UNIT 4 REFRIGERANTS

Structure

4.1 INTRODUCTION

The working agent in a refrigerating system that absorbs carries or releases heat from the place to be cooled or refrigerated can be termed as a refrigerant. This heat transfer generally takes place through a phase change of the refrigerant. A more complete definition of a refrigerant could be given as follows:

"Refrigerant is the fluid used for heat transfer in a refrigerating system that absorbs heat during evaporation from the region of low temperature and pressure, and releases heat during condensation at a region of higher temperature and pressure."

Objectives

In this unit, we shall learn about the different refrigerants used in various refrigeration systems. At present, we have a large number of refrigerants available to us depending on the requirements of the particular refrigerating system. A detailed study of these refrigerants has thus become imperative. This unit is intended to serve as an introductory guide to the study of refrigerants.

After studying this unit, you should be able to learn

- the different classifications of refrigerants,
- naming convention for refrigerants,
- properties of individual refrigerants, and
- environmental effects related to the use of these refrigerants.

4.2 PRIMARY AND SECONDARY REFRIGERANTS

Primary refrigerants are those which can be directly used for the purpose of refrigeration. If the refrigerant is allowed to flow freely into the space to be refrigerated and there is no danger of possible harm to human beings, then primary refrigerants are used. The refrigerants used in home refrigerators like Freon-12 are primary refrigerants.

On the other hand, there may be certain situations in which we cannot allow the refrigerant to come in direct contact with the items being refrigerated, and then the refrigerant used is termed as a secondary refrigerant. As for example, we cannot allow a toxic refrigerant to be used for air conditioning in residential buildings. There are some refrigerants which are highly inflammable and so their direct use is forbidden for safety reasons. Again, it may so happen that if direct refrigeration, such as in cooling a big cold storage, is allowed, then the amount of refrigerant required may be so large that its cost becomes prohibitively high. These are some typical situations for which we favour the use of secondary refrigerants. Water and brine solutions are common examples of secondary refrigerants.

4.3 CLASSIFICATION OF REFRIGERANTS

Refrigerants can be broadly classified based on the following:

Working Principle

Under this heading, we have the primary or common refrigerants and the secondary refrigerants.

The primary refrigerants are those that pass through the processes of compression, cooling or condensation, expansion and evaporation or warming up during cyclic processes. Ammonia, R12, R22, carbon dioxide come under this class of refrigerants.

On the other hand, the medium which does not go through the cyclic processes in a refrigeration system and is only used as a medium for heat transfer are referred to as secondary refrigerants. Water, brine solutions of sodium chloride and calcium chloride come under this category.

Safety Considerations

Under this heading, we have the following three sub-divisions.

Safe refrigerants

These are the non-toxic, non-flammable refrigerants such as R11, R12, R13, R14, R21, R22, R113, R114, methyl chloride, carbon dioxide, water etc.

Toxic and moderately flammable

Dichloroethylene methyl format, ethylchloride, sulphur dioxide, ammonia etc. come under this category.

Highly flammable refrigerants

The refrigerants under this category are butane, isobutene, propane, ethane, methane, ethylene etc.

Chemical Compositions

They are further sub-divided as

Halocarbon compounds

These are obtained by replacing one or more hydrogen atoms in ethane or methane with halogens.

Azeotropes

These are the mixtures of two or more refrigerants and behave as a compound.

Oxygen and Nitrogen Compounds

Refrigerants having either oxygen or nitrogen molecules in their structure, such as ammonia, are grouped separately and have a separate nomenclature from the halogenated refrigerants.

Cyclic organic Compounds

The compounds coming under this class are R316, R317 and R318.

Inorganic Compounds

These are further divided into two categories: Cryogenic and Non-cryogenic.

Cryogenic fluids are those which are applied for achieving temperatures as low as – 160 ^{0}C to – 273 ^{0}C. Above this temperature range, we can use a multi-stage refrigeration system to realise the desired temperature. But below – 160 ^{0}C, this is not possible since the COP of the cycle becomes very low. To attain temperatures below – 160 ^{0}C, we use refrigerants such as nitrogen, oxygen, helium, hydrogen etc. and for temperatures close to – 273 ^{0}C, magnetic cooling is employed.

