CHAPTER II

Background of a Diffusion Absorption Refrigeration Cycle

This chapter provides a literature survey of past research on the diffusion absorption refrigeration cycle. Even though this system was invented and used for almost 70 years, very few literatures concerning this system were found.

2.1 System used as a domestic refrigerator

Figure 2.1 shows a concept of natural circulation system based on a thermo-siphon effect. Liquid in the pump tube is heated in order to generate vapor. Bubbles are formed, which float up and push the liquid up to the top. This effect is known as a concept of 'bubble pump'.

For an absorption system using ammonia/water, pressure difference between the generator and the absorber is normally high. Therefore, a bubble pump cannot directly replace a mechanical pump. To overcome this problem an inert gas is charged into the absorber and the evaporator. Then, during the operation, the pressure is equalized throughout the system. In a DAR, the entire system has a single pressure, the evaporator can produce low temperature and cooling effect by principle of the Dalton's law of partial pressure.

Figure 2.2 shows a schematic view of a diffusion absorption cycle, which is used as a domestic refrigerator. It uses ammonia as refrigerant, water as absorbent and hydrogen as auxiliary gas. At the storage tank, there is solution with concentration of 35% (ammonia 35% and water 65% by mass). This solution flows to the generator where it is heated to 180°C and some ammonia is evaporated out. The vapor forms bubbles that push columns of solution in the pump-tube up to the liquid-vapor separator. Weak solution with concentration of 10% collected at the separator returns back to the absorber via a solution heat exchanger (SHX).

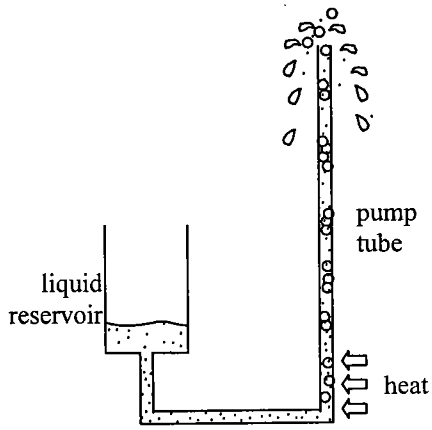

Figure 2.1 A simple set-up of a bubble-pump

The SHX allows the strong solution entering the generator to be preheated by hot solution flowing to the absorber. Using the SHX helps reduce heat input at the generator and thus increases the COP. At the separator, the vapor leaving the pump tube usually contains some quantity of water. Then, the vapor is purified at a rectifier where it is cooled down to 70°C. Water is condensed and drops back as condensate to the separator.

The pure ammonia vapor is then liquefied in the air-cooled condenser. For normal operating conditions, the system pressure is approximately 25 bar. The liquid passes to the evaporator, which is divided into two sections, a freezer and a food chiller. As the evaporator is charged with hydrogen, in the freezer the partial pressures of ammonia and hydrogen are approximately 1 and 24 bar respectively. At this condition, ammonia evaporates at -30 to -18°C. Since ammonia continues to evaporate, its partial pressure rises to 3 bar in the food chiller. This corresponds to an evaporating temperature at -5°C. The vapor is absorbed by the strong solution in the air-cooled absorber. Weak solution is then transferred to the storage tank to complete the cycle.

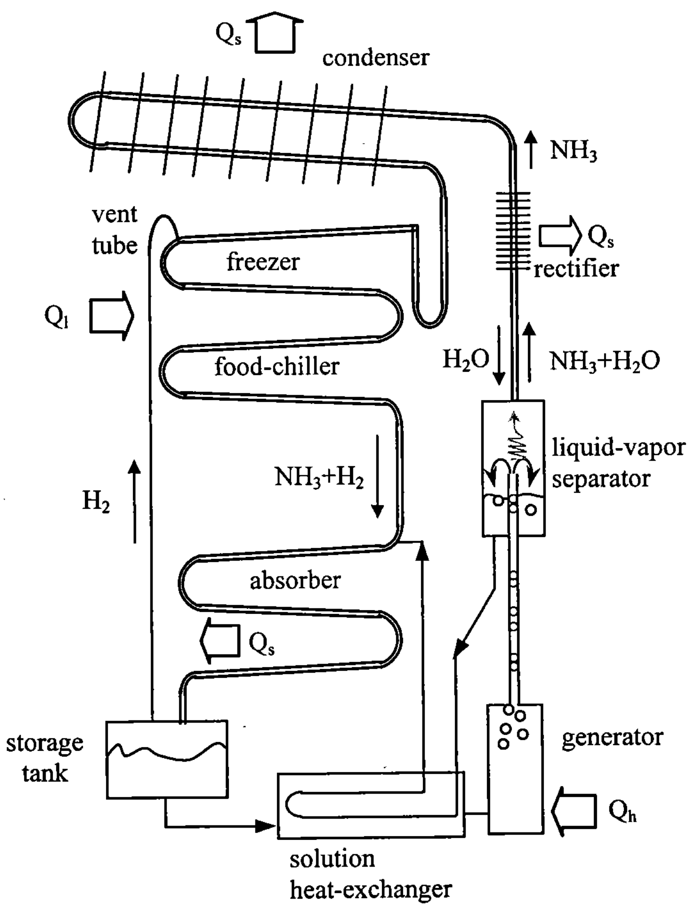

Figure 2.2 A schematic diagram of a diffusion absorption refrigeration cycle.

