THERMODYNAMIC ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM (ARS)

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ABSTRACT

Absorption refrigeration system (ARS) continuously shows a growing interest in many applications due to cheap energy consumption and environmental friendly system. Typically, ARS system uses ammonia-water mixture where ammonia as refrigerant and water as absorbent. The system also consist hydrogen as auxiliary inert gas. While in this research, it is operated by using liquefied petroleum gas (LPG) and electricity as sources of heat. From the various publications recently, despite the ARS system attract many interests, it is still need to further analyze system's thermodynamic for better process understanding and improvement. Hence, the purpose of this research are to investigate thermodynamically the Coefficient of Performance (COP), Carnot Coefficient or heat transfer rate (COP_C), Efficiency Ratio (δ) and exergy loss of each component in the system. Temperature surrounding is important data in this research are measured to determine all of the thermodynamic analysis highlighted using published equations. From the results, it is found that the ARS using LPG is higher of about 18 percent compared to electricity where surrounding temperature is the lowest which is during morning condition. Electricity supplied to the ARS in the case at 5 for the thermostat reading. The result of COP_C is basically follow COP's results in all cases. For efficiency ratio (δ), which a comparative efficiency between COP and COP_C show that the higher the value, the better process performance or the closer to the ideal value. Finally, exergy loss for both heat sources found to be highest value of 283185.2 kJ/g at evaporator as compared to other equipment in the ARS system. In conclusion, the higher COP and COP_C can be obtained in the system is by using LPG as a heat source instead of using the electricity with the thermostat in the morning condition. This is because the LPG provides direct heating to the boiler and less resistance occurs during the process as compared to electricity and also due to the fact that thermal load are low during morning condition. As a result, cooling effect from ARS is better for the lower surrounding temperature. Exegy loss is found to be higher in evaporator by

using LPG instead of electricity. It is recommended that renewable energy such as biomass and solar energy as a heat sources to the ARS system. This is because this energy is already available and can be utilised for better thermodynamic efficiency of any ARS application. Besides that, costing and economic analysis need to be addressed in order to make a quantitatively measure the energy saving and cost reduction.

ABSTRAK

Penyerapan sistem pendinginan (ARS) telah menunjukkan minat yang tumbuh dalam pelbagai aplikasi kerana penggunaan tenaga murah dan system yang tidak membahayakan alam sekitar. Biasanya, ARS ini menggunakan system campuran ammonia-air di mana ammonia sebagai bahan penyejuk dan air sebagai absorben. Sistem ini terdiri daripada hidrogen sebagai gas pembantu tetapi tidak bertindak balas dengan mana-mana pihak. Sistem ini beroperasi dengan menggunakan bahan api gas cair (LPG) dan elektrik.sebagai sumber pemanas. Dari pelbagai penerbitan baru baru ini, walaupun sistem ARS ini menarik minat ramai orang tetapi ia masih memerlukan pemahaman yang lanjut menganalisa sistem termodinamik untuk proses yang lebih baik dan perbaikannya. Oleh itu, tujuan kajian ini adalah untuk mengkaji termodinamik koefisien Prestasi (COP), Carnot koefisien atau perpindahan panas (COP_C), Efisiensi Nisbah (δ) dan kehilangan exergy pada setiap komponen dalam sistem. Suhu persekitaran adalah data yang penting dalam kajian ini digunakan untuk menentukan semua temodinamik analisis yang menggunakan persamaan yang diterbitan. Dari hasil kajian, telah didapati bahawa ARS yang menggunakan LPG lebih kurang 18 peratus lebih tinggi berbanding dengan menggunakan elektrik dimana suhu persekitaran adalah rendah pada sebelah pagi. Elektrik dengan termostat 5 menyediakan kuasa ke ARS. Keputusan COP_C pada dasarnya adalah berdasarkan COP. Bagi nisbah kecekapan (δ) di mana perbandingan COP dan COP_C telah menunjukan bahawa semakin nilai, prestasi proses yang lebih baik atau lebih dekat kepada ideal akan diperolehi. Akhirnya, kehilangan exergy untuk kedua-dua sumber pemanas telah didapati nilai yang tertinggi 283185.2kJ/g pada evaporator berbanding terhadap komponen sistem lain dalam ARS. Sebagai kesimpulan, COP dan COP_C yang lebih tinggi di sistem adalah dengan menggunakan LPG sebagai sumber pemanas daripada menggunakan elektrik dengan termostat pada sebelah pagi. Ini disebabkan LPG mengguankan pebakaran secara langung ke sistem tanpa melalui rintangan dan beban terma yang rendah

