $P_R = 1{,}2$ MPa.

$[\sigma]$ - Allowing stress of metal fabricated cap: $[\sigma] = 138{,}8$ MPa.

C - Additional thickness: $C = 0{,}003$ m

So:

$$S_n \geq \frac{1{,}2\ .\ 0{,}729}{2\ .\ 0{,}9\ .\ 138{,}8 - 0{,}5\ .\ 1{,}2} + 0{,}003 = 0{,}0065 \text{ m}$$

We choose the thickness of the lid: $S_n = 0{,}007 \text{ m} = 7 \text{ mm}$

7.2 EVAPORATOR OPTION

Specification | 60Hz

LG Life's Good

R134a (60Hz)

Model		Units	RCWW022CA2A	RCWW024CA2A	RCWW026CA2A	RCWW028CA2A	RCWW032CA2A	RCWW036CA2A	RCWW040CA2A
Standard Condition	Cooling capacity	kW	726	783	849	912	1,095	1,217	1,298
		usRT	206.4	222.5	241.5	259.3	311.4	346.1	369.1
	Input Power	kW	151.87	164.01	177.89	182.51	227.03	240.05	261.89
	COP		4.8	4.8	4.8	5	4.8	5.1	5
AHRI Conditions	Cooling capacity	kW	734.53	791.98	859.6	922.88	1,108.64	1,231.96	1,314.09
		usRT	208.9	225.2	244.4	262.4	315.2	350.3	373.6
	Input Power	kW	145.73	157.38	170.67	175.14	217.82	230.33	251.25
	COP		5	5	5	5.3	5.1	5.3	5.2
	IPLV		6.44	6.43	6.47	6.74	6.53	6.85	6.73
General Unit Data	Number of Circuits		2	2	2	2	2	2	2
	Refrigerant, R-134a	kg	95 / 95	100 / 100	110 / 110	115 / 115	145 / 145	160 / 160	175 / 175
	Oil Charge	l	18 / 18	20 / 20	23 / 23	20 / 20	28 / 28	28 / 28	28 / 28
Weight	Shipping Weight	kg	4,460	4,600	4,720	4770	5580	5910	5930
	Operating Weight	kg	4,780	4,940	5080	5150	6040	6430	6480
Compressors	Compressor type		Semi-hermetic twin screw						
	Quantity	EA	2	2	2	2	2	2	2
Condenser	Evaporator type	kW	Shell and Tube						
	Water Volume	kW	59	61	61	65	80	86	86
	Max. Water Pressure	MPa	1	1	1	1	1	1	1
	Max. Refrigerant Pressure	Mpa	1	1	1	1	1	1	1
	Min. Cooling Water Flow Rate	l/s	13.6	14.6	14.6	16.9	19	21.6	21.6
	Max. Cooling Water Flow Rate	l/s	54.4	58.6	58.6	67.7	76	86.5	86.5
	Water Connections	DN	150	150	150	150	200	200	200
Evaporator	Evaporator type		Shell and Tube						
	Water Volume	l	67	83	83	87	92	112	112
	Max. Water Pressure	MPa	1	1	1	1	1	1	1
	Max.Refrigerant Pressure	Mpa	1	1	1	1	1	1	1
	Min.Chilled Water Flow Rate	l/s	12.6	13.8	13.8	15.7	18	20.2	20.2
	Max.Chilled Water Flow Rate	l/s	50.2	55.1	55.1	62.8	71.8	80.9	80.9
	Water Connections	DN	150	150	150	150	200	200	200

7.3 ANCILLARY EQUIPMENT

7.3.1 Oil Separator :

The mission of the oil separator to reduce oil circulating in the system by the refrigerant being pulled under. Slightly agent mixed with oil after the oil separator through a portion of oil and condensed oil is recovered back to the compressor, steam lines come out of the condenser.