The inorganic compounds which are employed above the cryogenic temperature ranges come under the remaining sub-division of inorganic refrigerants.

Unsaturated Compounds

Compounds such as ethylene, propylene etc. are grouped under this head and grouped under the 1000 series for convenience.

Miscellaneous

This group contains those compounds which cannot be grouped under the other components. They are indicated by the 700 series with the last numbers being their molecular weight. Examples include air, carbon dioxide, sulphur dioxide etc.

As we can see from the above sub-divisions, they are not mutually exclusive. A compound may come under more than one sub-division. Hence, the importance of adopting the various naming conventions to designate the different refrigerants cannot be underestimated.

4.4 DESIGNATION OF REFRIGERANTS

The American Society of Refrigerating Engineers (ASRE) has developed certain conventions for use in naming different types of refrigerants. These naming conventions differ according to the type of refrigerant. Each refrigerant type is denoted by a different series. Thus, we have separate series for halogenated refrigerants and other types. The naming conventions are simple and easy to follow. These conventions are now accepted worldwide and help to name the large variety of refrigerants available commercially nowadays.

Halocarbon Compounds

These are represented by a three digit nomenclature. Here, the first digit represents the number of carbon atoms in the compound minus one, the second digit stands for the number of hydrogen atoms plus one while the third digit stands for the number of fluorine atoms. The remaining atoms are chlorine.

As an example, let us consider the refrigerant having R22 as its three digit nomenclature.

According to the above mentioned convention,

No. of C atoms in R22: C – 1 = 0 => C = 1

No. of H atoms in R22: H + 1 = 2 => H = 1

No. of F atoms in R22: F = 2

Since there is only one carbon atom in the compound, this compound has originated from the methane series (CH_4). From the calculation, we can see there is one hydrogen atom and two fluorine atoms. The remaining valence bond of carbon will be balanced by chlorine. Thus, the substance is

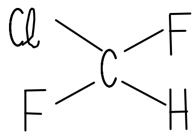

Figure 4.1 Graphical Representation of Monochloro-Difluoro-Methane

Therefore, chemical formula of R22 is $CHClF_2$ and has the name Monochloro-difluoro-methane (figure. 4.1).

Taking again the example of R134, we can calculate its chemical formula as above which gives us

No. of C atoms: C – 1 = 1 => C = 2

No. of H atoms: H + 1 = 3 => H = 2

No. of F atoms: F = 4

Therefore, no. of Cl atoms: Cl = 0

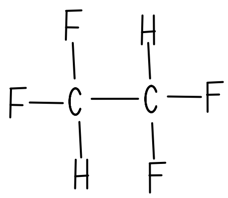

Figure 4.2 Graphical Representation of Tetrafluoroethane

The compound is $C_2H_2F_2$ and its name is Tetrafluoroethane (Figure. 4.2).

The non-halogenated refrigerants follow a different naming convention which is dependant upon the series of the refrigerant.

4.5 DESIRABLE PROPERTIES OF REFRIGERANTS

The vast number of refrigerants available in the market today allows us to choose a refrigerant depending upon the operating conditions of the refrigeration system. As such, there is no refrigerant that can be advantageously used under all operating conditions and in all types of refrigeration systems. In spite of that, we can state certain desirable properties that a refrigerant should posses. These properties can be divided into favourable thermodynamic, chemical and physical properties:

4.5.1 Thermodynamic Properties

Critical Temperature and Pressure

The critical temperature of the refrigerant should be as high as possible above the condensing temperature in order to have a greater heat transfer at a constant temperature. If this is not taken care of, then we will have excessive power consumption by the refrigeration system.

The critical pressure should be moderate and positive. A very high pressure will make the system heavy and bulky whereas in case of very low pressures, there is a possibility of air leaking into the refrigerating system.