berlaku pada sebelah pagi. Kesannya, pendinginan dari ARS adalah lebih baik untuk suhu sekitar yang lebih rendah. Kehilangan exergy yang tinggi boleh didapati di evaporator dengan menggunakan LPG berbanding dengan elektrik. Cadangan yang diberi adalah mengesyorkan bahawa tenaga boleh diperbaharui seperti biojisim dan tenaga suria digunakan sebagai sumber pemanas kepada system ARS. Hal ini kerana tenaga ini sudah wujud dan boleh dimanfaatkan untuk kecekapan termodinamik system ARS. Selain itu, kos dan analisis ekonomi perlu ditujukan untuk membuat kuantitatif mengetahui pengurangan dalam kos dan penjimatan tenaga.

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LIST OF ABBREVIATIONS

ARS	-	Absorption refrigeration system
R22	-	Aschlorodifluoromethane
R32	-	Difluoromethane
R124	-	2-chloro-1,1,1,2-tetrafluoroethane
R125	-	Pentafluoroethane
R134a	-	1,1,1,2-tetrafluoroethane
COP	-	Coefficient of performance
CO_2	-	Carbon dioxide
COP_c	-	Carnot coefficient of performance
°C	-	Celsius
LPG	-	Liquefied petroleum gas
NH_3-H_2O	-	Ammonia-water
Ppm	-	Part per million
SLT	-	Second law of thermodynamic
ψ	-	Exergy
ho	-	Enthalpy values of the fluid at the environmental temperature,T_0
s_0	-	Entropy values of the fluid at the environmental temperature, T_0
$\Delta\psi_B$	-	Boiler exergy
$\Delta\psi_C$	-	Condenser exergy
$\Delta\psi_E$	-	Evaporator exergy
$\Delta\psi_A$	-	Absorber exergy
Q_B	-	Heat flow rate of boiler
Q_C	-	Heat flow rate of condenser
Q_E	-	Heat flow rate of evaporator
Q_A	-	Heat flow rate of absorber
$\dot{m}_1$	-	Mass flow rate of vapor ammonia

$\dot{m}_2$	-	Mass flow rate of weak solution
$\dot{m}_3$	-	Mass flow rate of liquid ammonia
$\dot{m}_4$	-	Mass flow rate of ammonia-hydrogen
$\dot{m}_5$	-	Mass flow rate of gas hydrogen
$\dot{m}_6$	-	Mass flow rate of strong solution
T_0	-	Temperature of the environment
T_B	-	Temperature of boiler
T_E	-	Temperature of evaporator
T_C	-	Temperature condenser
T_L	-	Temperature of evaporator
T_C	-	Temperature condenser
T_s	-	Temperature of heat source
x_w	-	Weak solution concentration
x_s	-	Strong ammonia
NH_3-$LiNO_3$	-	Ammonia-lithium nitrate
NH_3-NaSCN	-	Ammonia-sodium thiocyanate

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Year 2009 is a very challenging year due to the global economic environment arising from the financial crisis in the US which has also affected in Europe and Asia. The international economic and financial conditions have deteriorated much more significantly. The major industrial economies are facing a recession especially manufacturing industries. Companies are trying to find an alternative way to reduce their energy consumption cost in order to increase their profit. Hence, more effort is required to find a way to improve their performance and reliability of machines that use energy such as refrigeration system in order to promote and extend their use in industrial and commercial applications (Fernandaz *et.al.*, 2005). The continuous increase in the cost and demand for energy has led to more research and development to utilize available energy resources efficiently by minimizing waste energy. It is important to note that system performance can be enhanced by reducing the irreversible losses in the system by using the principles of the second law of thermodynamics (Adewusi *et.al.*, 2003). In recent years, there has been a growing interest in the use of the principles of second law of thermodynamics for analyzing and evaluating the thermodynamic performance of thermal systems as well as their technologies. Second law analysis is based on the concept of exergy, which can be defined as a measure of work potential or quality of different forms of energy relative to environmental conditions (Kemal *et. al.*, 2004). The concept of exergy provides an estimate of the minimum theoretical resource requirement such as requirement for energy and material of a process. This provides information on the maximum savings that can be achieved by making use of new technology and new processes. New technology and new processes do not come about by themselves. By giving a deeper insight into processes, the exergy concept provides a better foundation for improvement and for calculating expected savings. As a complement to the present materials and energy balances, exergy calculations can provide increased and deeper insight into the process, as well as new unforeseen ideas for improvements (Kemal *et.al*., 2004).

