

Vapour Absorption Refrigeration Systems



7.1 Introduction

The vapour absorption refrigeration system is one of the oldest methods of producing refrigerating effect. The principle of vapour absorption was first discovered by Michael Faraday in 1824 while performing a set of experiments to liquify certain gases. The first vapour absorption refrigeration machine was developed by a French scientist, Ferdinand Carre, in 1860. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant, commonly used in a vapour absorption system, is ammonia.

The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the

1. Introduction.
2. Simple Vapour Absorption System.
3. Practical Vapour Absorption System.
4. Thermodynamic Requirements of Refrigerant-Absorbent Mixture.
5. Properties of Ideal Refrigerant-Absorbent Combination.
6. Comparison of Refrigerant-Liquid Absorbent Combination (say NH_3 -water) with Refrigerant-Solid Absorbent Combination (say $\text{NH}_3\text{-CaCl}_2$).
7. Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System.
8. Coefficient of Performance of an Ideal Vapour Absorption Refrigeration System.
9. Domestic Electrolux (Ammonia-Hydrogen) Refrigerator.
10. Lithium Bromide Absorption Refrigeration System.

conditions of the refrigerant required for the operation of the refrigeration cycle. We have discussed in the previous chapters that the function of a compressor, in a vapour compression system, is to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapours can reject heat in the condenser. The liquid refrigerant leaving the condenser is now ready to expand to the evaporator conditions again.

In the vapour absorption system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. These components in vapour absorption system perform the same function as that of a compressor in vapour compression system. In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquified. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

7.2 Simple Vapour Absorption System

The simple vapour absorption system, as shown in Fig. 7.1, consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.

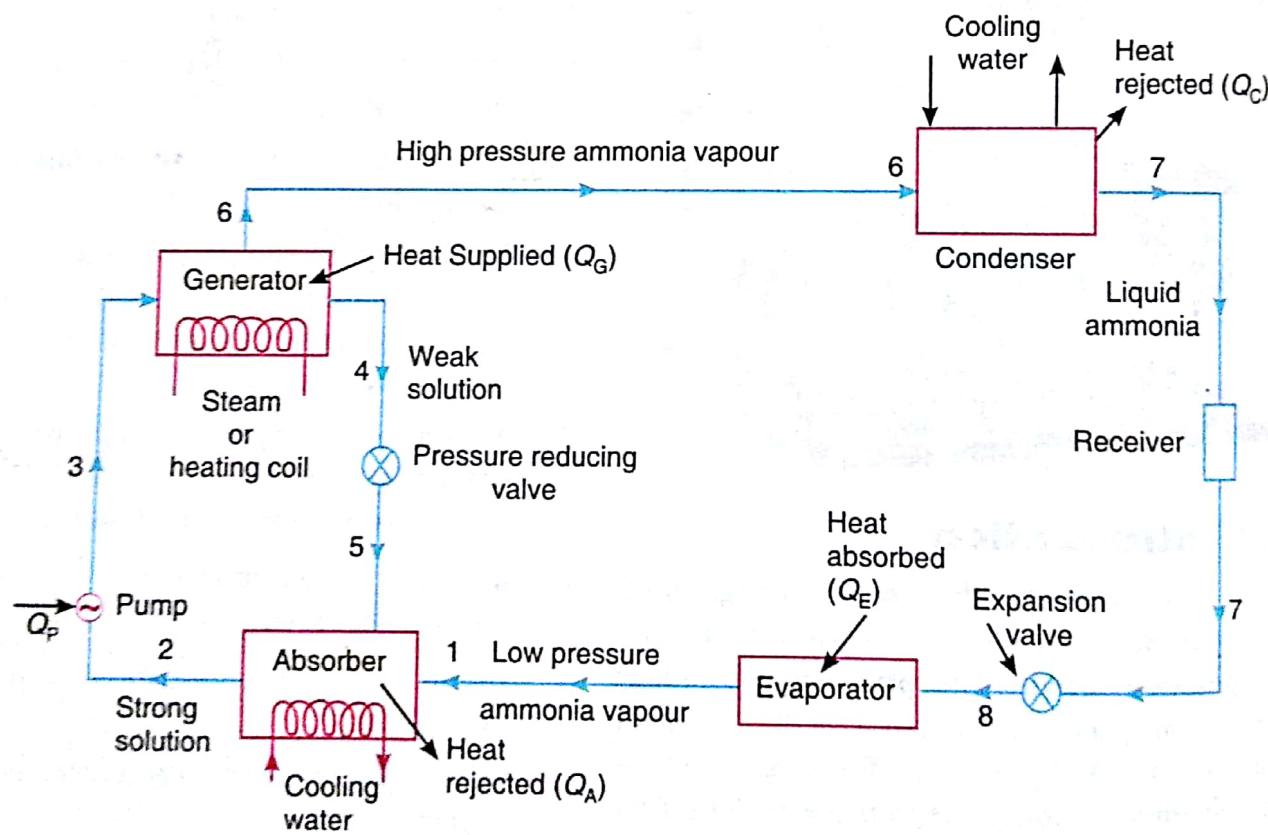
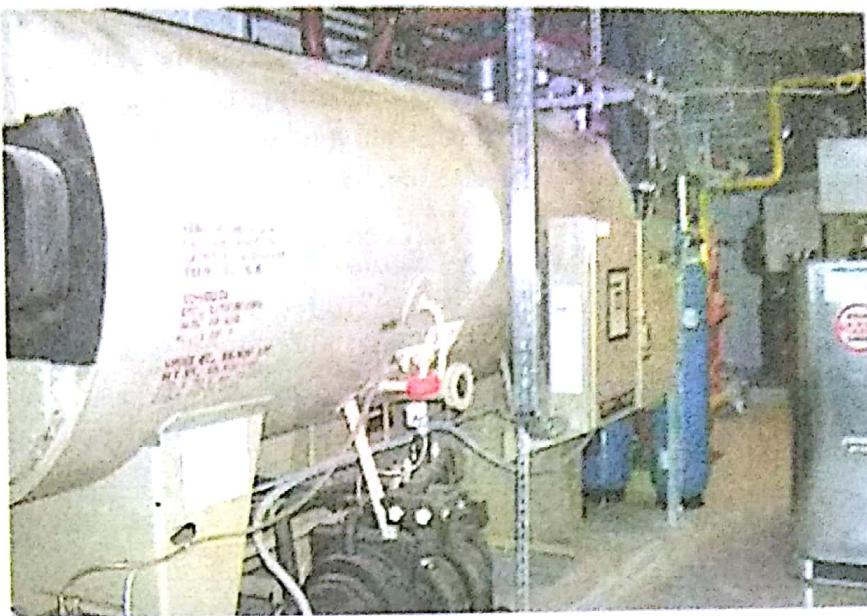