The density of ammonia is considerably greater than that of hydrogen. The vapor (ammonia and hydrogen) becomes heavier as ammonia is still being evaporated. Therefore, it drops from the freezer to the food chiller and enters the absorber. In the absorber, ammonia is absorbed into the solution, the vapor become lighter and thus it rises up to the top. This causes a circulation of hydrogen in the evaporator-absorber part. Hydrogen circulation affects rate of evaporation in the evaporator and absorption rate in the absorber. Hydrogen not only affects the mass transfer rate, its circulation also reduces the cooling capacity as the gas is warm when it leaves the absorber. A gas heat exchanger may be used to exchange heat between cold (evaporator exit) and warm (evaporator inlet) gases.

2.2 Literatures concerning a diffusion absorption system

The DAR was firstly invented by Platen and Munters in 1920, students at the Royal Institute of Technology, Stockholm in Sweden. However, most of the literatures found concerns improvements of the small domestic refrigerator such as redesign of the boiler, modification of traditional bubble-pump, or inclusion of the auxiliary gas heat exchanger.

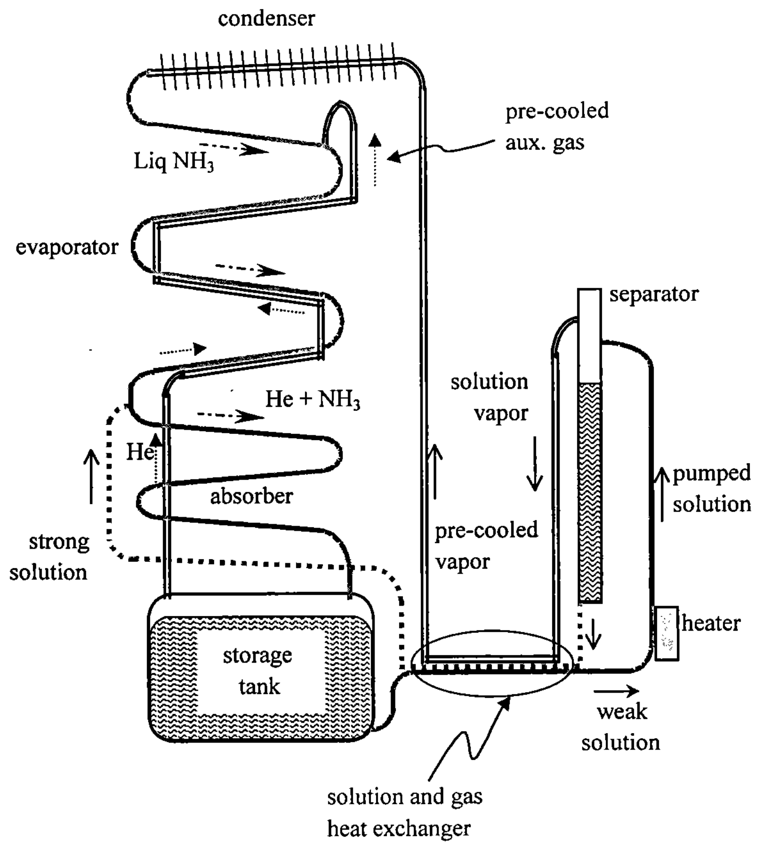

Figure 2.3 A schematic diagram of the integrated 3X-boiler DAR.

2.2.1 Development of the boiler

Normally one-third of heat input to the generator is rejected to the surroundings at the rectifier. This amount of heat could be recovered to improve the system performance. Stierlin and Ferguson [1990], designed a new generator. A solution heat exchanger and a rectifier were integrated as a single unit called 3X-boiler. The schematic diagram of the system integrated with 3X-boiler is shown in figure 2.3. It lets the three fluid streams (weak solution entering the generator, strong solution leaving the separator, and vapor leaving the separator) exchange heat with each other simultaneously. As a consequence of counter-flow heat exchange between these three fluids, the rectification heat was recovered usefully. It helps reduce the heat input to the generator. The system COP could be improved by not less than 50%. It was claimed that, a domestic refrigerator based on this design had a COP of 0.51. At surrounding temperature of 32°C, it operated at freezer and food chiller temperatures of -20°C and 5°C respectively.