Refrigeration is widely used in variety of thermal engineering application. Refrigeration is defined as the process of removal of heat from enclosed space, or from a substance, and rejecting it to elsewhere for primary purpose of lowering the temperature of the enclosed space or substances and maintaining at lower temperature. There are two general types of refrigeration system are mainly being used. These are compression refrigeration and absorption refrigeration. Compression system consists of four components: a compressor, a condenser, an expansion valve (also called a throttle valve), and an evaporator while absorption refrigeration consist of four main parts, namely the boiler or generator, condenser, evaporator and the absorber. Instead of using compressor, absorption refrigeration use generator to rise and carry the weak coolant through siphon pump when heat is supply to generator. Absorption refrigeration in this research is charged with a quantity of ammonia, water and hydrogen. It utilizes source of heat to provide the energy needed to drive the cooling process. Compression refrigeration meanwhile uses a circulation liquid refrigerant as a medium which absorb and remove the heat from the space to be cooled and subsequently reject the heat to elsewhere. It involved four processes that is isentropic compression in compressor, constant pressure heat injection in a condenser, throttling in an expansion device, constant pressure heat absorption in an evaporator

The developments in cooling systems show a growing interest in the application of absorption systems (Sencan et.al.,2005). Absorption refrigeration systems (*ARSs*) have became more attractive to the popularity when some factors such as total energy utilization and electricity demand management are considered. Besides that, ARS can be operated by using cheap alternative energy sources, such as geothermal, biomass, solar energy or a waste byproduct heat source. The waste heat can be recovered to reduce the carbon dioxide (CO_2) emissions. Therefore, in recent years, research has been done to improve of *ARSs*. The main way of improving efficiency is through thermodynamic analysis and optimization. Researches and studies also have been done to analyze energy and exergy for ARSs. These efforts are very important to ensure market competitiveness in this volatile economic environment.

1.2 Problem Statement

Previously the older refrigerator used chlorofluorocarbon as refrigerant but this gas was found harmful to the atmosphere if it leaks from refrigerators. So now, other chemicals such as tetrafluoroethane, lithium-water and ammonia-water are used system in slightly different process. In the recent year, absorption refrigeration system (ARS) is become more popular in the industry. ARS mostly consist of lithium bromide-water and ammonia-water. Lithium bromide-water cannot operate below 0^{o}C as its uses water as refrigerant. It is suitable use as air conditioning. The general premise of the absorption system is to transfer heat energy from one medium to another but the thermodynamic processes in the absorption refrigeration system release a large amount of heat. Hence, many researchers carried out the thermodynamic analysis in how to increase and optimize the system. The diffusion absorption refrigerator which consist of ammonia-water-hydrogen in the system have low coefficient of performance (COP). Hence, the researcher uses helium instead of hydrogen to improve the COP of the system. This system also use other refrigerants such aschlorodifluoromethane (R22), difluoromethane (R32), 2-chloro-1,1,1,2-tetrafluoroethane (R124), pentafluoroethane (R125) and 1,1,1,2-tetrafluoroethane (R134a) to investigate the COP. Since the previous research were emphasizing on the different types of working fluids, comparative study between different types of heat sources such as LPG and electricity is yet to be studied. Hence this research is going to analyze thermodynamically of the ARS for better process understanding improvement. The diffusion absorption refrigerator also system release a large amount of heat to environment. Hence, thermodynamic analysis such as exergy loss and COP of refrigeration need to be done to know the system's performance and heat loss to environment.