Fig. 7.1. Simple vapour absorption system.

In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb very large quantities of ammonia vapour and the solution, thus formed, is known as *aqua-ammonia*. The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved there. This is necessary in order to increase the absorption capacity of water.

because at higher temperature water absorbs less ammonia vapour. The strong solution thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution up to 10 bar.

The *strong solution of ammonia in the generator is heated by some external source such as gas or steam. During the heating process, the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator. This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia. This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This completes the simple vapour absorption cycle.



Simple vapour absorption machine.

7.3 Practical Vapour Absorption System

The simple absorption system as discussed in the previous article is not very economical. In order to make the system more practical, it is fitted with an analyser, a rectifier and two heat exchangers as shown in Fig. 7.2. These accessories help to improve the performance and working of the plant, as discussed below :

1. Analyser. When ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser along with the ammonia vapours in the simple system. If these unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze and choke the pipeline. In order to remove these unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of the generator or made as a separate piece of equipment. It consists of a series of trays mounted above the generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. In this way, considerable liquid surface area is exposed to the vapour rising from the generator. The vapour is cooled and most of the water vapour condenses, so that mainly ammonia vapour (approximately 99%) leaves the top of the analyser. Since the aqua is heated by the vapour, less external heat is required in the generator.

2. Rectifier. In case the water vapours are not completely removed in the analyser, a closed type vapour cooler called rectifier (also known as dehydrator) is used. It is generally water cooled and may be of the double pipe, shell and coil or shell and tube type. Its function is to cool further the ammonia vapours leaving the analyser so that the remaining water vapours are condensed. Thus, only dry or anhydrous ammonia vapours flow to the condenser. The condensate from the rectifier is returned to the top of the analyser by a drip return pipe.

* A strong ammonia solution contains as much ammonia as possible whereas a weak ammonia solution contains considerably less ammonia.

