'Development of New Refrigerant for Air-Conditioning System'

by

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1) Sodium chlorate
2) CHE -- Thesis

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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Approved by,

(Suriati Sufian)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources of persons.

Khoo Ee Fei

KHOO EE FEI

ABSTRACT

Ozone depletion and global warming or more accurately climate change are major environmental concerns with serious implications for the future development of the refrigerant based industries. The industry has reacted to reduce ozone depletion but the follow-on consequences of trying to react to the need to reduce the emission of greenhouse gasses. Consequent upon the Montreal Protocol and its adjustments came to measure to reduce the production and use of materials with high ozone depletion potentials. First, the halons were banned, then the chlorofluorocarbons (CFCs) and now there's a push to ban the hydrochlorofluorocarbon (HCFCs) on a time scale which becomes shorter with each new amendments to the protocol.

The rush for developing new refrigerant working fluid is at peak now considering the impact on ozone depletion, global warming, economics safety and efficiency.

In this study, six potential refrigerant working fluids are investigated based on the enthalpy of solution and the pH using calorimetry method.

Sodium chlorate of molaltiy 5.637 mol/kg is the most suitable refrigerant for the new air conditioning system using the membrane technology. The 15°C temperature decrement of the solution provides a large driving force for heat transfer from ambient to the endothermic salt solution. Experiment results shows that in a well insulated system, the endothermic salt solution could provide cooling of hot air to 18°C – 20°C for up to 50 minutes.

Sodium chlorate is also non-toxic as compared to Freon-22, highly stable and do not corrode copper coils. This eliminates the waste treatment required by Freon-22.

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ABBREVIATION AND NOMENCLATURE

$\Delta_{sol}H_m$	Enthalpy of solution
$\Delta_{sol}H_m(z\ K)$	Enthalpy of solution at z Kelvin
∞	Infinite dilution
ρ	Density of water
σ	Staverman's reflection coefficient
ΔH	Heat or enthalpy change of solution
ΔH_{hydr}	Heat or enthalpy change of hydration
$\Delta H_{lattice}$	Lattice energy
ΔH_{solute}	Heat or enthalpy change of solute
ΔH_{soln}	Heat or enthalpy change of solution per mole of solute, molar enthalpy of solution
$\Delta H_{solvent}$	Heat or enthalpy change of solvent
ΔH_{mix}	Heat or enthalpy change of solute and solvent mixture
Δ_P, ΔP	Pressure difference between the high and low pressure sides of the membrane
ΔT	Time interval
ΔT, ΔT_{hw}, ΔT_{cw}	Change of temperature (termed as T_{final} - $T_{initial}$) or change in temperature of the calorimeter, of temperature hot water and of cold water
Δ_π, $\Delta\pi$	Differential osmotic pressure across the membrane

<T>	Average of the initial and final temperature of the calorimetric experiment
<n&(n+1)>	Average between n and (n+1)
$[OH^-]$	Hydroxide ion
$[H^+]$	Hydrogen ion
$[H_3O^+]$	Hydronium ion
$AlCl_3$	Aluminium chloride
$Al_2(SO_4)_3$	Aluminium sulphate
A_m	Membrane surface area
Aq	Aqueous solution of unspecified dilution
$Ba(NO_3)_2$	Barium nitrate
C	Specific heat capacity
C_F	Concentration of water in feed
C_P	Concentration of water in permeate
C_w	Specific heat capacity of water
C', $C'_{calorimeter}$	Heat capacity of the calorimeter vessel
CAS	Chemical Abstract Service
CFC	Chloroflourocarbon
Ebullioscopy	Boiling point of liquid
HCFC	Hydrochlorofluorocarbon
HCFC-22	Chlorodifluoromethane
HCFC–31	Chlorofluoromethane
HCFC-123	Dichlorotrifluoroethane
HCFC– 151a	1-Chloro-1-fluoroethane
HFC	Hydrofluorocarbons
HFC-134a	1,2,2,2-Tetrafluoroethane
HFC-236ea	1,1,1,2,3,3-Hexafluoropropane
HFC-236fa	1,1,1,3,3-Pentafluoropropane
HFC-245ca	1,1,2,2,3-Pentafluoropropane
HFC-245fa	1,1,1,3,3-Pentafluoropropane

J_s	Solute flux
J_w, J_{wo}	Water flux, pure water flux
k	Thermal conductivity
KNO_3	Potassium nitrate
LiBr	Lithium bromide
LiI	Lithium iodide
m, m_{hw}, m_{cw}	Mass of substance or matter, of hot water and of cold water
m_f	Molality of solution or mixture
MF	Microfiltration
$NaClO_3$	Sodium chlorate
O_3	Ozone
$PbBr_2$	Lead (II) bromide
pH	Negativelogarithm of hydronium ion concentration
pK, pK_w	Negative logarithm of equilibrium constant
pOH	Negative logarithm of hydroxide ion concentration
$q_{\text{hot substances}}$	Heat of hot substances
$q_{\text{cold substances}}$	Heat of cold substances
$q_{\text{calorimeter}}$	Heat of calorimeter
r	Water recovery
R	Salt rejection coefficient
RO	Reverse osmosis
R717	Ammonia
T	Initial temperature of the ice water
T_f	Final temperature of the calorimeter system
T_{final}	Final temperature
T_{initial}	Initial temperature
T_o	Initial temperature of the calorimeter system and hot water
Teratogenic	Substance or process that induces the formation of developmental abnormalities in a foetus[7]
UF	Ultrafiltration
V	Volume of water

V_F	Volume of feed
x_i	Number of moles of solute

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The control of indoor climate in the form of winter heating or summer cooling is an important industry throughout the world, in order for people to live comfortably and work effectively all year round.

The science and practice of creating a controlled climate in indoor spaces is called air conditioning. An air conditioner works like an uninsulated refrigerator, where an uninsulated space is being cooled. An air conditioner provides comfort cooling for a given room. In tropical country like Malaysia, where the climate is hot and humid, indoor cooling plays an important role in the everyday lives of the people. Therefore, focus of this project will be developing a new air conditioning refrigerant.

Today, indoor climate are being modified in homes, factories, commercial establishments, hospitals and offices in almost every country in the world. Temperature and humidity conditions would become intolerable most of the time, industrial production would be adversely affected and activities involving computers, electronics, precision manufacturing and communication network would come to a halt when air conditioning system in the world stop operating. Therefore, air conditioning is an essential part of modern living especially in businesses, industries, schools, hospitals, hotels, restaurants and homes.

In this study, enthalpy of solution and pH for the aqueous solution of the below salts will be investigated:

- Aluminium chloride
- Aluminium sulphate
- Barium nitrate
- Lead (II) bromide
- Potassium nitrate
- Sodium chlorate

1.2 Problem Statement

1.2.1 Problem Identification

The Montreal Protocol on Substances that Deplete the Ozone Layer is a landmark international agreement designed to protect the stratospheric ozone layer. The treaty was originally signed in 1987 and amended in 1990 and 1992. The Montreal Protocol stipulates that the production and consumption of compounds that deplete ozone for example chlorofluorocarbons (CFCs), halons, carbon tetrachloride and methyl chloroform are to be phased out by 2000 (2005 for methyl chloroform)[2].

The 1985 discovery of an "ozone hole" over Antarctica focused attention on the idea that humans can have a significant impact on the global environment. This discovery, along with evidence that ozone is being lost at nearly all latitudes outside the tropics, has prompted much research into the causes of ozone depletion and the biological effects of increased ultraviolet radiation exposure. The potential effects on humans and the environment have led to international resolutions designed to gradually phase out production of ozone-depleting substances. As a result, the scientific and industrial communities have collaborated to find safe and economical replacements for the manmade chemicals implicated in ozone loss - chlorofluorocarbons (CFCs).[2]

Being a part of the scientific community, which new refrigerant is the best choice for the future? What is the alternative air conditioning system? An alternative refrigerant should be introduced by considering impact on:

- Global warming
- Economics
- Safety
- Efficiency

1.2.2 Significance of the Project

Ozone is a molecule composed of three oxygen atoms, designated by the chemical symbol O_3. Approximately 90% of all ozone is contained in the region of the atmosphere called stratosphere, which lies between 15 to 50 km above the earth's surface. Kowalok gives a brief synopsis of important discoveries and events leading to an understanding of stratospheric ozone and the discovery of destructive capabilities of CFCs in his paper "Common Threads: Research Lessons from Acid Rain, Ozone Depletion and Global Warming".[3]

Manmade CFC compounds were developed in the early 1930s for a variety of industrial and commercial applications, but it was not until the 1970s that these and other chlorine-containing substances were suspected of having the potential to destroy atmospheric ozone. In 1985 a team of British researchers first reported unusually low ozone levels over Halley Bay, Antarctica, which was caused by chemical reactions with chlorine and nitrogen compounds. Research was initiated that found CFCs to be largely responsible for the anomalously low levels during the polar springtime.

The hydrochlorofluorocarbon (HCFC) family was the most frequently identified substances that were being proposed in the fourth meeting of the parties to the Montreal Protocol and used as alternatives for CFCs. These substances are now being produced and can replace CFCs in many applications.

Nevertheless, HCFCs like HCFC-123 (dichlorotrifluoroethane) and HCFC-22 (chlorodifluoromethane) also contain some chlorine and therefore destroy approximately one-tenth lesser of the stratospheric ozone compared to CFC.[4]

S. Solomon and D.L. Albritton have proved, for this reason, it is generally accepted that HCFCs are not the final and definitive solution to the CFC problem in the paper titled "Time-Dependent Ozone Depletion Potentials for Short and Long term Forecasts".[5]

Notwithstanding the example of the CFCs and HCFCs refrigerants, in the case for ozone-benign alternatives was not strong. Hydrofluorocarbons (HFCs) is a family of chlorine-free substitutes that are strong greenhouse gases. Examples of HFCs are HFC-134a (1,2,2,2-tetrafluoroethane), HFC-236ea (1,1,1,2,3,3-hexafluoropropane) and HFC-245fa (1,1,1,3,3-pentafluoropropane). However, the more traditional chemicals, such as ammonia, butane and pentane, have problems with toxicity and flammability.

One of challenges for the scientific community is to develop on the absorption chillers refrigerants. The only absorption refrigeration system available to market is the Lithium bromide-water absorption system. Using the fundamentals of the absorption chiller technology, alternate refrigerants can be developed as an alternative to Lithium bromide-water absorption system. However, data on the thermodynamics properties are limited and absorption system is suitable only for industrial use.

The proposed new approach in air conditioning system will utilise the membrane separation to achieve air cooling. Many processes for separation of gaseous or liquid mixtures use semi permeable membranes. There are four developed membrane separation process are microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO) and electrodialysis (ED). In MF, UF and RO, a solution containing dissolved or suspended solids is forced through a membrane filter. The solvent passes through the membrane while the solutes are retained. The three processes differ principally by the pore size of the membranes from 0.1μm to 10μm. In RO, the membrane pore diameter ranges from 0.0005 μm – 0.002 μm. RO can be used to separate dissolved microsolutes such as salt from water.

To ensure constant absorption of heat, salt solution is pumped from tank and pumped through the membrane to concentrate the salt solution. Purified water removed is later used to dilute the concentrated salt solution to allow more heat to be absorbed by the salt solution and decreasing the air temperature.

1.3 Objective and Scope of the Project

This study is relevant to the fundamentals of physical chemistry and chemical thermodynamics. This study has the below objectives:

a) to measure experimentally the heat involved in dissolving of salt
b) to observe relationship between heats of solution, concentration of solution and pH
c) to suggest the suitable endothermic salt with the optimum salt concentration to be used as the refrigerant in the new air conditioning system considering toxicity, safety and reactivity, efficiency and it's effect on global warming and economy

1.3.1 Feasibility of the project within the Scope and Time Frame

The Gantt Chart as appended as Appendix 1.3.1 suggests that the scope of the project is parallel to the time frame of 14 weeks. Literature review, laboratory work, data collection and analysis have to been planned to meet the time frame.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Existing Air Conditioning System and Refrigerant

2.1.1 Existing Air Conditioning System

There are two scales of air conditioning namely industrial scale air conditioning and domestic air conditioning.

There are two main types of industrial air conditioning. They are absorption chiller and chilled water centrifugal chiller.

The two types of domestic air conditioners are air conditioner window unit and air conditioner split unit. The main difference between the window unit and split unit is the window unit house the all parts of the air conditioner in one box while the split unit whereas the split unit has it's condenser installed outside a building.

2.1.2 Existing Refrigerant

Prior to the mandated phase out of chlorofluorocarbon (CFC) refrigerants that took effect on January 1, 1996, the industry widely uses CFC-114 (1,1,2,2-tetrafluoroethane).

Substances from the hydrochlorofluorocarbon (HCFC) family are the most frequently identified substances used as alternatives for CFCs. These substances are now being produced and can replace CFCs in many applications especially in the industrial air-conditioning system.

However, HCFCs like HCFC-123 (dichlorotrifluoroethane), HCFC–123a (1,2-dichloro-1,1,2-trifluoroethane), HCFC-22 (chlorodifluoromethane), HCFC– 31 (chlorofluoromethane) and HCFC– 151a (1-chloro-1-fluoroethane) also contain some chlorine and therefore destroy approximately one-tenth lesser of the stratospheric ozone compared to CFC.[4] HCFC has a shorter atmospheric lifetime. This shorter lifetime, however, means that the HCFC's destruction of ozone will also take place much sooner.[6] S. Solomon and D.L. Albritton have proved, for this reason, it is generally accepted that HCFCs are not the final and definitive solution to the CFC problem in the paper titled "Time-Dependent Ozone Depletion Potentials for Short and Long term Forecasts".[5]

Notwithstanding the example of the CFCs and HCFCs refrigerants, in the case for ozone-benign alternatives was not strong. Hydrofluorocarbons (HFCs) is a family of chlorine-free substitutes that are strong greenhouse gases. Examples of HFCs are HFC-134a (1,2,2,2-tetrafluoroethane), HFC-236ea (1,1,1,2,3,3-hexafluoropropane), HFC-236fa (1,1,1,3,3-pentafluoropropane), HFC-245ca (1,1,2,2,3-pentafluoropropane) and HFC-245eb (1,1,1,2,3-pentafluoropropane)

However, the more traditional chemicals, such as R717 (ammonia), butane and pentane, have problems with toxicity and flammability.

