Development of New drying system using salt solution

By

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CERTIFICATION OF APPROVAL

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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 that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Rozilawati Binti Abdul Latip

ABSTRACT

The title of this project is *Development of New Drying System using salt solution.* The topic is actually to investigate for the salt solution to be as an alternative refrigerant in the drying system. Seven types of salt involved in this project and the properties of each salt are determine via experimental work. The process of dissolving salt has an energy change associated with it, which are endothermic and exothermic heats of solution. The main properties for the salt solution to be an alternative refrigerant in this research is the salt solution that involved in the exothermic reaction. There are three objective needs to be achieved in the project, which are to measure the heat involved of solution of salts, to relate the heat of solution involved to the two-step process of dissolving and to identify the best salt solutions for drying system. Two experimental works is done to achieve all objectives and to prove the topic given. Based on the result, three salts among seven salts experienced an exothermic reaction and the other is endothermic reaction. From the experimental results it prove that exothermic salt solution can be as alternative refrigerant, where the heat release from the reaction can be used as a drying agent. Modification to the existing refrigerator system need to be done to suited the application of salt solution as an alternative refrigerant.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

This research project is focused on finding the best salt solution as an alternative refrigerant and the selected solution will be used to replace existing refrigerant but in different function. There are many type of refrigerant been used in industries and in home appliance; Air-Condition and Domestic refrigerator. Refrigerant is a chemical compound that can be alternately compressed and condensed into a liquid and then slowed to expand into vapor or gas as they are pumped through a mechanical refrigeration system. All refrigerant give the same principles, which is applied as a cooling medium in any related mechanism. As an example, in the domestic refrigerator, refrigerant 134a is used as a cooling liquid which function to cool the selected space by the heat transfer. This can be done by the principles of the refrigeration cycles, where the purpose of refrigeration cycle is to remove unwanted heat from one place and transfer it to another.

In this research project, the salt solution that will be selected as an alternative refrigerant will use as a drying purposes. It is vise versa with the application of existing refrigerant. The heat released from the exothermic when dissolving the salt in the water is used for a drying. Modification to the existing refrigerator needs to be done to suite the application of this salt solution as an alternative refrigerant for a drying system.

Drying system is widely applied in various types of industries such as food industries, oil and gas, and textile industries. This system normally used for drying a product or feed and others component in the process. The different between all the drying systems is the drying medium used in the drying system. Example of common drying medium used is steam heated-air, natural air, and salt, vacuum and refrigerant. The drying system processes can be divided into two, batch and continuous drying process. For batch drying system, the material inserted into the drying equipment and drying proceeds fro a given period of time. While, in continuous drying system the material added and drying process are continuously.

The purpose of the drying system is to dried or removed amount of water from the process material or other substances. This is required to maintain the quality of product or process materials. The common industries that apply the drying system are food industries where the products need to be dried to maintain the quality and to extend the storage time. With the present of water, the microorganism in the food itself will be active and cause the food spoilage. Thus the application of drying system is important in various industries.

1.2 Problem statement

Among the seven of salt sample, the best solution will be choosing as an alternative refrigerant for the new drying system. To achieve this target, it required the salt that involved exothermic reaction instead of endothermic reaction. The heat release from the exothermic reaction will be used for drying purpose. The dissolving processes of salts always involve two step of reaction, breaking down the solid crystals (endothermic) and hydrating of individual particles released into the solvent. Thus the exothermic reaction occurs when the energy for hydrating of individual particles is higher from energy required for breaking down the solid crystals. Two salts are currently available for the experiment and the result from both salts is compared. Between those two salts the best salt solution will be choosing for an alternative refrigerant regarding to higher temperature changes and higher heat of solution.

1.3 Objective

There are three objectives need to be achieved in this project in order to find best the salts solution for drying system. The objectives are as per below:

1. To measure experimentally the heat involved in dissolving of solution of salts.

2. To relate the heat of solutions involved to the two step process of dissolving: breaking down solid crystals and hydrating the individual particles released into the solvent

3. To identify best salt solutions for drying system.

All of the objectives are achieved by experiment and its involved seven different types of salts. The results of the experiment are then will be compared to the literature result. This will to show the relevancy of the experimental result to the theory or literature result.

1.4 Scope of study

Related to the dissolving process of salts, the scope of study cover the behavior of salts itself and the theory of endothermic and exothermic reaction. The physicals and chemical properties of each salts involved is studied, such as solubility of salt in water, pH, molecular weight and heat of solution. The scope of study also covered on heat of solution of each salts involved, where included the behavior of endothermic and exothermic reactions. The effect of several factors to both endothermic and exothermic reaction will be study such as, the effect of solubility, the effect of concentration and pH effect. All of the effect will get from the literature review and also from the experimental activity

The scope of study for this research project is divided into two activities which are experimental and research activity. There are two types of experiment need to be done throughout this research project. The first experiment is to determine or choose the best salt solution to be as an alternative refrigerant. Then for the second experiment, the effect of salt solution toward the air temperature flow in the copper coil. The results obtained from the experiment are study and discussed. The calculation is done after all the experiment is completed. From the calculation, the amount of heat released when dissolving the individual salts is obtained and comparison will be made between the solutions, to choose the best salt solution as an alternative refrigerant. The result is then compared with the theoretical result of individual salt, whether the reaction is exothermic or endothermic.

The information that will be gathered are related to the behavior of the individual salts itself and also the properties of the existing refrigerant which is refrigerant 134a. The properties of the refrigerant will then be compared with the properties of salts. The purpose is to choose the best salt solution to be as an alternative refrigerant and also to proven whether the salt solution are able to act as a drying medium.

CHAPTER 2

LITERATURE REVIEW

2.1. Properties of Salts

Salts are an inorganic compound that normally formed from the reaction between an acid and a base called neutralization reaction. Which means salts is a combination of the cation from the certain base and the anion from the certain acid. The general form of neutralization reaction is:

$$Acid + Base \rightarrow Salt + water\ or\ other\ products$$

An example of salt formation is the reaction (neutralization reaction) between solution of hydrochloric acid (HCl) and solution of Sodium hydroxide base (NaOH):

$$\underset{(Acid)}{HCl(aq)} + \underset{(Base)}{NaOH(aq)} \rightarrow \underset{(Salt)}{NaCl(aq)} + \underset{(Water)}{H_2O(l)}$$

By removing the water contain from the above reaction mixture, the ionic solid salts remains which is sodium chloride. Solid salts usually consist in the form of crystals and sometimes including specific molar amounts of water, called *water of hydration* into the crystal. Other than neutralization, there are other methods used to prepare salts which are:

- *Direct combination*

Reaction of metal and non-metal component, for example when the metal magnesium is burned in chlorine gas, the salt magnesium chloride is formed.

- *Metal oxide and acid*

  The reaction of metal oxide with acid, for example, calcium oxide reacts with nitric acid formed a salt calcium nitrate.

This project involved seven different type of salt and the heat of solution for each salt need to be determined by experiment. Since each salt have a different behavior when dissolve in the water, the properties of each salt is studied. The properties of all salt are summarized in the table below.

Table 2.1: salt properties

Salts	**Formula**	**MW (g/mole)**	**Solubility in water T=20°C (g/L)**	**pH**
Aluminium Sulfate	$Al_2(SO4)_3$	342.12	600	3.5
Aluminium Chloride	$AlCl_3$	133.34	450	2.4
Lead (II) Bromide	$PbBr_2$	367.01	5	-
Potassium Nitrate	KNO_3	101.11	320	5.5-8.0
Sodium Chlorate	$NaClO_3$	106.44	1000	5.0 - 7.0
Barium Nitrate	$Ba(NO_3)_2$	261.35	90	5.2
Calcium Chloride	$CaCl_2$	147.02	Freely soluble	5-6

Each salts have different pH values when it dissolved in the water, it is depends on type of cation and anion, solubility of the salts, the temperature of the solutions and the concentration of the salts. The theory of pH value of the salts solution is as per below:

- A salt that consists of the anion of strong acid and the cation of strong base will be neutral salts solution because the ions do not react with water.

- A salt that consist of the anion of the strong acid and the cation of weak base, will be an acidic salts solutions because the cation act as a weak acid.

- A salt that consists of the anion of weak acids and the cation of strong base will be alkali salt solution because the anion acts as a weak acid.

2.2. The solution process

Solution is a homogenous mixture of two or more pure substances and it can be mixture of solid, liquid or gaseous. Dissolution of certain solid in water will contribute to the formation of solution due to attraction between individual solid molecules or ions with water molecules. Therefore, when salt solid is dissolved in water, it usually disassociates into the anions and cations that make up the salt and attract with water molecules to form a salt solution.

Within any solution there are electrical interactions called intermolecular forces between the solute and solvent molecules. Take an example of ionic substance NaCl, when it been added to water, the water molecules will surround each solute molecule and form a "solvent cage" isolating each solute molecule. Where the positive end of the water dipole is oriented toward the Cl^- ions and the negative end of water dipole is oriented towards the Na^+ ions. This ion-dipole attraction will separate or dissolved the crystals into water, which is the Na^+ and Cl^- ions are surrounded by water molecules as shown in Figure 2.1. Such interactions like this between solute and solvents molecules are known as solvation, but when the solvent is water, the interaction is called hydration.

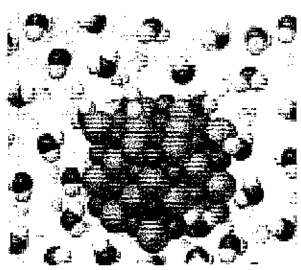

Figure 2.1: solid substance is hydrated by water molecules

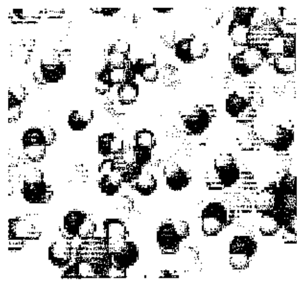

Figure 2.2: solid particles dissolved in water

2.3. Heat of solutions

Naturally, the formation of solution from solute and solvent will cause an energy changed between both particles. Some energy is adsorbed when particles separate and some energy is released when they mix and attract each other. This process called endothermic and exothermic reaction. An endothermic process absorbs heat while exothermic process releases heat during the reaction between solute and solvent. Thus, in exothermic process, enthalpy decreases due to heat release while in endothermic process enthalpy increasing because the absorption of heat. There are three step involved when solute and solvent dissolved in each other, the steps are per below:

i. solid particles breaking down/separates from each other
ii. some solvent particles separates to make room for solid particles
iii. Mixing of solute and solvent particles.

From the individual enthalpy change of each step, the total enthalpy change can be calculated. This total enthalpy change also known as heat of solution (ΔH_{soln}) and the overall process shown below:

$$\Delta H_{soln} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$$

The heat of solution of various crystalline salts is different and it has positive or negative value depending on whether the process of dissolving salts in water is endothermic or exothermic. The heat of solution will have a positive value (endothermic) if the lattice energy is greater than heat of hydration. Then if the lattice energy is less than the heat of hydration, the heat of solution will have negative value (exothermic). Heat of hydration (ΔH_{hydr}) is a combination of enthalpy changes for separating the water molecules ($\Delta H_{solvent}$) and mixing the solute with water (ΔH_{mix}). The lattice energy is the energy required to separate an ionic solute into gaseous of ions.

The heat of solution of all salts involved in this project is determined, to compare the value with the experimental result. The theoretical value gathered from Perry's Chemical Handbook, seventh edition, is summarized in the table 2 below:

Table 2.2: heat of solution of each salt

Salts	Heat of solution (kg cal/g mole)	Types of process
Aluminium Sulfate	126	exothermic
Aluminium Chloride	77.9	exothermic
Pumbum bromide	-10.1	endothermic
Potassium Nitrate	-8.633	endothermic
Sodium chlorate	-5.37	endothermic
Barium nitrate	-10.2	endothermic
Calcium Chloride	-4.9	exothermic

Based on the heat of solution, theoretically the salts can be divided into cooling and heating effect. The salt solution involved exothermic reaction can be applied as a heating medium due to energy released during the process. Where else the endothermic salt solution can be used as cooling medium since the reaction absorbs heat. The concept can be applied as a drying method, where the energy released during the reaction of salt solution can be used in the drying system which dried a certain amount substances. This will relate to the alternative refrigerant using salt solution, where the alternative refrigerants can be applied as cooling medium and also as heating medium.