2.2.2 Alteration of auxiliary gas and inclusion of gas heat exchanger

Circulation of the auxiliary gas inside the evaporator and the absorber results from density change due to the evaporation of ammonia. Hydrogen, the lowest density vapor, seems to be the most suitable auxiliary gas for a diffusion absorption system. However, hydrogen is extremely flammable. In order to exclude any possibility of explosions, hydrogen may be replaced with helium [Narayankhedkar and Maiya, 1985]. Helium is heavier than hydrogen, thus it affects circulation rate of gas circuit and mass transfer performance. However, helium has lower thermal conductivity and specific heat capacity than hydrogen, internal heat load caused by circulation of gas is reduced. Therefore, the cooling capacity and COP remains unaffected.

The auxiliary gas circulation rate was proposed to cause effect on the system performance [Watts and Gulland, 1958]. An auxiliary gas heat exchanger, GHX, was included to transfer heat from the auxiliary gas after absorption process to that before being absorbed. Some amount of heat from absorption process accumulated in the auxiliary gas was considered as internal load. This amount of heat is normally transferred to the evaporator as an internal load. Higher gas circulation rate normally increases mass transfer in the evaporator-absorber. It accelerates evaporation rate of ammonia in the evaporator.

However, it increases the internal load to the evaporator, which reduces useful refrigerating effect. It is recommended that good mass transfer surfaces and highly efficient GHX are required for enhancement of the net refrigerating effect. Eber [1975] introduced new compact heat exchangers for absorption cooling units. The heat exchanger was designed to have a compact size with cylindrical fins. It caused the GHX to have better heat transfer performance while flow resistance was minimized.

Chen et al. [1996] conducted experiments on a small commercial refrigerator. Performance was obtained based on measured heat transfer through the cabinet and electrical energy required by the generator heater. When the heater power, at the generator, was increased from a certain value, cooling capacity and COP increased rapidly due to the start up of the bubble pump. Then the COP remained constant while the cooling capacity increased as more ammonia was produced. In this range, ammonia was completely evaporated in the evaporator. If the heater power continued to increase, more ammonia was produced. However, it could not completely evaporate due to the capacity of the evaporator or the absorber. As the heat input increased while the cooling capacity remained constant, COP dropped. Similar to Stierlin and Ferguson [1990], Chen et al designed a generator for a small refrigerator. Released heat from rectification process was used to preheat the weak solution before entering the generator. It was claimed that, COP was increased from 0.2 to 0.3, a 50% increased.

2.2.3 Improvement of the bubble pump

The DAR was optimally operated within a specific operating range. Variation of heat input at the generator would stop operation of the unit intermittently. This normally happened whenever variation of the refrigerating load was required. Various designs of hydraulic trap were installed and tested with the domestic refrigerators [Sellerio, 1951].

Some designs were proposed to enhance pumping performance. Attenuation of intermittence in liquid pumping was obtained. Moreover, it could be operated with higher pumping effect. Lucus [1967] proposed a specially design boiler. It was designed to serve the system operation in both low and high input power. Therefore, the system could be operated continuously with a wider range of input power. This concept was similar to the boiler designed by Stierlin [1967], which uses the evaporator partially as the gas heat exchanger. Heat could be exchanged internally in the system. This boiler design was intended to be used in the deep-freezer absorption unit.

Performance of a bubble-pump may be defined as the pumping ratio, which is given as a ratio between volume flow rate of liquid and vapor through the pump-tube. Experimental studies using water/lithium bromide as fluid were conducted [Pfaff et al., 1998]. Pump tubes with diameter of 10, 14 an 18 mm were used. For fixed level of liquid in a reservoir and length of pump-tube, liquid flow rate increased linearly with the power input to the generator and pumping ratio was constant. The pumping ratio increased when the level of liquid in the reservoir was increased or the tube length was reduced. Pumping action was not found for 18mm tube as vapor formed small bubbles and caused the liquid to sparkle. This caused the liquid to oscillate in the tube without being lifted up. For smaller tubes, bubbles covered the whole cross section of the tube. The bubbles acted like a piston and lifted the liquid up.

2.3 Conclusion

From the literature, many researchers tried to improve performance of the diffusion absorption systems, which were used as domestic refrigerators. Most of them tried to improve the COP by reducing heat input to the generator. One notable approach was to integrate a rectifier and a solution heat exchanger together. Thus, the rectification heat could be recovered to the generator.

It must be noted that there was no attempt to design or construct a system totally different from those used as domestic refrigerators. Therefore, the effect of operating temperatures, charging of working fluid, and component design could not be clearly understood.

Although a diffusion absorption system has relatively poor COP compared with other refrigeration systems, it provides many advantages. Before a more advanced system can be developed, extensive research concerning a diffusion absorption refrigeration system is needed.