The natural successor of CFCs, HCFCs and HFCs refrigerants will be the ones used in the absorption chillers refrigerants. However, the absorption chiller systems available to market are of Lithium bromide-water and Ammonia-water absorption system. These systems are of industrial scale and are not suitable for domestic use.

2.2 Membrane Technology

Membranes have gained an important place in chemical technology and are being used increasingly in a broad range of applications such as wastewater treatment, water desalination and food processing. Membrane is exploited in many applications because it can control the permeation of a chemical species in contact with it. In the packaging applications, the use of membrane is to prevent permeation completely. On the other hand, in separation applications, membranes is use to allow one component of a mixture to permeate the membrane freely, while hindering permeation of other components.

2.2.1 Types of Membrane

Membranes have a variety of chemical and physical composition and differ in the way they operate. In the nutshell, a membrane is a discrete, thin interface that moderates the permeation of chemical species in contact with it. This interface may be molecularly homogeneous (uniform in composition and structure) or chemically or physically heterogeneous (holes or pores of finite dimensions).[14]

2.2.1.1 Isotropic Microporous Membranes

A microporous membrane is similar in its structure and function to a conventional filter. It has a rigid, highly voided structure with randomly distributed, interconnected pores. However, these pores differ from those in a conventional filter by being extremely small, of the order of 0.01 µm - 10 µm in diameter.[14] All particles larger than the largest pores are completely rejected by the membrane. Particles smaller than the largest pores but larger than the smallest pores are partially rejected according to the pore size distribution membrane. Therefore, separation of solutes by microporous membranes is mainly a function of molecular size and pore size distribution. In general, only molecules that differ considerably in size can be separated effectively by microporous membranes. The ultrafiltration and microfiltration uses this membrane.

2.2.1.2 Nonporous Dense Membranes

Nonporous dense membranes consist of a dense film through which permeates are transported by diffusion under the driving force of a pressure, concentration or electrical potential gradient The separation of various components of a solution is related directly to their relative transport rate within the membrane. This is determined by their diffusivity and solubility in the membrane material. An important property of nonporous dense membranes is that even permeates of similar size may be separated when their concentration in the membrane material differs significantly. Most gas separation, pervaporation and reverse osmosis membranes use dense membranes to perform the separation.

2.2.1.3 Electrically Charged Membranes

Electrically charged membranes can be dense microporous but are most commonly microporous. The pore walls carries fixed positively or negatively charged ions. A membrane with positively charged ions is refereed to as anion-exchanged membrane because it binds anions in the surrounding fluid. Similarly, a membrane containing negatively charged ions is called a cation-exchange membrane. Separation with charged membranes is achieved mainly by exclusion of ions of the same charge as the fixed ions of the membrane structure and to much lesser extent by the pore size. The separation is affected by the charge and concentration of the ions in solution. Electrically charged membranes are used for processing electrolyte solutions in electrodialysis.

2.2.1.4 Asymmetric Membranes

The transport rate of a species through a membrane is inversely proportional to the membrane thickness. High transport rates are desirable in membrane should be as thin as possible Conventional film fabrications technology limits manufacture of mechanically strong, defect-free films to about 20 μm thickness.

The development of membrane fabrication techniques to produce asymmetric membrane structures was one of the breakthroughs of membrane technology. Asymmetric membranes consist of an extremely thin surface layer supported on a much thicker porous dense substructure. The surface layer and its substructure may be formed in a single operation or formed separately. The separation properties and permeation rates of the membrane are mechanical support. The advantages of the higher fluxes provided by asymmetric membranes are so great that almost all commercial processes use such membranes.

2.2.1.5 Ceramic, Metal and Liquid Membranes

The majority of membranes used commercially are polymer based. The interest in membranes formed from less conventional materials has increased throughout the years. Ceramic membranes, a special class of microporous membranes are being used in ultrafiltration and microfiltration applications, for which solvent resistance and thermal stability are required. Dense metal membranes, particularly palladium membranes are being considered for the separation of hydrogen from gas mixtures and supported or emulsified liquid films are being developed coupled and facilitated transport processes.

2.2.2 Membrane Application

The principal use of membranes in the chemical processing industry is in various separation processes. Membranes are used widely as packaging materials. The four developed separation processes are microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO) and electrodialysis (ED). In MF, UF and RO, a solution containing dissolved or suspended solids is forced through a membrane filter. The solvent passes through the membrane and the solutes are retained.

The three processes differ principally is considered to refer to membranes with pore diameters from 0.1 μm to 10 μm.[14] MF membranes are used to filter suspended particulates, bacteria or large colloids from solutions. UF refers to membranes having pore diameter in the range of 0.002 μm – 0.1 μm.[14] UF membranes can be used to filter dissolved macromolecules such as proteins from solution. Typical applications of UF membranes are concentrating proteins from milk whey or recovering colloidal paint particles from the electrocoating paint rinse water.

In RO membranes, the pores are very small in the pore diameter range of 0.0005 μm – 0.002 μm.[14] This pore diameter range of RO membranes are within the range of the thermal motion of the polymer chains. The most widely accepted theory of RO transport considers the membrane to have no permanent pores at all. RO membranes are used to separate dissolved microsolutes such as salt from water. The principal application of RO is the production of drinking water from brackish groundwater or seawater.

The fourth fully developed membrane process is electrodialysis, in which charged membranes are used to separate ions from aqueous solutions under the driving force of an electrical potential difference. The process utilizes an electrodialysis stack built on the plate-and-frame principles containing several hundred individual cells formed by a pair of anion and cation-exchange membranes. The principal application of electrodialysis is the desalting of brackish groundwater. However, industrial use of the process in the food industry is to deionize cheese whey.

2.2.3 Reverse Osmosis

Reverse osmosis (RO) is a fairly mature technology used in the area of seawater and brackish water desalination. Use of RO as a separation tool is a relatively young technology. Osmosis can happen when solutions of different concentrations are separated by a semi-permeable membrane. The tendency to reach a stale equilibrium between two solutions caused a pressure that is called osmotic pressure, π. When a pressure greater than the natural osmotic pressure, the membrane allows water from the salt solution to continuously pass into the pure solution while rejecting most dissolved solids. The phenomenon is called reverse osmosis.

2.2.3.1 The Principles of Reverse Osmosis

The first reverse osmosis modules made from cellulose diacetate had a salt rejection of approximately 97% - 98%. This was enough to produce water from brackish water sources. However, this is not enough to desalinate seawater efficiently.

The reverse osmosis process is relatively simple in design. It consists of a feed water sources, feed treatment, high pressure pump, reverse osmosis membrane modules and in some cases post-treatment steps. The three streams and associated variables of the reverse osmosis membrane process are:

a. the feed
b. the product stream, permeate
c. the concentrated reject stream, concentrate or retentate

The performance of reverse osmosis is generally described by the water and salt fluxes. The water flux, J_w is linked to the pressure and concentration gradients across the membrane by:

$$J_w = \frac{\textit{volumetric or mass permeation rate}}{\textit{membrane area}}$$

$$Jw = \Delta(\Delta P - \Delta\pi) \qquad \textit{Equation 2.2.3.1.1}$$

where ΔP is the pressure difference across the membrane
$\Delta\pi$ is the differential osmotic pressure across the membrane

When $\Delta P < \Delta\pi$, water flows from the dilute to the concentrated salt solution side of the membrane by normal osmosis. When $\Delta P = \Delta\pi$, there is no flow across the membrane. When the applied pressure is higher than the osmotic pressure $\Delta P >$

$\Delta\pi$, water flows from the concentrate to the dilute salt solution side of the membrane.

D

The salt flux, J_s across a reverse osmosis membrane can be described by equation 2.2.3.1.2.

$$J_s = \frac{mass\ permeation\ rate}{membrane\ area}$$

$$J_s = B(C_P - C_F) \qquad \textit{Equation 2.2.3.1.2}$$

where B is a constant

$(C_p - C_F)$ is the salt concentration difference across the membrane

Equation 2.2.3.1.2 is proportional to the applied pressure but the salt flux is independent of pressure. This means that the membrane becomes more selective as pressure increases. Selectivity can be measure conventionally by salt rejection coefficient, R.

$$R = 1 - \frac{C_P}{C_F} \qquad \textit{Equation 2.2.3.1.3}$$

The quantity of feed water that passes through the membrane known as permeate is measure in terms of water recovery, r.

For batch reverse osmosis, water recovery , r is defined in equation 2.2.3.1.4.

$$r = \frac{\sum J_w A_w \Delta t}{V_F}$$

$$r = \frac{V_P}{V_F} \qquad \textit{Equation 2.2.3.1.4}$$

where A_m is the membrane surface area

Δt is the time interval

V_F is the volume of the feed

For continuous reverse osmosis, water recovery , r is defined in equation 2.2.3.1.5.

$$r = \frac{\sum J_w A_w}{F_F}$$

$$r = \frac{F_P}{F_F} \qquad \text{Equation 2.2.3.1.5}$$

where F_F is the feed flow rates
F_P is the permeate flow rates

In a batch membrane system, water is recovered from the system while the concentrate is recycled to the feed tank. As a result, the solute is rejected, the feed concentration, C_F concentrates over time. For a continuous membrane system, fresh feed is continuously supplied to the membrane.

Water flux is sometimes normalised according to the initial or pure water flux, J_{wo} as J_w/J_{wo} or as flux drop.

$$Flux\ drop = 1 - \frac{J_w}{J_{wo}} \qquad \text{Equation 2.2.3.1.6}$$

The net driving force for water transport across the membrane is described in equation 2.2.3.1.7.

$$Net\ driving\ force = \Delta P - \sigma\Delta\pi \qquad \text{Equation 2.2.3.1.7}$$

where ΔP is the pressure difference between the high and low pressure sides of the membrane
σ is the Staverman reflection coefficient
$\Delta\pi$ is the osmotic pressure difference across the membrane

When the Staverman reflection coefficient, σ is 1, this means 100% solute rejection.

2.2.3.2 Reverse Osmosis Modules

The common types of module designs are plate-and-frame, spiral-wound, four-leaf spiral wound, hollow-fibre, tubular and monolithic.

Figure 2.2.3.2: *Common membrane modules: (a) plate-and-frame, (b) spiral-wound, (c) four-leaf spiral wound, (d) hollow-fibre, (e) tubular and (f) monolithic*

2.2.3.3 Study on Reverse Osmosis Variable

Factors affecting reverse osmosis membrane separation and water flux include feed variable such as solute concentration, temperature, pH and pretreament requirements. Membrane variables such as polymer type, module geometry and module arrangement and process variable such as feed flow rate, operating time and pressure and water recovery.

One of the primary concerns of reverse osmosis processing is the irreversible fouling of the membrane surface. This can lead to product flex decline as well as possible changes in rejection and selectivity. Fouling is a broad term that refers to the deposition or association of feed stream constituents on the membrane surface or within the membrane pores, consequently on the membrane surface or within the membrane pores. This will lead to a decrease in membrane performance. The cause fouling can generally be traced to constituents in the membrane feed stream. Several general categories of foulants found in process streams can be identified in relation to reverse osmosis processes like biological fouling agents, colloids, scaling agents, organic, metal oxides and suspended solids in general. Depending on the particular application, one or several of these categories may become a factor in the reverse osmosis process.

2.3 Heat Transfer

Heat transfer is defined as the means which heat passes energy from one place to another or from one substance to another by conduction, convection and or radiation. In other words, it is merely the flow or movement of heat.

Air conditioning is the application of heat flow processes. Heat is supplied to air or removed from air depending on the temperature of the surroundings. These processes are energised by a variety of different sources and by the use of many different kinds of equipment. The actual process of supplying and removing heat often cannot take place directly within the space to be air conditioned, so heat energy must be transmitted from one place or substance to another.

2.3.1 Cooling Coils

In conventional air condition units, warm air is directed through cooling coils containing evaporating refrigerant or chilled water. Heat energy is removed from the warm air by contact with the cold coil surface. The resulting cool air is blown back to the conditioned space where it absorbs heat from room air.

In this project, the cooling coil is immersed in an endothermic salt solution and warm air is passed through the cooling coil. Due to the nature of the salt solution, heat energy is absorbed from the warm air by contact with the cooling coil. The cool air that exits from the cooling coil is then blown back into the surroundings.

Heat exchange occurring through the cooling coil should be maximised to ensure that heat is transferred from the air to the salt solution with minimal resistance. This can be done by using good conductor like copper, aluminium or iron. Copper cooling coils are normally preferred due to it's high conductivity which is 386 W/m.K[13]. However, aluminium cooling coils are also commonly found but aluminium has a relatively lower thermal conductivity as compared to copper which is 204 W/m.K[13]. Aluminium also is less durable but is cheaper compared to copper cooling coils. Table 2.3.1.1 summarizes the thermal conductivity of a variety of metals at 20°C.

Table 2.3.1.1: *Thermal Conductivity of Metals at 20°C*[13]

Metal	Thermal conductivity, k [W/m.K]
Aluminium	
- Pure	204.0
- Al-Cu (Duralumin); 94-96% Al, 3-5% Cu, trace Mg	164.0
- Al-Si (Silumin); 86.5% Al, 1% Cu	137.0
- Al-Si (Alusil); 78-80% Al, 20-22% Si	161.0
- Al-Mg-Si; 97% Al, 1% Mg, 1% Si, 1% Mn	177.0
Copper	
- Pure	386.0
- Brass; 70% Cu, 30% Zn	111.0
- Aluminium bronze; 95% Cu, 5% Al	83.0
Steel	
- Carbon steel; 0.5% C	54.0
- Carbon steel; 1.0% C	43.0
- Nickel steel; 1.0% Ni	73.0
- Chrome steel; 1.0% Cr	61.0
- Tungsten steel; 1.0% W	66.0
Tungsten, pure	163.0
Zinc, pure	112.2

2.4 Chemicals Properties of Identified Refrigerant Fluid for this Study

The identified chemicals that will be used in this study are as below:

- Aluminium chloride
- Aluminium sulphate
- Barium nitrate
- Lead (II) bromide
- Potassium nitrate
- Sodium chlorate

The chemicals are in solid state for the laboratory work. However, these chemicals could be categorised as irritant, harmful, corrosive, toxic and oxidising agent. Good practice and care need to be exercised throughout the experimentation work. Fume hood need to be used for Lead (II) bromide due to the teratogenic effect – process that induces the formation of developmental abnormalities in a foetus[7] – and it has chronic sterilisation effect on women.