Specific Heat

The specific heat of the liquid should be as small as possible. This ensures that the irreversibilities associated with throttling are small and there is greater subcooling of the liquid. On the other hand, the specific heat of vapor should be high to have less superheating of the vapor.

Enthalpy of Vaporization

This should be as large as possible to minimize the area under superheat and the area reduction due to throttling. Also, the higher value of enthalpy of vaporization lowers the required flow rate per ton of refrigeration.

Taking these three factors into account, the T-s and p-h diagrams of an ideal refrigerant would be as shown in Figures. 4.3 (a) and 4.3 (b).

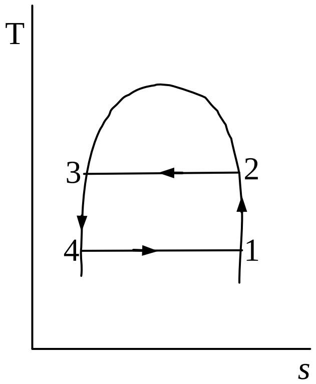

Figure 4.3(a) *T-S* Plot of an Ideal Refrigerant

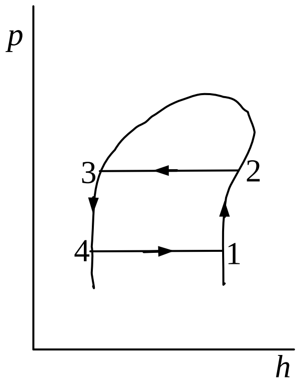

Figure 4.3(b) *p-h* Plot of an Ideal Refrigerant

These properties are practically not found in any refrigerant. So, a trade-off has to be done in order to achieve as high a COP as possible.

Conductivity

The conductivity of the refrigerant should be as high as possible so that the size of the evaporator and condenser is manageable. From this viewpoint, ammonia has a better conductivity than that of R12 or R22 and is more suitable than the latter. But, ammonia is toxic and this does not allow its use in home refrigeration systems.

Evaporator and Condenser Pressure

Both the evaporator and condenser pressures need to be above atmospheric pressure otherwise there is a possibility of air leaking into the system. Presence of air drastically reduces the capacity of the refrigeration system. Also, due to presence of moisture in air, acids or other corrosive compounds may form and this may affect the tubing of the refrigeration system.

Compression Ratio

The compression ratio needs to be as small as possible otherwise the leakage of refrigerant occurs across the piston. Also, the volumetric efficiency is affected.

Freezing Point

It should be as low as possible or else there will be a possibility of blockage of passages during flow of fluid through evaporator.

Volume of Refrigerant Handled Per Ton of Refrigeration

This should be as small as possible in order to have a small size of the compressor. The type of compressor is decided by this value. For refrigerants like R12, R500, R22 etc., a reciprocating compressor is suitable. For others like R11 and water, a centrifugal compressor is required to handle the large volume.

Coefficient of Performance

The Coefficient of performance or COP has a direct bearing on the running cost of the refrigeration system. Higher the magnitude of COP, lower will be the running cost. Since, the COP of any refrigeration system is limited by the Carnot COP, for large operating pressures a multi-stage refrigeration system should be employed. CO_2 has a very low COP. Hence, it is not suitable for use as a refrigerant.

Density

The density of the refrigerant should be as large as possible. In reciprocating compressors, the pressure rise is accomplished by squeezing the entrapped fluid inside the piston-cylinder assembly. Hence, density decides the size of the cylinder. Again in centrifugal compressors pressure rise is related to the density of the vapor. A high value of density results in high pressure rise.

Compression Temperature

Whenever a refrigerant gets compressed, there is a rise in the temperature of the refrigerant resulting in the heating of the cylinder walls of the compressor. This necessitates external cooling of the cylinder walls to prevent volumetric and material losses. Refrigerants having lowest compression temperatures are thus better than others.

4.5.2Chemical Properties

Chemical Stability and Inertness

It should be chemically stable for the operating ranges of temperature. Also, it should not react with the materials of the refrigeration system or with which it comes into contact. Further, it should be chemically inert and must not undergo polymerization reactions at either the lower or higher ranges of temperatures.

