Design of Two Stage Vapour Compression Refrigeration System with Water Intercooler

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Abstract— **Refrigeration is the process of reducing and maintaining the temperature of a space or material below the temperature of surrounding. In practical applications, vapour compression refrigeration systems are the most commonly used refrigeration systems, and each system employs a compressor. Basic vapour compression refrigeration cycle consists of four major thermal processes; evaporation, compression, condensation and expansion. There are many applications where refrigeration plant is required to meet the various refrigerating loads at different low temperatures. When there is case of low temperature by default there is increase in pressure and compression ratio of cycle. But sometimes the vapour refrigerant is required to be delivered at a very high pressure as in case of low temperature refrigerating system. In such case either we should compress the vapour refrigerant by employing a single stage compressor with a very high pressure ratio between the condenser and evaporator or compress it in two or more compressors placed in series .Compression carried out in two or more stages is called compound or multistage compression refrigeration system.**

Index Terms—**Condenser load, Compressor capacity, Hub ratio, Intercooler**

I. INTRODUCTION

Vapour compression refrigeration systems are the most commonly used refrigeration systems, and each system employs a compressor. Basic vapour compression refrigeration cycle consists of four major thermal processes; evaporation, compression, condensation and expansion .According to the requirement, vapour compression system is further modified for better performance and control. Such systems are compound multistage systems, cascade systems and multi evaporator systems. There are many applications where refrigeration plant is required to meet the various refrigerating loads at different low temperatures. When there is case of low temperature by default there is increase in pressure and compression ratio of cycle. This will not good for that particular plant to operate in good manner. In simple vapour compression refrigeration system in which low pressure vapour refrigerant from the evaporator is compressed in single stage or single compressor and then delivered to condenser at high pressure. But sometimes the vapour refrigerant is required to delivered at a very high pressure as in case of low temperature refrigerating system. In such case either we should compress the vapour refrigerant by employing a single stage compressor with a very high pressure ratio between the condenser and evaporator or compress it in two or more compressor placed in series .Compression carried out in two or more compression is called compound or multistage compression

II. NEED OF MULTISTAGE REFRIGERATION SYSTEM

Simple vapour compression refrigeration system consists of mainly four parts compressor, condenser , expansion valve and evaporator. These all four components run a simple vapour compression refrigeration system. In simple vapour compression refrigeration system pressure ration up to specific limit can be achieved. Normally by experimentation and theoretical result all previous researcher reached to conclusion that pressure ratio which is ratio of condensing pressure to evaporating pressure which give effective result up to pressure ratio of 4 or 5. But there are some application where we have to reach up to very lower temperature or in some case condensing pressure is increasing so that automatically pressure ratio will be more. Due to increase in pressure ratio there is increase in condensing temperature, and high condensing temperature cause decrease in volumetric efficiency. Volumetric efficiency is main parameter which give actual efficiency of compressor. Decrease in volumetric efficiency is due to some factors such as compressor clearance, cylinder heating, and valve and piston leakage. This factor tend to limit the volume of suction vapour compressed per working stroke. But achievement of very lower temperature is need for some application and for this some necessary arrangement should be required to achieve the same with lowest possible cost. The method which overcome some of the disadvantages of simple vapour compression refrigeration system at lower temperature is called compound vapour compression refrigeration system or multistage refrigeration system.

Refrigerant—Refrigerant plays a key role when you’re considering the longevity of your equipment, regardless of whether you are retrofitting or constructing from scratch. In less than a decade, the most common refrigerant in the world, HCFC R-22, will be phased out of production because of its ozone depleting properties. It will be banned from use in new equipment after 2010. While R-22 refrigerant will be available after 2010, service will have to come from reclaimed refrigerant. New families of refrigerants with no ozone depleting properties (such as HFC R-134a, R-410A and R-407C) have the same safety classifications as the refrigerants you’re currently using. And, they are safe, efficient and will be available for the foreseeable future. Taking a proactive approach of asking that new equipment uses these refrigerants not only helps to make sure that it can be fully supported for its useful life, it also helps to protect our environment from the harmful effects of ozone depletion.