A summary of the following information can be obtained from *Appendix 2.4: Table 2.4: Summary of Critical Chemical Information* [8]

- Molecular formula
- Molecular weight
- CAS-No.
- Appearance
- Flash point
- Melting point
- Boiling point
- Vapour pressure
- Specific density
- Solubility in water (at 20°C)
- Bulk density
- pH value
- Threshold limit value
- Risk phrases
- Safety phrases
- Toxicological data
- Personal protective equipment
- Storage and Handling information

2.4.1 Availability of Chemical and Thermodynamic Data of Identified Refrigerant and Predicted Characteristic of Identified Refrigerant for this Study

Negative enthalpy denotes exothermic effect while positive enthalpy denotes endothermic effect. This denotation is consistent throughout the study.

Enthalpy of solution for Aluminium chloride and Aluminium sulphate has been reported by Beggerow[15] for Aluminium sulphate at inifinite dilution as $\Delta_{sol}H_m(282.15K)$ = -234.3kJ.mol^{-1} and for Aluminium chloride at infinite dilution is $\Delta_{sol}H_m(298.15K)$ = -332.4kJ.mol^{-1}.

In published journal published by Apelblat et al[12] supplements as one of the reference of this study for the enthalpy of solution of Aluminium chloride and Aluminium sulphate. Summary of published data on enthalpy of solution for Aluminium chloride and Aluminium sulphate is tabulated in *Table 2.4.1.1: Summary of Published Data of Enthalpy of Solution, the Corresponding Molality and Average Temperature for Aluminium chloride*[12]
and *Table 2.4.1.2: Summary of Published Data of Enthalpy of Solution, the Corresponding Molality and Average Temperature for Aluminium sulphate*[12]. It's hope to investigate enthalpy of solution at lower and higher molality of the Aluminium salts investigated by Apelblat et al.

There is no other published enthalpy of solution data for Barium nitrate, Lead (II) bromide, Lithium iodide, Potassium nitrate and Sodium chlorate found except as published by Perry et al[9]. Therefore, investigation of enthalpy of solution for the above mentioned chemicals will be based only on the reported value by Perry et al.

Summary of reported heats of solution data published by Perry et al for chemicals used in this study can be found in Table 2.4.1.3: Summary of Heats of Solution for Chemicals with Exothermic Change of Enthalpy[9] and Table 2.4.1.4: Summary of Heats of Solution for Chemicals with Endothermic Change of Enthalpy[9]. Note that published the enthalpy denotation has been changed to accustom to denotation.

Table 2.4.1.1: *Summary of Published Data of Enthalpy of Solution, the Corresponding Molality and Average Temperature for Aluminium chloride*[12]

Molality mf, [mol/kg]	$\Delta_{sol}H_m$ [J/mol]	<T>, [K]
0.02071	-55820	297.17
0.02072	-52540	293.86
0.02072	-57980	294.40
0.02073	-57200	296.63
0.02079	-52480	292.73
0.02080	-52080	292.81
0.02081	-54700	296.49
0.02085	-56620	296.06
0.02087	-54780	298.07
0.02090	-54470	292.55
0.02091	-50930	293.17
0.02094	-53860	294.81
0.02099	-54970	296.42
0.02107	-56270	295.00

Table 2..4.1.2: *Summary of Published Data of Enthalpy of Solution, the Corresponding Molality and Average Temperature for Aluminium sulphate*[12]

Molality mf, [mol/kg]	deltaHsoln	<T>, [K]
0.007485	-41960	297.54
0.007539	-46040	295.64
0.007541	-47840	298.84
0.007556	-47540	297.19
0.007557	-47400	298.4
0.007574	-46380	298.49
0.007583	-42870	297.13
0.0075893	-46990	297.58
0.0075897	-48650	297.6

***Table 2.4.1.3**: Summary of Heats of Solution for Chemicals with Exothermic Change of Enthalpy*[9]

No.	Substance	Dilution*	Molecular Formula	Heat [kg-cal/g-mole]	Heat [kJoule/ mole]
1	Aluminium chloride	600	$AlCl_3$	-77.9	-18.61
2	Aluminium sulphate	Aq	$Al_2(SO_4)_3$	-126.0	-30.09
3	Lithium bromide	∞	LiBr	-11.54	-2.76
4	Lithium iodide	∞	LiI	-14.92	-3.6

***Table 2.4.1.4:** Summary of Heats of Solution for Chemicals with Endothermic Change of Enthalpy*[9]

No.	Substance	Dilution*	Molecular Formula	Heat [kg-cal/g-mole]	Heat [kJoule/ mole]
1	Barium nitrate	∞	$Ba(NO_3)_2$	+10.2	+2.44
2	Lead bromide	Aq	$PbBr_2$	+10.1	+2.41
3	Potassium nitrate	∞	KNO_3	+8.663	+2.07
4	Sodium chlorate	∞	$NaClO_3$	+5.37	+1.28

** The numbers represent moles of water used to dissolve 1g formula weight of substance; ∞ means "infinite dilution"; and aq means "aqueous solution of unspecified dilution."*

This preliminary identification of the endothermic characteristic of salt has streamlined a more rigorous study in the physiochemical nature to achieve the objectives.

For all the identified refrigerants, data of pH is not available.

2.4.2 Electric Potential of Salt and Cooling Element

To select the most suitable salt as a refrigerant, a number of factors had to be considered. The factors are high enthalpy of solution, non-toxic and will not corrode the copper cooling coil. The cooling coil selected for this project is copper cooling coil.

Table 2.4.2.1 summarises the standard electrical potential of the selected salts as refrigerant.

Table 2.4.2.1: *Standard Electric Potential of Selected Ions and Metal*

Reaction	Half-Reaction Equation	Standard Electric Potential [V]
Oxidation	$Cu - 2e^- \rightarrow Cu^{2+}$	E = +0.34 V
Reduction	$K^+ + e^- \rightarrow K$	E = -2.92 V
	$Ba^{2+} + 2e^- \rightarrow Ba$	E = -2.90 V
	$Na^+ + e^- \rightarrow Na$	E = -2.71 V
	$Al^{3+} + 3e^- \rightarrow Al^{3+}$	E = +1.66 V

By comparing the potential difference of metal ion and metal, the stability between the metal ion and metal can be determined. The Redox reaction is the sum of reduction half cell and the oxidation half cell.

Taking Sodium chlorate solution and the copper cooling coil, the half cell reactions and the overall reaction is as below.

$$\begin{array}{lll} & & \textit{Standard Cell Potential} \\ \textit{Reduction:} & Na^+ + e^- \rightarrow Na & (E = -2.7109V) \\ \textit{Oxidation:} & Cu - 2e^- \rightarrow Cu^{2+} & (E = +0.3402V) \\ \textit{Overall Reaction:} & 2Na^+ + Cu \rightarrow 2Na + Cu^{2+} & (E = -5.0816V) \end{array}$$

The reaction the sodium ion and copper metal yields an overall standard electric potential of -5.08 V. This negative value shows that the reaction is not spontaneous. Therefore, the copper metal will not be oxidised to copper ion. Therefore, it can be concluded that the sodium salt will not corrode the copper cooling cool.

2.5 Enthalpy of Solution

For one substance to dissolve in another, three events must occur: [10]

1) Solute particles must separate from each other. This step involves overcoming intermolecular attractions, therefore this step is endothermic.
   Solute (aggregrated) + heat → solute (separated) $\Delta H_{solute} > 0$
2) Some solvent particles must separate to make room for the solute particles. This step also involves overcoming intermolecular attractions, therefore this step is endothermic.
   Solvent (aggregrated) + heat→ solvent (separated) $\Delta H_{solvent} > 0$
3) Solute and solvent particles must mix together. The particles attract each other, therefore this step is exothermic.
   Solute (separated) + solvent (separated) → solution + heat $\Delta H_{mix} < 0$

Combining the above three equations will yield the total enthalpy change that occurs when a solution forms from solute and solvent is the heat of solution Using Hess's Law: $\Delta H_{soln} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$ *Equation 2.5.1*

When the sum of endothermic terms (ΔH_{solute} + $\Delta H_{solvent}$) is larger than the exothermic term (ΔH_{mix}), ΔH_{soln} will be positive. Therefore, process is endothermic and the solution becomes cooler as it folrms.

When the sum of endothermic terms is smaller than the exothermic term, ΔH_{soln} will be negative, process is exothermic and the solution becomes warmer as it forms.

Heat of solution is based on the dissolution of 1 mole of solute. If we take species 1 as the solute, then x_1 is the mole of solute per mole of solution. Since ΔH is the heat effect per mole of solution $\Delta H/x_1$ is the heat effect per mole of solute.[11] Thus,

$$\Delta H_{soln} = \frac{\Delta H}{x_1}.$$

2.6 Heat of Hydration for Ionic Solid in Water

The $\Delta H_{solvent}$ and ΔH_{mix} in the heats of solution especially difficult to measure individually.[10] The combined term of $\Delta H_{solvent}$ and ΔH_{mix} represent the enthalpy change during salvation – process of surrounding a solute particle with solvent particles. Solvation in water is called hydration.

Therefore, the combined terms of $\Delta H_{solvent}$ and ΔH_{mix} is termed to be heat of hydration (ΔH_{hydr}). Making a simplification from *equation 2.5.1* will result in *equiation 2.6.1*

$$\Delta H_{soln} = \Delta H_{solute} + \Delta H_{hydr}$$

Equation 2.6.1

Breaking several hydrogen bonds in water is more than compensate for when several strong ion-dipole forces form, so hydration of an ion is always exothermic.[10]

Heats of hydration exhibits trends based on the charge density of the ion - the ratio of the ion's charge to its volume. In general, the higher the charge density, the more negative ΔH_{hydr}. According to Coulumb's law, the greater the ion's charge is and the close the ion can approach the charge of water dipole, the stronger the attraction.

The energy required to separate an ionic solute (ΔH_{solute}) into gaseous ions is the negative of it's lattice energy ($-\Delta H_{lattice}$) is highly positive.

Substituting the lattice energy into equation 2.6.1 will result in equation 2.6.2

$$\Delta H_{soln} = - \Delta H_{lattice} + \Delta H_{hydr} \text{ of the ions}$$

Equation 2.6.2

The study between ΔH_{soln} and the $-\Delta H_{lattice}$ will help determine the concentration of solution where the $-\Delta H_{lattice}$ term is small enough compared to the combined ion is heats of hydration, so process will become exothermic.

2.7 Calorimetry

The equation relating heat, mass, and temperature change is put to use in a technique called calorimetry, the method of measuring heat transferred during a reaction or physical process. The key piece of equipment in calorimetry is the calorimeter, a thermometer-equipped vessel which ideally thermally isolates the process being studied by preventing heat transfer to or from the calorimeter's surroundings. The calorimeter may consist a Dewar bottle or a covered acrylic glass beaker in an insulating jacket to prevent heat exchange with the surrounding. As a "perfect insulator", the calorimeter allows all the heat evolved or absorbed within it to be measured by a thermometer and recorded by an observer. In the perfect insulator case, heat lost equals to the heat gained, $q_{in} = q_{out}$ Clearly, there is no perfectly insulating calorimeter, the heat gained or lost from the calorimeter has to be accounted.

Consider the final temperature of the hot water will be less than its initial temperature, therefore $\Delta T = T_{final} - T_{initial}$ is negative and since mass and specific heats are positive quantities , heat will be a negative quantity (exothermic process s and reactions such as cooling of a hot substance always have negative value of heat). Similarly, the final temperature of cold water will be greater than its initial temperature. Therefore, ΔT for the cold water will be positive (endothermic processes and reactions such as the heating of a hot substance always have positive values of enthalpy).

The calorimeter is weighted and its temperature before and after heating or cooling is measured by assuming the calorimeter is in thermal equilibrium with its contents. It's known that hot water will release heat therefore negative sign which represent exothermic process, cold water and the calorimeter will absorb heat therefore given a positive sign which represent endothermic processes.

From First Law of Thermodynamics, law of energy conservation, energy can neither be created nor destroyed. We can derive *Equation 2.7.1* by equating heat lost by hot substances with heat gained by cold substances.

$$-q_{hot\ subtances} = q_{cold\ subtances} + q_{calorimeter} \qquad \textit{Equation 2.7.1}$$

Knowing the general equation of $q = mC\Delta T$ where q represents the quantity of heat, m is mass in grams, ΔT is defined as $T_{final} - T_{inifital}$ and C as specific heat capacity in unit of J/g.°C.

Equation 2.7.1 is used to determine the heat capacity of the calorimeter which will be valid for any heat investigation. From *equation 2.7.1*, in a hot water, cold water and calorimeter system, equation is generalised to $-q_{hot\ water} = q_{cold\ water} + q_{calorimeter}$, substituting $q=mC\Delta T$ and recognising the hot and cold water will have the same final temperature, $m_{hw}.C_{water\cdot\Delta Tfhw} = m_{cw}.C_{water}.\Delta T_{cw} + C'_{calorimeter}.\Delta T_{calorimeter}$ substituting $q=mC\Delta T$ and recognising the hot and cold water will have the same final temperature,
$-\ m_{hw}.C_{water}.\Delta T_{hw} = m_{cw}.C_{water}.\Delta T_{cw} + C'_{calorimeter}.\Delta T_{calorimeter.}$ Rearranging,

$$C'_{calorimeter}\Delta T_{calorimeter} = -m_{cw}.C_{water}.\Delta T_{cw} - m_{hw}.C_{water}.\Delta T_{hw}$$

$$C'_{calorimeter} = \frac{-m_{cw}\cdot C_{water}\cdot \Delta T_{cw} - m_{hw}\cdot C_{water}\cdot \Delta T_{hw}}{\Delta T_{calorimeter}}$$

$$C'_{calorimeter} = \frac{-(\rho_{cw}\cdot V_{cw})\cdot C_{water}\cdot (T_f - T) - (\rho_{hw}\cdot V_{hw})\cdot C_{water}\cdot (T_f - T_o)}{(T_f - T_o)} \qquad \textit{Equation 2.7.2}$$

where T_f represents the final temperature of the calorimeter system [°C],
T_o represents the initial temperature of the calorimeter system and hot water [°C],
T represents the initial temperature of the ice water [°C],
ΔT is the change in the temperature of the calorimeter $T_f - T_o$ [°C],
m represents the mass of water [g],
ρ represents the density water [g/cm^3],
V represents the volume of water [cm^3]

$C'_{calorimeter}$ is the heat capacity of the calorimeter vessel $\left[\frac{\text{J}}{^{\circ}\text{C}}\right]$,
hw represents hot water, and
cw represents cold water.