Action on Rubber or Plastics

Rubber and plastics are used extensively in the refrigeration system. These materials are mostly used in the seals and gaskets of the refrigeration system. They help to prevent the leakage of the refrigerant and ensure the smooth functioning of the compressor. The refrigerant should not react with them or else there might be leakage of refrigerant from the system or loss of functioning of the compressor.

Flammability

The refrigerant should be inert and not catch fire when subjected to high temperatures. From this viewpoint CO_2 is the most suitable as it is not only non-flammable, but also acts as a fire-extinguisher. Ethane, butane, isobutene are highly undesirable as they catch fire quickly.

Effect on Oil

The refrigerant should not react with the lubricating oil else, there is a possibility of loss of lubricating action due to either thickening or thinning of the oil. It should not be soluble in the oil else there will be reduction in the viscosity of the lubricating oil.

Effect on Commodity

If the refrigerant is directly used for chilling, then it should not affect the commodity kept in the conditioned space. Also, in case where direct cooling is not employed, the refrigerant should still not affect the commodity if there is any leakage.

Toxicity

The refrigerant used in air conditioning, food preservation etc. should not be toxic as they will come into contact with human beings.

4.5.3 Physical Properties

Leakage and Detection

Since pressures higher than atmospheric are usually employed in refrigeration systems, there is a possibility of leakage of refrigerants after long period of operation. It is desirable to detect this leak early else the system would operate under reduced capacity or stop functioning altogether. Hence, it is desirable that the refrigerant has a pungent smell so that its leakage can be detected immediately.

Miscibility with Oil

The refrigerant should not be miscible with the oil else the lubricating strength will be reduced.

Viscosity

It should be as small as possible to ensure that the pressure drop in the system is as small as possible. A low viscosity refrigerant will require less energy for its circulation through the refrigeration system.

4.5.4 Safety Criteria

Under safety criteria, we consider the toxicity, flammability, action on perishable food and formation of explosive compound on exposure to air. An ideal refrigerant should be non-toxic, non-flammable, have no effect on food products and should not react with atmospheric air. No refrigerant satisfy these criteria fully. We can therefore, group refrigerants into different sub-groups based on their flammability and toxicity levels.

4.5.5 Economic Criteria

Apart from the thermodynamic, chemical, physical and safety criteria, there is another criterion by which we judge an ideal refrigerant. The economic criterion takes into account the cost of the refrigerant, the availability and supply levels of the refrigerant, cost of storage and handling. We discuss each of these in detail below.

Cost of Refrigerant

The cost of the refrigerant has a big impact on the overall cost of the refrigeration system. Hence, its cost should be as low as possible. From this viewpoint, ammonia and water are ideally suited, but their low thermodynamic and chemical properties restrict their use in all types of refrigeration systems. Particularly, for flooded type evaporator or condenser, the refrigerant amount required is high and their cost needs to be factored in while making the initial investments.

Availability and Supply

The refrigerant should be easily available in the market and in abundant quantity. This ensures that the cost of the refrigerant is not prohibitive. An abundant and free supply of the refrigerant ensures that refrigeration systems will be designed specifically for use with them.

Storage and Handling

The refrigerant should be such that it can be conveniently stored and handled during transportation and charging. It should be stored in as small a pressure vessel as possible. Also, if we have to handle a toxic or flammable refrigerant, then the cost involved will be higher compared to handling and storage cost of non-toxic and non-flammable refrigerant.

From the above discussions of the ideal properties of refrigerants, we can come to the conclusion that none of the refrigerants in current use and available satisfy these conditions fully. As such, we have to make a detailed analysis of the different factors like cost, performance of the refrigeration system and safety issues before deciding on using a particular refrigerant.