3. Heat exchangers. The heat exchanger provided between the pump and the generator is used to cool the weak hot solution returning from the generator to the absorber. The heat removed from the weak solution raises the temperature of the strong solution leaving the pump and going to analyser and generator. This operation reduces the heat supplied to the generator and the amount of cooling required for the absorber. Thus the economy of the plant increases.

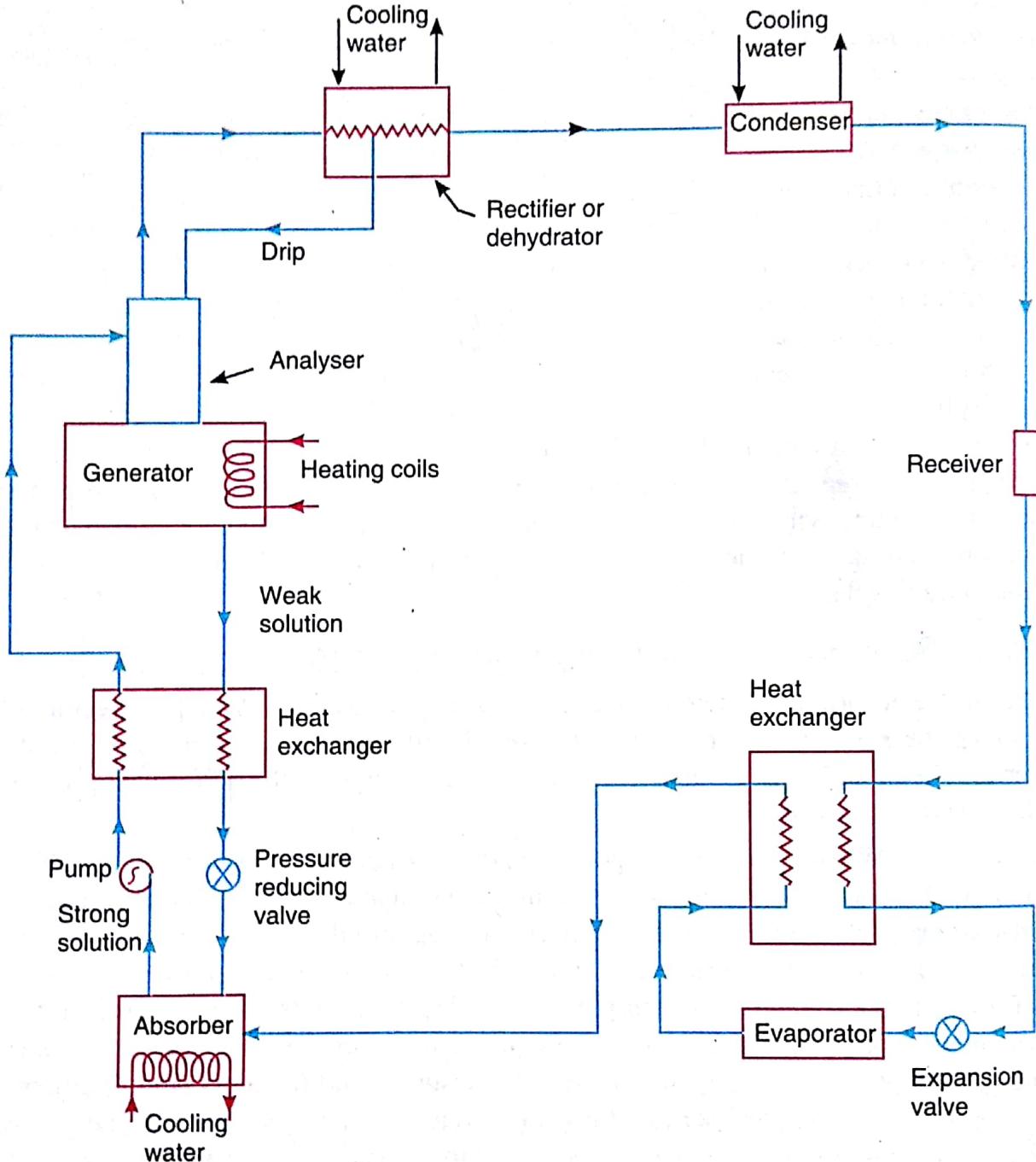


Fig. 7.2

The heat exchanger provided between the condenser and the evaporator may also be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub-cooled by the low temperature ammonia vapour from the evaporator as shown in Fig. 7.2. This sub-cooled liquid is now passed to the expansion valve and then to the evaporator.