Figure 7.1: Oil Separator

7.3.2 Dehumidifier filter

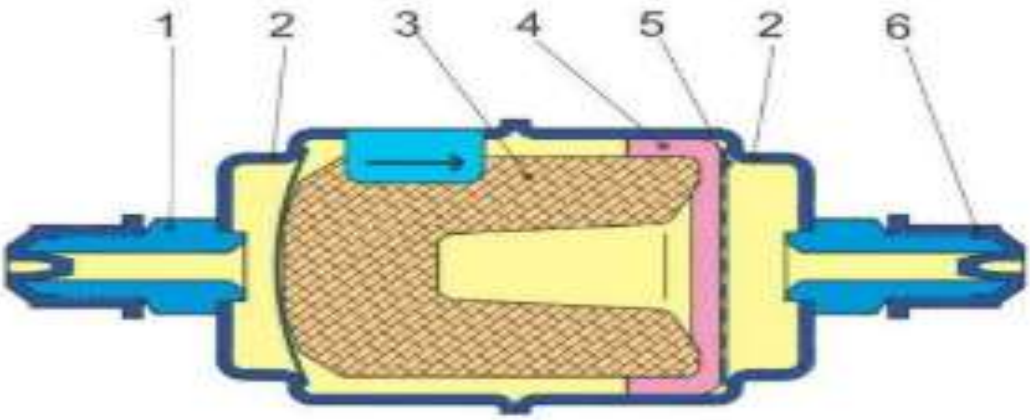

Figure 7.2: Dehumidifier filter

Where:

1. The entrance
2. Springs
3. Shaped filter core
4. Pads
5. Perforated sheet

6. Flared-type plug caps

Welding cap sealing type

Filter arranged before the throttle to prevent dirty work off the throttle. With the arrangement of filters and the liquid in the vapor path to ensure reliable operation and safety of the system. In the system to fight off the moisture, drying the coffee pot we must arrange for dehumidification system

With systems using Freon refrigerant, due to use of lubricant so as the temperature in the system exceeds certain provisions are capable of chewing up the acid. Therefore, we must remove the acid to prevent corrosion of equipment and parts in the system.

7.3.3 Types of valves:

- Check valve:

One-way valve is mounted on the discharge line from the compressor to the condenser. With a mission to prevent refrigerant condensing or compressor on the compressor in case of stopping the compressor, compressor repair or compressor breakdown.

Only one-way valve for refrigerant lines to follow a certain direction, opposite hampered.

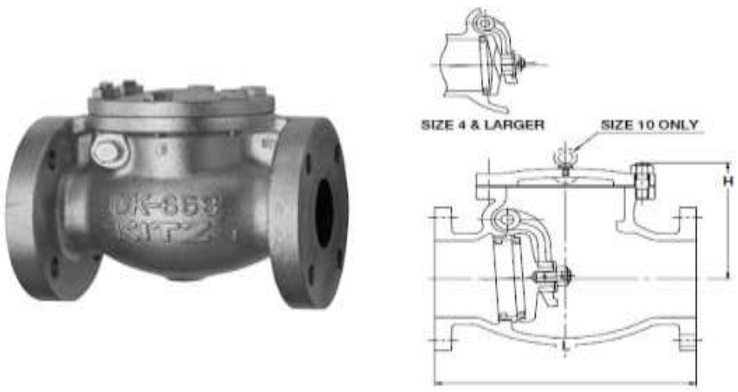

Figure 7.3 Check valve

- Gate valve:

Anatomy of valves, valve depends on the functionality and utility of the valves, valve size and flow through the valve.

When operating, maintenance and repair of air conditioning needed to lock or open the refrigerant flows in the refrigerant cycle. Then the valves, valve undertake that task.

Figure 7.4: Gate valve

- Throttle valve:

Thermal expansion valve is used to throttle the liquid agent from condensing pressure to the pressure boiling pk po and to control the flow agent into the evaporator to the load at that time.