4.6 COMMON REFRIGERANTS

The refrigerants which are available commercially in the market are numerous. Some of them which are in common use are mentioned below:

Air

Air (molecular weight 28.97, specific heats c_p = 1.04 kJ/kgK and c_v = 0.712 kJ/kg-K) is one of the earliest refrigerant to be used in the refrigeration systems. Its advantages are that it is available free of cost, is non-toxic and non-flammable and does not affect the commodity if pure. However, air suffers from a number of drawbacks. Air contains moisture and this reacts with the material of the evaporator and condenser severely affecting their working capacity. Further, there is a possibility that the passages may be blocked by the formation of ice from this moisture. The COP of air is of the order of 0.6 and thus, not suitable for use in refrigeration systems on a commercial scale. It is mainly used for air conditioning in aircrafts where efficiency of operation is of secondary importance.

Ammonia

Ammonia (molecular weight 17) is one of the oldest refrigerants and it was commonly employed in places where toxicity effects were of secondary importance. Its advantages are its low cost, low specific volume, high COP (of the order of 4.0) and high refrigeration effect per unit mass of the refrigerant. Its primary drawback is its toxicity which prevents its use in air-conditioning and food preservation systems. Ammonia has a boiling point of -33 ^{0}C at atmospheric pressure.

Carbon Dioxide

Carbon dioxide (molecular weight 44) is a non-toxic and non-poisonous refrigerant. Also, it is not only non-flammable but and is an excellent extinguishing agent as well. Its other advantages are that it is chemically stable, immiscible with the lubricating oil and does not affect the metal used in the system. It has a low specific volume and this requires volume displacement per ton of refrigeration. However, its critical pressure is too high. Also, its critical temperature is only 31 ^{0}C which makes it unsuitable for use in countries with a hot climate like India. It is an excellent refrigerant for low temperature refrigeration.

Sulphur Dioxide

Sulphur dioxide (molecular weight 64) is a colourless, suffocating and irritating gas and is twice as heavy as air at atmospheric conditions. It was mostly used as a household refrigerant in the older days, but has since been discarded for better refrigerants. It suffers from a lot of disadvantages. Sulphur dioxide reacts with water forming sulphurous acid, which in presence of oxygen becomes sulphuric acid, a corrosive compound for metals. It is non-flammable but attacks foodstuff on coming in contact with it. It is also partially miscible with the lubricating oil.

Hydrocarbons

This group consists of colourless fluids normally in gaseous state and made up of various combinations of carbon and hydrogen. Most of the refrigerants from this category are suitable for low temperature refrigeration. Isobutane falls in this category and has been suitable for domestic refrigeration. They are non-poisonous, but are flammable and highly explosive when exposed to air. The molecular weight and boiling point of each gas varies according to the number of hydrogen and carbon atoms. The larger the number of hydrogen and carbon atoms, the heavier is the gas and higher is its boiling point.

Halocarbon Refrigerants

The halocarbon refrigerants are formed by replacing one or more of hydrogen atoms of methane or ethane by one or more atoms of the three halogens: fluorine, chlorine or bromine. Some of the refrigerants coming under this category are mentioned below:

Refrigerant R12

The refrigerant R12 is the most widely used refrigerant in the domestic and large commercial establishments. Its chemical formula is CCl_2F_2 and its boiling point is -30^{0}C at 1 bar. It is a non-flammable, non-explosive, non-irritating, non-toxic and odourless refrigerant. It remains chemically stable up to 550^0C. Also, it does not affect the material of the refrigeration system. It is available in abundance and is quite cheap. However, its use is being discontinued nowadays for its contribution to ozone depletion which will be discussed later.

Refrigerant R13

Its chemical formula is $CClF_3$. it is a non-flammable, non-toxic and stable refrigerant. It is very suitable for achieving low temperatures in a cascade refrigeration system. Its specific volume is high and therefore, it is suitable for centrifugal compressors. However, it also has a negative effect on ozone depletion.

Refrigerant R22

Its chemical formula is $CHClF_2$. it is also a non-toxic, non-flammable, non-corrosive and non-irritating refrigerant. It is the most common refrigerant for use in large refrigeration systems and is preferred to R12.

