THEORETICAL ANALYSIS OF ABSORPTION CHILLER SYSTEM

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ABSTRACT

Absorption chiller is a cooling system that uses heat instead of electricity to cool something. The different types of absorption chillers are solar, water, gas, and bromide with steam. The process to cool a building with an absorption chiller is similar to that used by conventional air conditioning systems in that there is compressor, condenser, and evaporator equipment within the system. Refrigerant, normally lithium bromide is subjected to pressure and builds up heat in the compressor. As the pressure and heat build, the liquid is converted to a vapor gas. The gas then moves to the condenser where the heat dissipates and it is turned back into a liquid. The cooled liquid is directed into the evaporator, where it turns into a gas and pulls heat from the air; fan blowers send the cool air into the building. The gas moves from the evaporator into the compressor and the process starts again. In traditional air conditioning systems, this process is achieved with the use of an electric powered pump. In a gas absorption chiller, the pump is run by a natural gas line attached to the system. When the system is powered on, the natural gas activates the pump to flow refrigerant through the compressor. These systems run more efficiently than electric air conditioning systems but are still more costly to operate than solar varieties. In areas where sunlight is not available for extended periods of time, a gas absorption chiller is more often used. As we know that the COP of absorption chiller is low to be compared with the refrigerant system. This problem actually can be resolved by doing an analysis and a study of each component in the absorption chiller especially the condenser that plays the main role to remove heat from the system. It will be a good system if the condenser can remove heat as much as possible. Normally, we will use a forced type of air condenser which uses a fan to blow out the heated air from the system. It also the same with an evaporator but differently functions as the evaporator has a great capacity when the temperature differences between outlet and inlet is high. Talking about capacity, it surely will relate to resistance in the evaporator. The metal is known to offer less resistance but it actually depends on what type of refrigerant we are going to use. Iron and steel are very suitable for ammonia while brass and copper are for the other type of refrigerant. It is very important to have a high velocity for the flow of refrigerant and fluid over the evaporator. For the generator, it is an energy source for the absorption chiller system and usually the direct flow and heat pipe evacuated tube collector solar will be used as the generator because of their potential and efficiencies even though it is the reason why the absorption is highly cost. To determine the efficiency of a system, it can be shown by a COP for the system. For new condenser concept will lowering the condensing temperature. Hence the cooling capacity will increased. So it could enable the compressor to operate at higher load for more longer time. Other than that, chiller with higher cooling capacity could carry a higher loads with higher COP.