1.3 Research Objective

In this analysis, the main objective is to analyze and compare the ARS that use different types of heat sources which are LPG and electricity. This analysis focus on thermodynamic point of view and indicator such as coefficient of performance (COP), Carnot coefficient of performance (COP_C), efficiency ratio (δ) and exergy loss.

1.4 Scope of Research Work

This research was to analyze the performance of a single-stage ammonia-hydrogen-water absorption refrigeration system, RF10 (*ARS*). The equipment that will be used to conduct this research was gas absorption refrigeration system which available in FKKSA laboratory, University Malaysia Pahang. This system was charged with a quantity of ammonia, water and hydrogen. An electrical supply 240 V and LPG which contain 30% propane and 70% butane will be used to conduct in this experiment. Thermostat within the ranges of 1, 3 and 5 will be used to control the temperature of gas adsorption system by using electrical supply and LPG. Record the readings of all four temperature measurement points at regular intervals (every 5 minutes) until it become constant. After that, coefficient of performance (COP), Carnot coefficient of performance (COP_c) and efficiency ratio (δ) will be calculated base on published equations. For exergy loss calculation, a model of material and energy balance of the equipment will be constructed. Some assumption such as concentration of the ammonia is assumed to be 1 after came out from boiler used in this system to enable the system's calculation. Based on the mass and energy balance and the assumption, the exergy loss will be calculated

1.6 Significant of Research

In motivation to reduce energy consumption comparison between refrigeration and absorption refrigeration showed that the absorption refrigeration is more preferable to be used. This is because it can use alternative energy such as biomass and solar as a heat sources to operate the system. However, typical ARS shows the lower performance and need to be analyzed especially in terms of thermodynamic efficiency. As a result, better ARS system can be designed as well as better modification for improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to Adewusi and Zubair (2003), the absorption refrigeration system (ARS) is becoming more important because it can produce higher cooling capacity than vapor compression systems, and it can be powered by other sources of energy like waste heat from gas and steam turbines, sun, geothermal, biomass than electricity. Ammonia-water absorption refrigeration technology has been in existence since 1860. From the beginning, its development has been linked to periods of high energy prices (Seara and Vazquez, 2000). During the past decade, many companies are concentrating on ARSs due to increasing of energy prices and environmental impact of refrigerant. They are now doing a lot of research and development on these ARSs because the markets demand on this system is increasing dramatically. This absorption refrigeration system enable for energy saving because they can use heat energy to produce cooling, instead of electricity used by conventional vapour compression chillers. Nowadays, absorption system is become popular in many industries due to the increasing of cost and the environmental impact of generating electricity.

Industrial and domestic applications for ARS increase because of the advantages over other refrigeration system such as compression refrigeration system. This absorption refrigeration operate quietly compare to compression refrigeration which produce a lot of noise. Besides, there is no cycling loss during on-off operation while compression refrigeration produces a lot of waste heat. ARSs need a low running cost on cheap fuel such as waste heat or biomass while compression refrigeration need high cost due to electricity as energy input. It need very low maintenance costs due to no reciprocating parts but compression refrigeration system need a high maintenance costs. By using ARSs, there is no loss of efficiency at part load and we can improve the efficiency at part load. There will be loss of efficiency at part load due to fixed mechanical loss by using compression refrigeration system. There is low foundation cost is needed by using ARS due to no reciprocating parts compare to compression refrigeration system which needed high foundation costs due to reciprocating compressors. Compression refrigeration system is low services life than ARSs. There is also some limitation of ARSs because this system cannot run to too low temperature compare to compression refrigeration system. Generally, the ARSs performance of is less than compression refrigerator. Table 2.1 shows that a comparison between compression and absorption refrigeration systems.