2.3.1 The calculation step for heat of solution

The experiment set up for this project are in the condition of constant pressure calorimetery, where two Styrofoam cup are used and set-up as calorimeter. The principle of this Styrofoam cup almost the same with the actual calorimeter accept the reaction occurs under the essentially constant pressure of the atmosphere. Taken as consideration the reaction of Aluminium sulfate dissolved in water to produce an aqueous Aluminium sulfate solution:

$$Al_2(SO_4)_3(s) \rightarrow Al^{3+}(aq) + SO_4^{2-}$$

$$Al_2(SO_4)_3(s) + H_2O(l) \rightarrow Al_2(SO_4)_3(aq)$$

It is assume that the Styrofoam cup calorimeter does not absorb heat, because calorimeter has a very low thermal conductivity and heat capacity. Thus, in these situation only two types of heat involves in the reaction, heat produced by the reaction (q_{rxn}) and the heat gained by the solution (q_{soln}). Therefore the heats balance for this experiment:

$$0 = q_{rxn} + q_{so\ln}$$

Thus the heat produced by the reaction, q_{rxn} can be calculated because the value of q_{soln} is readily calculated form the mass of solution, its specific heat and the temperature changes

$$q_{so\ln} = -q_{rxn}$$

$$q_{so\ln} = m_{so\ln} C_{so\ln} (T_f - T_i)$$

The mass of solution is the sum of the masses of the water and Aluminium Sulfate involved in the experiment. The specific heat capacity of the aqueous solution is usually close to that of pure water (4.184 $J^{o}C^{1}g^{-1}$). The molar enthalpy of solution (ΔH_{soln}) is the heat of solution (q_{rxn}) per mole of solute (n). In this experiment the reaction is performed under conditions of constant pressure and the only work is "PV-work"; under these conditions the heat flow for the process equals the enthalpy change for the process.

$$\Delta H_{so\ln} = \frac{q_{rxn}}{n}$$

2.4 Study of refrigerant 134 (HFC-134)

Commonly, refrigerant is a working fluid that used in refrigerant cycle, absorbing heat from a reservoir at low temperature and rejecting heat at a higher temperature. Beside used as a cooling medium, refrigerant also can be as heating medium. There are three main types of refrigerant that are commonly used, CFCs (chlorofluorocarbon), HCFCs (hydrochloro-fluorocarbons) and HFCs (Hydrofluorocarbons).

CFCs is a very stable refrigerant event when released into the atmosphere, this due to no hydrogen contain in it. Because of the chlorine component in CFCs, it causes depletion of the stratosphere ozone layer and to possible global warming by their action as greenhouse gasses. In HCFCs, it contains chlorine but also contains hydrogen which is chemically less stable once they enter the atmosphere. Thus HFCs decompose when released in the lower atmosphere and small amount will reaches the ozone layer, therefore have a lower ozone-depletion potential.

However, HFCs refrigerant contains no chlorine component and have an ozone-depletion potential of zero. The existing HFCs refrigerant been used and replacing CFC-12 is HFC-134 (1,1,1,2-Tetrafluoroethane CF_3CH_2F). Event HFCs cause no depletions of ozone layer but it still contributes to the global warming problem. Therefore, in this project refrigerant using salt solution is studied for replacing the existing refrigerant. The ideal refrigerant consists of non-toxic, non-flammable and completely stable inside the system.

2.4.1 Refrigerant 134a properties

The predominant refrigerants in use today are members of the Halocarbon family of chemical compounds. There are three main types of refrigerant that are commonly used in the industries which are CFCs (chlorofluorocarbon), HCFCs (hydrochloro-fluorocarbons) and HFCs (Hydrofluorocarbons). The refrigerant 134a are commonly used for various types of application in industries. The objective of the project is to select the best salt solution as an alternative refrigerant, thus the properties of existing refrigerant is study. This is to relate the required properties for the existing refrigerant to the new refrigerant (salt solution).

2.4.1.1 Physical properties of HFC-134a

The physical properties of refrigerant 134a are study and familiarize. The physical properties of refrigerant 134a are summarized in the table below:

Table 2.3: Properties of refrigerant 134a

Physical properties	Unit	HFC-134a
Chemical name	-	Ethane, 1,1,1,2-Tetrafluoro
Chemical formula		CH_2FCF_3
Molecular weight		102.03
Boiling point at 1 atm	°C	26.1
Freezing point	°C	103.3
Vapor Pressure at 25°C	kPa	666.1
Vapor at 1 atm	W/m·K	0.0145
Solubility of HFC-134a. in Water at 25°C (77°F) and 1 atm	wt%	0.15
Solubility of Water in HFC-134a at 25°C	wt%	0.11
Halocarbon Global Warming Potential (HGWP) - (For CFC-11, HGWP = 1)		0.28
Global Warming Potential (GWP)		1,200

From the physical properties, it been observed that HFC-134a have quite high Global warming potential (GWP) value. GWP is the index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations.

2.4.1.2 Requirement of alternative refrigerant

Basically, to replace the existing refrigerant, there are certain requirements that need to be fulfilled. These properties are applicable to any new alternative refrigerant and the requirements for are as per below:

- chemical stability
  - All other properties would be meaningless if the fluid decomposed or reacted in use to form something else

- health and safety
  - Safety codes require the use of a non-flammable refrigerant with a very low order of toxicity in residential and most commercial applications

- Environmental
  - should not contribute to stratospheric ozone depletion
  - low level smog formation or greenhouse warming

- The thermophysical properties
  - Should be good, such as critical and boiling point temperature for the applications, low molar vapor heat capacity, low viscosity and high thermal conductivity.

- The refrigerant should be soluble in lubricating oil
- Can be easily detectable (leakage) and available at a low cost.

2.4.2 Advantages and disadvantages of HFC-134a

2.4.2.1 Advantages

The refrigerant 134a or HFC-134a contributes several advantages and disadvantages. HFC-134a features properties that are advantageous for high value-in-use products and meets the requirements of safety or environmental issues. Other advantages of HFC-134a is its properties which are non-flammable, has negligible photochemical reactivity, and low vapor thermal conductivity. HFC-134a is also being developed for use in pharmaceutical inhalers because of its low toxicity and non-flammability. Other aerosol applications may use HFC-134a where these properties are critical. HFCs refrigerant contains no chlorine component and have an ozone-depletion potential of zero

2.4.2.2 Disadvantages

HFC-134a vapors will decompose when exposed to high temperatures from flames or electric resistance heaters. Decomposition may produce toxic and irritating compounds, such as hydrogen fluoride. Event HFCs cause no depletions of ozone layer but it still contributes to the global warming problem.

2.4.2.3 Comparison between Salt solution and HFC-134a

Based on the properties of HFC-134a, the comparison between the salt solutions is made and summarized in the table below:

Table 2.4: Comparison between salt solution and HFC134a

Component	Advantages	Disadvantages
Refrigerant 134a (HFC-134a)	▪ its properties non flammable ▪ low toxicity	decompose when exposed to high temperatures produce toxic and irritating compounds Event HFCs cause no depletions of ozone layer but it still contributes to the global warming problem
Salt solutions	▪ no global warming ▪ cheaper than refrigerant ▪ does not contribute to ozone depletions of ozone layer ▪ new development system, i.e for drying purposes	maybe can cause corrosion

2.5 Refrigerator and refrigerant cycles

2.5.1 The principle of The Refrigeration cycle

The purpose of this study is to familiarize with the refrigeration cycle mechanism and able to relate the mechanism with alternative salt solution. Thus, this research is done to investigate whether the alternative salt solution is suitable with the existing domestic refrigerator mechanism or either some modification need to be applied with existing mechanism .The existing domestic refrigerator consist of three main component which are evaporator, condenser and compressor. In a refrigeration process, thermal energy is removed from the area to be cooled and transferred to another object or area in continuous cycle. This function is performs by an evaporator in a mechanical refrigeration systems, where the temperature of evaporator's surface is maintained below than the desired temperature of the product. The simple refrigeration cycle is shown below:

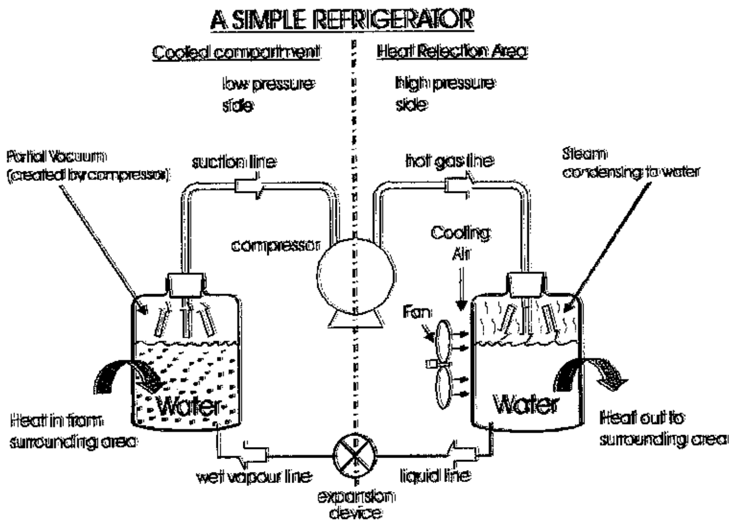

Figure 2.3: Simple refrigeration cycle

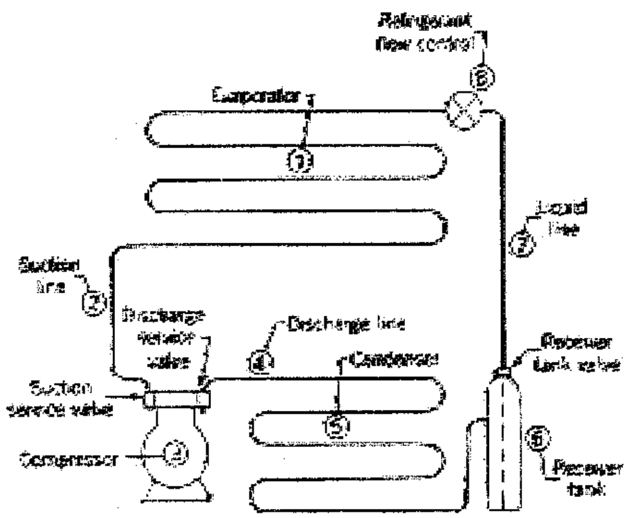

Figure 2.4: Domestic refrigerator mechanism

Basically, mechanism refrigeration systems were developed to provide a continuous cooling process at lower temperatures than can be attained using solid cooling agents. The principle components of refrigeration cycle shown in the Figure 2.4 are:

- *Evaporator*

An evaporator is a heat transfer coil that allows heat to be conducted from the spacing being cooled to the cooling agent flowing within its pipe.

- *Compressor*

An electromechanical device that is used to developed and maintains the flow of the working fluid through the refrigeration system.

- *Condenser*

The heat transfer coil used to conduct heat from the hot refrigerant vapors leaving the compressor to the ambient surrounding the coil.

- *Metering device or capillary*

A modulating valve or capillary tube that used to vary a flow of refrigerant into the evaporators based on the current thermal load.

2.5.1.1 Refrigerant cycles

The cycles of refrigerant is start from receiver tank, the refrigerant condition is in liquid and vapor phase at high temperature and pressure. The liquid refrigerant flows into the liquid line to the inlet port of the metering device. The pressure of the liquid refrigerant is reduces from the system of condensing pressure to the pressure in the evaporator in this metering devices. Then, the mixture of liquid-vapor refrigerant leaves the metering device and enters the evaporators.

In the evaporators, the liquid vaporizes at the saturation temperature based on the pressure of evaporators. The vaporizing liquid absorbs latent heat from the thermal energy in the refrigerated space. The vapor then flow into the compressor. In the compressor the low pressure and temperature refrigerant vapors is compressed into a high pressure, high temperature gas through kinetic energy transfer. This process raises the saturation temperature of the vapor to the level that permits it to condense at normal ambient temperatures. The superheated vapor refrigerant from the compressor is then flow into a condenser. In this process, as heat is removed from the vapor, a change of state takes place and the vapor is condensed back into a liquid, which is still at high pressure, but at a lot lower temperature.