Upon determination of heat capacity of the calorimeter $C'_{calorimeter}$, the heat gained or lost by the calorimeter system in experiment of dissolution of anhydrous salt crystals in water by multiplying $C'_{calorimeter}$ by ΔT, the temperature rise or fall obtained.

$$q_{calorimeter} = C'_{calorimeter} \cdot \Delta T \qquad \textit{Equation 2.7.3}$$

For the experiment to determine heat of solution ΔH_{soln} in J/mol, general relationship is established using the following equation $x_1 \Delta H_{soln} = -q_{water} - q_{calorimeter}$. Rearranging, to get the expression of ΔH_{soln} in *equation 2.7.4.*

$$\Delta H_{soln} = \frac{-m_{water} \cdot C_{water} \cdot (T_f - T_o) - C'_{calorimeter}(T_f - T_o)}{x_1} \qquad \textit{Equation 2.7.4}$$

Number of moles of solute x_1 is calculated from

$$x_1 = \frac{mass\ of\ solute}{molecular\ weight\ of\ solute} \qquad \textit{Equation 2.7.5}$$

2.8 pH Determination

pH is the negative logarithm of hydronium ion concentration, $[H_3O^+]$. To handle numbers with negative exponents more conveniently in calculations, these numbers are converted to positive numbers using a numerical system called p-scale, the negative of the common (base-10) logarithm of the number. Applying the p-scale to $[H_3O^+]$ gives pH, the negative logarithm of $[H^+]$ or $[H_3O^+]$[16]:

$$pH = -\log [H_3O^+] \qquad \textit{Equation 2.8.1}$$

The higher the pH, the lower the $[H_3O^+]$. An acidic solution has lower pH but higher $[H_3O^+]$ compared to a basic solution.

pH of a neutral solution is	$= 7.00$
pH of an acidic solution is	< 7.00
pH of a basic solution is	> 7.00

There are also other p-scales to express hydroxide ion concentration and equilibrium constant.

Hydroxide ion $[OH^-]$ concentration can be expressed as pOH[18]:

$$pOH = -\log [OH^-] \qquad \textit{Equation 2.8.2}$$

Acidic solutions have a higher pOH but lower $[OH^-]$ as compared to basic solutions.

Equilibrium constant can be expressed as pK[18]:

$$pK = -\log K \qquad \textit{Equation 2.8.3}$$

Low value of pK corresponds to a high value of K. Reaction that reaches equilibrium with mostly products has a low pK but high K value, while reaction that equilibrate with mostly reactant will have a high pK but low K value.

The relationship between pH, pOH and pK_w are as follow[18]:

$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14} \text{ (at 298.15K)} \qquad \textit{Equation 2.8.4}$$

$-\log K_w = (-\log [H_3O^+]) + (-\log [OH^-]) = -\log (1.0 \times 10^{-14})$ *Equation 2.8.5*

$pK_w = pH + pOH = 14$ (at 298.15K) *Equation 2.8.6*

From one of the above values, it's possible to determine the others at 298.1K or 25°C.

2.8.1 Measuring pH

At a laboratory scale, pH values can be measure with an acid-base indicator or a pH meter.

Acid base indicators are organic molecules which colour depends on the acidity or basicity of the solution in which it's dissolved. Normally, method of using a pH paper to perform a drop test before comparing the colour of the strip with a colour chart supplied by the pH paper manufacturer. This method is quick but has very low accuracy as the colour scale marked at each 1.0 pH interval.

pH meter measure $[H_3O^+]$ by means of two electrodes immersed in test solution. One electrode provides a stable reference voltage while the other has an extremely thin, conducting glass membrane that separates a known internal $[H_3O^+]$. The difference in $[H_3O^+]$ creates a voltage difference across the membrane, which is measured and displayed in pH units.

In this study, pH meter sensION1 manufactured by Hach is used.

Figure 2.8.1: Hach sensION1 pH meter

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Apparatus/Equipment Required

1) Electronic balance
2) Magnetic stirrer
3) Thermometer
4) Dewar flask
5) Retort stand
6) Electronic stop watch
7) pH meter with temperature probe
8) Stirring rod
9) Spatula
10) Petri dish
11) Burette
12) Cornical funnel
13) Volumetric flask
14) Beaker
15) Polystyrene cup
16) Polyurethane
17) Cotton
18) Insulating tape
19) Aluminium foil

3.2 Chemicals/Materials Required

1) Aluminium chloride
2) Aluminium sulphate
3) Barium nitrate
4) Lead (II) bromide

5) Lithium bromide
6) Lithium iodide
7) Potassium nitrate
8) Sodium chlorate

3.3 Procedure Identification

Referring to, the calorimeter consists of a 1-pt Dewar flask and temperature probe supported on a magnetic stirrer.

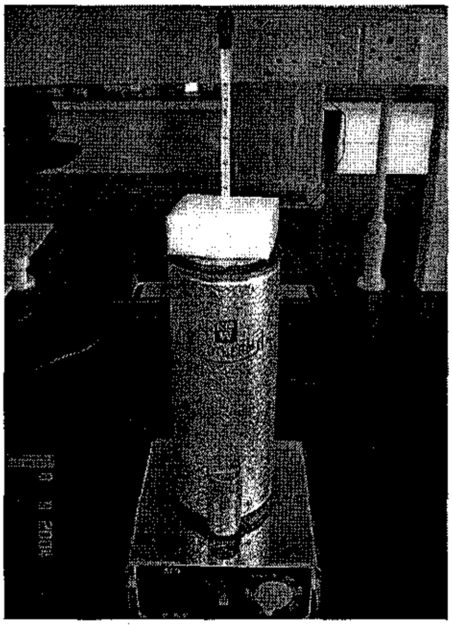

Figure 3.3: **Calorimeter Assembly**

3.3.1 Material Preparation

1. Water content of hydrous salts is determined gravimetricaly. Two samples were heated for 1 hour, cooled in silica gel and weighted.

2. These samples are heated, weighted and heated at a higher temperature until constant mass was obtained.

3.3.2 Calibration – Calorimeter System Heat Capacity

Objective: To determine the calorimeter system heat capacity

1. Heat capacity for the calorimeter system determined by measuring 250 ml of distilled water at room temperature is measured into the clean, dry Dewar flask.

2. Water is stirred at a moderate rate and the temperature is read every 20 seconds until it becomes constant within 0.1°C.

3. 50 ml of ice water is transferred into the Dewar flask with a pipette. Ice water is withdrawn with a chilled pipette to form an ice-water mixture.

4. Temperature of the ice water in the thermos is recorded.

5. Water in the calorimeter is stirred and the temperature is read every 20 seconds until a value constant within 0.1°C is obtained. This process is repeated and the average of the data is taken for the calculation of the heat capacity.

3.3.3 Determination of Enthalpy of Solution

Objective: To determine optimum concentration

1. Thoroughly, the Dewar flask is dried and 100ml to 250 ml of distilled water is carefully measured into the calorimeter.

2. Water in the Dewar flask is stirred and the temperature reading is recorded every 20 seconds until three values constant within 0.1°C is obtained.

3. Weight 1 g of salt or solutes. Quickly, salt is added into the Dewar flask and flask is covered. Salt is not weigh at the early of the experiment to prevent absorption of water from ambient. The temperature reading is recorded every 20 seconds and the largest temperature change is observed.

4. pH is measured and recorded once temperature reading in procedure 8 have reached constant.

5. Experiment repeated by repeating procedure 1-4.

6. Experiment is repeated for procedure 1 – 5 for mass of solute or salt for incremental mass.

7. Procedure 1 – 6 is repeated for other solutes or salts.

3.3.4 Experimental Testing on a Insulated System

Objective: To observe heat transfer between endothermic salt solution and hot air

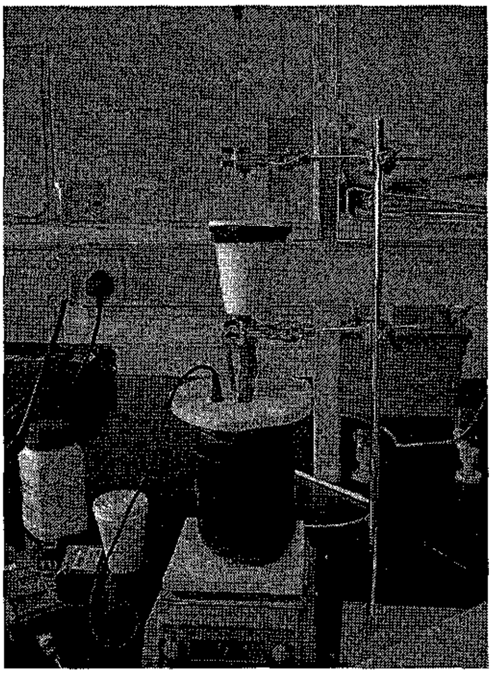

Figure 3.3.4.1: *Hot Air-Endothermic Salt Solution Heat Exchanger Set Up*

1. Apparatus is set up according to Figure 3.3.4.1.

2. Optimum salt solution is prepared, stirrer is started.

3. Temperature of the endothermic salt solution is recorded.

4. Once the lowest temperature of the salt solution is reached, the air compressor is started. Time is started. Air flow pressure is recorded.

5. Air outlet temperature and the endothermic salt solution temperature is recorded at 20 seconds interval.

3.4 Method of Calculation

1. The heat capacity of the calorimeter system is assumed that when filled with water is the same as the heat capacity of the calorimeter system with the solute and solvent.

2. The processes involved are assumed adiabatic.

3. In calculating the heat capacity of the calorimeter system, using of the fact that the heat gained by the ice water is equal numerically to the heat lost by the Dewar flask and the 250 ml of water. This equality may be represented by *equation 2.7.2*

$$C'_{calorimeter} = \frac{-(\rho_{cw} \cdot V_{cw}) \cdot C_{water} \cdot (T_f - T) - (\rho_{hw} \cdot V_{hw}) \cdot C_{water} \cdot (T_f - T_o)}{(T_f - T_o)}$$

   which is used to calculate the heat capacity of the Dewar flaks. Sample calculation is appended as Appendix 3.3.2.

4. The temperature change (rise and fall) in the calorimeter is due to the absorption and release of the heat associated with the dissolution of 5 g of salt or solute in 100 ml – 250 ml of distilled water. Knowing heat capacity of the

calorimeter $C'_{calorimeter}$ from *equation 2.7.2*, we can obtain the heat gained or lost by the calorimeter system in the dissolution of salt in water by using *equation 2.7.3* $Q_{calorimeter} = C_{calorimeter} \cdot \Delta T$

The heat of solution ΔH_{soln} in J/mol is then calculated using *equation 2.7.4* $\Delta H = \frac{-m_{water} \cdot C_{water} \cdot (T_f - T_o) - C'_{calorimeter}(T_f - T_o)}{x_1}$ and number of moles solute x_1 is calculated from *equation 2.7.4*, $x_1 = \frac{mass\ of\ salt}{molecular\ weight}$. Sample calculation is appended as Appendix 3.3.3

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Calibration of Calorimeter System

The record and sample calculation for part 3.3.2 Calibration – Calorimeter System Heat Capacity is appended as Appendix 3.3.2. The experimental result used to compute the heat capacity of the Dewar flask used. The mean Dewar flask heat capacity C' is found to be 159.045 J/^{o}C.

Calibration is repeated to get the mean or average of the heat capacity of the system. Every calorimeter system needs to be calibrated because there is no absolute insulator. Therefore, every heat loss or heat gained need to be accounted for.

4.2 Exothermic Enthalpy of Solution – Aluminium sulphate and Aluminium chloride

Among the six salts that were investigated, Aluminium sulphate and Aluminium chloride are exothermic salts. This is in accordance of the predicted behaviour of Perry's and Apelblat. However, Perry's reported that the exothermic enthalpy of solution of Aluminium sulphate to be higher than the exothermic enthalpy of solution of Aluminium chloride. This is opposite of Apelblat's findings in enthalpy of solution of Aluminium chloride and Aluminium sulphate. Apelblat's finding is published in year 2002 while the values in Perry's was computed from Bichowsky et al from the book of Thermochemistry of Chemical Substances was published in year 1936. In this project, the findings could be determined to follow Apelblat's or Perry's finding because the molality of the Aluminium chloride used in this project is not comparable to those used in Aluminium sulphate.

Both exothermic salt Aluminium chloride and Aluminium sulphate are not suitable as refrigerant for the new air conditioning system because of its exothermic nature.

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Calibration is repeated to get the mean or average of the heat capacity of the system. Every calorimeter system needs to be calibrated because there is no absolute insulator. Therefore, every heat loss or heat gained need to be accounted for.

4.2 Exothermic Enthalpy of Solution – Aluminium sulphate and Aluminium chloride

Among the six salts that were investigated, Aluminium sulphate and Aluminium chloride are exothermic salts. This is in accordance of the predicted behaviour of Perry's and Apelblat. However, Perry's reported that the exothermic enthalpy of solution of Aluminium sulphate to be higher than the exothermic enthalpy of solution of Aluminium chloride. This is opposite of Apelblat's findings in enthalpy of solution of Aluminium chloride and Aluminium sulphate. Apelblat's finding is published in year 2002 while the values in Perry's was computed from Bichowsky et al from the book of Thermochemistry of Chemical Substances was published in year 1936. In this project, the findings could be determined to follow Apelblat's or Perry's finding because the molality of the Aluminium chloride used in this project is not comparable to those used in Aluminium sulphate.

Both exothermic salt Aluminium chloride and Aluminium sulphate are not suitable as refrigerant for the new air conditioning system because of its exothermic nature.

In published journal published by Apelblat et al[12] on the enthalpy of solution of Aluminium chloride and Aluminium sulphate. Enthalpy of solution ΔH_{soln} for Aluminium sulphate is determined from the molality region of 0.007485mol/kg – 0.0075897mol/kg[12]. Summary of the enthalpy data is tabulated in *Table 2.4.2.* The trend of enthalpy solution reported by Apelblat et al[2] is appended as Appendix 4.2.3 and Appendix 4.2.4. In this journal, it has been found that the enthalpy of solution is negative, indicating an exothermic effect. This is in agreement with the experimental results obtained. The experimental enthalpy of solution here within the molality range of 0.0059mol/kg – 0.0117mol/kg is in the range of -164,767.33J/mol to 123,365.9861J/mol. This range of enthalpy of solution is within Apelblat's range of enthalpy of solution for the molality range of 0.007485mol/kg – 0.0075897mol/kg.