In this system, the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the sum of work done by the pump and the heat supplied in the generator. Therefore, the coefficient of performance of the system is given by

$$\text{C.O.P.} = \frac{\text{Heat absorbed in evaporator}}{\text{Work done by pump} + \text{Heat supplied in generator}}$$

7.4 Thermodynamic Requirements of Refrigerant-Absorbent Mixture

The two main thermodynamic requirements of the refrigerant-absorbent mixture are as follows :

1. *Solubility requirement.* The refrigerant should have more than Raoult's law solubility in the absorbent so that a strong solution, highly rich in the refrigerant, is formed in the absorber by the absorption of the refrigerant vapour.

2. *Boiling points requirement.* There should be a large difference in the normal boiling points of the two substances, at least 200°C , so that the absorbent exerts negligible vapour pressure at the generator temperature. Thus, almost absorbent-free refrigerant is boiled off from the generator and the absorbent alone returns to the absorber.

In addition, the refrigerant-absorbent mixture should possess the following desirable characteristics :

- (a) It should have low viscosity to minimise pump work.
- (b) It should have low freezing point.
- (c) It should have good chemical and thermal stability.
- (d) The irreversible chemical reactions of all kinds such as decomposition, polymerization, corrosion etc. are to be avoided.

7.5 Properties of Ideal Refrigerant-Absorbent Combination

The ideal refrigerant-absorbent combination should possess the following qualities :

1. The refrigerant should have high affinity for the absorber at low temperature and less affinity at high temperature.
2. The combination should have high degree of negative deviation from Raoult's law.
3. The mixture should have low specific heat and low viscosity.
4. The mixture (solution) should be non-corrosive.
5. The mixture should have a small heat.
6. The mixture should have low freezing point.
7. There should be a large difference in normal boiling points of the refrigerants and the absorbent.

Note : Out of the many combinations tried so far, the following two combinations are in common use in air conditioning applications :

- (a) Ammonia-water combination ; and (b) Lithium-bromide water combination.

The ammonia-water absorption system finds a significant place in large tonnage industrial applications.

7.7 Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System

Following are the advantages of vapour absorption system over vapour compression system :

1. In the vapour absorption system, the only moving part of the entire system is a pump which has a small motor. Thus, the operation of this system is essentially quiet and is subjected to little wear.

The vapour compression system of the same capacity has more wear, tear and noise due to moving parts of the compressor.

2. The vapour absorption system uses heat energy to change the condition of the refrigerant from the evaporator. The vapour compression system uses mechanical energy to change the condition of the refrigerant from the evaporator.

3. The vapour absorption systems are usually designed to use steam, either at high pressure or low pressure. The exhaust steam from furnaces and solar energy may also be used. Thus this system can be used where the electric power is difficult to obtain or is very expensive.

4. The vapour absorption systems can operate at reduced evaporator pressure and temperature by increasing the steam pressure to the generator, with little decrease in capacity. But the capacity of vapour compression system drops rapidly with lowered evaporator pressure.

5. The load variations do not affect the performance of a vapour absorption system. The load variations are met by controlling the quantity of aqua circulated and the quantity of steam supplied to the generator.

The performance of a vapour compression system at partial loads is poor.

6. In the vapour absorption system, the liquid refrigerant leaving the evaporator has no bad effect on the system except that of reducing the refrigerating effect. In the vapour compression system, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.

7. The vapour absorption systems can be built in capacities well above 1000 tonnes of refrigeration each, which is the largest size for single compressor units.

8. The space requirements and automatic control requirements favour the absorption system more and more as the desired evaporator temperature drops.

7.9 Domestic Electrolux (Ammonia Hydrogen) Refrigerator

The domestic absorption type refrigerator was invented by two Swedish engineers, Carl Munters and Baltzer Von Platan, in 1925 while they were studying for their undergraduate course of Royal Institute of Technology in Stockholm. The idea was first developed by the 'Electrolux Company' of Luton, England.