CHAPTER 3

METHODOLOGY AND PROJECT WORKS

There are two methodologies have been used to achieve the objectives of this project which are literature review related on refrigerant 134a and its mechanism and also experimental activity. Two experiments have been conducted throughout this research project; the determination of heat of solution of each salt and the determination of the effect of different inlet air flow-rate to outlet air temperature.

3.1 Literature review and information gathering

Throughout this research project the information regarding to existing refrigerant 134a properties and its mechanism is gathered. The refrigerant properties this then compared with the selected salt solution properties in order to find the pro and con between this two components. Thus, it can prove whether the selected salt solution can be as an alternative refrigerant. The scope of study on mechanism of refrigerant is narrowed down to domestic refrigerator. All this information is gathered via internet and other sources such as literature books and journal.

3.2 Experiment 1: Determination of heat of solution and selection of best salt

In this experiment, simple calorimeter consists of Styrofoam cup and thermometer is assembled to measure a heat transfer or heat of solution. Salt solid is dissolved in distilled water using this simple calorimeter and the heat of solution is calculated. The objective of this experiment is to determined the heat of solution of each salt and choose the best salt solution (highly exothermic) to be as an alternative refrigerant. The chemicals, apparatus and procedure of the experiment will be discussed in the next topic.

3.2.1 Chemicals and apparatus used

There are seven different types of salt involved in this experiment and the heat of solution of each salt is calculated based on the temperature changes when dissolving the salt. The solutes or salts used are summarized in the table below:

Table 3.1: Types of salt used

No	Name	Formula
1	Aluminium Sulfate	$Al_2(SO_4)_3$
2	Aluminium chloride	$AlCl_3$
3	Lead bromide	$PbBr_2$
4	Potassium Nitrate	KNO_3
5	Sodium chlorate	$NaClO_3$
6	Barium nitrate	$Ba(NO_3)_2$
7	Calcium Chloride	$CaCl_2$

To proceed with the experiment, only simple apparatus and glassware used to determine the heat of reaction of each salt. The apparatus used in this experiment is summarized in the table below:

Table 3.2: List of apparatus

No	Apparatus	Quantity
1	Styrofoam cups	2
2	Thermometer	1
3	Stirring rod	1
4	Electronic balance	1
5	100mL graduated cylinder	1
6	Beakers	2
7	Stop watch	1
8	Magnetic stirrer	1
9	pH probe	1

Normally, calorimeter is a simple device that used to measure the temperatures changes that accompanies the reaction at a constant pressure. It is assumed that the calorimeter perfectly prevent the gain or loss of heat from the solutions to its surrounding, where the heat produced by the reaction is entirely adsorbed by the solution. It also assumed that the Styrofoam cup calorimeter itself does not adsorb heat from the reaction; this is reasonable approximation because it has very low thermal conductivity and heat capacity. The calorimeter set up for this experiment is shown in the figure 1 below:

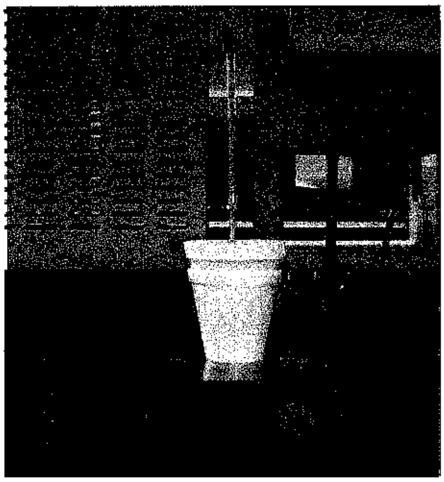

Figure 3.1: Simple Calorimeter

3.2.2 Experimental procedure

Some modification of procedure has been made to improve the result and to increase the accuracy of result. There are three different weights required for each salts to be tested in this experiment in order to investigate the temperature changes and heat of solution of different concentration of salt. To dissolve the solute, distilled water is used instead of tap water. This is because distilled water is de-ionized water and there is no free ion that will effect the reaction of dissolving solute. The procedure of this experiment is as per below (take an example of Aluminium Sulfate):

1. An empty peltry dish and 15 g of Aluminium Sulfate is weighted by using an electronic balance.

2. 100mL of distilled water is measured in graduated cylinder and an empty Styrofoam cup is weighted using electronic balance. Then, an empty Styrofoam cup is filled with measured distilled water.

3. The mass of Styrofoam cup and distilled water is weighted and measured the initial temperature of water (T_i) for 1 minute.

4. Then, Aluminium Sulfate is dissolved in distilled water and the solution is stirred using magnetic stirrer. Where the solution is automatically been stirred. The temperature changes are observed and recorded for every 30sec for 20 minutes.

5. Procedure 1- 4 is repeated for 30g and 60g mass of Aluminium Sulfate and for each salt the heat of solution is calculated.

6. The same procedure is repeated for each sample of salts.

The procedure is suitable for all salt except for Lead (II) Bromide ($PbBr_2$) and Barium Nitrate ($Ba(NO_3)_2$), since both salts have low solubility in water. The solubility of PbBr2 and $Ba(NO_3)_2$ are 5g/L (0.5g/mL) and 90g/L (9g/mL) respectively. Therefore, due to this problem, the amount of solute for each salt is reduced to be compatible with the maximum solubility. The mass of PbBr2 used are 1g, 5g and 10g, while for $Ba(NO_3)_2$ the mass used for the experiment are 5g, 10g and 30g.

3.3 Experiment 2: Determination of the effect of exothermic reaction of salt solution to the air flow.

The objective of this experiment is to observe and determine the effect of heat produced from the salt solution to the air flow through the coil. This experiment will prove whether the heat of solution of selected salt can be as a drying agent by increasing the outlet air temperature. The heat released from the reaction of salt solution will be transferred through copper coil to the air flow in the coil. The outlet air temperature is measured and compared with the inlet air temperature.

3.3.1 Chemical and apparatus used

The simple apparatus is used to assemble the model for this experiment and it is summarized in the table below:

Table 3.3: List of apparatus for experiment 2

No	Apparatus	Quantity
1	1L beakers	2
2	Thermometer	3
3	Pressure gauge	1
4	Electronic balance	1
5	200mL graduated cylinder	1
6	Styrofoam cup	1
7	Magnetic stirrer	1
8	Air compressor	1
9	Copper coil	1
10	Stop watch	1
11	Retort stand	2

3.3.2 Experimental set-up and procedure

3.2.2.1 Experimental set-up

In this experiment, 1L beaker is insulated with one layer of cotton, a layer of aluminium foil and a layer of polyvinyl tape. The purpose of this insulation is to prevent heat loss and heat gain to and from the ambient during the reaction of salt in water. Cotton is known as a good insulator that can minimize the heat transfer between two medium. Figure 3.2 and Figure 3.3 showed the insulation process.

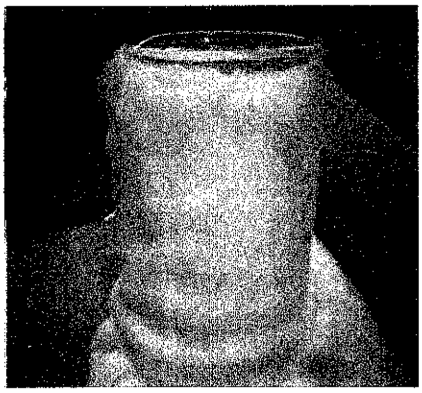

Figure 3.2: First layer of insulation using cotton

Figure 3.3: Insulated beaker

After the insulation, the model for this experiment is set-up according to the schematic diagram below:

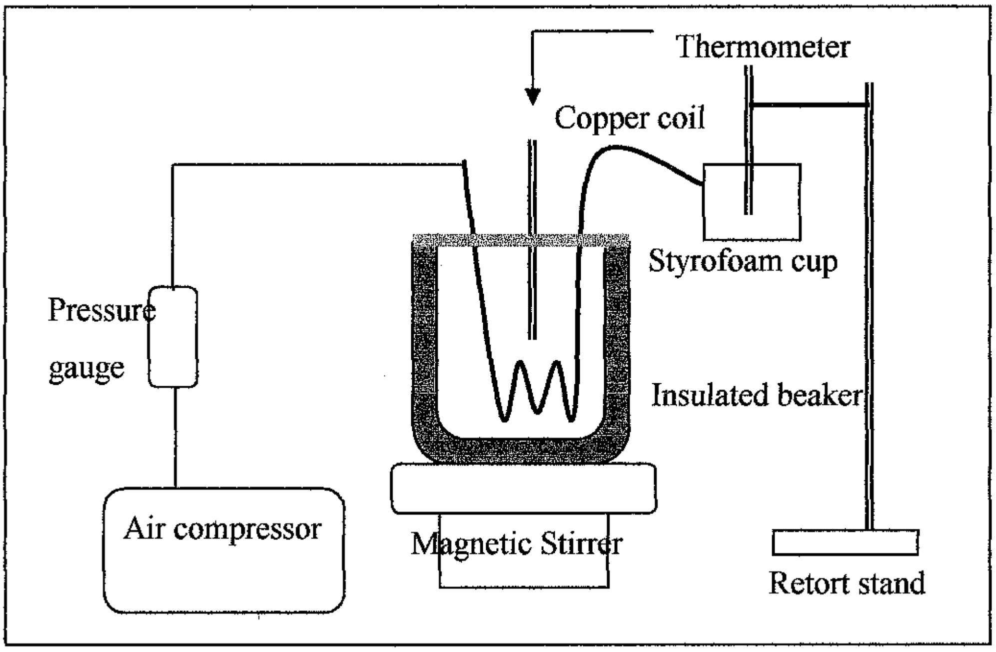

Figure 3.4: Schematic diagram

The air compressor is used to supply air into the copper coil, thus the effect of heat evolved from the reaction of salt solution can be observed. Air flowrate is regulated by the valve mounted on the compressor and the desired air flow rate is determined by the pressure gauge. Based on figure 3.4, air from compressor will flow through the copper coil that placed in the insulated beaker and the outlet air temperature is measured from the thermometer that placed in the Styrofoam cup. Styrofoam cup act as an insulated container, which prevent outlet air from copper coil mixed with the atmosphere. Magnetic stirrer is used to stir the solute automatically and therefore the salt will be dissolved constantly. The actual diagram for this model is shown in figure 3.5 below.

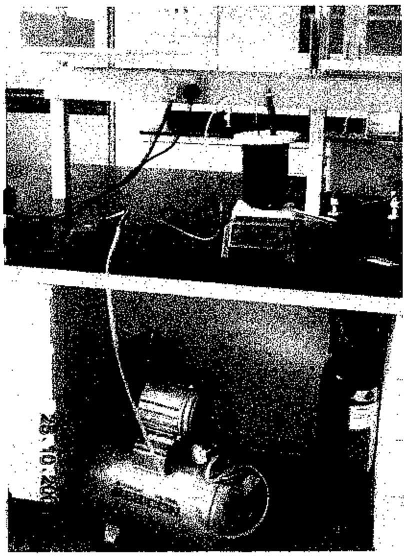

Figure 3.5: Actual model for the experiment

3.2.2.2 Procedure

1. 300g of Calcium chloride ($CaCl_2$) is weighted and 200ml of distilled is measured using graduated cylinder.

2. The insulated beaker was then filled with 200mL of distillated water and the initial temperature of water is measured

3. The set-up of the experiment is prepared (as shown is figure 3.4) and the air compressor is started to the desired air flow-rate. In this experiment the air flow is regulated to 2.5kPa using pressure gauge.

4. Inlet air temperature (ambient temperature) and initial outlet air temperature is measured and recorded.

5. 300g $CaCl_2$ was then poured into the insulated beaker and automatically stirred using magnetic stirrer. The salt solution temperature and outlet air

temperature is recorded for every 30sec time interval until all solute is fully dissolved.