III. ADVANTAGES OF MULTISTAGE REFRIGERATION

Any refrigeration system which operating between different temperature limits is advantageous only when it will give required low temperature and refrigerating effect. With the use of compound compression refrigeration system , some advantages are

1. Work done per kg of refrigerant is reduced in compound compression with intercooler as compared to simple vapour compression with intercooler for same delivery pressure .
2. It improves volumetric efficiency for given pressure ratio.
3. The size of two cylinder high and low pressure may adjusted to suit the volume and pressure of refrigerant.
4. The size of two cylinder high and low pressure may be adjusted to suit the volume and pressure of refrigerant.
5. It reduces leakage loss considerably.
6. It gives more uniform torque; hence smaller size flywheel is needed.
7. It provides effective lubrication because of lower temperature range.
8. It reduce cost of compressor.

IV. PROPOSED SET UP DIAGRAM

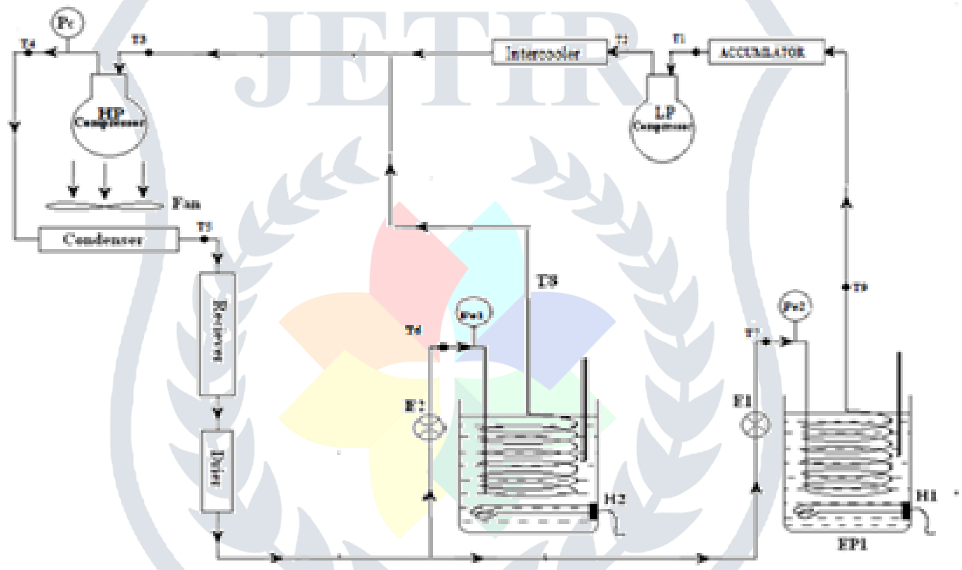


Fig. Set-up diagram

Components used for Multistage Refrigeration Set-Up:

1. Compressor

Compressor is basic part of refrigeration system. Compressor work as compressing the refrigerant from evaporating temperature to condensing temperature . Here in the multistage refrigeration system we are going to use open type slow speed compressor of 1TR for low stage condition and 2 TR for high stage application. Open type compressor is selected cause it is useful for manually adjustment of capacity compressor. In open type compressor the rotating shaft of the compressor extends through a seal in the crankcase for external drive. The external drive may be an electrical motor or an engine. Open type compressors are normally used in medium to large capacity refrigeration system for all refrigerants. However, since the shaft has to extend through the seal, refrigerant leakage from the system cannot be eliminated completely. Hence refrigeration systems using open type compressors require a refrigerant reservoir to take care of the refrigerant leakage for some time, and then regular maintenance for charging the system with refrigerant.

2. Condenser

Condenser a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. Condenser is one of the type of heat exchanger used for rejecting heat to the cooling medium. Here in this set up we are going to use air cooled condenser because of its advantages over water cooled condenser. It required air which is abduntly available in atmosphere. Fouling problem is reduced, cost of condenser reduces.

3. Evaporator

Here in this study we are going to use two evaporators in series with different capacities of evaporator at different temperature. Two bare tube type evaporators are used with different evaporator coil length.