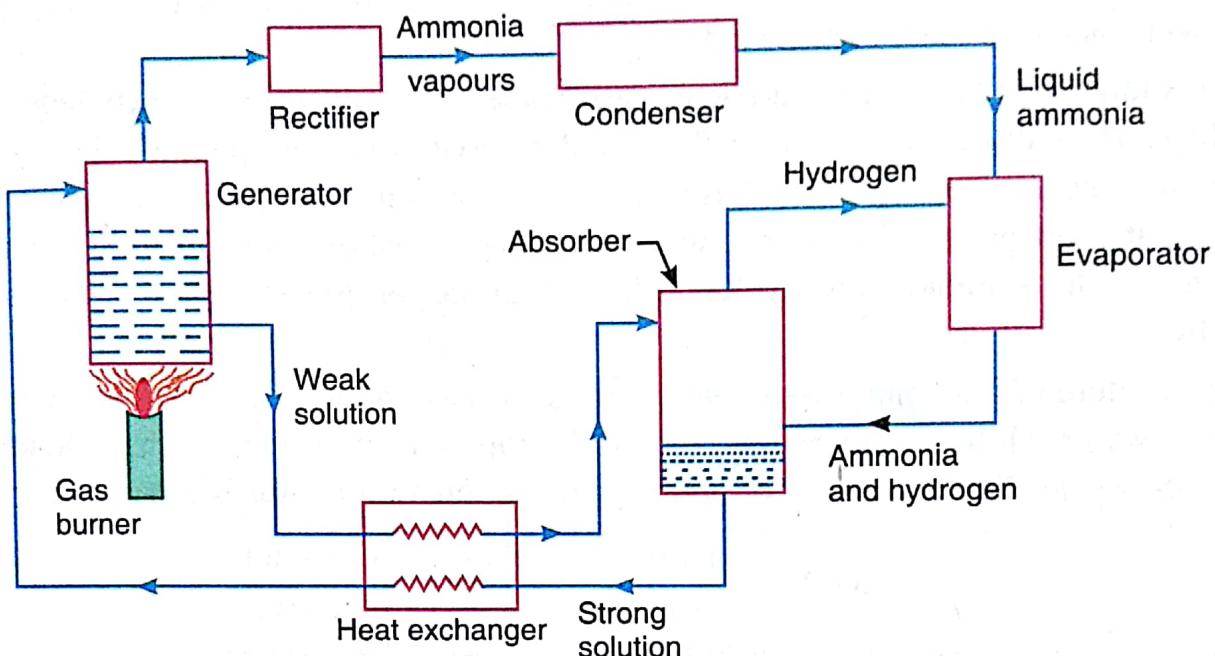
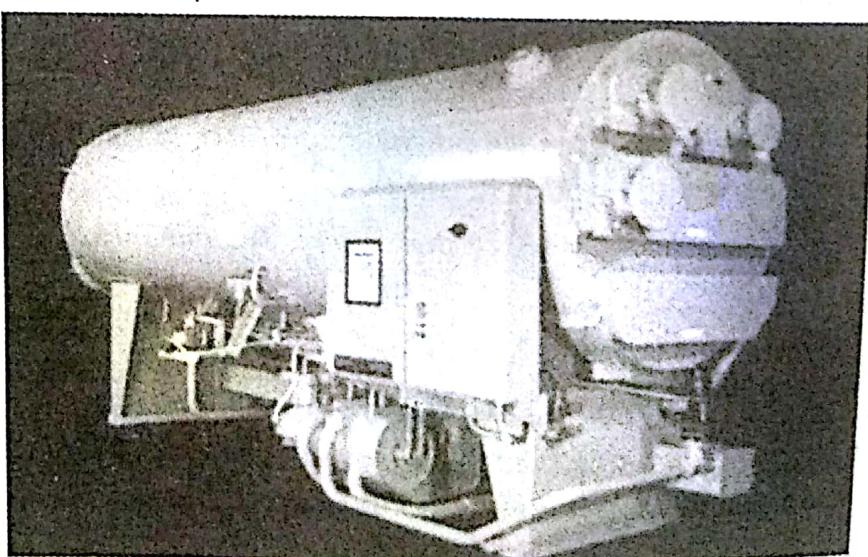


Fig. 7.5. Domestic electrolux type refrigerator.

This type of refrigerator is also called *three-fluid absorption system*. The main purpose of this system is to eliminate the pump so that in the absence of moving parts, the machine becomes noiseless. The three fluids used in this system are ammonia, hydrogen and water. The ammonia is used as a refrigerant because it possesses most of the desirable properties. It is toxic, but due to absence of moving parts, there is very little chance for the leakage and the total amount of refrigerant used is small. The hydrogen, being the lightest gas, is used to increase the rate of *evaporation of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. This is used in the low-pressure side of the system. The water is used as a solvent because it has the ability to absorb ammonia readily. The principle of operation of a domestic electrolux type refrigerator, as shown in Fig. 7.5, is discussed below :

The strong ammonia solution from the absorber through heat exchanger is heated in the generator by applying heat from an external source, usually a gas burner. During this heating process, ammonia vapours are removed from the solution and passed to the condenser. A rectifier or a water separator fitted before the condenser removes



Absorption machine.