ABSTRAK

Absorption chiller adalah sistem pendingin yang menggunakan haba sebagai ganti kepada tenaga elektrik untuk menyejukkan sesuatu. Perbezaaan yang ada dalam absorption chiller ialah solar, air, gas dan bromida bersama stim. Proses untuk menyejukkan bangunan menggunakan absorption chiller adalah sama seperti menggunakan system penyejukkan biasa yang mengandungi komponen seperti compressor, condenser dan evaporator di dalam system itu. (refrigerant), yang biasa digunakan ialah litium bromida yang dikaitkan dengan tekanan dan untuk meningkatkan haba didalam compressor. Bila tekanan dan haba ditingkatkan, cecair akan ditukarkan ke gas stim. Gas itu kemudiannya akan bergerak ke condenser dimana haba dibebaskan dan bertukar semula bentuk cecair. Cecair yang sejuk akan ke evaporator diamana dia akan bertukar bentuk ke gas semula dan menarik haba daripada udara. Alat peniup akan menghantar udara sejuk kedalam bangunan. Gas itu akan bergerak dari evaporator ke compressor dan proses yang sama akan berulang semula. Dalam sistem penyejukkan biasa, proses ini akan berlaku dengan menggunakan pam elektrik. Manakala didalam absorption chiller, pam digerakkan menggunakan gas semulajadi yang terdapat didalam sistem itu. Bila sistem itu dihidupkan, gas semulajadi akan mengaktifkan pam untuk menghantar refrigerant melalui compressor. Sistem ini beroperasi dengan lebih cekap dibandingkan dengan pendingin hawa elektrik tetapi masih mahal kerana menggunakan sistem solar. Di kawasan yang sinar matahari tidak tersedia untuk waktu yang lama, absorption chiller gas lebih kerap digunakan. Seperti kita ketahui bahawa absorption chiller mempunyai COP yang lebih rendah untuk dibandingkan dengan sistem pendingin lain. Masalah ini sebenarnya boleh diselesaikan dengan melakukan analisis dan kajian dari setiap komponen yang terdapat didalam absorption chiller terutama kondensor yang memainkan peranan utama untuk menghilangkan haba dari sistem. Ini akan menjadi sistem yang baik jika kondensor boleh mengeluarkan haba sebanyak mungkin. Biasanya, kita akan menggunakan jenis paksa udara kondensor yang menggunakan kipas untuk meniup udara panas dari sistem. Hal ini juga sama dengan evaporator tetapi mempunyai fungsi yang berbeza. Evaporator mempunyai kapasiti yang besar jika perbezaan suhu di antara masuk dan keluar tinggi. Berbicara tentang kapasiti, itu pasti akan berkaitan dengan rintangan pada evaporator. Logam dikenali memberikan rintangan yang kurang tetapi sebenarnya bergantung pada jenis refrigeran yang kita akan gunakan. Besi dan keluli sangat sesuai untuk ammonia sementara kuningan dan tembaga adalah untuk jenis refrigerant lain. Hal ini sangat penting untuk memiliki kelajuan tinggi dalam aliran refrigeran dan cairan di evaporator. Untuk generator, itu adalah sumber tenaga untuk sistem absorption chiller dan biasanya aliran langsung dan paip panas dievakuasi tabung kolektor suria akan digunakan sebagai generator kerana kecekapan ia dan walaupun itu adalah alasan mengapa absorption chiller sangat mahal. Untuk menentukan kecekapan sistem, boleh ditunjukkan oleh COP untuk sistem. Untuk konsep kondensor baru akan menurunkan suhu kondensasi. Maka kapasiti pendinginan akan meningkat. Sehingga dapat membolehkan kompresor untuk beroperasi pada beban yang lebih tinggi lebih lama masa. Selain itu, chiller ' kapasiti pendinginan yang lebih tinggi boleh membawa beban lebih tinggi deng, yang lebih tinggi.

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LIST OF SYMBOLS

Q_{cold} heat rejected (kW)

Q_{heat} heat required (kW)

COP_{conv} coefficient of performance of conventional electrically compression chiller

Σm_i mass flow of the fluid (kg s^{-1})

Δh_i change of specific enthalpy of the fluid (kJ kg^{-1})

Q   heat transfer (kW)

A   area of heat transfer (m²)

U   overall conductance factor

Q_h heat remove (kW)

Q_{gen} heat generated (kW)

W   work output (m^2 kg s^{-2})

T_s heat from sources (kW)

T_L heat from refrigerated space (kW)

T_o heat from environment (kW)

$\dot{m}$ mass flow rate (kg s^{-1})

$\dot{m}_{steam}$ flow rate of the steam supply (kg s^{-1})

x_{out} the weight concentration of the water LiBr sorbent solution (kg ms^{-2})

$\dot{Q}$ quantity of heat transfer (kW)

W_{shaft} quantity of shaft work (m^2 kg s^{-2})

h   enthalpy (kJ kg^{-1})

h_{steam} enthalpies of the steam supply (kJ kg^{-1})

$h_{condensate}$ enthalpies of the condensate (kJ kg^{-1})