4. Expansion devices

Expansion devices are used to expand the refrigerant from condensing pressure to evaporating pressure with stages . One expansion devices used is capillary tube and other one is expansion valve.

5. Intercooler

Intercooler is heat exchanging device which is used to transfer heat from one fluid to another fluid with direct contact or indirectly. Here by considering tube in tube type heat exchanger.in this type of water intercooler hot vapour refrigerant enters at top of the condenser. The Water absorbs the heat from the refrigerant and the condensed liquid refrigerant flows at the bottom .Since the refrigerant tubes are exposed to ambient air. Therefore some heat is absorbed by ambient air by natural convention. Water is coming from upward flowing in down ward direction and refrigerant which is flowing in inner tube flowing exactly opposite to water flow so that called counter flow system.

V. DESIGN AND SELECTION OF COMPONENTS FOR MULTISTAGE

The last decade has been radical changes in the selection and uses of refrigerants, mainly in response to the environmental issues of holes and the ozone layer and global warming or greenhouse effect. Previously there had not been much discussion about the choice of refrigerant, as the majority of applications could be met by the well-known and well – tested fluids, R11, R22, R502 and ammonia (R717). At the time of selection of refrigerant with their chemical, physical properties. At the time of selection we have to know that condensing pressure and evaporating temperature that is temperature range of application. Before selection of compressor and condenser we should know the refrigerant. We have considered different refrigerant for study

		Evaporating		Condensing	
Sr. no	Name of Refrigerants	Temp. °C	Pressure (bar)	Temp. °C	Pressure(Bar)
1	Ammonia (R717)	-35	1	30	12
2	Tetra fluro ethane (R134a)	-26	1	30	7.7
3	Difluro methane(R407C)	-36.6	1	30	13
4	R502	-40	1	30	13.8
5	Carbon	-15	19	30	72
6	Chlorodifloromethane(R22)	-40	1	55	22

Table- Refrigerant selection

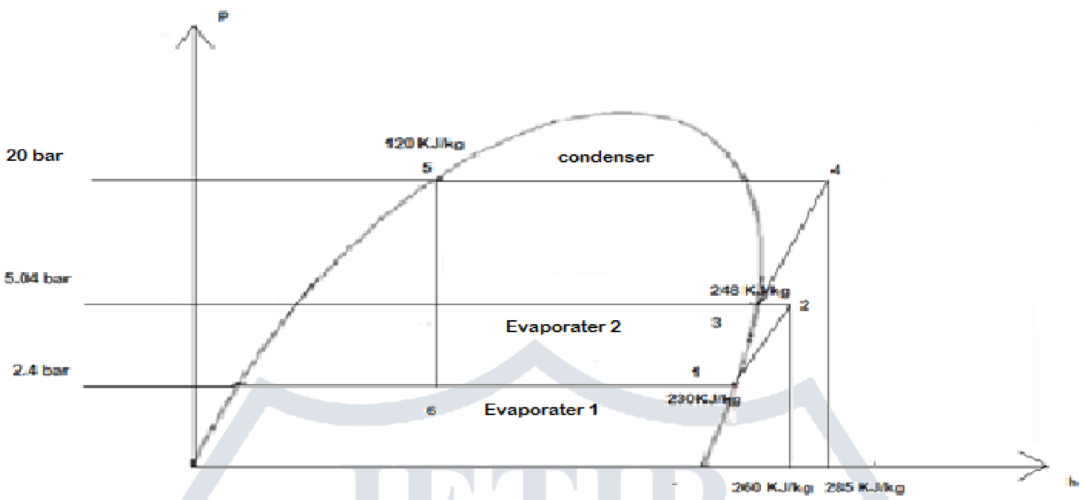
Here after studying various refrigerant of different group we have selected R-22 as refrigerant for my Set-Up. For this application we have considered different parameters such as evaporating temperature required condensing temperature required corresponding pressure also considered for the selection of refrigerant. Because before selection of any other components such as compressor or condenser design or other design such as intercooler.