Refrigerant R114

Its chemical formula is $C_2Cl_2F_4$. Its boiling point corresponding to 1 bar is about 3^0C. It has properties very similar to those of R12 with respect to water and oil combination. It is not suitable for low temperature refrigeration since it has negative evaporator pressure even at around $9\ ^0C$. It is non-toxic, non-explosive and non-corrosive even in the presence of water.

4.7 OZONE DEPLETION AND GLOBAL WARMING POTENTIAL

An issue of growing concern for the present day environment is the impact of the various refrigerants on the ozone depletion and global warming of the environment. The main culprits in this case are the chlorine containing halogenated hydrocarbons, commonly known as chlorofluorocarbons or CFC which are being used as refrigerants.

The Earth's atmosphere is made up of various layers. The layer just above the Earth's surface is known as the troposphere. The troposphere extends up to 10 km from the surface. The ozone layer is just above the troposphere and located in the stratosphere. The stratospheric ozone is Earth's natural protection to harmful ultraviolet (UV) radiation from the sun. UV radiation is harmful to human, plant and animal life. The ozone layer gets depleted by the action of these refrigerants.

CFCs, when they are released from the surface of the Earth, rise slowly into the stratosphere. Here they are bombarded by the incoming UV light from the Sun, which releases the chlorine atoms from the parent compound. It is this chlorine atom which reacts with the ozone molecules. The detailed reactions are given below:

Chlorofluorocarbon Irradiated with UV light $\rightarrow$ free Cl

$Cl + O_3$ $ClO + O_2$

$ClO + O \rightarrow Cl + O_2$

The free chlorine atom can again take part in the reaction with another ozone atom. A single chlorine atom, released by the action of UV radiation on CFCs, can catalytically destroy tens of thousands of ozone molecules during its residence in the stratosphere Figure 4.4.

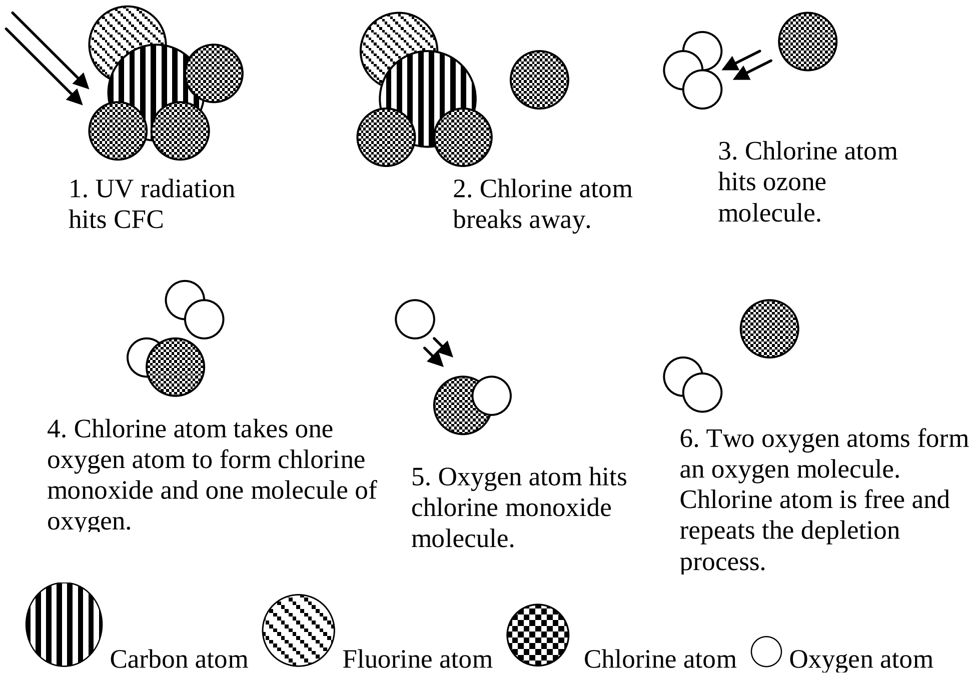

Figure 4.4. Graphical Representation of the Reactions Involved in Ozone Depletion

Ozone depletion will permit UV rays to reach earth which can result in several harmful effects on living creatures. The UV radiation can cause skin cancer, cataracts and destruction of the body's immune system.

