CHAPTER I

Introduction

Most industrial processes use a lot of thermal energy by burning fossil fuel to produce steam or heat for various purposes. After the processes, an amount of heat is rejected to the surrounding as waste. The waste heat can be converted to useful refrigeration by using a heat operated refrigeration system, such as an absorption refrigeration cycle. As a result electricity purchased from utility companies for conventional vapor compression refrigerators can be reduced. Moreover, the use of heat operated refrigeration systems helps reduce problems related to the global environment, such as the so called greenhouse effect from CO_2 emission from the combustion of fossil fuels in utility power plants.

Another difference between absorption systems and conventional vapor compression systems is the working fluid used. Most vapor compression systems commonly use chlorofluorocarbon refrigerants (CFCs). The use of CFCs is restricted throughout the globe due to depletion of the ozone layer. This makes absorption systems more prominent. Although absorption systems seem to provide many advantages, vapor compression systems still dominate all market sectors. In order to promote the use of absorption systems, further development is required to improve their performance and reduce cost.

The early development of an absorption cycle dated back to the 1700's. It was known that ice could be produced by evaporation of pure water from a vessel contained within an evacuated container in the presence of sulfuric acid [Herold and Radermacher, 1989]. As the acid absorbed water vapor, causing a reduction of temperature, layers of ice were formed on the water surface. The major problems of this system were corrosion and leakage of air into the vacuum vessel. In 1859, Ferdinand Carre′ introduced a novel machine using water/ammonia as the working fluid. This machine shown in Figure 1.1 was granted a US patent in 1860 [Gosney, 1982]. Machines based on this patent were used to make ice and store food. It was used as a basic design in the early age of refrigeration development.

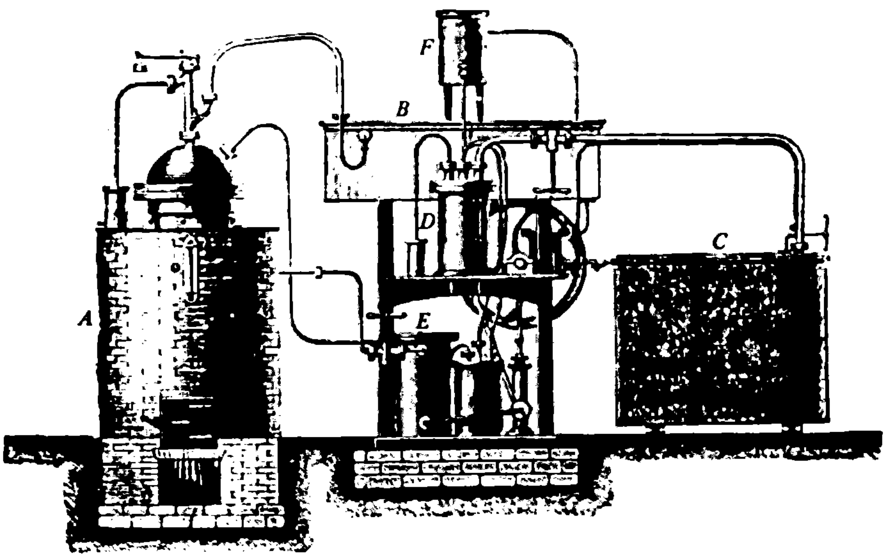

Figure 1.1 Carre′ continuous absorption machine. A : boiler, B : condenser C : evaporator D : absorber E : solution heat exchanger and F : header tank for cooling water (Gosney, 1982).

In 1950's, a system using lithium-bromide/water as the working fluid was introduced for industrial applications. A few years later, a double-effect absorption system was introduced and has been used as an industrial standard for a high performance heat-operated refrigeration cycle. Various types of absorption refrigeration cycles have been discussed in literature [Srikhirin et al., 2001; Eames and Aphornratana, 1993].

Considering a system containing two vessels connected to each other as shown in Figure 1.2. Inside the left vessel, there is liquid refrigerant. The other vessel contains a binary solution of absorbent/refrigerant. The solution in the right vessel will absorb refrigerant vapor from the left vessel. While the refrigerant vapor is being absorbed, the temperature of the remaining refrigerant will reduce as a result of its vaporization.

Refrigeration effect occurs inside the left vessel. At the same time the solution inside the right vessel becomes more diluted because of the higher content of absorbed refrigerant. This is called "absorption process".