Q_{energy}	thermal energy (kW)
E_{power}	electrical energy (kW)
$\dot{m}_{chw}$	flow rate of chilled water (kg s^{-1})
T_{chwr}	temperature of the chilled water entering the chiller (ºC)
T_{chws}	temperature of the chilled water leaving the chiller (ºC)
C_p	specific heat of water (4.19 kJ kg^{-1} ºC^{-1})
C_{pa}	specific heat-capacity of air (1.02 kJ kg^{-1} ºC^{-1})
Q_{cl}	cooling capacity (kW)
E_{ch}	chilled power (kW)
E_{cc}	compressor power (kW)
E_{cf}	condenser fan power (kW)
m_w	chilled water flow (kg s^{-1})
m_r	refrigerant mass flow/compressor (kg s^{-1})
q_{rf}	refrigerant effect (kJ kg^{-1})
T_{ev}	evaporating temperature (ºC)
AU_{ev}	heat-transfer coefficient of the evaporator (kW ºC)
v_{vd}	volumetric displacement (m³ s^{-1})
V_r	specific volume of superheated refrigerant (m³ kg^{-1})
$ŋ_v$	volumetric efficiency
$ŋ_{isen}$	isentropic efficiency
$ŋ_{cc}$	transmission efficiency
T_{cd}	condensing temperature (ºC)
$m_{r.tot}$	total mass-flow rate of the refrigerant (kg s^{-1})
K_{ex}	characteristic constant

q_{ex} density of the liquid refrigerant before expansion (kg m^{-3})

ΔP_{ex} pressure difference drop across the expansion valve (kPa)

Q_{cd} heat rejection (kW)

$\text{A}U_{cd}$ heat-transfer coefficient of the condenser (kW $^{\circ}$C^{-1})

V_a heat-rejection airflow (kW $^{\circ}$C^{-1})

T_{cdae} temperature of air entering the condenser ($^{\circ}$C)

T_{cdal} temperature of air leaving the condenser ($^{\circ}$C)

LMTD   log mean temperature different ($^{\circ}$C)

m_i mass flow of the fluid (kg s^{-1})

Δh_i change of specific enthalpy of the fluid (kJ kg^{-1})

ρ_a air density (1.2 kg m^{-3})

LIST OF ABBREVIATION

COP	coefficient of performance
H_2O	water
NH_3	ammonia
H_2O-NH_3	ammonia with water
kg	kilogram
hr	hour
U.S	United State
Fig	figure
BTU	British Thermal Unit
TD	temperature different
METD	mean effective temperature difference
LiBr	lithium bromide
HPC	head pressure control
PLR	part load ratio
CFC	chlorofluorocarbon
MRI	magnetic resonance imaging
kW	kilowatt

CHAPTER 1

INTRODUCTION

1.1   PROJECT BACKGROUND

The world demand of energy for air conditioning system has been increasing tremendously for the past decade. Especially in tropical country like Malaysia, where most of the cooling units are electrically powered and we all know that the cost to produce electricity will keep increasing mainly due to the stem of fossil fired plants, this also increase the global warming. In order to reduce electricity consumption and to go green, the waste heat or solar energy drive absorption chillers will be a solution for the future design of cooling plant.

Thermally driven chillers may be characterized by three temperature levels:
   a) A high temperature level at which the driving temperature of the process is provided.
   b) A low temperature level at which the chilling process is operated.
   c) A medium temperature level at which both the heat rejected from the chilled water cycle and the driving heat have to be removed. For this heat removal, in most cases, a wet-cooling tower is used

Basic scheme of the process: Q_{cold} is the heat rejected from the chilled water in the evaporator of the chiller (chilling power), Q_{heat} is the required heat in the generation part to drive the process, and the amount of Q_{reject}, the sum of Q_{cold} and Q_{heat}, has to be removed at a medium temperature level. Q_{heat} is delivered either by the solar system or by backup heat sources, e.g. by district heat or by a gas burner (Dai, Y.Q. Geng, H.B. 1994)

Fig 1.0 describes the efficiency of a thermally driven chiller is the thermal Coefficient Of Performance (COP), defined as the fraction of heat rejected from the chilled water cycle and the required driving heat ($COP_{thermal} = Q_{cold} / Q_{heat}$). This is different to the COP_{conv} of a conventional electrically driven compression chiller, defined by $COP_{conv} = Q_{cold} /$ Electric, with Electric representing the electricity consumption of the chiller.
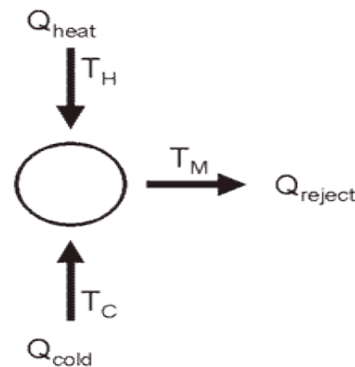
Figure 1.0. Efficiency of a thermal driven chiller