Along with ozone depletion, CFC refrigerants also contribute to a large extent in the global warming of the planet. These gases create a greenhouse effect which traps the heat in the lower atmosphere. This makes the Earth warmer because the green house gases do not allow infrared radiation to pas through tem. The earth emits IR rays during its cooling when sun is not there. CO_2 is the most important green house gas but one molecule of CFC has warming potential which is more than 1000 times the warming potential of one molecule of CO_2. Sun's rays are allowed into the lower atmosphere, but the heat from these rays is not allowed to escape.

The "Montreal Protocol on Substances that Deplete the Ozone Layer" signed in 1987 by several countries stipulates the gradual phase-out of CFC refrigerants. Use of HCFC refrigerant is advocated as an interim measure, but even these are to be eventually phased out. This therefore necessitates the need for new refrigerants which can atleast perform as well as the refrigerants they replace without harming the atmosphere. Based on this requirement, HFC 134a emerges as the refrigerant of the future.

4.8 SECONDARY REFRIGERANTS

In some refrigeration systems, the refrigerant is not put into direct use. This is done mainly out of safety considerations. As an example, it is not desirable to use toxic refrigerants like ammonia in home air- conditioning and home refrigeration systems. Also, in some cases the size of the refrigerated space may be so large that direct refrigeration may be uneconomical. In such case, an indirect way is employed. The refrigerants used in this way do not pass through the cyclic process and are referred to as secondary refrigerants. The refrigerants commonly used in this way are water and brine solutions of calcium or sodium. This therefore allows the use of a smaller size refrigerator with a considerably less amount of refrigerant. Also, since the refrigerant does not come in direct contact, cheaper grade materials can be used for the heat exchanger.

Due to its toxicity, ammonia cannot be used as a refrigerant in residential air conditioners. Therefore, the usual practice is to chill brine over the evaporator coil and then air is cooled by passing over the brine coil. This method eliminates the dangers of toxification on account of ammonia leakage into the air streams.

Sodium chloride brine solutions are most common up to – 15 ^{0}C while calcium chloride brine solutions can be used up to – 50 ^{0}C. However, these solutions are very corrosive to metals such as brass, copper and aluminium. In place of them, sometimes certain chemicals known as antifreeze are used with water to prevent clogging.

4.9 ILLUSTRATIVE PROBLEMS

A refrigerator is to be designed to operate between 228 K (– 45 ^{0}C) and 273 K (0 ^{0}C). The selection is to be made out of the refrigerants: R12 and ammonia. From the data provided in the table below, calculate the following: a) COP, b) power per ton, c) compression ratio, d) working pressure of condenser and evaporator and e) compression temperature.

Refrigerants	**Sat. temp.(^{0}C)**	**Sat. pressure(bar)**	**h_f (kJ/kg)**	**h_g (kJ/kg)**	**s_f (kJ/kgK)**	**s_g (kJ/kgK)**	**c_{pg} (kJ/kgK)**
R12	– 45	0.505	– 4.4	167.84	0.0190	0.7360	------
	0	3.09	36.15	188.69	0.1420	0.7008	0.62
Ammonia	– 40	0.535	– 22.4	1378.76	0.0961	6.0475	------
	0	4.242	180.88	1443.34	0.7139	5.3368	2.72

Solution

Referring to the T-s diagram given below (Figure 4.5), it can be seen:

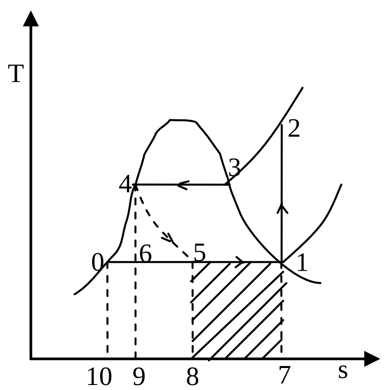

Figure 4.5. T-*S* Diagram of the Problem

R12 (dichlorodifluoromethane)

$$s_1 = 0.7360 = s_2 = s_3 + c_p \ln\left(\frac{T_2}{T_3}\right) = 0.7008 + 0.62 \ln\left(\frac{T_2}{273}\right)$$

$$i.e. T_2 = 288.95K$$

Then,

$$h_2 = h_3 + c_p \left(T_2 - T_3\right) = 188.69 + 0.62(288.95 - 273)$$
$$i.e. h_2 = 198.58 \, \text{kJ/kg}$$

(a) $\text{COP} = (h_1 - h_4) \big/ (h_2 - h_1) = \dfrac{167.84\text{-}36.15}{198.58\text{-}167.84} = 4.284$

(b) Power per ton is given by: $3.5/\text{COP} = 0.8169\text{kW}$

R717 (Ammonia)

$$s_1 = 6.0475 = s_2 = s_3 + c_p \ln\left(\frac{T_2}{T_3}\right) = 5.3368 + 2.72 \ln\left(\frac{T_2}{273}\right)$$

$$i.e. T_2 = 354.52\text{K}$$

Then,

$$h_2 = h_3 + c_p \left(T_2 - T_3\right) = 1443.34 + 2.72(354.52 - 273)$$
$$i.e. h_2 = 1665.07 \, \text{kJ/kg}$$

(a) $\text{COP} = (h_1 - h_4) \big/ (h_2 - h_1) = \dfrac{1378.76\text{-}180.00}{1665.07\text{-}1378.76} = 4.184$

(b) Power per ton is given by: $3.5/\text{COP} = 0.8365\text{kW}$

The table for the comparison of the above refrigerants is presented below:

Refrigerants	**COP**	**Power per ton**	**Compression pressure (p_2/p_1)**	**Comp. Temp**		**Compression pressure (bar)**	**Evaporator pressure (bar)**
				K	**^{0}C**		
R12	4.284	817	6.19	288.95	15.95	3.09	0.505
Ammonia	4.184	837	7.93	354.52	81.52	4.22	0.535

From the tabular values, we can see that from the view of power consumption, R12 is better than ammonia. But, it gives negative evaporator pressure which is less than the atmospheric pressure. Ammonia, too suffers from the same problem. Also, we can see that the difference in COP and power consumption of ammonia and R12 is not very much. However, since ammonia is toxic, its use is very restricted. R12 is widely used in home refrigeration systems. The problem of negative evaporator pressures is overcome by employing a *hermetically sealed compressor* which prevents the leakage of air into the evaporator.

4.10 SUMMARY

Here, in this chapter we have undertaken a detailed and complete study of the various refrigerants used in the home air-conditioning and refrigeration systems as well as those used in industrial refrigeration systems.

We have learnt the basis of nomenclature of the various refrigerants. This nomenclature allows us to easily identify each and every refrigerant available in the market today.

In the preceding sections, we have studied the thermal, physical and chemical characteristics which an ideal refrigerant should posses. We have also studied the actual thermal, chemical and physical properties of some of the common refrigerants available commercially. From our discussion, we have realised that no refrigerant satisfies fully the characteristics of an ideal refrigerant. Hence, we have to make an informed choice about the refrigerant we will use depending upon the purpose of the refrigeration system.

The field of refrigeration and air-conditioning has undergone tremendous changes in the last century. More and more new refrigerants having improved properties are being produced globally. Research in this field is now directed towards producing better environment friendly refrigerants and in replacing old refrigeration systems using halogenated refrigerants with the newer ones. We can be sure that in the future, refrigerants will be produced which will not only match the performance characteristics of the present day refrigerants, but also surpass them. And all this will be done without causing any destructive effect upon the environment.

4.11 ANSWERS TO SAQs

Refer the relevant preceding texts in the unit or other useful books on the topic listed in the section “Further Readings” to get the answers of the SAQs.