Table 2.1: Comparison between compression and absorption refrigeration systems

Compression Systems	**Absorption Systems**
Work operated	Heat operated
High COP	Low COP
Lot of heat loss	Less heat loss
Regular maintenance required	Very low maintenance required
Higher noise	Less noise
Many moving parts	Less moving parts
Higher cost due to electricity as energy input	Cheap fuel such as waste heat or biomass

2.2 Refrigerants-Absorbent

Refrigerant-absorbent combination also called working fluid and these combinations are basically used in absorption refrigeration and heat pump. Refrigerant-absorbent are mainly come from inorganic and organic sources. Two common examples are ammonia-water and water-lithium bromide. The thermophysical properties of the refrigerant and absorbent are important to determine the cycle efficiency ARS. According to Ibrahim Dincer (2003), the most important properties of selection of working fluid are vapor pressure, solubility, density, viscosity and thermal stability. Knowledge of these properties is required to determine the other physical and chemical properties as well as parameter affecting performance, size and cost. A refrigerant-absorbent should have the property of high solubility at condition in absorber but should have low solubility at condition in generator. Besides, refrigerant and absorbent must be incapable of any non-reversible chemical action with each other within a practical temperature range, for example from -5°C to 120°C. Moreover, refrigerant-absorbent combination should have low surface tension which can influence heat transfer and absorption. This working fluid should exhibit low viscosity which can influence heat transfer and power for pumping.

Ammonia-water is most common used in ARSs. This is because ammonia is lower cost, better cycle efficiency, higher heat transfer coefficient (required smaller and low cost of heat exchanger), greater delectability in the event of leaks (Cengel and Boles, 2006). Ammonia also exhibit a lower pumping cost for liquid recirculation system, more tolerance of water contaminant and have no environmental impact such as global warming potential and green house effect. Ammonia also exhibits some disadvantages such as it is poisonous and can burn with air. It is lighter than air and the leak of ammonia can easily detect smell at a concentration far below a dangerous level. There are effects of various concentrations of ammonia to our body and health. If expose to concentration of ammonia is 500ppm or below, it will cause no permanent eye damage to even chronic exposure. Eyes and throat will be irritated if expose to 100-200 ppm and 400 ppm ammonia respectively. If we expose to 2400 ppm ammonia, it will threat to life after 30 minutes. Ammonia is major use in food refrigeration factory such as cooling fresh fruit, vegetable, meat; refrigeration of beverages and dairy product such as beer, wine milk, ice production and cheese and low temperature refrigeration in pharmaceutical and other process industries.

2.3 Exergy

Exergy is introduced by Darrieus in 1930 and Keenan in 1932 called the availability in steady flow. It is called exergy by Rant in 1956 as a special case of essergy. According to Ibrahim Dincer (2003), exergy is defined as the maximum of work which can be produced by stream of matter, heat or work as it comes to equilibrium with a references environment. It is a measure of the potential of a stream to cause change, as a consequence of not being completely stable relative to the reference environment. For the exergy analysis, the state of references environment, or references state, must be specified completely. This is commonly done by specifying the temperature, pressure and chemical composition of the references environment. Exergy is not subjected to the conservation law. Rather exergy is consumed or destroyed, due to irreversibility in any process.

Exergy is a measure of usefulness, quality or potential of a stream to cause change and effective measure of the potential of a substance to impact the environment. Exergy analysis is a method that uses the conversation of mass and conversion of energy principle together with second law of thermodynamic (SLT) for the design and analysis of refrigeration systems and application. The exergy method can be suitable for furthering the goal of more efficient energy-resource use, for it enables the locations, types and true magnitudes of waste and losses to be determined. Therefore, exergy analysis can reveal whether or not and by how much it is possible to design more efficient energy systems (Dincer, 2003). Exergy analysis can become a tool to determine the optimum working condition refrigeration system. The equations of exergy are as below:

$\psi = (h - h_0) - T_0(s - s_0)$ Equation 2.3.1

$\psi = [h(T, X) - h_0] - T_0[s(T, X) - s_0]$ Equation 2.3.2

$\Delta\psi_{B,\text{ in}} = \dot{m}_2\psi_2 + \dot{m}_1\psi_1 - \dot{m}_6\psi_6 - Q_G \left|1 - \frac{T_0}{T_B}\right|$ Equation 2.3.3

$\Delta\psi_{C,\text{ in}} = \dot{m}_3(\psi_1\text{-}\psi_3) - Q_C \left|1 - \frac{T_0}{T_C}\right|$ Equation 2.3.4

$\Delta\psi_{E,\text{ in}} = \dot{m}_4(\psi_4\text{-}\psi_3) - Q_E \left|1 - \frac{T_0}{T_E}\right|$ Equation 2.3.5