(Source: http://www.raee.org/climatisationsolaire/gb/solar.php.1999)

This definition of the $COP_{thermal}$ does not include any additional electric power consumption. A realistic comparison of different technologies thus requires the consideration of the total energy input for heat as well as for pumps, fans, etc. It has to be noted that the smaller the COP, the more heat input is required and the more heat has to be removed by the cooling tower. Vice versa, a high COP value is of advantage in reducing both heat input and electric power for the pumps in the heating cycle and in the re-cooling cycle (Sakraida, V.A. Leed, P.E. 1998).

Absorption refrigeration system is another form of refrigeration that becomes economically attractive when there is a source of inexpensive thermal energy at a temperature of 100 to 200ºC. Some examples of inexpensive thermal energy source include geothermal energy, solar energy, and waste heat from cogeneration or process steam plant and even natural gas when it is available at a relatively low price.

As the name implies, absorption refrigeration system involve the absorption of a refrigerant by a transport medium. The most widely used absorption refrigeration system is the ammonia-water system, where ammonia serves as the refrigerant and water as the transport medium. Other absorption refrigeration includes system water lithium bromide and water lithium chloride system, where water serves as the refrigerant. The latter two systems are limited to applications such as air conditioning where the minimum temperature is above the freezing point of water.

Absorption chillers are the most distributed chillers worldwide. A thermal compression of the refrigerant is achieved by using a liquid refrigerant or sorbent solution and a heat source, thereby replacing the electric power consumption of a mechanical compressor. For chilled water above 0°C, as it is used in air conditioning, typically a liquid NH_3/H_2O solution is applied with water as refrigerant. Most systems use an internal solution pump, but consuming little electric power only. In the operation of an NH_3/H_2O absorption chiller, a crystallization of the solution has to be avoided by an internal control of the heat rejection temperature in the machine. The main components of an absorption chiller are shown in the Fig 1.1 (Boles, C. 2004).
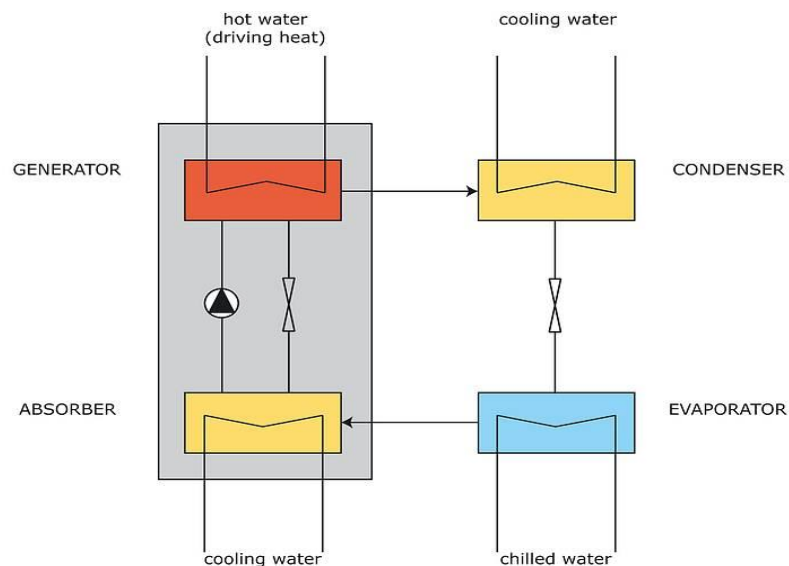

Figure 1.1 Main components of an absorption chiller

(Source: http://www.raee.org/climatisationsolaire/gb/solar.php.1999)

The main components of an absorption chiller are the generator, the condenser, the evaporator and the absorber. The cooling effect is based on the evaporation of the refrigerant (water) in the evaporator at very low pressure. The vaporized refrigerant is absorbed in the absorber, thereby diluting the NH_3/H_2O solution. To make the absorption process efficient, the process has to be cooled. The solution is continuously pumped into the generator, where the regeneration of the solution is achieved by applying the driving heat such as from hot water supplied by a solar collector. The refrigerant leaving the generator by this process condenses through the application of cooling water in the condenser and circulates by means of an expansion valve again into the evaporator.