6. The outlet air temperature is observed throughout the experiment.

7. The experiment is repeat with other salt sample; Aluminium Chloride and Aluminium Sulfate

In this experiment, the outlet air flow must be increase from the initial value due to heat transfer from the salt solution. Heat released from the reaction of salt in water will be transferred to air flow in the coil, thus the outlet air temperature will increase from its initial value. The graph of temperature versus time for outlet air flow and salt solution is observed and discussed. The detail of this experiment will be discussed in next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experiment : determination of heat of solution and selection of best salt solution

In the first experiment which is determination of heat of solution, there are seven type of salt involved. The heat of solution for each salt is determined using simple Styrofoam cup calorimeter, as discussed in the chapter 3. The main target for this experiment is to find the salt solution that release more heat during the reaction. The reactions of endothermic and exothermic have been observed and determine in this experiment.

Based on the experimental result, among seven salt involved, three salts give an exothermic reaction while the other is endothermic. The result is tabulated in the table below, where heat of solution of dissolving the 60g of each solute is compared.

Table 4.1: Summarized result

Salts	Heat of solution (kJ/mol)	Types of reaction
Aluminium Sulfate ($Al_2(SO4)_3$)	-31.9253	exothermic
Aluminium Chloride ($AlCl_3$)	-37.4354	exothermic
Calcium Chloride ($CaCl_2$)	-39.3984	exothermic
Pumbum bromide ($PbBr_2$)	6.6724	endothermic
Potassium Nitrate (KNO_3)	15.4300	endothermic
Sodium chlorate ($NaClO_3$)	13.1921	endothermic
Barium nitrate ($Ba(NO_3)_2$)	16.0996	endothermic

To determine the heat of solution, each salt was dissolve in distilled water and the temperature changes during the reaction is observed and recorded. From the data recorded, the heat of solution is calculated and compared, to select the best salt solution as an alternative refrigerant.

According to table 4.1, there are four salts that experienced an endothermic reaction when dissolved in water. Endothermic is a process where heat is absorbed during the reaction of solid salt in water at constant pressure. Therefore, an enthalpy change is increasing during the reaction. This can be proven, from the positive value of heat of solution of each endothermic salt, as stated in table 4.1. In endothermic reaction, temperature decreases from its initial value due to absorption of heat during the reaction.

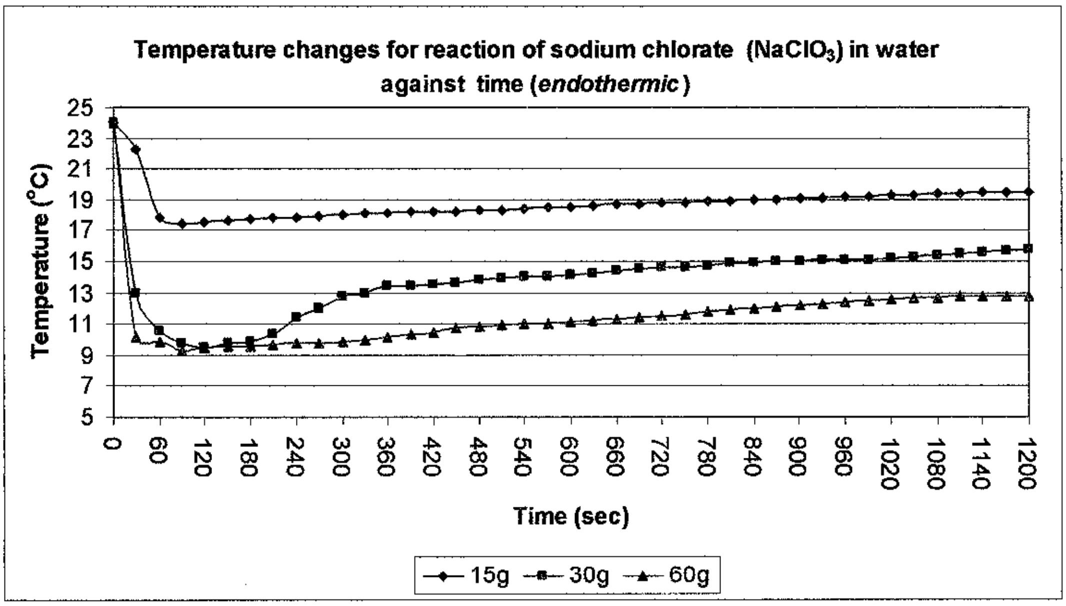

Figure 4.1: Graph temperature versus time of $NaClO_3$

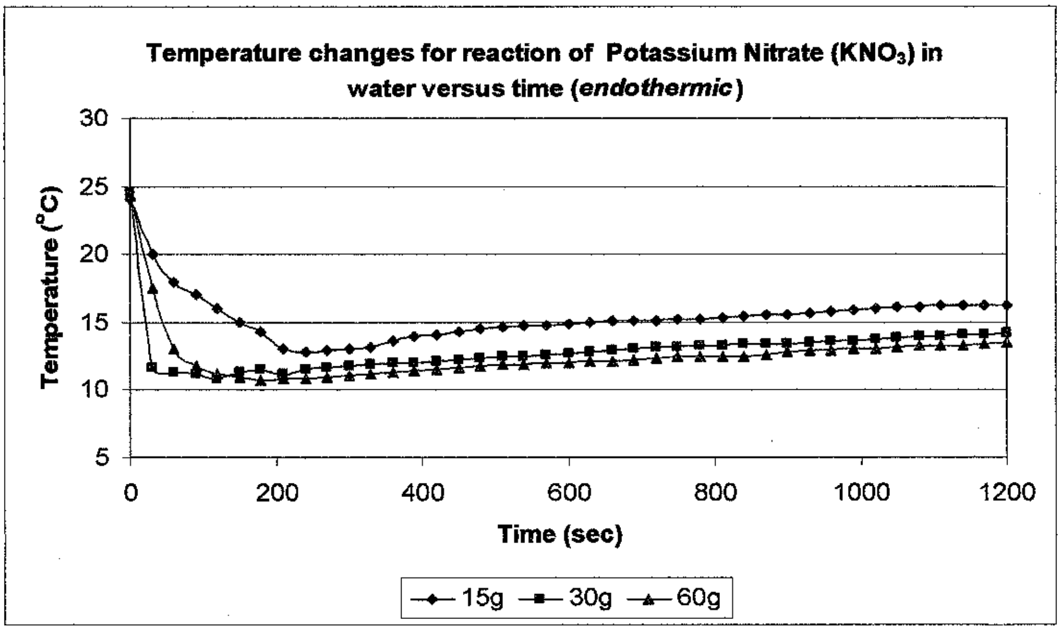

Figure 4.2: Graph temperature versus time of KNO_3

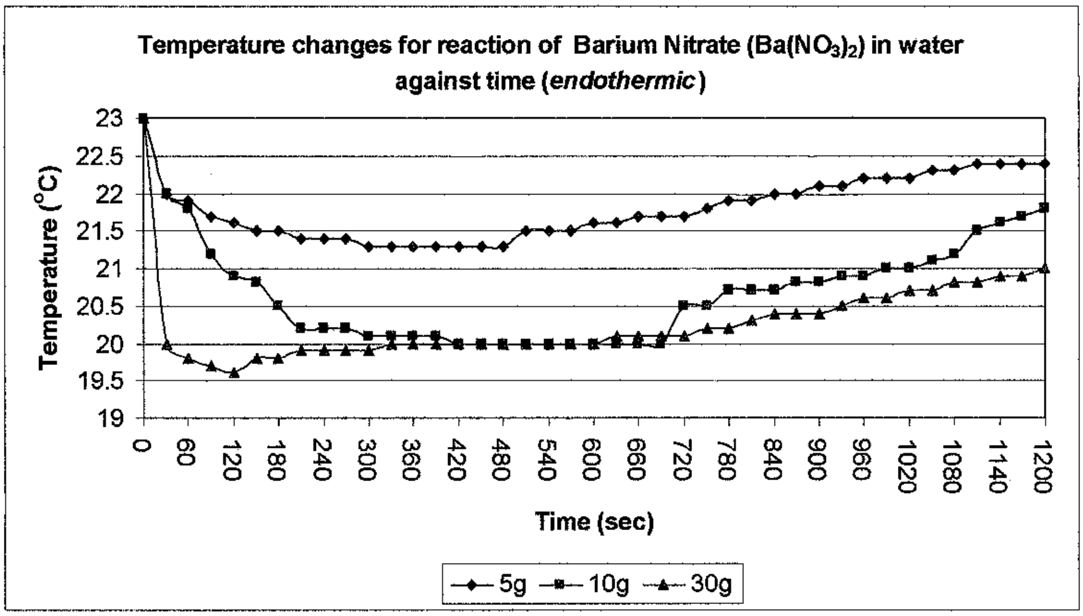

Figure 4.3: Graph temperature versus time of $Ba(NO_3)$

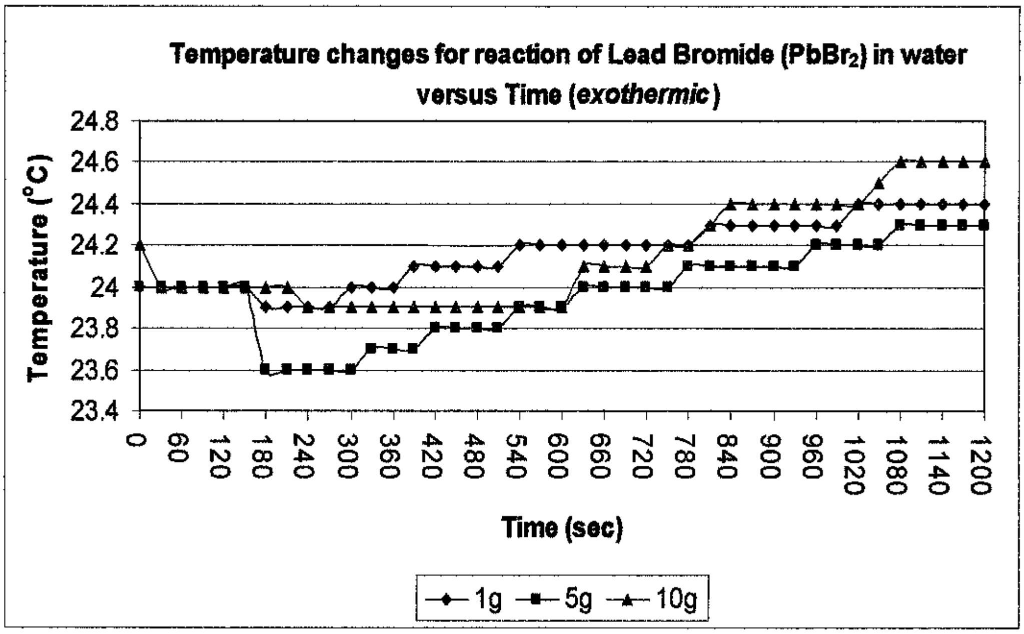

Figure 4.4: Graph temperature versus time of $PbBr_2$

Figure 4.1 to Figure 4.4, showed the temperature changes for Sodium chlorate, Potassium Nitrate, Barium Nitrate and Lead (II) Bromide respectively. Temperature decreases from its initial value due to endothermic reaction and therefore it is proven that heat is adsorbed during the dissolving process. Sodium Chlorate absorbs more heat during the reaction compared with other salts; this is because the reaction reached the lowest temperature almost 9°C with temperature different of 15°C. Thus, sodium chlorate is more endothermic salt solution compared with others. Since this research is focused on exothermic salt solution, the endothermic reaction will not be discussed any further. Please refer to appendices 1 for the result and experimental data for each endothermic salt solution

Based on the result, another three salt involved in this experiment are exothermic salt solution, which is Aluminium Sulfate, Aluminium Chloride and Calcium Chloride. Contradict with endothermic reaction, exothermic is a process where heat is released during the reaction of solute and solvent. Therefore, at constant pressure the enthalpy of the reaction is decreases throughout the process. It is observed that, for exothermic process, temperature increases from its initial value due to heat evolve during the reaction. It is shown in the figures below:

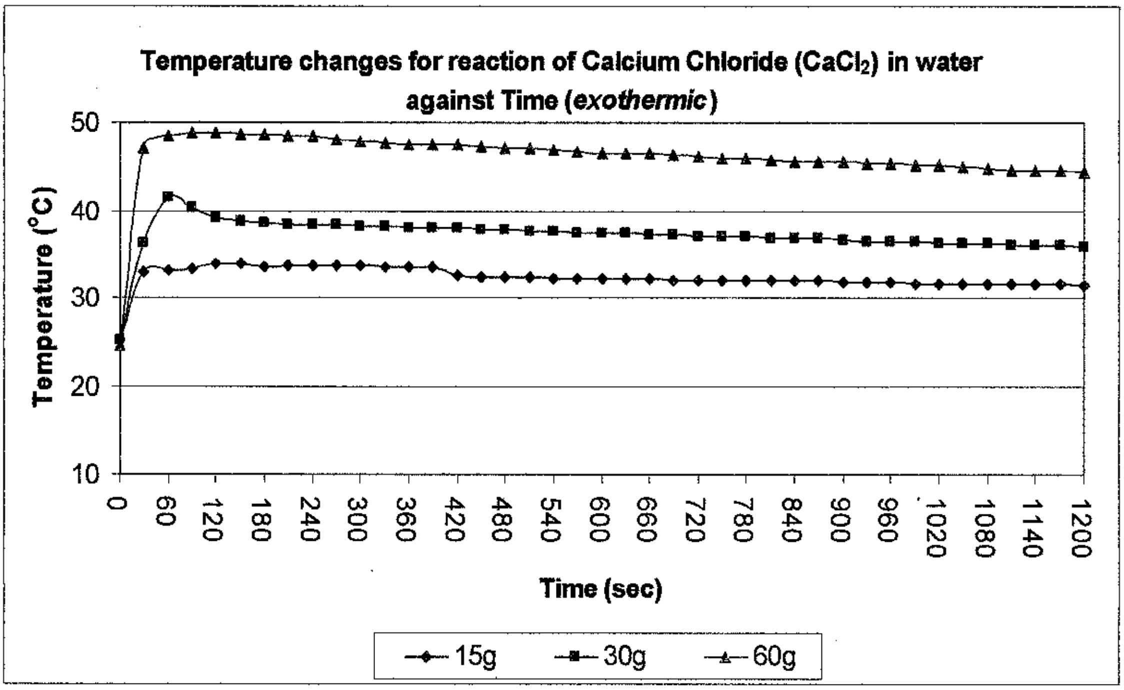

Figure 4.5: Graph temperature versus time of $CaCl_2$

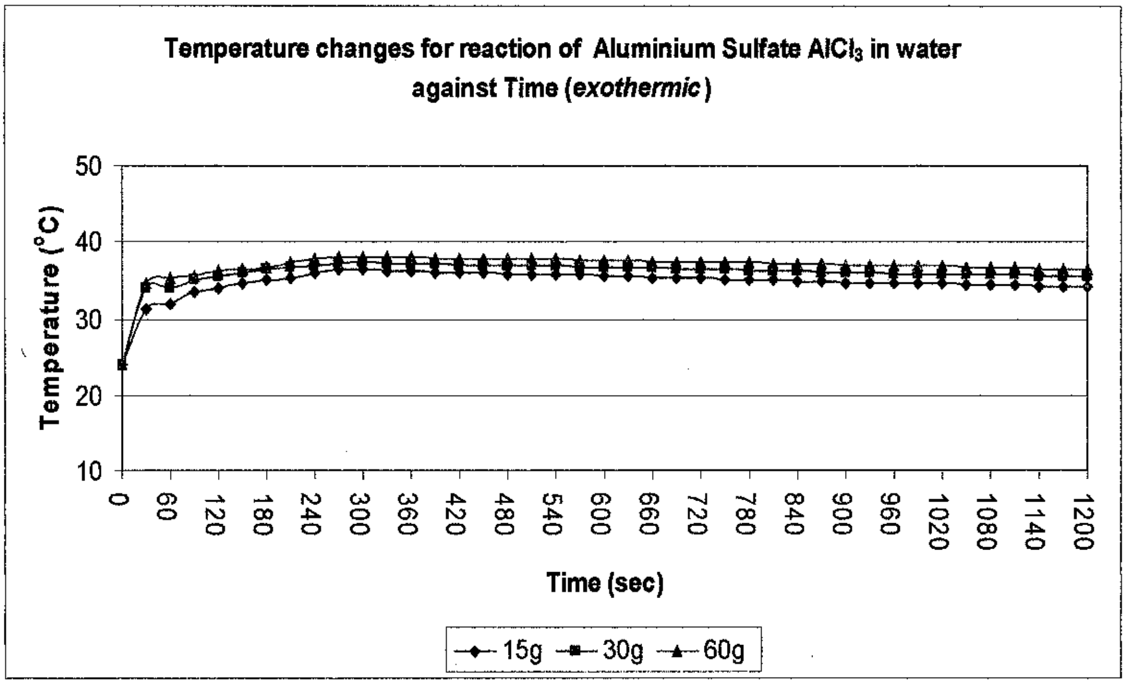

Figure 4.6: Graph temperature versus time of $AlCl_3$

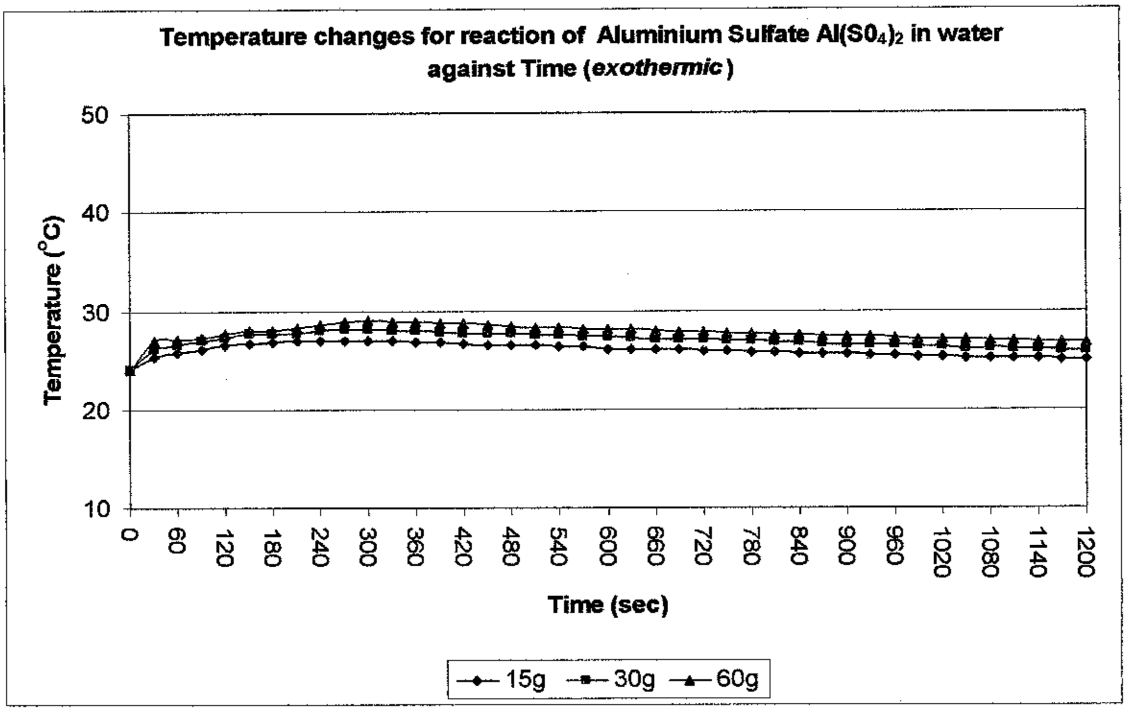

Figure 4.7: Graph temperature versus time of $Al_2(SO4)_3$

Figure 4.4 to Figure 4.7 showed the graph of temperature changes for each exothermic salt solution. Each salt is dissolved in distilled water with different mass of solute, which is 15g, 30g and 60g in the 100mL of water. Thus the effect of exothermic reaction can be seen clearly via different concentration of solution. Therefore, the heat of solution of the different concentration of salt solution can be observed same goes to the heat of reaction. It is proven that in exothermic reaction, temperature increases when solid salts are dissolved in water, because of releasing of heat from the reaction. Form the graphs (Figure 4.4 to Figure 4.7), initially the temperature increases at the higher peak it can achieve and at after certain time the temperature decreases towards the ambient temperature. This behavior happen because of no reaction occurs in the solution due to 100% dissolved of solute in water. Thus, the temperature of salt solution reduces to its initial or ambient temperature. Such behavior will be good properties for salt solution to be an alternative refrigerant that applied as a drying agent.

This temperature different will determine which salt solution able released more heat during the reaction of salt in water. The amount of heat released is an important aspect to choose the best salt solution as an alternative refrigerant. The requirement for alternative refrigerant in this research project is the salt solution that produces high exothermic reaction. In other words, salt solution that contributes to high heat of solution. The heat of solution of each salt involved is calculated based on the experimental data and the calculation is done by using the equation below:

$$\Delta H_{soln} = \frac{q_{rxn}}{n} \quad (1)$$

The heat produce in the reaction, q_{rxn} is calculated based on the temperature different, mass of salt and water and also heat capacity of water, as indicates below:

$$q_{soln} = m_{soln} C_{soln} (T_f - T_i) \quad (2)$$

** Please refer to appendices 3 for sample calculation*

Table 4.2: Calculated data for Calcium chloride, $CaCl_2$

	15g	30g	60g
Mass of empty Styrofoam cup (g)	3.24	3.23	3.23
Mass of cup and water (g)	102.235	102.445	102.37
Mass of water (g)	99.00	99.22	99.15
Mass of solute (g)	15	30	60
Initial temperature (°C)	25.2	25.1	24.5
Final temperature (°C)	34	39.1	48.8
Heat,q (J)	-4197.3888	-7569.19	-16180.5
Molecular weight (g/mole)	147.02	147.02	147.02
Mole, n	0.1020	0.2041	0.4081
Heat of solution (kJ/mol)	-41.1400	-37.0941	-39.6475
pH	6	5.81	5.27

Table 4.1 summarized the calculation of heat of solution for Calcium Chloride, $CaCl_2$. The pH value of Calcium Chloride is in the range of 5-6 and it is in the region of less acidic. In this experiment, the higher temperature different, ΔT achieved by the reaction of $CaCl_2$ in water is 24.3°C, which is in dissolving 60g of $CaCl_2$.

Table 4.2: Calculated data for Aluminium Chloride, $AlCl_3$

	15g	**30g**	**60g**
Mass of empty styrofoam cup (g)	3.23	3.21	3.22
Mass of cup and water (g)	101.03	101.55	100.915
Mass of water (g)	97.81	98.34	97.70
Mass of solute (g)	15	30	60
Initial temperature (°C)	24	24	24
Final temperature (°C)	36	37.1	38.1
Heat,q (J)	-5663.71	-7034.37	-9303.42
Molecular weight (g/mole)	241.43	241.43	241.43
Mole, n	0.0621	0.1243	0.2485
Heat of solution (kJ/mol)	-91.1594	-56.6102	-37.4354
pH	3.5	3.24	3.03

Table 4.2 shows the calculated heat of solution of Aluminium Chloride in distilled water with different weight of solute. The temperature different when dissolved 60g of $AlCl_3$ in water is, $\Delta T = 14.1°C$. The value of temperature different increased when amount of solute increases from 15g to 60g.

Table 4.3: Calculated data for Aluminium Sulfate, $Al_2(SO4)_3$

	15g	**30g**	**60g**
Mass of empty styrofoam cup (g)	3.205	3.21	3.215
Mass of cup and water (g)	101.08	101.135	101.11
Mass of water (g)	97.88	97.93	97.90
Mass of solute (g)	15	30	60
Initial temperature (°C)	24	24	24
Final temperature (°C)	27	28.1	28.6
Heat,q (J)	-1416.81	-2194.48	-3038.91
Molecular weight (g/mole)	630.39	630.39	630.39
Mole, n	0.0238	0.0476	0.0952
Heat of solution (kJ/mol)	-59.5427	-46.1125	-31.9283
pH	3.05	3.03	3.01

Same goes to Aluminium Sulfate; the calculated heat of solution is summarized in the Table 4.3 above. The temperature different when dissolving 60g of $Al_2 (SO4)_3$ in water is 4.6°C, which become lesser compared with temperature different of $AlCl_3$ and $CaCl_2$. It is observed that as amount of solute increased the temperature different also increases event in the same volume of water.