Compressor is basic part of any refrigeration system. In other words we call it as heart of refrigeration system. Now days various type of compressor are used in refrigeration industry for operation. A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapour compression refrigeration system (VCRS). The function of a compressor in a VCRS is to continuously draw the refrigerant vapour from the evaporator, so that a low pressure and low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space. The compressor then has to raise the pressure of the refrigerant to a level at which it can condense by rejecting heat to the cooling medium in the condenser. Refrigerants are classified by considering various factors such as based on working principle, based on compressor motor drive or external drive. Mostly for this set-up we will deals with open type slow speed compressor of making Seabird/Amoking for operation. In open type compressors the rotating shaft of the compressor extends through a seal in the crankcase for an external drive. The external drive may be an electrical motor or an engine (e.g. diesel engine). The compressor may be belt driven or gear driven. Open type compressors are normally used in medium to large capacity refrigeration system for all refrigerants and for ammonia (due to its incompatibility with hermetic motor materials). Open type compressors are characterized by high efficiency, flexibility, better compressor cooling and serviceability. However, since the shaft has to extend through the seal, refrigerant leakage from the system cannot be eliminated completely. Hence refrigeration systems using open type compressors require a refrigerant reservoir to take care of the refrigerant leakage for some time, and then regular maintenance for charging the system with refrigerant, changing of seals, gaskets etc.

At the time of selection of compressor basic step to be considered are its condenser pressure and temperature, evaporator pressure, it's bore diameter, stroke of piston and revolution per minute. By considering this information we were searched for various manufacturing company and finally selected Amoking compressor of model No. 250/IVL and 300/VL compressor which fulfill all the requirements and requirements.

Calculation for low stage compressor (250/IVL):

For 250/IVL compressor various parameters are mentioned on website



p-h diagram for R-22

h_1=230 KJ/kg h_2=260 KJ/kg at 50°C

h_3=248 KJ/kg h_4=285 KJ/kg

h_5=120KJ/kg V_{s1}=0.0930 m^3/kg

Temperature of condenser T_c= 50°C Temperature of Evaporator T_e = -15°C

Condensing pressure P_c= 19.613 bar Evaporating pressure P_e= 2.9 bar

$$V_1=\frac{\pi}{4} \times D^2 \times L \times N$$
$$= \frac{\pi}{4} \times 0.065^2 \times 0.05 \times 750$$
$$V_1= 0.1244 \quad m^3/min$$

And for higher stage compressor swept volume can be calculated as

$$V_2=\frac{\pi}{4} \times D^2 \times L \times N$$
$$=\frac{\pi}{4} \times 0.085^2 \times 0.060 \times 700$$
$$= 0.2383 \quad m^3/min$$

We have taken two evaporator at different temperature of different capacity 1.2 TR and 0.8 TR according this our further work is to calculate mass flow rate flowing through these two evaporator and after this compressor capacity required is calculated. Compressor is calculated according to this calculation and availability of compressor in market.

$$m_1 = 210 \times \frac{Q_1}{h_1 - h_{f5}}$$

Where Q_1 in TR

$$= 210 \times \frac{0.8}{230-120}$$
$$m_1 = 1.52 \quad kg/min$$
$$m_2 = 210 \times \frac{Q2}{h3-h_{f5}}$$
$$= 210 \times \frac{1.2}{248-120}$$
$$= 1.91 \text{ kg/min}$$

$$W_{c1}= \frac{m_1(h_2-h_1)}{60}$$
$$= \frac{1.5(272-240)}{60}$$

= 0.9 TR

From above calculations of low stage compressor mass flow rate of refrigerant flowing through the low stage compressor is 1.5 1.5 kg/min and compressor power required is calculated as 0.9 TR. That's why by observation we can say that compressor of 1 TR should be sufficient for application and seabird making compressor one tons is finalized. External motor required to run the Compressor of 1 HP. And same calculation when done for high stage compressor we got the result which have value of 2 TR Compressor capacity and motor required is of 2HP.

summary of selected compressor are given below with necessary parameter required for calculation as

Compressor type	Motor pulley	Compressor speed with motor speed 1450/min	Displacement (m^3/hr)	Bore	Stroke	Oil charge	Stage
250/IVL	200	750	14.92	65	50	1.5	low
300/VL	220	700	28.61	85	60	2.5	high