The Parr 1455 Solution Calorimeter used in Apelblat's experiment is more accurate equipment with have relative standard deviation of 0.4% to 1%. However, Parr 1455 uses the fully silvered glass Dewar supported within stainless steel air can which is later mounted on an aluminium case. This provide a well insulated reaction chamber.

The experimental data obtained in this study may deviate from Apelblat's due to the imperfect insulation of the Dewar flask. The actual enthalpy of solution may be higher than the experimental value reported, but often negligible.

The heats of solution data tabulated in *Table 2.4.3* by Perry et al[17] in Chemical Engineer's Handbook, the enthalpy of solution for Aluminium sulphate solution of unspecified dilution is -126kcal/mol or -30,090J/mol. From another report by Beggerow[17] the enthalpy of solution for Aluminium sulphate at infinite dilution is -234,300J/mol. By comparing with all the three sources of enthalpy of solution, it can be presumed that the experimental enthalpy of solution in this study as an expected effect.

4.3 Endothermic Enthalpy of Solution – Barium nitrate, Lead (II) bromide, Potassium nitrate and Sodium chlorate

4.3.1 Barium nitrate

Table 4.3.1.1 shows that for the molality of Barium nitrate of 0.0154 mol/kg – 0.3521 mol/kg, the enthalpy of solution ranges from 52 kJ/mol – 150 kJ/mol while pH ranges from 5.70 – 6.00. The reported value by Perry's et al for Barium nitrate is 2.44 kJ/mol for infinite dilution. However in this experiment the most positive enthalpy of solution is 150 kJ/mol. The experimental value is higher than the value reported by Perry's et al (2.44 kJ/mol).

The maximum temperature decrement is 3.8°C at molality of 0.3521 mol/kg. This molality (0.3521 mol/kg) above to the reference solubility limit of 90 g/litre at 20°C. The reference saturation of Barium nitrate at 20°C is at 0.3444 mol/kg. This shows the maximum temperature reduction potential is only 3.8°C.

Due to the solubility limitation, the minimum temperature of 19.2°C does not provide sufficient heat transfer driving force for cooling hot air from ambient of 30°C to below 20°C requirement.

Referring at *Table 4.3.1.2* at molality of 0.3521 mol/kg, the duration at minimum temperature 19.2°C is only for 180 seconds while at molality of 0.3062 mol/kg, the duration at minimum temperature 19.5°C is for 300 seconds and at molality of 0.2756 mol/kg at minimum temperature of 19.6°C is for 260 seconds. *Figure 4.3.1.1* and *Figure 4.3.1.2* shows the maximum temperature and temperature profile of Barium nitrate at various molality.

In the occasion of Barium nitrate is to be chosen as the new refrigerant, optimum Barium nitrate molality would be at 0.3062. This is because of the requirement to supply work to the reverse osmosis air conditioning system pump would be lesser, when the duration at minimum temperature is longer. However, the economic analysis is not done in this project to investigate the trade-off between raw material cost and operational cost.

Table 4.3.1.1: *Summary of Experimental Results of Enthalpy of Solution for Barium nitrate*

Molarity m [mol/kg]	ΔT [deg C]	ΔH_{soln} [J/mol]	pH
0.0154	-1.0	150239	5.89
0.0766	-1.5	45223	5.72
0.1225	-2.0	78705	5.94
0.1531	-2.3	72416	6.00
0.1990	-2.6	62970	6.03
0.2311	-3.0	62583	6.07
0.2756	-3.4	59462	6.05
0.3062	-3.5	55100	6.00
0.3521	-3.8	52022	6.20

Table 4.3.1.2: *Summary of Duration of Time at Minimum Temperature for Barium nitrate*

Molarity m [mol/kg]	Minimum Temperature	Duration at Time at Minimum Temperature [sec]
0.0154	22.0	60
0.0766	21.5	240
0.1225	21.0	240
0.1531	20.7	240
0.1990	20.4	240
0.2311	20.0	240
0.2756	19.6	260
0.3062	19.5	300
0.3521	19.2	180

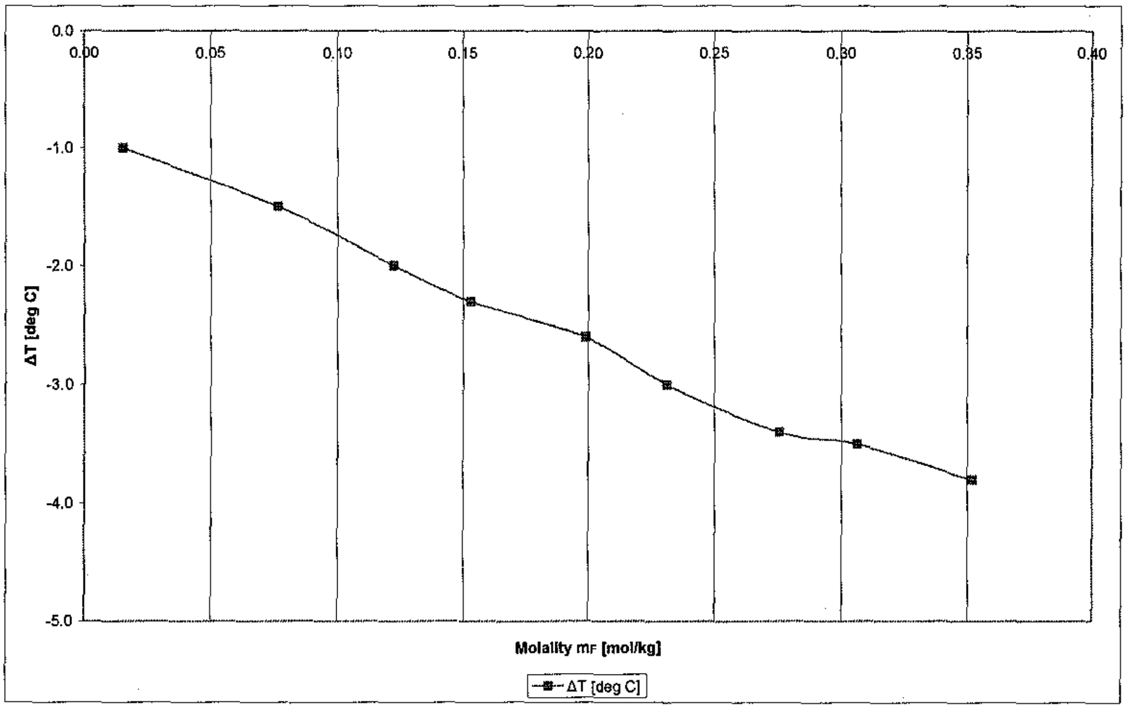

__Figure 4.3.1.1:__ Graph of Maximum Temperature Difference versus Molality for Barium nitrate

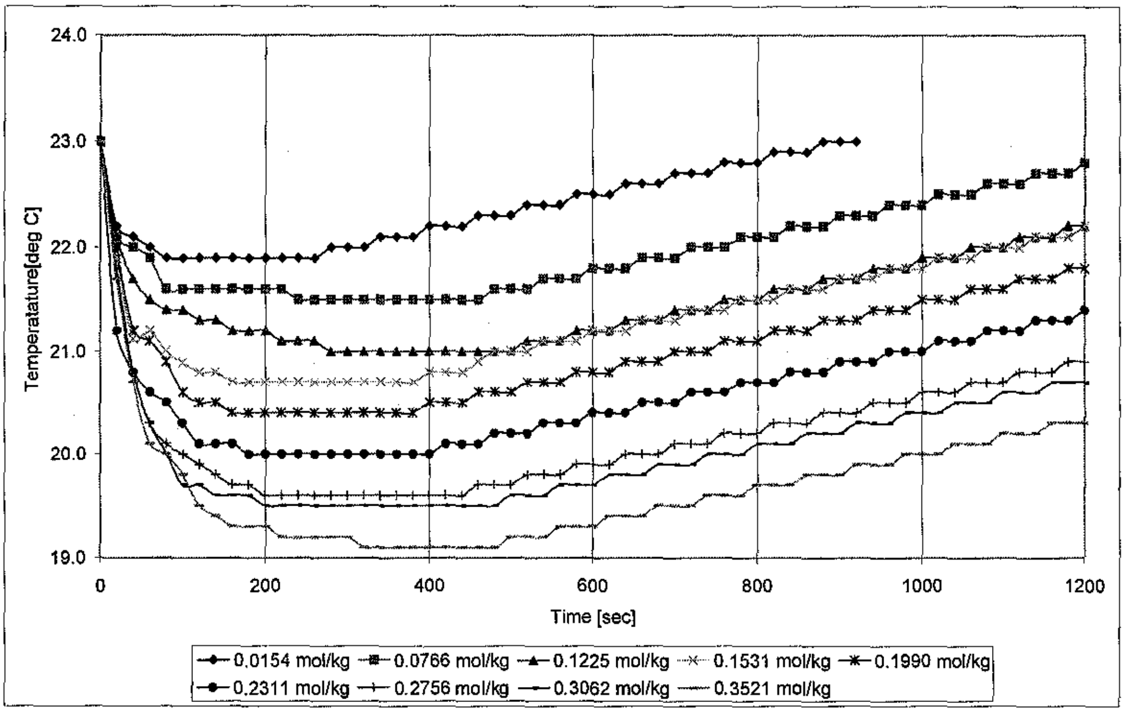

__Figure 4.3.1.2:__ Temperature Profile of Various Molality versus Time for Barium nitrate

4.3.2 Lead (II) bromide

Table 4.3.2.1 shows that for the molality of Lead (II) bromide of 0.0011 mol/kg – 0.0111 mol/kg, the enthalpy of solution ranges from 42 kJ/mol – 43 kJ/mol while pH ranges from 4.50 – 5.70. The reported value by Perry's et al for Lead (II) bromide is 2.41 kJ/mol for unspecified dilution. However in this experiment the most positive enthalpy of solution is 74 kJ/mol. The experimental value is higher than the reported by Perry's et al (2.41 kJ/mol)

The maximum temperature decrement is 0.7°C at molality 0.0022 mol/kg. The solubility of Lead (II) bromide is 5 g/litre at 20°C. Due to the solubility limitation, Lead (II) bromide does not provide much temperature decrement. The lesser the temperature, the solubility will decrease. Moreover, Lead (II) bromide is toxic. Therefore, Lead (II) bromide would not be an appropriate candidate for the new air conditioning system because of its inefficiency and toxicity.

<u>Table 4.3.2.1:</u> *Summary of Experimental Results of Enthalpy of Solution for Lead (II) bromide*

Molarity m [mol/kg]	ΔT [deg C]	ΔH_{soln} [J/mol]	pH
0.0011	-0.2	423022	5.66
0.0022	-0.7	740288	5.31
0.0111	-1.0	435225	4.56

<u>Table 4.3.2.2:</u> *Summary of Duration of Time at Minimum Temperature for Lead (II) bromide*

Molarity m [mol/kg]	Minimum Temperature	Duration at Time at Minimum Temperature [sec]
0.0011	22.0	880
0.0022	21.5	240
0.0111	21.6	60

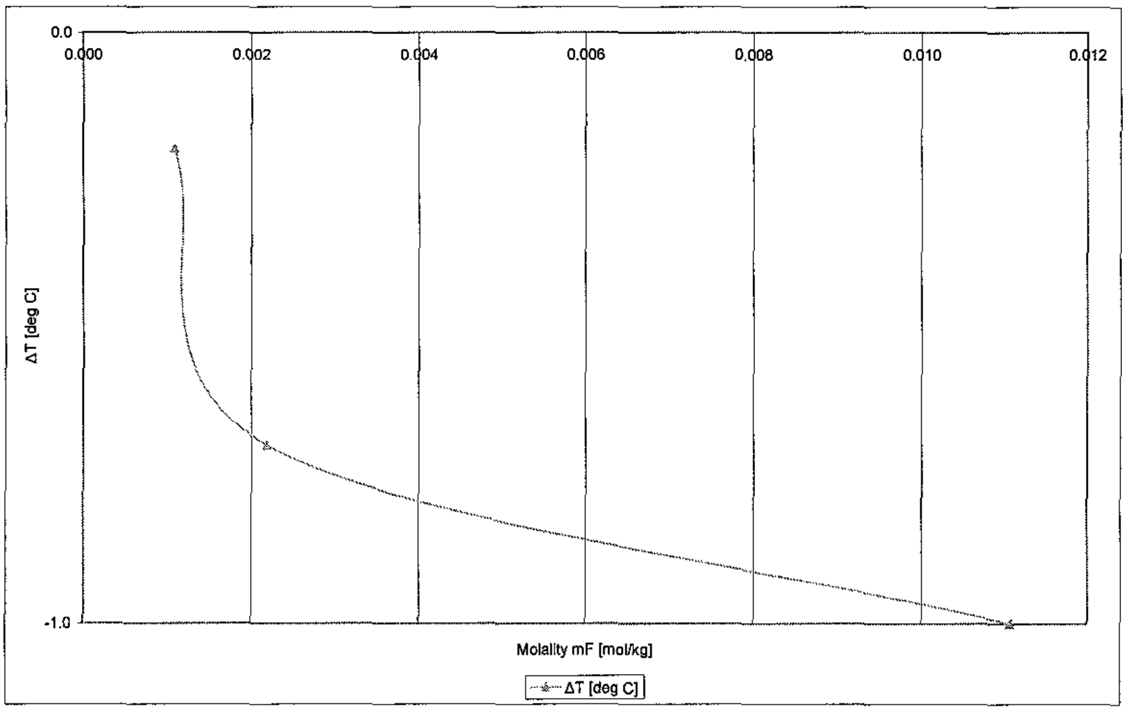

Figure 4.3.2.1: *Graph of Maximum Temperature Difference versus Molality for Lead (II) bromide*