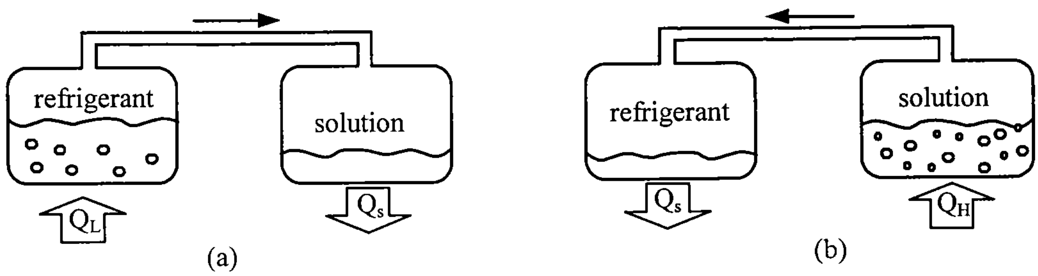

Figure 1.2 a) absorption process and b) refrigerant separation process.

On the other hand, when the refrigerant is absorbed until the solution cannot continue the absorption process, it must be separated out from the diluted solution. Heat is the key of the separation process. It is applied to the right vessel in order to expel the refrigerant from the solution. Transferring heat to the surroundings causes condensation of the refrigerant vapor. With these processes, the refrigeration effect can be produced using thermal energy. However, this cannot be done continuously as the process cannot be done simultaneously. Therefore, an absorption refrigeration cycle is a combination of these two processes as shown in Figure 1.3. As the separation process occurs at a higher pressure than the absorption process, a circulation pump is required to circulate the solution. Coefficient of Performance of an absorption refrigeration system is obtained from;

$$COP = \frac{\text{cooling capacity obtained at evaporator}}{\text{heat input for the generator} + \text{work input for the pump}} \qquad (1.1)$$

The work input for the pump is negligible relative to the heat input at the generator, therefore, the pump work is often neglected in the analysis.

Using heat as primary energy input, a simple vapor absorption cycle has a relatively low COP comparing with the vapor compression cycle. Even the prime energy for the absorption system is in a form of heat, electricity still being required to drive a circulation pump. However, there is a type of absorption cycle that does not require any circulation pump. In such a system, working fluid is circulated by the thermo-siphon effect known as a bubble pump. The noted examples are water chillers manufactured by Yazaki and domestic refrigerators manufactured by Electrolux.

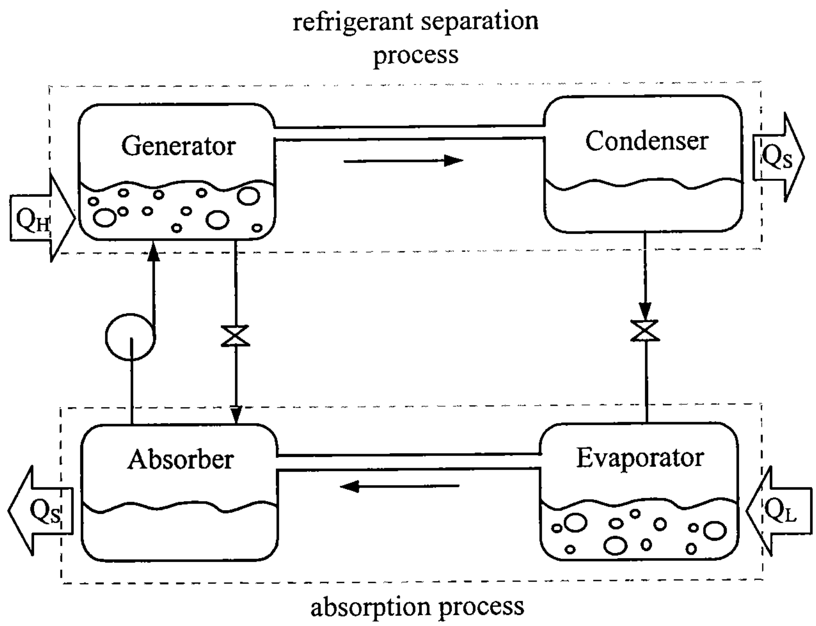

Figure 1.3 Vapor absorption refrigeration cycle.

Yazaki Inc. of Japan introduced a self-circulating absorption refrigeration system based on a single-effect system using lithium-bromide/water. Using water as a refrigerant, differential pressure between the condenser and the evaporator is very low and can be maintained by using the principle of hydrostatic head. Solution from the absorber can be circulated through the generator by a bubble pump. The weak refrigerant solution returns gravitationally back to absorber. A schematic diagram of this system is shown in Figure 1.4. With the effect of bubble pump, the solution is boiled and pumped simultaneously.

As water is the refrigerant, the cooling temperature is limited to be above freezing point (0°C). The entire system is operated under vacuum condition, therefore leak of air into the system is not easy to avoid. The system requires cooling water for its condenser and absorber in order to prevent crystallization of lithium-bromide.