1.2   PROBLEM STATEMENT

Using waste heat could be one of the largest conservation and green house gas reduction opportunities. Heat recovery is an opportunity to recycle energy that is typically wasted. That is why the absorption chiller is become more popular today in all fields. By using absorption chillers, it can save electricity even when the overall COP absorption chiller is low, but it can be overcomed by doing an analysis of all of components in the system especially a condenser to get a better COP.

1.3   OBJECTIVES

The objectives of the project that need to be achieved are:
a) To study a system of absorption chiller
b) To understand the working process in every system that consists in absorption chiller such as condenser, evaporator, compressor (generator and absorber) and heat exchanger.
c) To calculate the COP of the absorption chiller

1.4   SCOPE

Design and development system of component of absorption thermally driver chillers based on mathematical analysis on each corresponding component and the behaviour of the circuit. Mathematical model analysis of corresponding component (condenser, evaporator, absorber, and generator) is necessary.

CHAPTER 2

LITERATURE REVIEW

2.1   INTRODUCTION

This chapter contains a review of published information about the issues related to this project. The operation of each component in this system such as evaporator, condenser, compressor, heat exchanger and other related terms will also include in this chapter. All of the information is gathered from books, journal and article. This literature review not only attempts to collect and categorize previous research, but also to attempts to analyze and evaluate previous works leading to this project's framework.

2.2   CHILLERS

Chillers make things cool. Chillers generally refer to devices that cool fluids. There are a wide variety of chillers, because there are many different fluids to cool (including air), for a wide variety of uses. One common use for chillers is in cooling buildings. Chillers will cool water, which is circulated through a building's cooling system to keep things comfortable.

2.2.1   HOW CHILLER WORKS

Absorption chillers use low-grade waste heat to do the chilling. They lack the motorized compressor used by other chillers types. Absorption chillers use a special solution to absorb low-pressure refrigerant vapor, which is then sent to a high-pressure generator where the refrigerant is desorbed and vaporized by the waste heat. The refrigerant is then condensed to a high-pressure liquid, and passed through an expansion

valve and into an evaporator, which cools the evaporator. The vapors leave the evaporator and go back to be recombined with the absorbent, and the process starts all over again. Absorption chillers are useful in situations where waste heat (or a cheap supply of fuel) is available, or where cost or other limitations prevent the use of a mechanical compressor.

2.2.2   CHILLER USES

a) To convert waste heat from manufacturing processes for use in cooling.

b) Directing chilled air into gas turbines and compressors will increase their efficiency

c) Chilled brine is used to create ice

d) Drinking water is often chilled before consumption

e) Chillers are essential to plasma etch processes used in semiconductor manufacturing

f) High-intensity lasers create waste heat, and require special chillers to function

g) Chillers are used to cool objects being cut by machine tools

h) Chillers regulate temperature in reaction vessels used by the pharmaceutical industry

I) MRI equipment requires careful thermal control to function, making chillers necessary

2.3   ABSORPTION CHILLER

Absorption chillers use heat instead of mechanical energy to provide cooling. A thermal compressor consists of an absorber, a generator, a pump, and a throttling device, and replaces the mechanical vapor compressor. The two most common refrigerant and absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water. Compared with mechanical chillers, absorption chillers have a low coefficient of performance (COP = chiller load/heat input). However, absorption chillers can reduce operating costs because they are powered by low-grade waste heat. Vapor compression chillers, by contrast, must be motor or engine-driven.

A single-effect absorption machine means all condensing heat cools and condenses in the condenser. From there it is released to the cooling water. A double-effect machine adopts a higher heat efficiency of condensation and divides the generator into a high-temperature and a low-temperature generator.