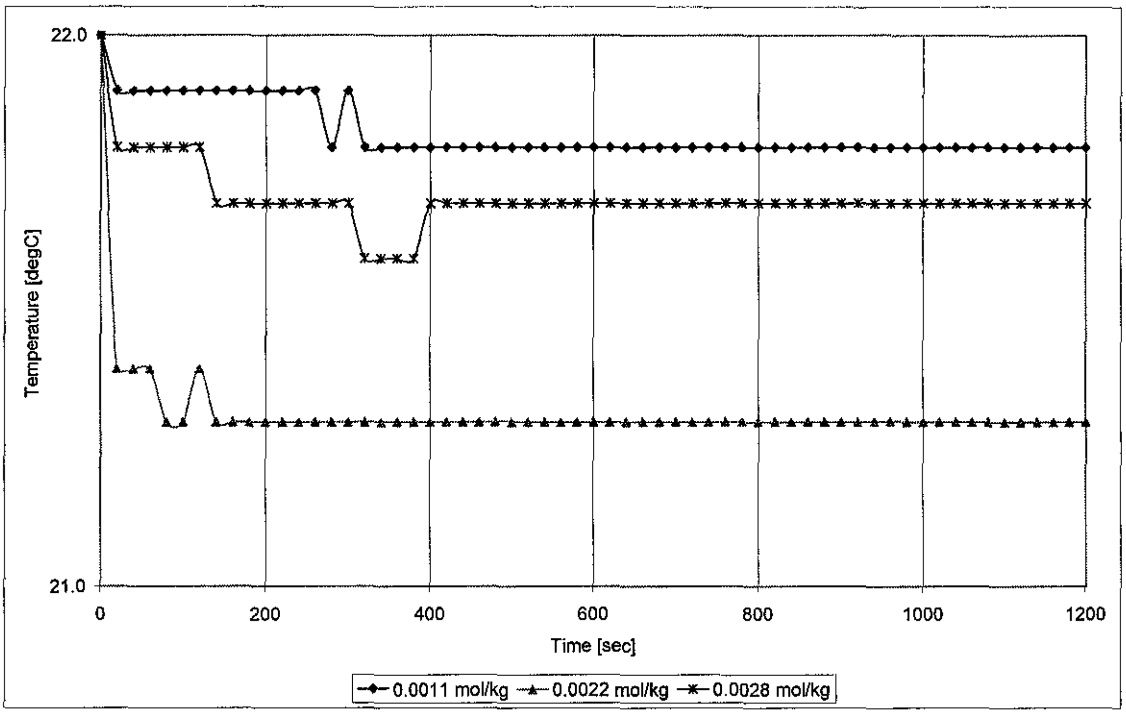

Figure 4.3.2.2: *Temperature Profile of Various Molality versus Time for Lead (II) bromide*

4.3.3 Potassium nitrate

Table 4.3.3.1 shows that for the molality of Potassium nitrate of 0.0235 mol/kg – 2.1363 mol/kg, the enthalpy of solution ranges from 19 kJ/mol – 97 kJ/mol while pH ranges from 5.20 – 6.20. The reported value by Perry's et al for Potassium nitrate is 2.07 kJ/mol for infinite dilution. However in this experiment the most positive enthalpy of solution is 97 kJ/mol. The experimental value is higher than the value reported by Perry's et al (2.07 kJ/mol).

The maximum temperature decrement is 12.7°C at molality of 2.12363 mol/kg. This molality (2.12363 mol/kg) below to the reference solubility limit of 320 g/litre at 20°C. The reference saturation of Potassium nitrate at 20°C is at 3.1648 mol/kg. This shows the maximum temperature reduction potential has not been investigated. However, during the experiment, once the stirrer is stopped, white precipitates begins to form at 10.9°C. There is no reported value of solubility of Potassium nitrate at 10 °C. One of the reason the precipitate is formed is due to the lower solubility of Potassium nitrate at 10°C. The salt precipitate at minimum temperature of 10°C could cause irreversible fouling on the reverse osmosis membrane. Thus, lowering the separation efficiency.

Potassium nitrate of molality between 0.9891 mol/kg and 2.1363 mol/kg can be a good candidate as a refrigerant for the new air conditioning system. The conventional air conditioning units cools air to a minimum temperature of 16°C. Therefore, Potassium nitrate can be used to maintain air within 16 °C and 18 °C.

Referring at *Table 4.3.3.2* at molality of 2.1363 mol/kg, the duration at minimum temperature 10.9°C is only for 160 seconds while at molality of 0.9891 mol/kg, the duration at minimum temperature 19.5°C is for 300 seconds and at molality of 0.2756 mol/kg at minimum temperature of 15.6°C is for 100 seconds. *Figure 4.3.3.1* and *Figure 4.3.3.2* shows the maximum temperature and temperature profile of Barium nitrate at various molality.

In the occasion of Potassium nitrate is to be chosen as the new refrigerant, optimum Barium nitrate molality would be between 0.9891 and 2.1363. However, as the duration at minimum temperature is between 100 seconds – 160 seconds, the requirement to supply work to the reverse osmosis air conditioning system pump would need to be considered.

<u>Table 4.3.3.1:</u> *Summary of Experimental Results of Enthalpy of Solution for Potassium nitrate*

Molarity m [mol/kg]	ΔT [deg C]	ΔH_{soln} [J/mol]	pH
0.0235	-0.2	19682	5.20
0.0398	-0.4	23236	5.40
0.0797	-1.6	96801	5.63
0.1193	-1.9	76795	5.72
0.1978	-1.5	36545	5.81
0.3171	-2.4	36481	5.92
0.3959	-2.9	35307	6.03
0.5144	-4.2	39353	5.80
0.9891	-6.7	32650	6.04
2.1363	-12.7	28655	6.16

<u>Table 4.3.3.2:</u> *Summary of Duration of Time at Minimum Temperature for Potassium nitrate*

Molarity m [mol/kg]	Minimum Temperature	Duration at Time at Minimum Temperature [sec]
0.0235	22.3	80
0.0398	22.1	80
0.0797	21.9	80
0.1193	21.7	80
0.1978	20.8	100
0.3171	20.4	80
0.3959	19.0	80
0.5144	18.4	80
0.9891	15.6	100
2.1363	10.9	160

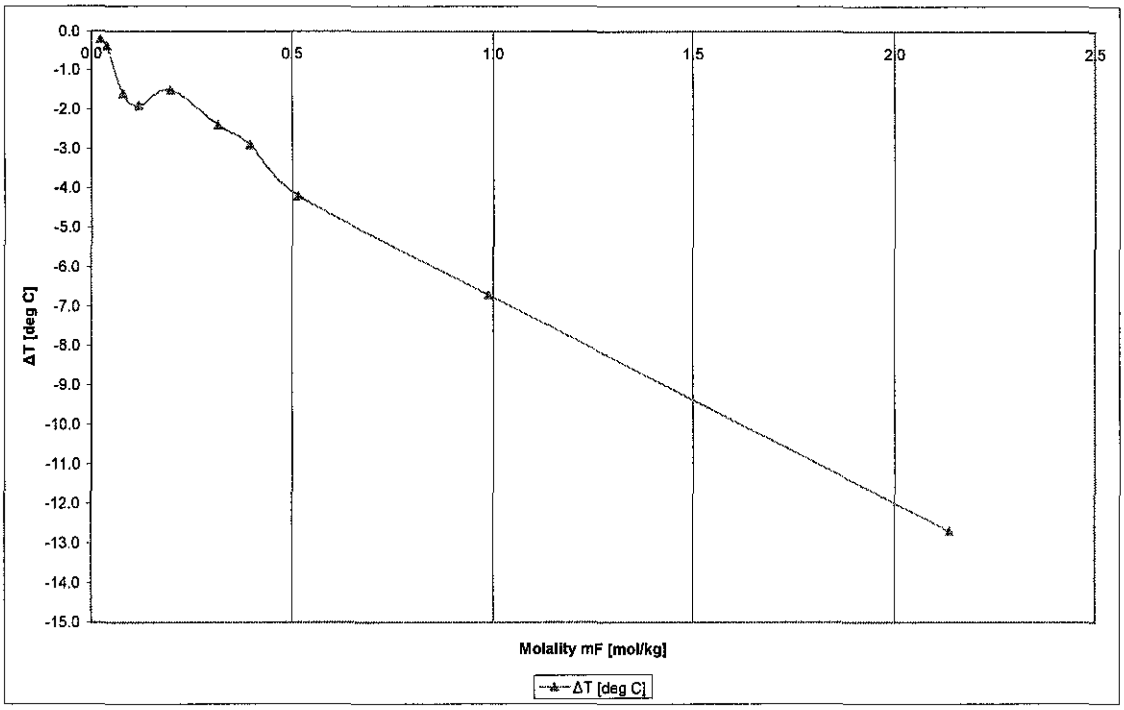

Figure 4.3.3.1: *Graph of Maximum Temperature Difference versus Molality for Potassium nitrate*

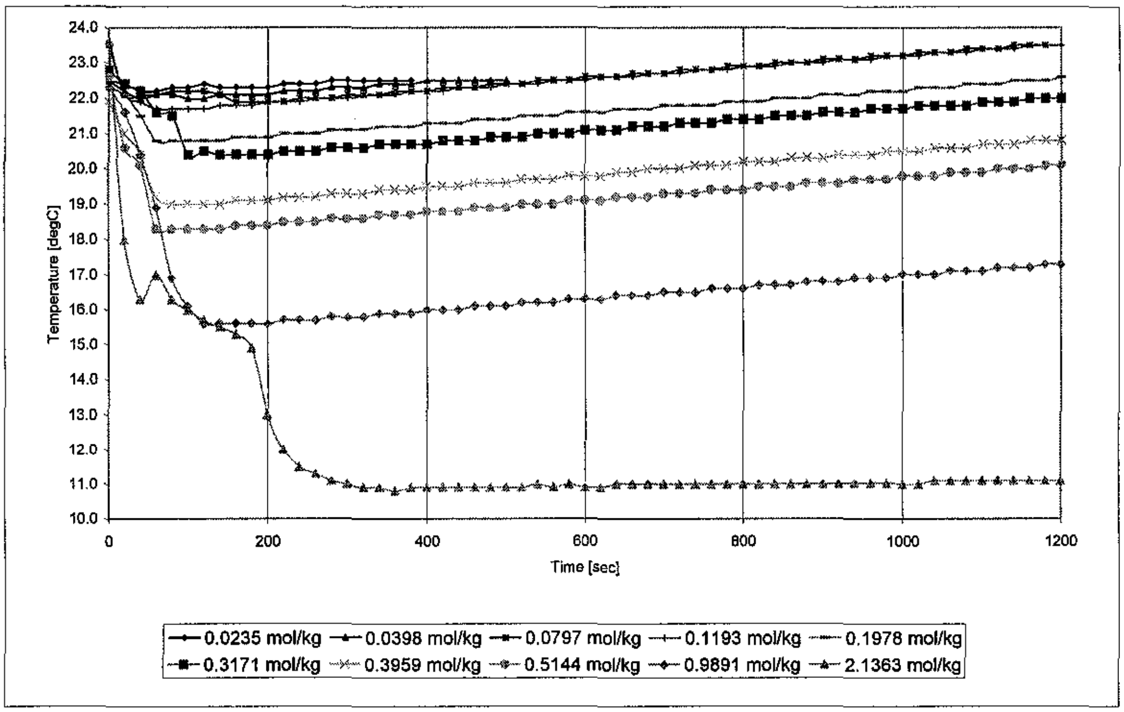

Figure 4.3.3.2: *Temperature Profile of Various Molality versus Time for Potassium nitrate*

4.3.4 Sodium chlorate

Table 4.3.4.1 shows that for the molality of Sodium chlorate of 0.0376 mol/kg – 8.4555 mol/kg, the enthalpy of solution ranges from 7 kJ/mol – 27 kJ/mol while pH ranges from 5.40 – 6.00. The reported value by Perry's et al for Sodium chlorate is 1.28 kJ/mol for infinite dilution. However in this experiment the most positive enthalpy of solution is 27 kJ/mol. The experimental value is higher than the value reported by Perry's et al (1.28 kJ/mol).

The maximum temperature decrement is 19.3°C at molality of 8.4555 mol/kg. This molality (8.4555 mol/kg) is well below to the reference solubility limit of 1000 g/litre at 20°C. The reference saturation of Sodium chlorate at 20°C is at 9.3949 mol/kg. This shows the maximum temperature reduction potential has not been investigated.

At minimum temperature of 3.7 °C at the high molality of 8.4555 mol/kg, there is no precipitation observed. This high solubility at low temperature makes Sodium chlorate a very good potential as the refrigerant for the new air conditioning system. High solubility in low concentration signifies less irreversible fouling on the reverse osmosis membrane. Thus, optimising the separation efficiency.

Sodium chlorate of molality 5.6370 mol/kg is determined to the most optimum concentration as refrigerant for the new air conditioning system. The conventional air conditioning units cools air to a minimum temperature of 16 °C. Therefore, Sodium chlorate can be used to maintain air within 16 °C and 18 °C.

Referring at *Table 4.3.4.2* at molality of 2.1363 mol/kg, the duration at minimum temperature 7.2 °C is only for 700 seconds while at molality of 8.4555 mol/kg, the duration at minimum temperature 3.7°C is only for 140 seconds. This long duration at minimum temperature of 7.2 °C translates into lesser requirement for work supplied to the reverse osmosis air conditioning pump.

Figure 4.3.4.1, *Figure 4.3.4.2(a)* and *Figure 4.3.4.2(b)* shows the maximum temperature and temperature profile of Barium nitrate at various molality.