286 ■ A Textbook of Refrigeration and Air Conditioning

water vapour carried with the ammonia vapours, so that dry ammonia vapours are supplied to the condenser. These water vapours, if not removed, will enter into the evaporator causing freezing and choking of the machine. The hot weak solution left behind in the generator flows to the absorber through the heat exchanger. This hot weak solution while passing through the exchanger is cooled. The heat removed by the weak solution is utilised in raising the temperature of strong solution passing through the heat exchanger. In this way, the absorption is accelerated and the improvement in the performance of a plant is achieved.

The ammonia vapours in the condenser are condensed by using external cooling source. The liquid refrigerant leaving the condenser flows under gravity to the evaporator where it meets the hydrogen gas. The hydrogen gas which is being fed to the evaporator permits the liquid to evaporate at a low pressure and temperature according to Dalton's principle. During the process of evaporation, the ammonia absorbs latent heat from the refrigerated space and thus produces cooling effect.

The mixture of ammonia vapour and hydrogen is passed to the absorber where ammonia is absorbed in water while the hydrogen rises to the top and flows back to the evaporator. This completes the cycle. The coefficient of performance of this refrigerator is given by :

$$\text{C.O.P.} = \frac{\text{Heat absorbed in the evaporator}}{\text{Heat supplied in the generator}}$$

- Notes :**
1. The hydrogen gas only circulates from the absorber to the evaporator and back.
 2. The whole cycle is carried out entirely by gravity flow of the refrigerant.
 3. It cannot be used for industrial purposes as the C.O.P. of the system is very low.

7.10 Lithium Bromide Absorption Refrigeration System

The lithium bromide absorption refrigeration system uses a solution of lithium bromide in water. In this system, the *water is being used as a refrigerant whereas lithium bromide, which is a highly hydroscopic salt, as an absorbent. The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure. Since lithium bromide solution is corrosive, therefore, inhibitors should be added in order to protect the metal parts of the system against corrosion. Lithium chromate is often used as a corrosion inhibitor. This system is very popular for air-conditioning in which low refrigeration temperatures (not below 0°C)** are required.

-
- * In the domestic type absorption refrigerator (discussed in the previous article), the water is being used as absorbent and the ammonia as refrigerant.
 - ** Since water is used as a refrigerant, therefore, the refrigeration temperature must be kept above the freezing point of water (0° C).

Fig. 7.7 shows a lithium bromide vapour absorption system. In this system, the absorber and the evaporator are placed in one shell which operates at the same low pressure of the system. The generator and condenser are placed in another shell which operates at the same high pressure of the system. The principle of operation of this system is discussed below :