2.4 EVAPORATORS

Like the condenser, the evaporator is just a finned coil in the air-conditioning system. Almost all are made of copper tubes with aluminium fins. The evaporator is the cooling and dehumidifying coil in the air-conditioning circuit. It mentions this because the typical residential/light-commercial air-conditioning system expends about a third of its energy dehumidifying the air, with the other two-thirds just performing straight (sensible) cooling. The major requirement in the field of evaporation technology is to maintain the quality of the liquid during evaporation and to avoid damage to the product. This may require the liquid to be exposed to the lowest possible boiling temperature for the shortest period of time.

This and numerous other requirements and limitations have resulted in a wide variation of designs available today. In almost all evaporators the heating medium is steam, which heats a product on the other side of a heat transfer surface (Waltrich, P.J. Jader, R. et al. 2002)

2.4.1 HISTORY OF EVAPORATORS

The evaporative cooler was design in the twentieth century. Starting in 1906. It used excelsior (wood wool) pads as the elements to bring a large volume of water in contact with moving air to allow evaporation to occur. A typical design, as shown in a 1945 patent, includes a water reservoir (with level controlled by a float valve), a pump to circulate water over the excelsior pads, and a squirrel-cage fan to draw air through the pads and into the house. This design and this material remain dominant in evaporative coolers in the American Southwest, where they are also used to increase humidity (Gutenberg, A.W. 1995)

There are three main measures of evaporator performance:

1. Capacity (kg vaporized / time)
2. Economy (kg vaporized / kg steam input)
3. Steam Consumption (kg / hr)

Economy calculations are determined using enthalpy balances. The key factor in determining the economy of an evaporator is the number of effects. The economy of a single effect evaporator is always less than 1.0. Multiple effect evaporators have higher economy but lower capacity than single effect.

The thermal condition of the evaporator feed has an important impact on economy and performance. If the feed is not already at its boiling point, heat effects must be considered. If the feed is cold (below boiling) some of the heat going into the evaporator must be used to raise the feed to boiling before evaporation can begin. This reduces the capacity. If the feed is above the boiling point, some flash evaporation occurs on entry (Chen, W. et al. 2002).

2.4.2   HOW AN EVAPORATOR WORKS.

From Fig 2.0 diluted process material (purple) is introduced into the tangential feed inlets above the thermal body section. The material is then evenly distributed over the internal wall of the evaporator by means of a distribution ring that is an integral part of the evaporator rotor.

As gravity draws the process material downward into the heated thermal sections, the rotor blades keep the material spread over the heated surface creating effective film turbulence. This turbulence, which has been intentionally designed into the evaporator, continually re-exposes all of the process material to the heated surface. The continual rotation of process materials prevents localized over-heating and thus helps to prevent the "fouling" of the evaporator. Since the evaporator provides a condition of high heat transfer and short residence time, rapid vaporization is attained. At extremely low bottom output rates, an additional ring may be installed in the bottom of the thermal section to increase residence time. This ring effectively acts as a dam,

causing the process flow to backup into the lower portion of the thermal sections insuring proper process wetting in the heated vessel wall.

The resultant escaping vapours (blue) travel upward toward the vapour outlet, being separated from the incoming feed by the distribution ring. Liquids, entrained in the vapour steam, are trapped in the vapour section and drain back into the thermal bodies. The "liquid free" vapours pass through the vapour outlet ready to be condensed. Meanwhile, the non-volatile processed product or residue (red) passes from the thermal bodies to a bottoms cone and is discharged.
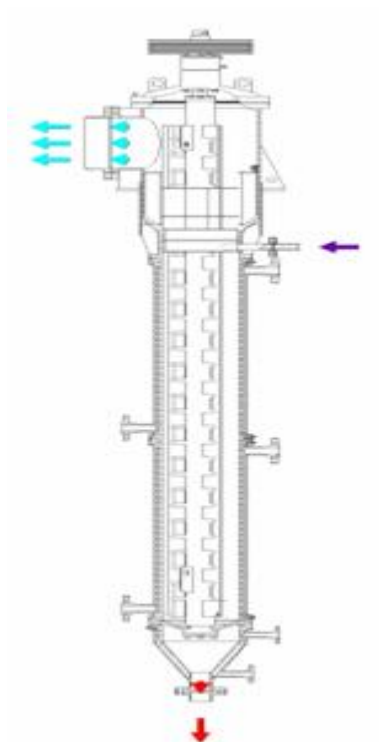