Table 4.3.4.1: *Summary of Experimental Results of Enthalpy of Solution for Sodium chlorate*

Molarity m [mol/kg]	ΔT [deg C]	ΔH_{soln} [J/mol]	pH
0.0376	-0.5	30695	5.40
0.1880	-0.6	7370	5.57
0.3007	-1.4	22443	5.89
0.3758	-1.8	23087	5.91
0.4890	-2.1	20701	5.86
0.5639	-2.8	23933	5.86
0.6766	-3.0	21374	5.89
0.7539	-3.2	20459	5.97
0.8650	-3.4	18946	5.83
0.9395	-3.1	15905	5.82
1.3998	-5.0	17217	5.91
2.8185	-15.3	26166	5.56
5.6370	-15.6	13340	5.96
8.4555	-19.3	11002	5.88

Table 4.3.4.2: *Summary of Duration of Time at Minimum Temperature for Sodium chlorate*

Molarity m_F [mol/kg]	Minimum Temperature	Duration at Time at Minimum Temperature [sec]
0.0376	21.8	100
0.1880	20.6	120
0.3007	21.0	120
0.3758	20.9	120
0.4890	20.4	120
0.5639	20.0	120
0.6766	19.8	120
0.7539	19.6	80
0.8650	19.4	120
0.9395	18.9	120
1.3998	17.0	80
2.8185	7.5	200
5.6370	7.2	760
8.4555	3.7	140

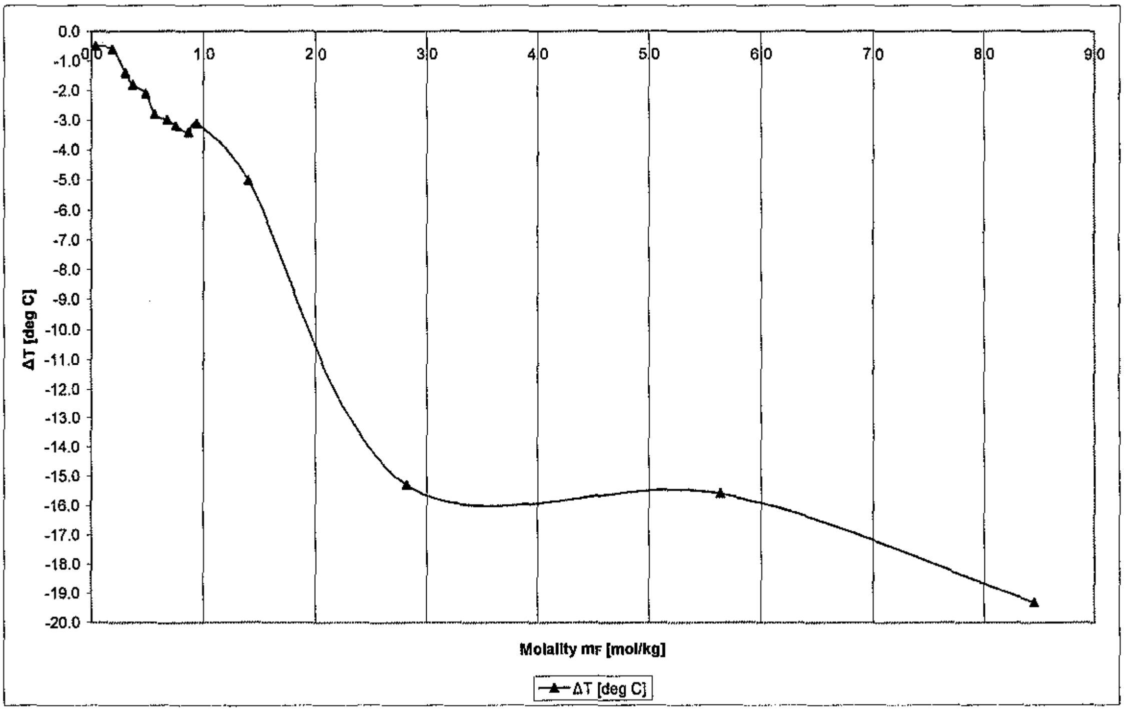

Figure 4.3.4.1: *Graph of Maximum Temperature Difference versus Molality for Sodium chlorate*

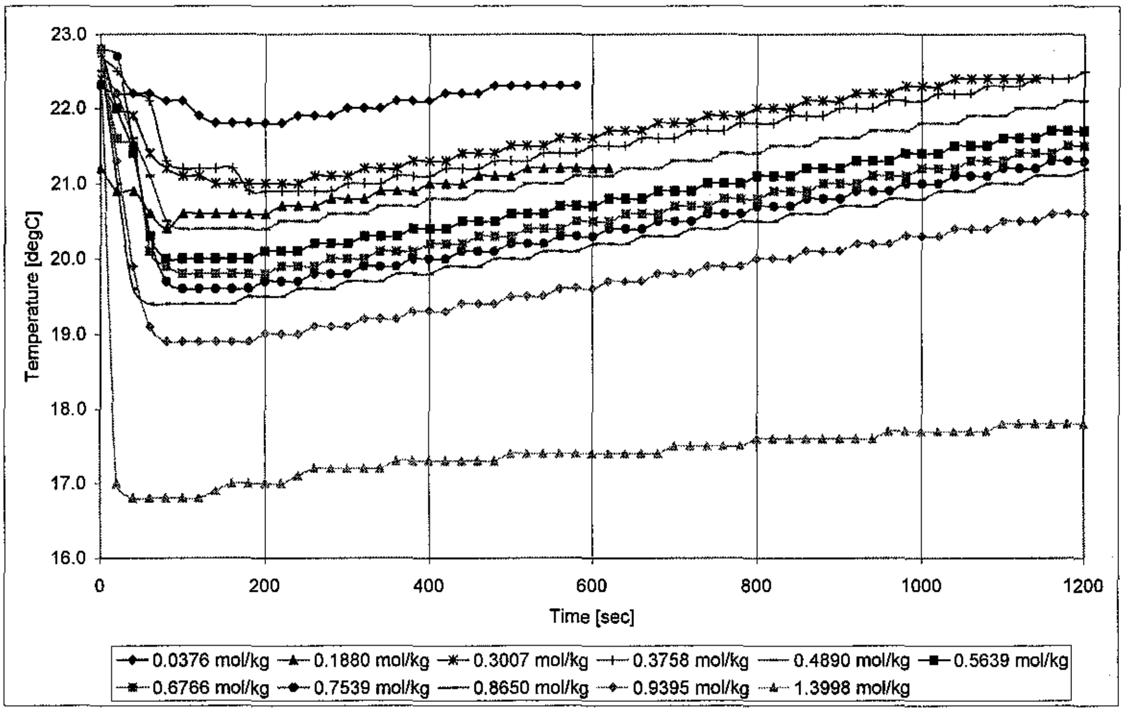

Figure 4.3.4.2(a): *Temperature Profile of Various Molality (0.0376 mol/kg – 1.3998 mol/kg) versus Time for Sodium chlorate*

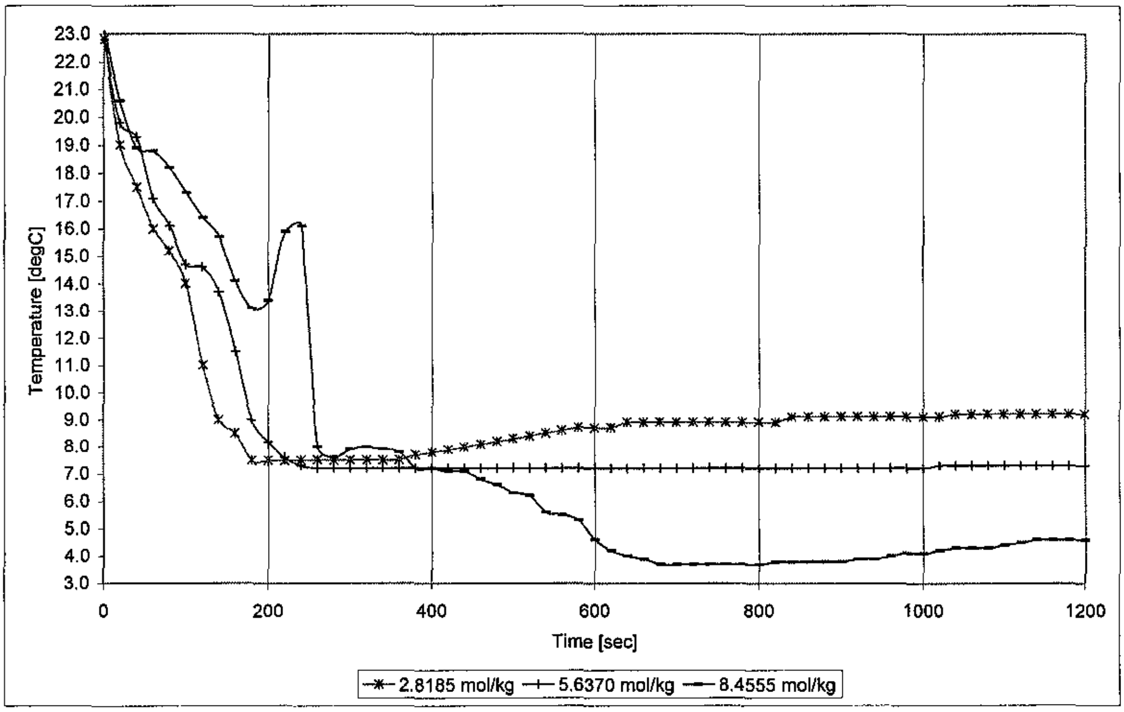

Figure 4.3.4.2(b): *Temperature Profile of Various Molality (2.8185 mol/kg – 8.4555 mol/kg) versus Time for Sodium chlorate*

4.3.5 Suitable Refrigerant Working Fluid

4.3.5.1 Choosing the Suitable Refrigerant Working Fluid

Table 4.3.5.1 summarizes the finding of this project. It can be seen clearly that Barium nitrate, Lead (II) bromide and Potassium nitrate are not suitable refrigerant working fluid due to the following:

- Solubility limit of salt
- Toxicity issue

Table4.3.5.1: *Summary of Experimental Findings for Barium nitrate, Lead (II) bromide, Potassium nitrate and Sodium chlorate*

Molality	Temperature Decrement	pH	Enthalpy of Solution
0.0154 mol/kg – 0.3521 mol/kg	(-1) - (-3.8)	5.70 – 6.00	52 kJ/mol – 150 kJ/mol
42 kJ/mol – 43 kJ/mol	(-0.2) - (-1.0)	4.50 – 5.70	42 kJ/mol - 74 kJ/mol
0.0235 mol/kg – 2.1363 mol/kg	(-0.2) - (-12.7)	5.20 – 6.20	19 kJ/mol - 97 kJ/mol
0.0376 mol/kg – 8.4555 mol/kg	(-0.5) - (-19.3)	5.40 – 6.00	7 kJ/mol – 27 kJ/mol

Naturally, Barium nitrate will be most suitable refrigerant working fluid considering the high solubility limit.

Sodium ions in the Sodium chlorate solutions are non-reactive with the Copper material used in the air-conditioning material.

4.3.5.2 Optimum Concentration of Sodium chlorate

The concentrations of Sodium chlorate experimented were from 0.0376 mol/kg – 8.4555 mol/kg. Within the concentration range, the concentration 5.6370 mol/kg is selected as the optimum endothermic salt solution as the refrigerant for the new air conditioning system for the following reasons as determined in part 3.3.3 Determination of Enthalpy of Solution:

- Reasonable temperature decrement ΔT (15.6°C)
- Long duration (760 seconds) at minimum temperature

A reasonable temperature decrement ΔT was required to provide a temperature driving force to cool ambient temperature air to controlled temperature air to the temperature range of 18.5°C – 20°C.

Long duration at the minimum temperature translate into lesser utility requirement to operate the reverse osmosis pumps. Refer to 5.2 Recommendations for the reverse osmosis rig schematic diagram.

4.4 Hot Air-Endothermic Salt Solution Heat Exchanger

Sodium chlorate of molality 5.6370 mol/kg is tested on the heat air-endothermic salt solution heat exchanger setup as stated in part 3.3.4 Experimental Testing on Insulated System to validate heat transfer from hot air to the endothermic salt solution.

This heat exchanger set up is calculated to have heat transfer area of 0.001m^2 at the inner tubing of the copper coil. The internal diameter of the copper coil is 0.004 m while the length immersed in the endothermic salt solution is 0.043 m. The pressure of air used in this experiment is 2.5 kPa.

Ambient Air Temperature	23°C
Lowest Sodium chlorate Solution Temperature	6.923°C
Duration to In Accepted Cooled Air Temperature of 20°C	3100 seconds

The ambient air temperature at 23°C is due to the instrument limitations.

This heat exchanger set up has validated the heat transfer from hot air to the endothermic salt solution. This set up also proves that heat transfer from hot air to the endothermic salt solution up to 50 minute in the temperature range of 18.5°C – 20°C. Therefore, it gives an illustration on the heat transfer will take place before the endothermic salt solution no longer provides cooling. However, in this project, different air flowrate is not investigated.

Figure 4.4.1 shows the temperature profile for Sodium chlorate solution and the air outlet. The record for the ambient air temperature and sodium chlorate solution temperature is appended as Appendix 4.4.1.

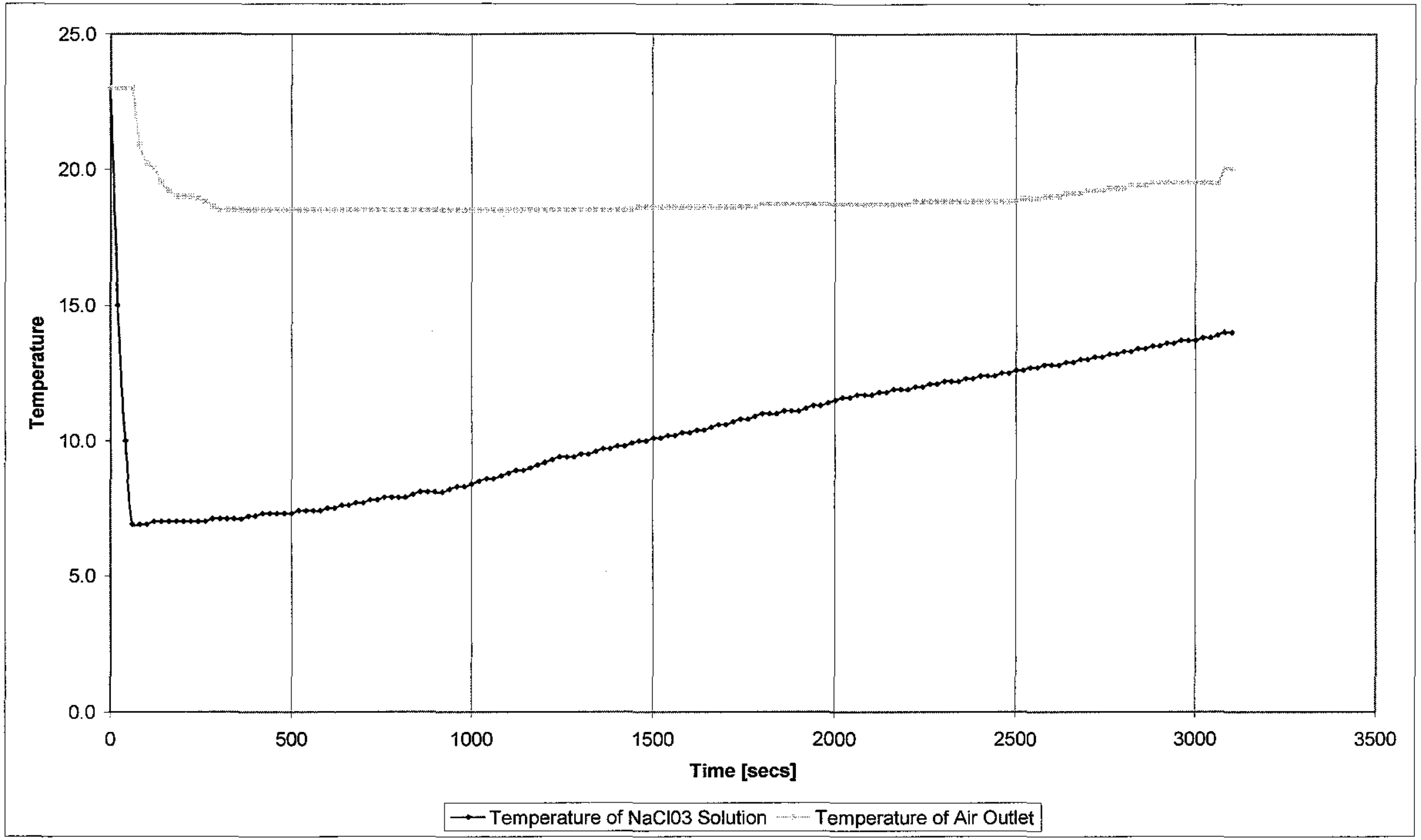

Figure 4.4.1: *Temperature Profile of Sodium chlorate and Air Outlet*

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The sodium chlorate solution used in this project provided the satisfactory results as refrigerant for the new air conditioning design.