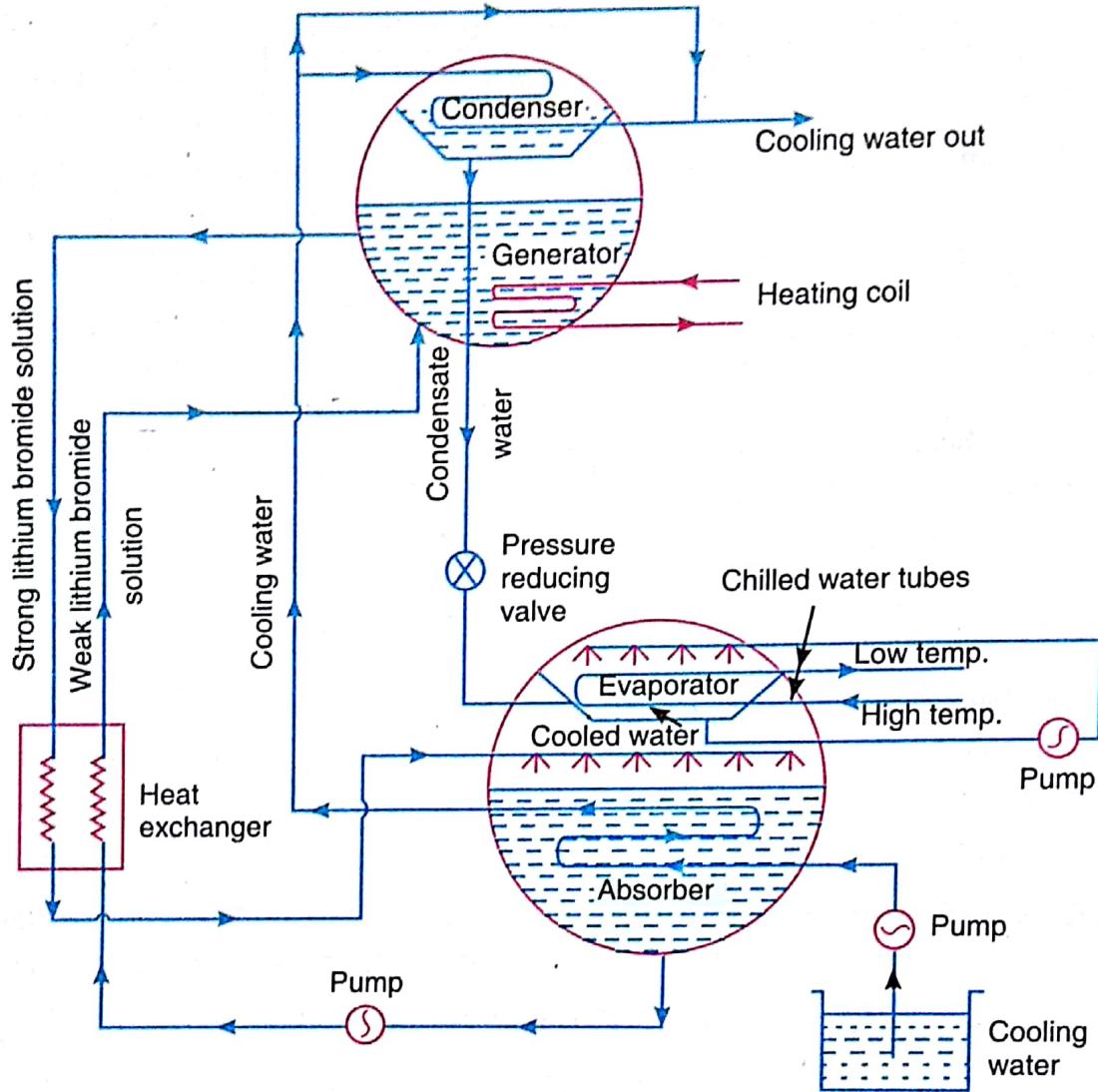


Fig. 7.7. Lithium-Bromide absorption refrigeration system.

The water for air-conditioning coils or process requirements is chilled as it is pumped through the chilled water tubes in the evaporator by giving up heat to the refrigerant water sprayed over the tubes. Since the pressure inside the evaporator is maintained very low, therefore, the refrigerant water evaporates. The water vapours thus formed will be absorbed by the strong lithium bromide solution which is sprayed in the absorber. In absorbing the water vapour, the lithium bromide solution helps in maintaining very low pressure (high vacuum) needed in the evaporator, and the solution becomes weak. This weak solution is pumped by a pump to the generator where it is heated up by using steam or hot water in the heating coils. A portion of water is evaporated by the heat and the solution now becomes more strong. This strong solution is passed through the heat exchanger and then sprayed in the absorber as discussed above. The weak solution of lithium bromide from the absorber to the generator is also passed through the heat exchanger. This weak solution gets heat from the strong solution in the heat exchanger, thus reducing the quantity of steam required to heat the weak solution in the generator.

The refrigerant water vapours formed in the generator due to heating of solution are passed to the condenser where they are cooled and condensed by the cooling water flowing through the condenser water tubes. The cooling water for condensing is pumped from the cooling water pond or tower. This cooling water first enters the absorber where it takes away the heat of condensation and dilution. The condensate from the condenser is supplied to the evaporator to compensate the

Chapter 7 : Vapour Absorption Refrigeration Systems ■ 289

water vapour formed in the evaporator. The pressure reducing valve reduces the pressure of condensate from the condenser pressure to the evaporator pressure. The cooled water from the evaporator is pumped and sprayed in the evaporator in order to cool the water for air-conditioning flowing through the chilled tubes. This completes the cycle.

Note : The pressure difference between the generator and the absorber and the gravity due to the height difference of the two shells is utilised to create the pressure for the spray.