$\Delta\psi\text{A, in} = \dot{m}4\psi4 + \dot{m}2\psi2 - \dot{m}6\psi6 - \text{QA}\left|1 - \frac{\text{T0}}{\text{TA}}\right|$ Equation 2.3.6

Where:

ψ = Exergy

h_o = enthalpy values of the fluid at the environmental temperature,T_0

s_0 = entropy values of the fluid at the environmental temperature, T_0

$\Delta\psi_B$ = Boiler exergy

$\Delta\psi_C$ = Condenser exergy

$\Delta\psi_E$ = Evaporator exergy

$\Delta\psi_A$ = Absorber exergy

Q_B = Heat flow rate of boiler

Q_C = Heat flow rate of condenser

Q_E = Heat flow rate of evaporator

Q_A = Heat flow rate of absorber

$\dot{m}_1$= Mass flow rate of vapor ammonia

$\dot{m}_2$= Mass flow rate of weak solution

$\dot{m}_3$= Mass flow rate of liquid ammonia

$\dot{m}_4$= Mass flow rate of ammonia-hydrogen

$\dot{m}_5$= Mass flow rate of gas hydrogen

$\dot{m}_6$= Mass flow rate of strong solution

T_0 = Temperature of the environment

T_B = Temperature of boiler

T_E = Temperature of evaporator

T_C = Temperature condenser

2.4 Types of Absorption Refrigeration

There are three types of absorption refrigeration system. These are single effect, double effect, and triple effect.

2.4.1 Single Effect Absorption Refrigeration

This single effect consists of four main components such as absorber, evaporator, generator and condenser. It uses low pressure stream or hot water as heat source. The thermal efficiency of this system is low.

2.4.2 Double Effect Absorption Refrigeration

The double-effect absorption refrigeration system differs from single effect because it has two generators and two condensers to allow more refrigerant boil-off from absorbent solution which is shown in Figure 2.1. The energy efficiency of this system can be improved by recovering some of the heat normally rejected to the cooling circuit. A two stage ARS accomplishes this by taking vapors driven off by heating the first stage generator to drive off more water in second stage. Many manufacturers offer this higher efficiency alternative (Dincer, 2003).

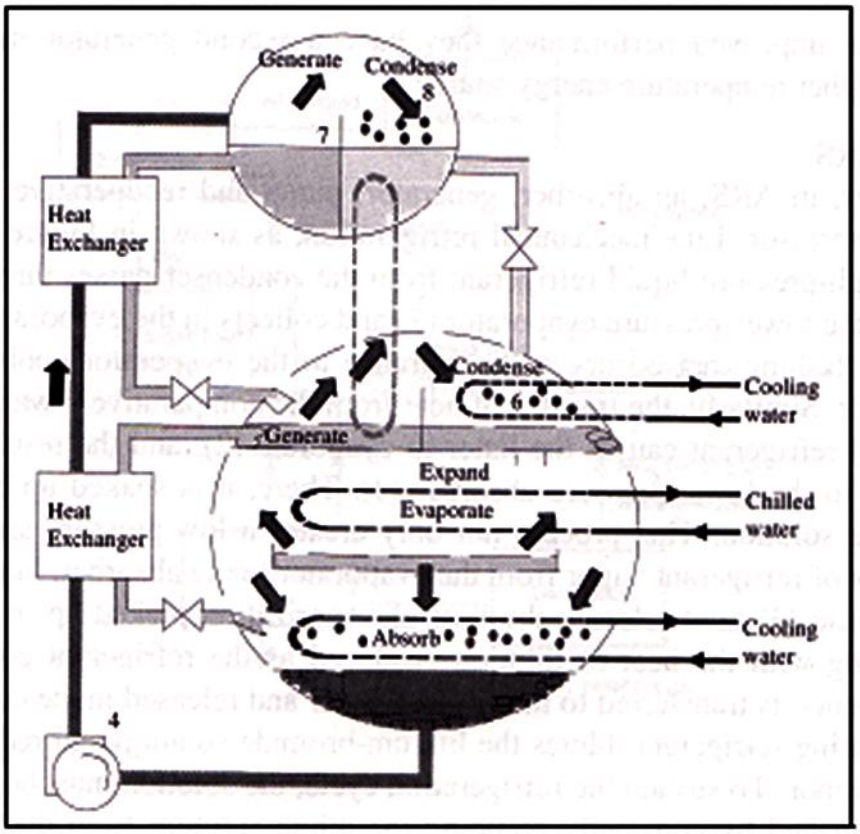

Figure 2.1: Schematic of a double-effect absorption system (Dincer, 2003)