As stated earlier, the heat release from the reaction of solute and solvent is required for drying a agent in the new refrigeration system. Thus, from the tabulated results and graphs, between the three exothermic salt solutions it can be conclude that $CaCl_2$ experienced higher exothermic reaction other than the two salts. The temperature different in dissolving $CaCl_2$ (ΔT = 24.3°C) in water is larger than temperature different between $AlCl_3$ (ΔT = 14.1°C) and $Al_2 (SO4)_3$ (ΔT = 4.6°C). Graph in Figure 4.8 in the next page, show the relationship of temperature changes for this three exothermic salt solutions. The temperature different is compared based in dissolving 60g of each solute. Other than temperature different, heat of solution also can be proven that $CaCl_2$ is a highly exothermic salt solution. Refer to table 4.1, heat of solution of $CaCl_2$ is -39.3984kJ/mol while heat of solution of AlC13 and $Al_2 (SO4)_3$ is -37.4354kJ/mol and -31.9253kJ/mol respectively.

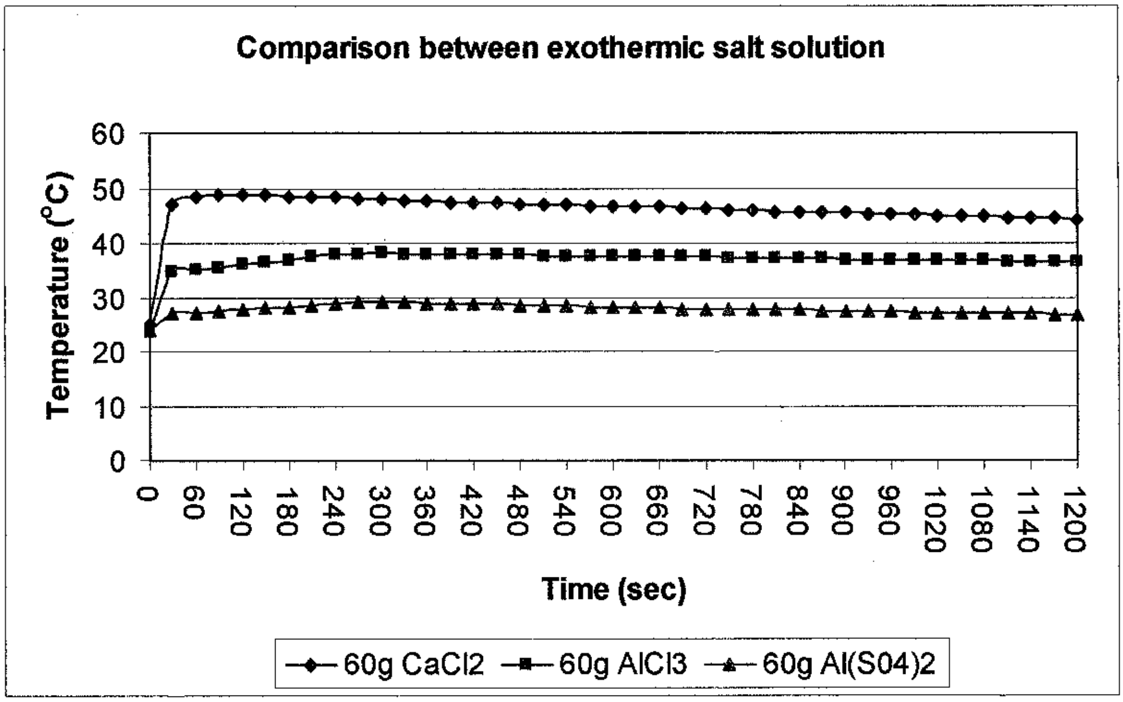

Figure 4.8: Relationship between exothermic salt solutions.

Figure 4.8 show that the reaction of $CaCl_2$ lead to higher temperature different compared with other salt solution. Thus, $CaCL_2$ is highly exothermic salt solution and will produce more heat during reaction. Event the temperature of $CaCl_2$ decreasing, Since $CaCl_2$ contribute to higher temperature different and heat of solution, it is decided to select $CaCl_2$ to be as an alternative refrigerant in the new drying system. The heat evolved from the reaction of this new alternative refrigerant will be used as a drying agent in the new drying system.

4.2 Experiment 2: Determination of the effect of exothermic reaction of salt solution to the air flow.

This experiment is done to satisfy or proves that the heat produced from the reaction of salt solution can be applied as a drying agent. In this level, the selected salt solution will be testing upon the air flow in the copper coil. Based on the thesis done [7], copper coil have been proposed as a heat transfer medium between salt solution and air flow. The properties of copper coil; which is a good conductor with high value thermal conductivity, low corrosion rate, cheap and easy obtainable is a factor of using the coil in this experiment.

In this experiment, the copper coil is immersed in the salt solution and the air will flow through the copper coil. The outlet air temperature from the copper coil is observed and recorded, to see the effect of heat produced from the reaction towards air flow. The air flowrate is constant throughout experiment, which the flowrate is set in term of pressure about 2.5kPa.

4.2.1 Result

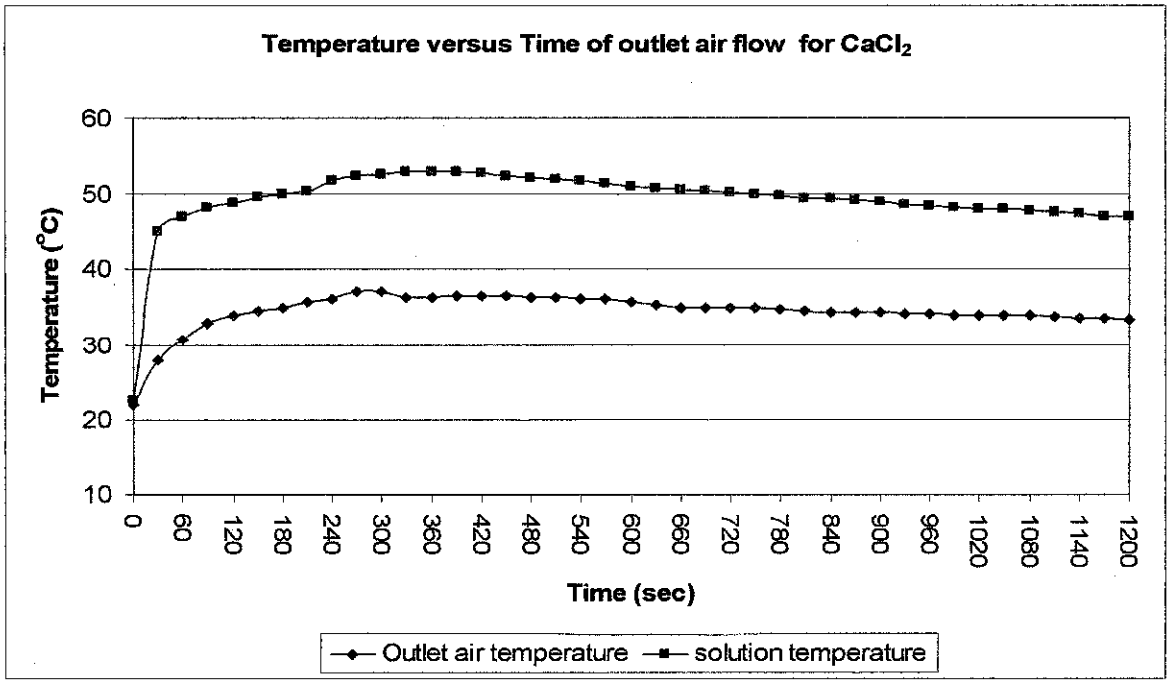

Figure 4.9: Effect of $CaCl_2$ solution on air flow of

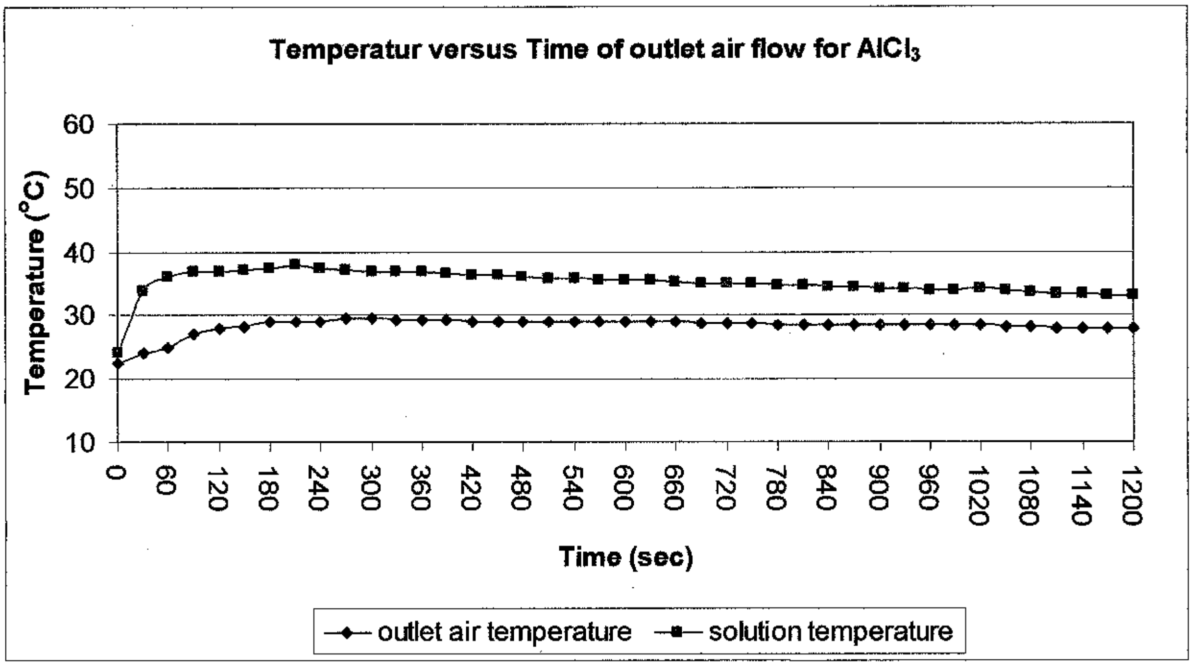

Figure 4.10: Effect of $AlCl_3$ solution on air flow

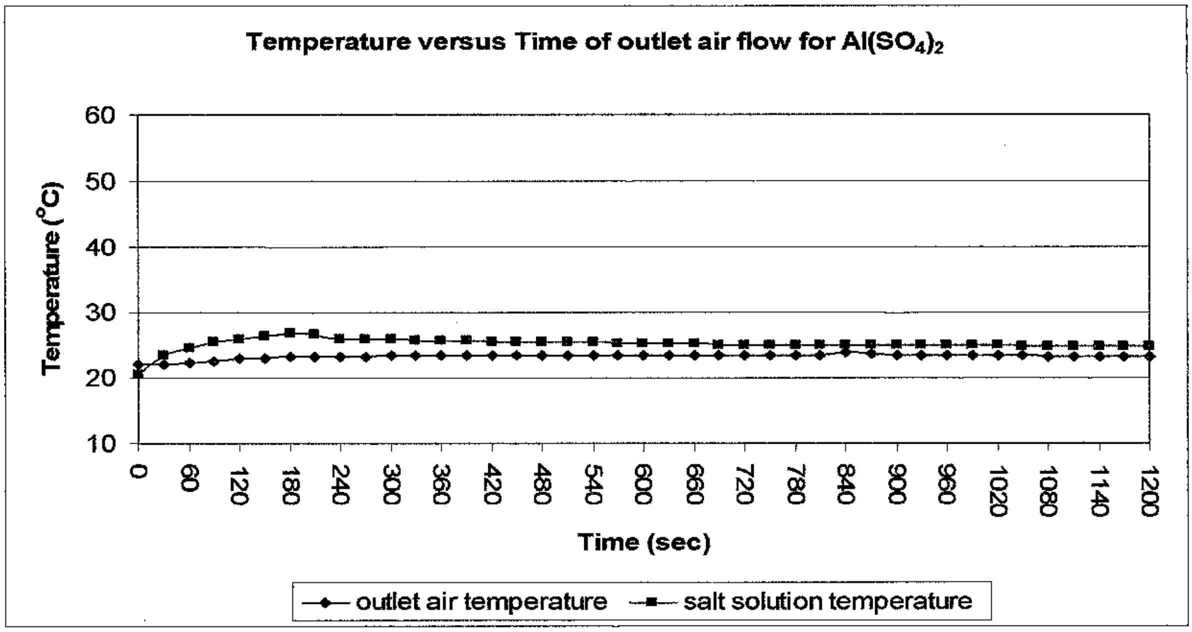

Figure 4.11: Effect of $Al_2(SO4)_3$ solution on air flow

Figure 4.9 to Figure 4.11 show the temperature changes of the outlet air flow and salt solution Calcium Chloride, Aluminium Chloride and Aluminium Sulfate respectively. When temperature of solution increases, the temperature of air flow in the copper coil also gives the same effect. Thus, the effect of reaction within salt solution increased the temperature of air flow in the coil.