From part 3.3.3 Determination of Enthalpy of Solution, Sodium chlorate achievable minimum temperature of 7.3°C is lesser than the minimum temperature attainable with the conventional air condition units. Besides, Sodium chlorate is non-toxic as compared to Freon-22, highly stable and do not corrode copper coils. This eliminates the waste treatment when the new air conditioning system is decommissioned.

From part 3.3.4 Experimental Testing of Sodium chlorate of molality 5.6370 mol/kg, the outlet temperature between the range of 18.5°C - 20°C was maintained for the duration of 50 minutes.

From the experimental results, sodium chlorate solution at molality of 5.6370 mol/kg is the most suitable refrigerant for the new air conditioning system using the membrane technology.

5.2 RECOMMENDATIONS

1. A reverse osmosis rig consisting of the below equipments could be built according to *Figure 5.2.1* to investigate other reverse osmosis variables.
    a. Two reverse osmosis pumps
    b. One refrigerant tank
    c. One water thank
    d. One membrane vessel

2. The reverse osmosis variables for example such as temperature, pressure, pH, pre-treatment requirements, reverse osmosis membrane polymer type, module geometry, module arrangement, hot air feed flowrate, operating time, water recovery and insulation.

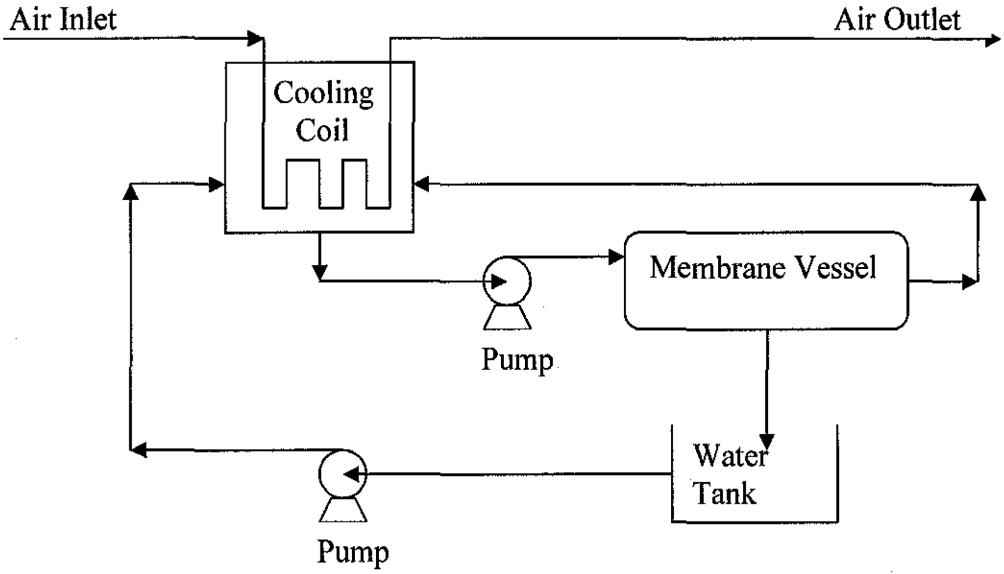

Figure 5.2: *Schematic Diagram of the Experimental Rig*

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APPENDICES

Appendix 1.3.1: Gantt Chart for Final Year Research Project Gannt Chart

No	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	*Propose Topic	▨													
	*Topic assigned to students	▨													
2	Preliminary Research/Design Work		■	■	■										
	*Introduction		▨												
	*Objective		▨												
	*List of references/Literature		▨	▨											
	*Project planning				▨										
3	Submission of Preliminary Report (Initial Proposal)				♦										
4	Project Work				■	■	■	■							
	*List of Reference/Literature				▨	▨									
	*Practical/Laboratory Work				▨	▨	▨	▨							
5	Submission of Progress Report								♦						
6	Project work continue								■	■	■	■			
	*Practical/Laboratory Work								▨	▨	▨	▨			
7	Submission of Dissertation Final Draft												♦		
8	Oral Presentation													♦	
9	Submission of Project Dissertation														♦

Appendix 2.4: *Table 2.4: Summary of Critical Chemical Information [Merck, 2000]*

CHEMICAL NAME	**Aluminium chloride, anhydrous**	**Aluminium sulfate 18-hydrate**	**Barium nitrate**	**Lead (II) bromide**
MOLECULAR FORMULA	$AlCl_3$	$Al_2(SO_4)_3.18H_2O$	$Ba(NO_3)_2$	$PbBr_2$
MOLECULAR WEIGHT	133.34 g/mol	666.42 g/mol		367.01 g/mol
CAS-No.	7446-70-0	7784-31-8	10022-31-8	10031-22-8
APPEARANCE	White/yellowish to grey powder (inorganic).Acid fumes in moist air are pungent and toxic.	Odourless white crystalline solid (powder, lumps, granules)	Crystal or crystalline powder	White crystalline powder
FLASH POINT	Non-flammable	Non-flammable	(Oxidising)	
MELTING POINT	180°C - 181°C (sublimed)	92°C	592°C - 595°C	372°C - 374°C
BOILING POINT	-	-	-	916°C
VAPOUR PRESSURE (20°C)	1 hPa	-	-	-
SPECIFIC DENSITY (20°C)	2.44 g/m^3	-	3.2 g/m^3	6.66 g/m^3
SOLUBILITY IN WATER (20°C)	450 g/l (decomposed) Reacts violently with water	600 g/l	90 g/l	5 g/l
BULK DENSITY	1200 kg/m^3	820 kg/m^3	1750 kg/m^3	-
pH VALUE	2.5 - 4 (100 g/l, H_2O, 20°C)	2.5 - 4 (20 g/l, H_2O, 20°C)	5.2 (50 g/l, H_2O, 20°C)	-
THRESHOLD LIMIT VALUE	0.2 mg/m^3 (TWA)	Not set	0.5 mg/m^3 (TWA)	0.1 mg/m^3 (TWA)
RISK PHRASES	Corrosive R34	Irritant R41	Harmful R20/22	Toxic for reproduction. Harmful. Dangerous for environment R61, R E20/22, R33, R50/53, R62
SAFETY PHRASES	S7/8, S28.1, S45	S26, S39	S28.1	S53, S45, S60, S61
TOXICOLOGICAL DATA	LD$_{50}$ Oral (Rat) = 3450 mg/kg	LD$_{50}$ Oral (Rat) = 9000 mg/kg	LD$_{50}$ Oral (Rat) = 355 mg/kg	
PERSONAL PROTECTIVE EQUIPMENT	• Nitrile gloves • Safety Goggles • Respirator	• Nitrile gloves • Safety Goggles	• Nitrile gloves • Safety Goggles	• Nitrile gloves • Safety Goggles • Respirator
STORAGE AND HANDLING	Classified as Class 8 (Corrosive) Not to be transported with: • Class 1 (Explosive) • Class 4.3 (dangerous When Wet Subtances) • Class 5.1 (Oxidising Agents) • Class 5.2 (organic Peroxides) • Class 6 (Poisonous Toxic) • Class 7 (Radioactive) • Foodstuffs and foodstuff empties	No special requirememt	Classified as Oxidizing agent / Poison	Not to be stored with strong alkali. Classified as Class 6 (Toxic and Infectious) Not to bed transporteed with: • Class 1 (Explosive) • Class 3 (dangerous When Wet Subtances) • Class 8 (Corrosive) • Foodstuffs and foodstuff empties

CHEMICAL NAME	Lithium bromide	Lithium iodide	Potassium nitrate	Sodium chlorate
MOLECULAR FORMULA	LiBr	LiI	KNO_3	$NaClO_3$
MOLECULAR WEIGHT	86.65 g/mol	133.84 g/mol	101.11 g/mol	106.44 g/mol
CAS-No.	7550-35-8	10377-51-2	7757-79-1	7775-09-9
APPEARANCE				
FLASH POINT				
MELTING POINT	547°C	450°C	334°C	255°C (decomposition)
BOILING POINT	1265°C	1180°C		
VAPOUR PRESSURE (20°C)				
SPECIFIC DENSITY (20°C)			2.11 g/m^3	2.49 g/m^3
SOLUBILITY IN WATER (20°C)	Freely	Freely	320 g/l	1000 g/l
BULK DENSITY			800 kg/m^3	
pH VALUE			5.5 - 8.0 (50 g/l, H_2O, 20°C)	5.7 (50 g/l, H_2O, 20°C)
THRESHOLD LIMIT VALUE				
RISK PHRASES	Harfmful R22		R8	Harmful R9, R22
SAFETY PHRASES			S16, S41	S2, S13, S17, S46
TOXICOLOGICAL DATA	LD_{50} Oral (Rat) = 1800 mg/kg		LD_{50} Oral (Rat) = 3750 mg/kg	LD_{50} Oral (Rat) = 1200 mg/kg
PERSONAL PROTECTIVE EQUIPMENT				
STORAGE AND HANDLING				

Appendix 4.4.1: Sodium chlorate and Air Outlet Temperature Record

Time	**Temperature of $NaClO_3$ Solution**	**Temperature of Air Outlet**
0	23.0	23.0
20	15.0	23.0
40	10.0	23.0
60	6.9	23.0
80	6.9	20.9
100	6.9	20.2
120	7.0	20.0
140	7.0	19.5
160	7.0	19.2
180	7.0	19.0
200	7.0	19.0
220	7.0	19.0
240	7.0	18.9
260	7.0	18.8
280	7.1	18.6
300	7.1	18.5
320	7.1	18.5
340	7.1	18.5
360	7.1	18.5
380	7.2	18.5
400	7.2	18.5
420	7.3	18.5
440	7.3	18.5
460	7.3	18.5
480	7.3	18.5
500	7.3	18.5
520	7.4	18.5
540	7.4	18.5
560	7.4	18.5
580	7.4	18.5
600	7.5	18.5
620	7.5	18.5
640	7.6	18.5
660	7.6	18.5
680	7.7	18.5
700	7.7	18.5
720	7.8	18.5
740	7.8	18.5
760	7.9	18.5
780	7.9	18.5
800	7.9	18.5
820	7.9	18.5

840	8.0	18.5
860	8.1	18.5
880	8.1	18.5
900	8.1	18.5
920	8.1	18.5
940	8.2	18.5
960	8.3	18.5
980	8.3	18.5
1000	8.4	18.5
1020	8.5	18.5
1040	8.6	18.5
1060	8.6	18.5
1080	8.7	18.5
1100	8.8	18.5
1120	8.9	18.5
1140	8.9	18.5
1160	9.0	18.5
1180	9.1	18.5
1200	9.2	18.5
1220	9.3	18.5
1240	9.4	18.5
1260	9.4	18.5
1280	9.4	18.5
1300	9.5	18.5
1320	9.5	18.5
1340	9.6	18.5
1360	9.7	18.5
1380	9.7	18.5
1400	9.8	18.5
1420	9.8	18.5
1440	9.9	18.5
1460	10.0	18.6
1480	10.0	18.6
1500	10.1	18.6
1520	10.1	18.6
1540	10.2	18.6
1560	10.2	18.6
1580	10.3	18.6
1600	10.3	18.6
1620	10.4	18.6
1640	10.4	18.6
1660	10.5	18.6
1680	10.6	18.6
1700	10.6	18.6
1720	10.7	18.6

1740	10.8	18.6
1760	10.8	18.6
1780	10.9	18.6
1800	11.0	18.7
1820	11.0	18.7
1840	11.0	18.7
1860	11.1	18.7
1880	11.1	18.7
1900	11.1	18.7
1920	11.2	18.7
1940	11.3	18.7
1960	11.3	18.7
1980	11.4	18.7
2000	11.5	18.7
2020	11.6	18.7
2040	11.6	18.7
2060	11.7	18.7
2080	11.7	18.7
2100	11.7	18.7
2120	11.8	18.7
2140	11.8	18.7
2160	11.9	18.7
2180	11.9	18.7
2200	11.9	18.7
2220	12.0	18.8
2240	12.0	18.8
2260	12.1	18.8
2280	12.1	18.8
2300	12.2	18.8
2320	12.2	18.8
2340	12.2	18.8
2360	12.3	18.8
2380	12.3	18.8
2400	12.4	18.8
2420	12.4	18.8
2440	12.4	18.8
2460	12.5	18.8
2480	12.5	18.8
2500	12.6	18.8
2520	12.6	18.9
2540	12.7	18.9
2560	12.7	18.9
2580	12.8	19.0
2600	12.8	19.0
2620	12.8	19.0

2640	12.9	19.1
2660	12.9	19.1
2680	13.0	19.1
2700	13.0	19.2
2720	13.1	19.2
2740	13.1	19.2
2760	13.2	19.3
2780	13.2	19.3
2800	13.3	19.3
2820	13.3	19.4
2840	13.4	19.4
2860	13.4	19.4
2880	13.5	19.5
2900	13.5	19.5
2920	13.6	19.5
2940	13.6	19.5
2960	13.7	19.5
2980	13.7	19.5
3000	13.7	19.5
3020	13.8	19.5
3040	13.8	19.5
3060	13.9	19.5
3080	14.0	20.0
3100	14.0	20.0
3120	14.1	20.1
3140	14.1	20.1
3160	14.2	20.1
3180	14.2	20.1
3200	14.3	20.1
3220	14.3	20.1
3240	14.4	20.1
3260	14.4	20.2
3280	14.5	20.2
3300	14.5	20.2
3320	14.6	21.0