2.4.3 Triple Effect Absorption Refrigeration

This system consists of three low temperature generator, medium temperature generator and high temperature generator which are shown in Figure 2.2. The refrigerant vapor from high and medium temperature generator is condensed and the heat is used to provide heat to next lower temperature generator. Triple-effect system can achieve even higher efficiency than double-effect chillers. However, this system required higher temperature to operate the system so it needs larger cost than double-effect system.

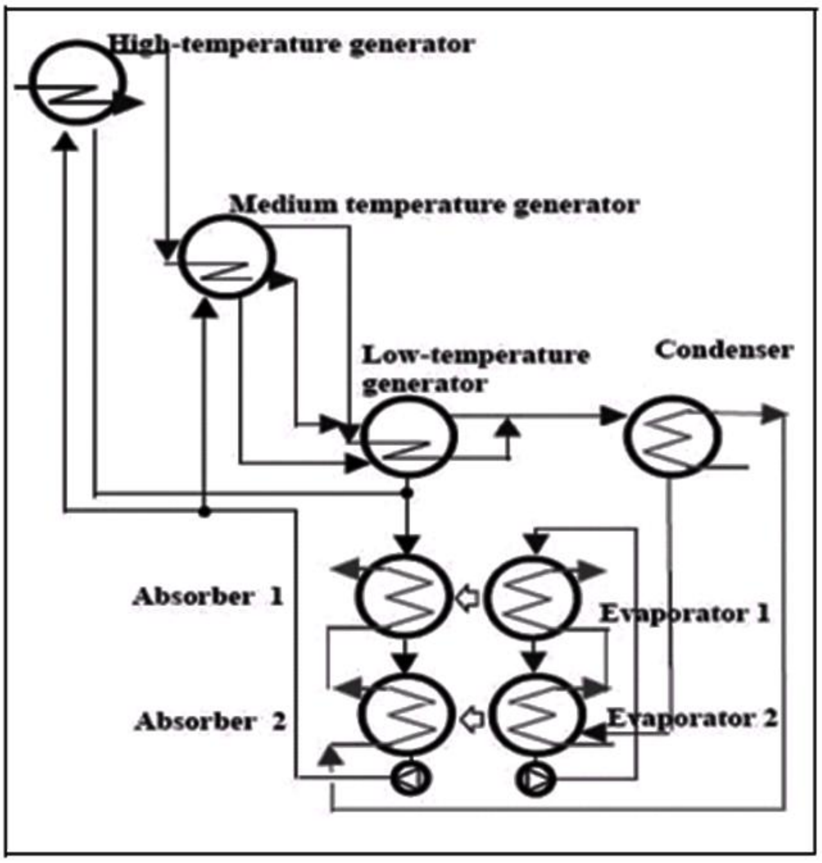

Figure 2.2: Schematic diagram of a triple-effect absorption system (Best, 2007)

2.5 Efficiency

Efficiency of ARS is described in the term of coefficient of performance (COP) which is desired output (Q_L) divided by required input (Q_{gen} + $W_{pump,\ in}$). Single effect ARS only consists of single generator. ARS usually using low pressure (135kpa or less) as a driving force and typically have COP of 0.7. Double effect of ARS usually using gas fired (either direct gas firing or hot exhaust gas from gas turbine engine) or steam-driven with high pressure steam (270-950kPa). These units typically have COP of 1.0 to 1.2 (Dincer, 2003). While for the triple effect of ARS, it consists of three stages with three generators and it is even more efficient with COP of 1.5 to 1.6. The COP of ARS and Carnot coefficient performance or Heat transfer rate (COP_C) is defined as equation 2.4.1 and 2.4.2 as below.