Table 4.4: Temperature changes for outlet air flow and salt solution

Salt solution	Initial outlet air temperature (°C)	Final outlet air temperature (°C)	Delta T for salt solution (°C)
Calcium Chloride	22.0	33.4	24.5
Aluminium Chloride	22.5	28.0	9.0
Aluminium Sulfate	22.0	23.2	4.3

The result of temperature changes for the three salt solutions is summarized in the table 4.4 above. It indicates the amount of temperatures changes within the salt solution in order to increase the air flow in the copper coil. Among the three salt solution, the effect of Calcium Chloride solution to the air flow is the higher with the temperature different of outlet air flow is 11.4°C (ΔT_{air}=11.4°C). The amount of heat released from the reaction of each salt is calculated, and summarized in the table 4.5 below.

Table 4.5: Calculated data of heat of solution

	$CaCl_2$	$AlCl_3$	$Al_2(SO4)_3$
Mass of water (g)	200	200	200
Mass of solute (g)	300	140	140
Initial temperature (°C)	22.5	24	20.4
Final temperature (°C)	47	33	24.7
Heat,q (J)	-51254.00	-12803.04	-6117.01
Molecular weight (g/mole)	147.020	241.430	630.390
Mole, n	2.041	0.580	0.222
Heat of solution (kJ/mol)	-25.118	-22.079	-27.544
Volume of water (l)	0.200	0.200	0.200
Concentration (mole/l)	10.203	2.899	1.110

4.2.2 Discussion.

The objective of this experiment is to observe and determine the effect of heat produced from the salt solution to the air flow through the coil. Based on the finding or result from the experimental activity, it is proven that the heat released from the reaction of the salt solution able to increase the temperature of air flow. This happen due to heat transferred from the salt solution into the air within the copper coil because of the temperature different. Such theory, is based on the definitions of heat itself, which is *heat is a form of energy that is transferred between tow systems by virtue of temperature difference* [3]. Therefore, heat from the salt solution can be transferred to the air within the copper coil by conduction. This principle also proves that heat released from the salt solution can be transferred into any medium as long as there is temperature different between the systems. The temperature different between the two system (salt solution and outlet air) can be seen clearly from the graph in figure 4.9 to figure 4.10.

Based on the result, Calcium Chloride is capable to be as an alternative refrigerant since it can increase the temperature of outlet air flow at higher temperature different. As compared with Aluminium Chloride and Aluminum sulfate, the effect of this salt solution in increasing the air temperature is less due to small temperature different. It is shown in the figure 4.12.

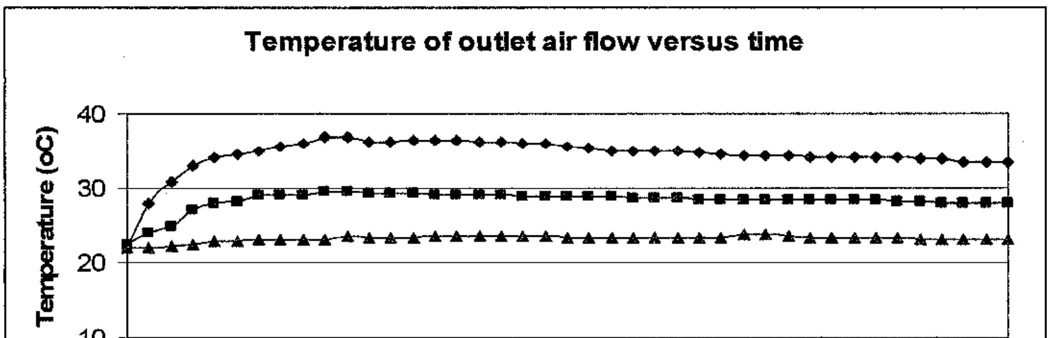

Figure 4.12: Comparison in outlet air flow

As a conclusion, Calcium Chloride is selected to be an alternative refrigerant in the new drying system. The heat evolved from the reaction of Calcium Chloride solution will be used as a drying agent for dry up any medium. To apply the alternative salt solution in to the new drying system, some modification with the refrigerant cycles need to be done.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Based on the research and experimental work done throughout this several month, the development of the new drying system using salt solution will be successfully achieved in the future. This is due to strong fundamental behavior of salt solution itself, where it released or absorbs heat when dissolved in water and it is proven from the result obtained by experiment.

The result get from the first experiment verified the first and second objective of this research project. In this project, there are four salt experienced an endothermic heat of solution and other three salts are exothermic heat of solution. For endothermic salt solution, temperature decreased from its initial value and the heat of solution increased. And for exothermic salt solution initial temperature value increases and the heat of solution decreased, thus heat evolved from the reaction.

The main focused on this research project is the exothermic salt solution, where heat of solution produced when dissolving a solid salt in water is used as a drying agent. Among the three exothermic salt solution; Aluminium Sulfate, Aliminium Chloride and Calcium Chloride, the highly exothermic solution is Calcium Chloride. Experimental result show that Calcium Chloride experienced high heat of solution and have high temperature different compare with other salts. Therefore, it is decided Calcium Chloride is the best solution to be as an alternative refrigerant.

The result obtain in the second experiment, proven that the heat released from the reaction of salt solution can be applied as a drying agent in the drying system. The results prove that the outlet air temperature increases from its initial value due to heat transfer from the solution. Once again, Calcium Chloride contributed to higher temperature different in the outlet air temperature.

In the future, it is recommended for further research on the selected salt solution whether it can be apply as a drying agent in the new drying system. Some modification on the existing refrigeration cycle system will be made to suit it with the selected salt solution. One application can be used in the new drying system to act similarly with the refrigerant cycles, is the application of membrane technology. Earlier research has been done due this method, which is *Design of a new air conditioning unit using membrane technology* [3]. Therefore, the research can be applied with the selected salt solution with the development of new drying system.

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[21] http://www.chem.iastate.edu

APPENDICES

Appendices 1: Experimental raw data for Experiment 1

Appendices 2: Experimental raw data fro Experiment 2

Appendices 3: Sample Calculations

APPENDICES 1

Appendix 1ai

Aluminium Sulfate ($Al_2(SO_4)_3$)

	15g		30g		60g	
	1	2	1	2	1	2
Mass of empty styrofoam cup (g)	3.21	3.2	3.21	3.21	3.22	3.21
Mass of cup and water (g)	101.2	100.96	101.4	100.87	101.35	101.9
Mass of water (g)	97.99	97.76	98.19	97.66	98.13	98.69
Mass of solute (g)	15	15	30	30	60	60
Initial temperature (°C)	24	24	24	24	24	24
Final temperature (°C)	27	27	28	28.2	28.5	28.5
Heat,q (J)	-1418.25	-1415.36	-2145.39	-2243.34	-2977.27	-2987.82
Molecular weight (g/mole)	630.39	630.39	630.39	630.39	630.39	630.39
Mole, n	0.0238	0.0238	0.0476	0.0476	0.0952	0.0952
Heat of solution (kJ/mol)	-59.6034	-59.4821	-45.0810	-47.1394	-31.2807	-31.3915

Appendix 1bi

Aluminium Chloride ($AlCl_3.6H_2O$)

	15g		30g		60g	
	1	2	1	2	1	2
Mass of empty styrofoam cup (g)	3.22	3.23	3.21	3.21	3.22	3.21
Mass of cup and water (g)	101.52	100.54	101.9	101.2	100.63	101.58
Mass of water (g)	98.3	97.31	98.69	97.99	97.41	98.37
Mass of solute (g)	15	15	30	30	60	60
Initial temperature (°C)	24	24	24	24	24	24
Final temperature (°C)	36	36	37.2	37	38	38.2
Heat,q (J)	-5688.57	-5638.86	-7107.39	-6961.63	-9220.45	-9409.21
Molecular weight (g/mole)	241.43	241.43	241.43	241.43	241.43	241.43
Mole, n	0.0621	0.0621	0.1243	0.1243	0.2485	0.2485
Heat of solution (kJ/mol)	-91.5594	-90.7593	-57.1979	-56.0249	-37.1015	-37.8611

Appendix 1ci

Calcium Chloride ($CaCl_2$)

	15g		30g		60g	
	1	2	1	2	1	2
Mass of empty styrofoam cup (g)	3.22	3.25	3.22	3.23	3.23	3.22
Mass of cup and water (g)	102.26	102.21	102.32	102.57	102.24	102.5
Mass of water (g)	99.04	98.96	99.1	99.34	99.01	99.28
Mass of solute (g)	15	15	30	30	60	60
Initial temperature (°C)	25.8	25.9	25.2	25	25.5	25.5
Final temperature (°C)	34.7	33.9	38	37.5	47	48
Heat,q (J)	-4246.58	-3814.47	-6913.98	-6764.48	-14303.90	-14994.62
Molecular weight (g/mole)	147.02	147.02	147.02	147.02	147.02	147.02
Mole, n	0.10	0.10	0.20	0.20	0.41	0.41
Heat of solution (kJ/mol)	-41.62	-37.39	-33.88	-33.15	-35.05	-36.74

Appendix 1di

Lead (II) Bromide ($PbBr_2$)

	15g	30g	60g
Mass of empty styrofoam cup (g)	3.22	3.21	3.21
Mass of cup and water (g)	100.84	102.73	101.84
Mass of water (g)	97.62	99.52	98.63
Mass of solute (g)	1	5	10
Initial temperature (°C)	24	24	24.2
Final temperature (°C)	23.9	23.6	24
Heat,q (J)	41.263	174.925	90.902
Molecular weight (g/mole)	367.01	367.01	367.01
Mole, n	0.0027	0.0136	0.0272
Heat of solution (kJ/mol)	15.1438	12.8398	3.3362

Appendix 1ei

Sodium Chlorate ($NaClO_3$)

	15g	**30g**	**60g**
Mass of empty styrofoam cup (g)	3.23	3.25	3.21
Mass of cup and water (g)	101.27	101.29	101.9
Mass of water (g)	98.04	98.04	98.69
Mass of solute (g)	15	30	60
Initial temperature (°C)	24	24	24
Final temperature (°C)	19.5	15.8	12.8
Heat,q (J)	2128.317	4392.899	7436.340
Molecular weight (g/mole)	106.44	106.44	106.44
Mole, n	0.1409	0.2818	0.5637
Heat of solution (kJ/mol)	15.1025	15.5860	13.1921

Appendix 1fi

Barium Nitrate ($Ba(NO_3)_2$)

	15g	**30g**	**60g**
Mass of empty styrofoam cup (g)	3.21	3.24	3.24
Mass of cup and water (g)	101.41	101.18	103.15
Mass of water (g)	98.2	97.94	99.91
Mass of solute (g)	5	10	30
Initial temperature (°C)	23	23	23
Final temperature (°C)	21.3	20	19.6
Heat,q (J)	734.041	1354.863	1848.048
Molecular weight (g/mole)	261.35	261.35	261.35
Mole, n	0.0191	0.0383	0.1148
Heat of solution (kJ/mol)	38.3683	35.4093	16.0996

Appendix 1gi

Potassium Nitrate (KNO_3)

	15g	**30g**	**60g**
Mass of empty styrofoam cup (g)	3.23	3.25	3.21
Mass of cup and water (g)	101.27	101.29	101.9
Mass of water (g)	98.04	98.04	98.69
Mass of solute (g)	15	30	60
Initial temperature (°C)	24	24	24
Final temperature (°C)	12.8	10.7	10.9
Heat,q (J)	5297.145	7125.067	8697.862
Molecular weight (g/mole)	101.11	101.11	101.11
Mole, n	0.1484	0.2967	0.5934
Heat of solution (kJ/mol)	35.7063	24.0139	14.6573