Table- Compressor Parameter Summary(Making of compressor Seabird)

Water intercooler is connected in between two compressor for desuperheating superheated vapour refrigerant from superheated state to saturated state by exchanging heat . Here by considering tube in tube type type heat exchanger .In this type of of Intercooler hot vapour refrigerant enters at top of the condenser. The water absorbs the heat from one refrigerant and the Condensed liquid flows at the bottom. Since the refrigerant tubes are exposed to ambient air. Water is coming from up Flowing in downward direction and refrigerant which is flowing in inner tube flowing exactly opposite as that of water Flow so that called counter flow system.

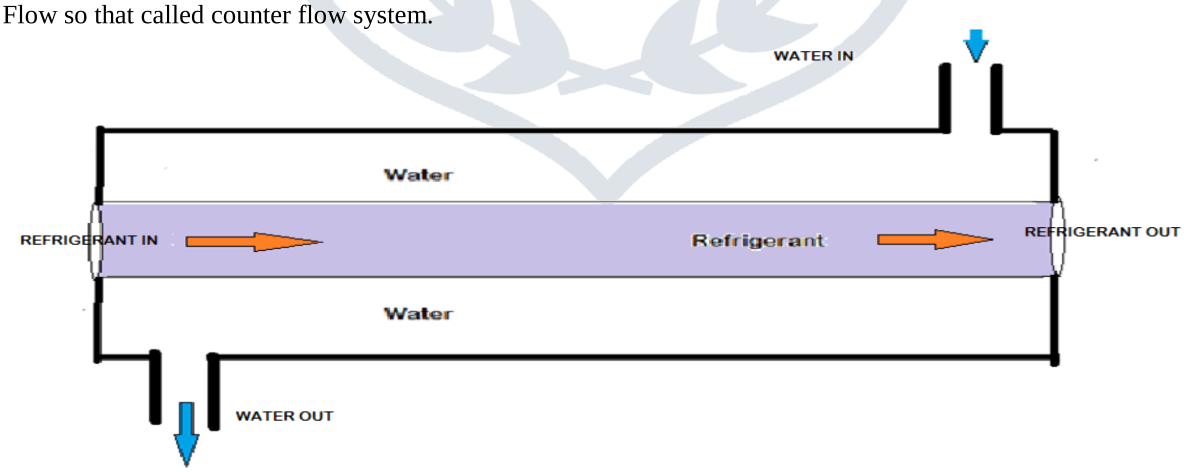


Fig. Water Intercooler

By calculation,

From p-h diag. we got some temperature i.e. water inlet temperature, water outlet temperature, refrigerant inlet and with Refrigerant outlet temperature and from this by taking these temperature and by considering tube in tube type of heat ex.

With counterflow arrangement some parameters are calculated such as LMTD of heat exchanger, heat which is to be we to be removed from water intercooler is 0.3 kw and mass of water which is required to flow through it is also calculated And finally length of heat exchanger i.e. copper tube required is calculated.

Specifications of water intercooler used

Diameter of cooper tube 2"(5 cm)
Length of cooper tube 35 cm

Condenser is one of the main parts of refrigerating system which is required to reject heat to the atmosphere by it Convention. Condenser is heat transfer surface like evaporator. In condenser copper tube transfer heat of refrigerant to the aluminum fins/foils which is cooled or rejected by with the help of fan. The condenser load is the total heat rejected at the condenser. It includes both the heat absorbed and the energy equivalent of the work of compression in compressor.

Advantages of air cooled condenser:

1. Air-cooled condensers are cooled by ambient air and no water is required.
2. There is also no need for a cooling tower and condenser water pump.
3. There no handling problem with air cooled condenser.
4. No problem with disposing used air as like water cooled condenser.
5. Fouling factor has less effect.
6. Maintaince cost is low.

For selection of condenser following parameters are considered

1) Cooling capacity

The amount of heat rejected by condenser to the surrounding medium is called as cooling capacity of condenser The amount of heat rejected include heat absorb in evaporator and work done by compressor. Air cooled condenser is at Available in various sizes from less than 1 kw to 500 kw or more according to heat rejection capacity.