Thermal expansion valve has two types:

+ Thermal expansion valve directly impact

+ Thermal expansion valve indirect effects

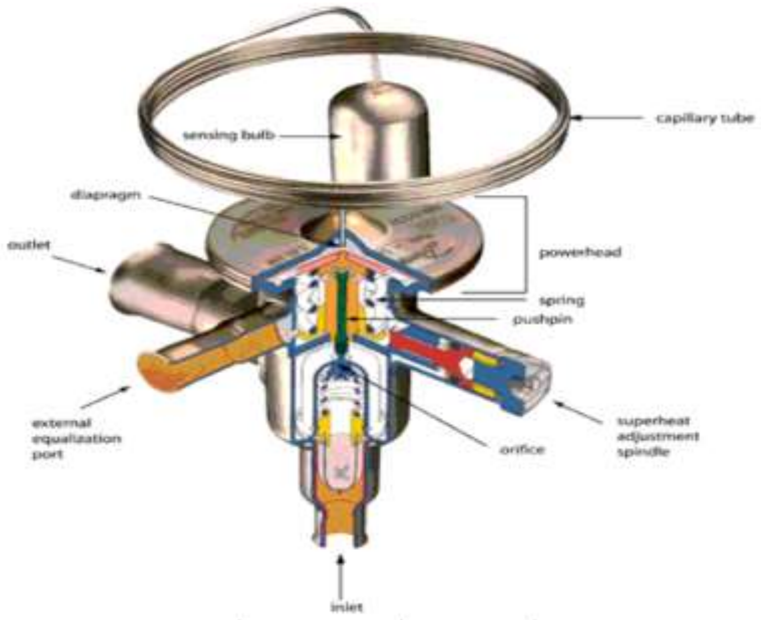

Figure 7.5: Thermal Expansion Valve

- **Safety valve:**

To ensure the safety of the device and the first pressure compressor, used van full. Safety valve has two types of plate and sprung, with the task of controlling the pressure in the pressure equipment and compressors. When the pressure in the pressure equipment exceeds the allowable value, the safety valve will open and discharge partially outside agent.

For the compressor, the pressure pushing excess sugar allowed, while safety valve open and somewhat relieved pushed suction line. Pressure discharge line up to the guidelines, the safety valve automatically closes. To be able to switch the safety valve, it is installed in parallel on each device 2 pressure safety valves are linked together by a special van three falls.

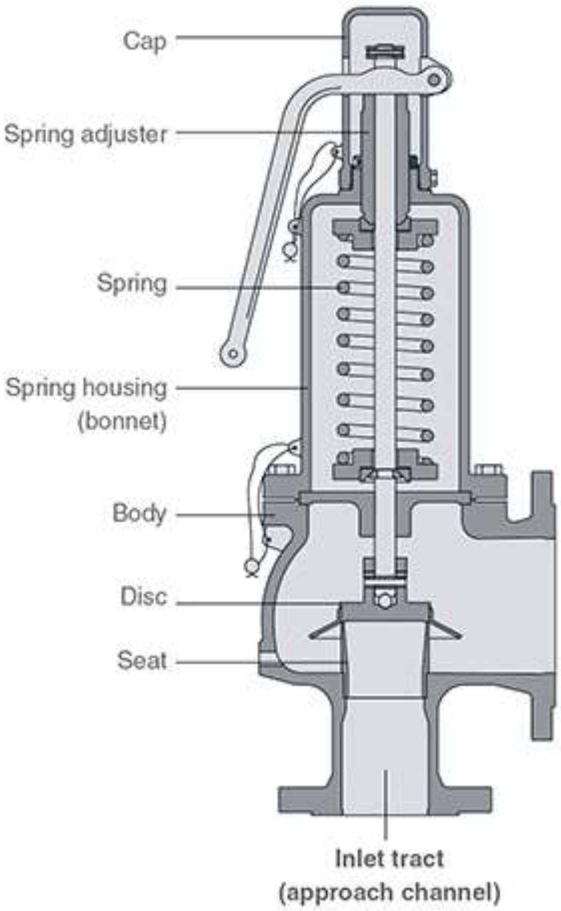

Figure 7.6: Safety valve