Figure 2.0 Evaporator

(Source: http://www.newtonmachine.com/evap-tof.htm.2007)

2.4.3   APPLICATION OF EVAPORATOR

The goal of evaporation is to concentrate a target liquid, and this needs to be achieved for many different targets today. One of the most important applications of evaporation is that on the food and drink industry. Many foods that are made to last for

a considerable amount of time or food that needs a certain consistency, like coffee, need to go through an evaporation step during processing. It is also used as a drying process and can be applied in this way to laboratories where preservation of long-term activity or stabilization is needed (for enzymes as an example). Evaporation is also used in order to recover expensive solvents such as hexane which would otherwise be wasted. Another example of evaporation is in the recovery of sodium hydroxide in Kraft pulping. Cutting down waste handling cost is another major application of evaporation for large companies. Legally, all producers of waste must dispose of the waste in methods that abides by environmental guidelines; these methods are costly. If up to 98% of wastes can be vaporized, industry can greatly reduce the amount of money that would otherwise be allocated towards waste handling (Chen W. et al. 2002).

Typical evaporator applications
- Product concentration
- Dryer feed pre-concentration
- Volume reduction
- Water / solvent recovery

2.4.4   TYPE OF EVAPORATORS

Different Evaporation Systems
- Falling Film Evaporators
- Rising Film Evaporators
- Forced Circulation Evaporators
- Plate Evaporators
- Compact Evaporators

2.5   CONDENSERS

Condensers are refrigeration devices that accept vaporized refrigerant from an evaporator and then compress and liquefy it for use in the system. There are generally two types of condensers, an air conditioning condenser and a refrigeration condenser. An air conditioning condenser is used to convert hot and high pressure refrigerant gas to

a sub cooled liquid. A heat exchange condenser located in a refrigeration system is known as a refrigeration condenser. Heating and cooling are the two main aspects of how condensers function. Heat loss and heat gain are the processes by which heat can be exchanged from the surroundings. Leaking and losing of heat at a specific low temperature in the region is known as heat loss whereas the quantity of heat that needs to be removed to maintain indoor comfort on a specific warm day is known as heat gain. Central heating stands for heating of a region from a central source. Central air conditioning is the process by which the region is cooled at the time of humid temperatures (Qureshi, A.B. Zubair, S.M. 2006).

2.5.1 HOW A CONDENSER WORK

Condensers consist of a condenser coil, compressor, fan, and control. In an air conditioning condenser the refrigerant is compressed and run through a series of tubes to remove as much heat as possible as an illustrated at Fig 2.1. The refrigerant is then piped to an evaporator coil as a warm liquid. Expansion of the compressed liquid causes it to cool, and as the air passes over the coil, heat is extracted. The cool liquid becomes a cool gas when it gathers heat from the air, and is drawn back to the compressor to start the procedure again.
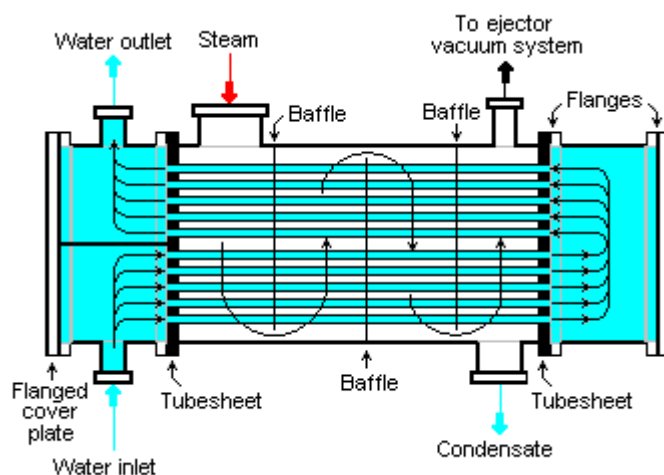

Figure 2.1 Example of Condenser

(Source: http://en.citizendium.org/wiki/Surface_condenser.2006)