2) Temperature difference

The heat transfer capacity of condenser greatly depends on the temperature difference between condensing medium and vapour refrigerant. As the temperature difference increases the heat transfer rate increase and therefore condenser capacity is increases. Most of air cooled condenser is design to operate temperature difference 14^0C

3) Refrigerant

Since property of refrigerant is differ so condensing and evaporative temperature depend upon the refrigerant used. So during selection of compressor and condenser the refrigerant must be known.

4) Altitude

In air cooled condenser air is used as condensing medium as altitude increases air density decreases so the cooling capacity of condenser reduces at same volume of air flow rate. Hence the proper correction factor in change in its altitude must be used while calculating heat rejection rate which decides size of condenser.

By considering all these parameters and our requirement we designed a air cooled condenser of specifications given below Specifications of condenser according to design:

Sr. No.	Parameter	Symbol	Quantity
1	Height of fins	H	0.44 meter
2	Width of fin	W	0.0875 meter
3	Fin length	L_f	0.56 meter
4	Number of fin per meter	N_f	392
5	Thickness of fin	t_f	$0.5*10^{-3}$
6	Number of rows	N_r	4
7	Number of passes	N_p	17
8	Outer radius of tube	r_o	$4.76*10^{-3}$ meter
9	Inner radius of tube	r_i	$4.05*10^{-3}$ meter
10	Mean radius of tube	r_m	$4.405*10^{-3}$ meter
11	Thickness of tube	T	$0.71*10^{-3}$m

Table – condenser specifications

Total condenser load = (load on first evaporator + load on second evaporator) *heat rejection factor
= ((1.2 + 0.8)*3.5)* 1.2
=8.2 kw

And we designed one condenser for 15 kw capacity which is shown in below diagram.

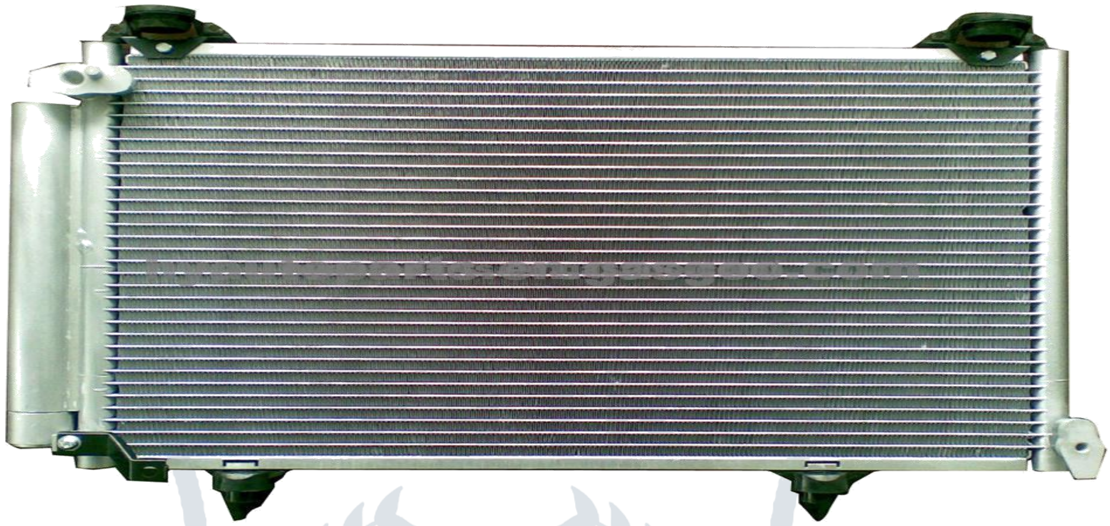


Fig. Condenser

Here it is air cooled condenser with fan connected so called as forced convention air cooled condenser axial fan is selected according to condenser load and requirement from condenser axial fan is selected from manufactures chart with calculating volume flow rate. Axial fan which are normally related with characteristics hub ratio. Hub ratio which is ratio of outer hub diameter to the diameter of impeller.