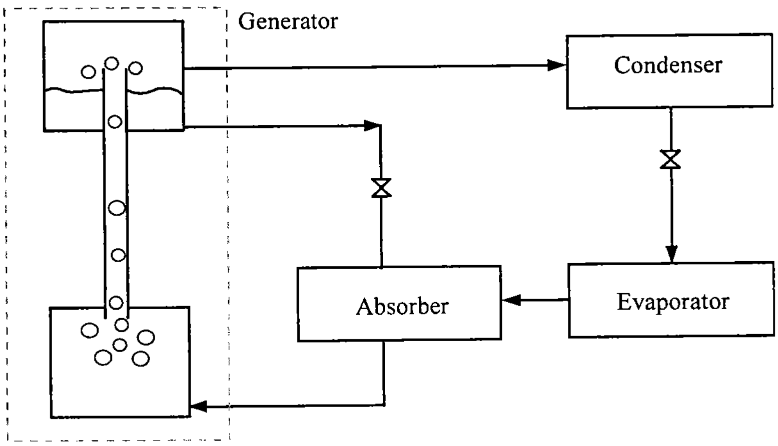

Figure 1.4 A schematic diagram of the Yazaki system vapor absorption cycle.

The Electrolux system is generally known as a Diffusion Absorption Refrigeration (DAR) system. Figure 1.5 shows a schematic diagram of a domestic refrigerator. The DAR is a type of self-circulating absorption system using water/ammonia. As ammonia is the working fluid, differential pressure between the condenser and the evaporator is too large to be overcome by a bubble pump. An auxiliary gas is charged into the evaporator and the absorber. There is no pressure differential in the system making use of the bubble pump possible. The obtained cooling effect is based on Dalton's principle of partial pressure. Because the auxiliary gas is charged into the evaporator and the absorber, the partial pressure of ammonia in both evaporator and absorber is kept low enough to correspond with the temperature required inside the evaporator. The auxiliary gas should be noncondensable such as hydrogen or helium.

The DAR can operate without any use of electrical and mechanical energy. As there is no moving part, system maintenance, noise, and vibration are at minimum. This system has been used for more than 70 years. Millions of such refrigerators have been built and are used mainly in domestic applications and for use in camping and caravans. They can be powered by kerosene or liquid petroleum gas. Electrically powered units are also available, which are suitable for quiet places such as hotel rooms.

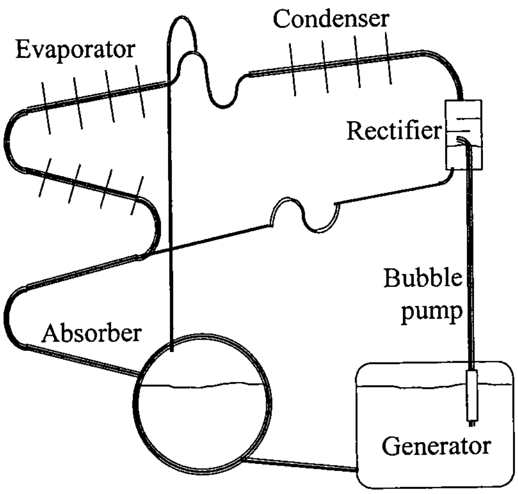

Figure 1.5 A schematic diagram of DAR.

Even though this system has been used for a long time, its application is limited to small refrigerators only. Its efficiency is relatively poor. Normally, a refrigerator based on this system provides cooling capacity up to 200 W with COP of 0.2. There have been many attempts to enhance the system performance. However, those researches were carried out with commercially designed refrigerators that were specifically designed as air-cooled systems.

The operation of the DAR is simple but its characteristics are not. To study the DAR characteristics, an experimental refrigerator based on the Platen-Munters cycle was designed and fabricated. It was designed so that later modifications could be done conveniently. Knowing that hydrogen can cause explosion if leaks, in this study helium was selected as the auxiliary gas instead of hydrogen for safety reason. The experimental refrigerator was tested under various operating conditions. A simple mathematical model was also developed. The experimental and calculated results were compared.

This thesis describes and evaluates both theoretical and experimental studies of a diffusion absorption refrigerator (DAR). Reviews of study in the field of vapor absorption system and DAR in the past are included in chapter 2. An experimental set-up was constructed with the details of construction, which are described in chapter 3. The bubble pump is considered as fundamental to the DAR, it was studied and is presented in chapter 4. A simple set-up was constructed for studying some characteristics of the bubble pump. A curve fitted equation of a bubble pump having similar dimensions as that used in the experimental DAR was obtained. A mathematical model was developed and used as a primary tool for analysis of the experimental DAR. The mathematical model concepts are explained in chapter 5. Actual performances of the experimental DAR are presented in chapter 6. The experimental and the calculated results are also compared and discussed. Discussions of system improvement are included in chapter 7. The system was analyzed theoretically. Some options are proposed as alternatives for system improvements. The last chapter, chapter 8, is conclusions of this study and recommendations for future study.