R_{Hub}= Hub Diameter/ diameter of impeller

Higher hub ratio which means greater conversion of velocity pressure to static pressure and also capacity and total pressure of axial fans can be increased by raising their rotating speed or through there adjustment of blade pitch angle to higher value . It is used for fans that are directly by motor without using belts**.**

Firstly condenser load (by calculations) =8.2 KW

$Q = m\,C_p\,(\wedge T)$
$8.2 \times 10^3 = m \times 1.005 \times 10^3 \times 20$
$M = 0.4079$ Kg
$\rho = m/v$
$1.2 = 0.4079/V$
$V = 0.3399\ m^3/s$
$V = 1223.64\ m^3/hr.$

From these calculations from axial fan catalogue fan model selected is 4E300.

Evaporator is part or component where actual heat is absorbed from evaporated space by refrigerant to cool space which is to be cooled. Here we were used bare tube type coil for evaporation. The simplest type of evaporator is bare tube type evaporator and also known as prime surface evaporator . because of it's simplest construction , the bare tube coil is easy to clean and defrost.

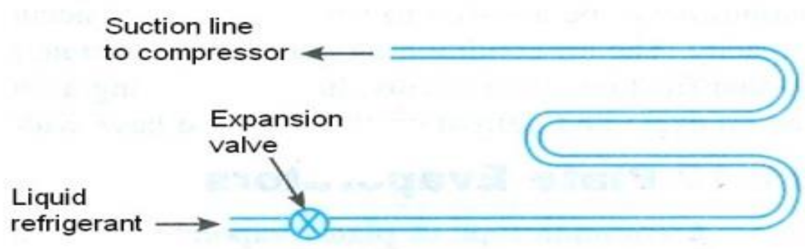


Fig. Bare Tube Coil Evaporators

A little consideration will show that this type of evaporator offers relatively little surface Contact area as compared to other types of coils. The amount of surface area may be increased by simply extending the length of the tube, but there are disadvantages of excessive tube length. The effective length of the tube is limited by the capacity of expansion valve. If the tube is too long for the valve's capacity, the liquid refrigerant will tend to completely vaporize early in its progress through the tube, thus leading to excessive superheating at the outlet. The long tubes will also cause considerably greater pressure drop between the inlet and outlet of the evaporator. This results in a reduced suction line pressure. By considering all these parameters and by calculation I got some result which is suitable for our system and our system capacity i.e. is 1.2 TR and 0.8 TR is fulfilled. The detailed specifications of evaporator coil and expansion device are given below

Specifications of two evaporators**:**
Evaporator-I
Type: Calorimeter type
Temperature of solution: -15˚C
Size of evaporator calorimeter: 40cm×40cm×50cm (galvanized)
Length of coil: 11m
Evaporator-II
Type: Calorimeter type
Temperature of solution: -5˚C
Size of evaporator calorimeter: 45cm×45cm×50cm (galvanized)
Length of coil: 16 m

Expansion devices:

Evaporator-I(-15˚C):
Expansion Device: Capillary tube
By calculations

L = 1.06 m = 3.2ft.
Using capillary tube length conversion chart ,
For TC-70,
L=2.2 m = 7.2 ft.
Evaporator-II (-5˚C):
As load on this evaporator is more, mass flow rate through this evaporator will be more.
Expansion Device: Thermostatic expansion valve (TEV)
Type: TX2 (R22/R407c)
Manufacturer: Danfoss
Temperature range: -40/+10˚C/-40/+50˚F
Flare: 3/8”×1/2” Angle way
Orifice: 03

VI Conclusions

This paper explains about the basic design of two stage vapour compressor refrigeration system. There is always need in scientific community to develop energy efficient refrigeration systems. Two stage vapour compression system is designed by considering two open type slow speed compressor which should efficiently operate refrigeration system. The various components of multistage system are designed and selected at given condition of temperature range and required refrigerating capacity. The main component selected in system is open type compressor and designed component is air cooled condenser and water intercooler. These all component are suitable for developing multistage refrigeration system of capacity 2 TR set-up according to design condition.

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