APPENDICES 2

ppendix 1aii

$Al_2(SO_4)_3$

15g			
Time (sec)	Temp °C	Temp °C	average
0	24	24	24.0
30	25.5	25.2	25.4
60	25.9	25.5	25.7
90	26	26	26.0
120	26.5	26.5	26.5
150	26.7	26.7	26.7
180	27	26.7	26.9
210	27	27	27.0
240	27	27	27.0
270	27	27	27.0
300	27	27	27.0
330	26.9	26.9	26.9
360	26.9	26.8	26.9
390	26.8	26.8	26.8
420	26.7	26.7	26.7
450	26.5	26.6	26.6
480	26.5	26.6	26.6
510	26.5	26.4	26.5
540	26.4	26.4	26.4
570	26.3	26.3	26.3
600	26	26.2	26.1
630	26	26	26.0
660	26	26.2	26.1
690	25.9	26.1	26.0
720	25.7	26.1	25.9
750	25.6	26.1	25.9
780	25.6	26	25.8
810	25.5	26	25.8
840	25.4	25.9	25.7
870	25.4	25.9	25.7
900	25.4	25.9	25.7
930	25.2	25.8	25.5
960	25.2	25.7	25.5
990	25.1	25.6	25.4
1020	25.1	25.5	25.3
1050	25	25.4	25.2
1080	25	25.4	25.2
1110	24.9	25.4	25.2
1140	24.9	25.3	25.1
1170	24.9	25	25.0
1200	24.9	25	25.0

30g			
Time (sec)	Temp °C	Temp °C	average
0	24	24	24.0
30	26	26.2	26.1
60	26.5	26.5	26.5
90	27	26.9	27.0
120	27.1	27.5	27.3
150	27.5	27.9	27.7
180	27.5	27.9	27.7
210	27.5	28	27.8
240	28	28	28.0
270	28	28.2	28.1
300	28	28.2	28.1
330	27.9	28	28.0
360	27.9	28	28.0
390	27.8	27.9	27.9
420	27.7	27.8	27.8
450	27.6	27.7	27.7
480	27.6	27.7	27.7
510	27.5	27.6	27.6
540	27.5	27.5	27.5
570	27.5	27.4	27.5
600	27.4	27.3	27.4
630	27.4	27.1	27.3
660	27.2	27.1	27.2
690	27.2	27	27.1
720	27.1	27	27.1
750	27	26.9	27.0
780	27	26.8	26.9
810	26.9	26.8	26.9
840	26.8	26.7	26.8
870	26.7	26.5	26.6
900	26.6	26.5	26.6
930	26.6	26.4	26.5
960	26.5	26.4	26.5
990	26.3	26.3	26.3
1020	26.3	26.3	26.3
1050	26.1	26.1	26.1
1080	26.1	26.2	26.2
1110	26	26.1	26.1
1140	26	26	26.0
1170	25.9	25.9	25.9
1200	25.9	25.9	25.9

60g			
ime (sec)	Temp ^{o}C	Temp ^{o}C	average
0	24	24	24.0
30	27	27	27.0
60	27.1	27	27.1
90	27.1	27.5	27.3
120	27.5	27.8	27.7
150	27.9	28	28.0
180	28	28	28.0
210	28.2	28.5	28.4
240	28.6	28.6	28.6
270	29	28.9	29.0
300	29	29	29.0
330	28.9	29	29.0
360	28.9	28.9	28.9
390	28.8	28.8	28.8
420	28.7	28.7	28.7
450	28.6	28.6	28.6
480	28.5	28.5	28.5
510	28.3	28.3	28.3
540	28.2	28.5	28.4
570	28.2	28.2	28.2
600	28.1	28.1	28.1
630	28.1	28.1	28.1
660	28	28	28.0
690	27.9	27.8	27.9
720	27.9	27.8	27.9
750	27.8	27.7	27.8
780	27.7	27.7	27.7
810	27.6	27.6	27.6
840	27.6	27.6	27.6
870	27.4	27.5	27.5
900	27.4	27.4	27.4
930	27.3	27.4	27.4
960	27.3	27.3	27.3
990	27.1	27.2	27.2
1020	27	27.1	27.1
1050	27	27.1	27.1
1080	26.9	27	27.0
1110	26.9	27	27.0
1140	26.8	26.9	26.9
1170	26.7	26.9	26.8
1200	26.7	26.8	26.8

ppendix 1bii

$lCl_3.6H_2O$

15g			
ime (sec)	Temp °C	Temp °C	average
0	24	24	24.0
30	31	31.5	31.3
60	32	32	32.0
90	33.5	33.5	33.5
120	34	34	34.0
150	34.9	34.5	34.7
180	35	35	35.0
210	35.3	35.2	35.3
240	36	36	36.0
270	36.4	36.5	36.5
300	36.5	36.5	36.5
330	36.2	36.4	36.3
360	36.2	36.2	36.2
390	36	36.2	36.1
420	36	36	36.0
450	35.9	36	36.0
480	35.8	35.9	35.9
510	35.7	35.9	35.8
540	35.7	35.8	35.8
570	35.6	35.7	35.7
600	35.5	35.6	35.6
630	35.5	35.5	35.5
660	35.3	35.5	35.4
690	35.2	35.3	35.3
720	35.2	35.3	35.3
750	35	35.2	35.1
780	35	35.2	35.1
810	34.9	35.2	35.1
840	34.8	35	34.9
870	34.7	35	34.9
900	34.5	34.9	34.7
930	34.5	34.9	34.7
960	34.4	34.8	34.6
990	34.4	34.8	34.6
1020	34.3	34.8	34.6
1050	34.2	34.7	34.5
1080	34.1	34.6	34.4
1110	34.1	34.6	34.4
1140	34	34.5	34.3
1170	34	34.5	34.3
1200	34	34.3	34.2

30g			
Time (sec)	Temp °C	Temp °C	average
0	24	24	24.0
30	34	33.8	33.9
60	34	34	34.0
90	35.5	34.5	35.0
120	35.9	35	35.5
150	36	35.8	35.9
180	36.8	36	36.4
210	37	36.5	36.8
240	37	37	37.0
270	37.2	37.2	37.2
300	37.4	37.2	37.3
330	37.2	37	37.1
360	37.2	37	37.1
390	37.1	37	37.1
420	37.1	36.9	37.0
450	37	36.9	37.0
480	37	36.7	36.9
510	36.9	36.7	36.8
540	36.9	36.7	36.8
570	36.8	36.6	36.7
600	36.8	36.5	36.7
630	36.8	36.5	36.7
660	36.7	36.5	36.6
690	36.6	36.3	36.5
720	36.6	36.3	36.5
750	36.5	36.2	36.4
780	36.5	36	36.3
810	36.5	36	36.3
840	36.4	36	36.2
870	36.3	35.9	36.1
900	36.2	35.9	36.1
930	36.1	35.8	36.0
960	36	35.7	35.9
990	36	35.6	35.8
1020	35.9	35.6	35.8
1050	35.9	35.5	35.7
1080	35.8	35.5	35.7
1110	35.8	35.5	35.7
1140	35.7	35.4	35.6
1170	35.6	35.4	35.5
1200	35.6	35.4	35.5

60g			
ime (sec)	Temp °C	Temp °C	average
0	24	24	24.0
30	34.5	34.9	34.7
60	35	35.5	35.3
90	35	36	35.5
120	35.9	36.5	36.2
150	36	36.9	36.5
180	36.5	37	36.8
210	36.9	37.9	37.4
240	37.5	38	37.8
270	37.9	38	38.0
300	38	38.2	38.1
330	38	38.1	38.1
360	38	38	38.0
390	37.9	37.9	37.9
420	37.9	37.9	37.9
450	37.8	37.8	37.8
480	37.8	37.8	37.8
510	37.7	37.7	37.7
540	37.7	37.7	37.7
570	37.6	37.6	37.6
600	37.5	37.6	37.6
630	37.5	37.6	37.6
660	37.4	37.4	37.4
690	37.4	37.4	37.4
720	37.4	37.4	37.4
750	37.3	37.3	37.3
780	37.3	37.3	37.3
810	37.2	37.2	37.2
840	37.2	37.2	37.2
870	37.2	37	37.1
900	37	37	37.0
930	37	37	37.0
960	36.9	36.9	36.9
990	36.8	36.9	36.9
1020	36.8	36.9	36.9
1050	36.7	36.8	36.8
1080	36.6	36.8	36.7
1110	36.5	36.8	36.7
1140	36.4	36.7	36.6
1170	36.4	36.6	36.5
1200	36.3	36.6	36.5

ppendix 1cii

aCl₂

15g			
Time (sec)	Temp °C	Temp °C	average
0	25.2	25.1	25.2
30	33	33	33.0
60	33.1	33.1	33.1
90	33.5	33.2	33.4
120	33.9	33.9	33.9
150	34	33.9	34.0
180	34.3	32.8	33.6
210	34.5	32.8	33.7
240	34.5	32.7	33.6
270	34.6	32.7	33.7
300	34.7	32.6	33.7
330	34.4	32.6	33.5
360	34.3	32.5	33.4
390	34.3	32.5	33.4
420	32.5	32.5	32.5
450	32.3	32.4	32.4
480	32.2	32.4	32.3
510	32.2	32.3	32.3
540	32.1	32.3	32.2
570	32	32.2	32.1
600	32	32.2	32.1
630	32	32.1	32.1
660	32	32.1	32.1
690	31.9	32	32.0
720	31.9	32	32.0
750	31.9	32	32.0
780	31.9	32	32.0
810	31.8	32	31.9
840	31.8	31.9	31.9
870	31.8	31.9	31.9
900	31.7	31.9	31.8
930	31.7	31.8	31.8
960	31.7	31.8	31.8
990	31.6	31.7	31.7
1020	31.6	31.7	31.7
1050	31.6	31.7	31.7
1080	31.6	31.6	31.6
1110	31.5	31.6	31.6
1140	31.5	31.6	31.6
1170	31.5	31.5	31.5
1200	31.4	31.5	31.5

30g			
Time (sec)	Temp °C	Temp °C	average
0	25.2	25	25.1
30	35	37.5	36.3
60	41	41.8	41.4
90	40	40.5	40.3
120	39	39.2	39.1
150	39	38.5	38.8
180	38.9	38.2	38.6
210	38.7	38.1	38.4
240	38.6	38	38.3
270	38.6	38	38.3
300	38.5	37.9	38.2
330	38.4	37.8	38.1
360	38.3	37.7	38.0
390	38.2	37.6	37.9
420	38.2	37.6	37.9
450	38	37.5	37.8
480	38	37.5	37.8
510	37.9	37.4	37.7
540	37.8	37.2	37.5
570	37.7	37.1	37.4
600	37.7	37.1	37.4
630	37.6	37	37.3
660	37.5	37	37.3
690	37.4	36.9	37.2
720	37.3	36.8	37.1
750	37.2	36.7	37.0
780	37.2	36.7	37.0
810	37.1	36.5	36.8
840	37	36.5	36.8
870	37	36.4	36.7
900	36.9	36.4	36.7
930	36.8	36.2	36.5
960	36.8	36.2	36.5
990	36.7	36.1	36.4
1020	36.6	36	36.3
1050	36.5	36	36.3
1080	36.4	35.9	36.2
1110	36.3	35.9	36.1
1140	36.3	35.8	36.1
1170	36.2	35.8	36.0
1200	36	35.7	35.9

60g			
me (sec)	Temp °C	Temp °C	average
0	25.5	24.5	25.0
30	42	52	47.0
60	47	49.8	48.4
90	48	49.5	48.8
120	48.2	49.4	48.8
150	48	49.3	48.7
180	48	49.1	48.6
210	47.9	49	48.5
240	47.8	48.9	48.4
270	47.5	48.7	48.1
300	47.3	48.5	47.9
330	47.2	48.2	47.7
360	47	48.1	47.6
390	47	48	47.5
420	46.9	48	47.5
450	46.8	47.9	47.4
480	46.6	47.7	47.2
510	46.5	47.5	47.0
540	46.4	47.4	46.9
570	46.2	47.2	46.7
600	46.1	47	46.6
630	46	47	46.5
660	46	47	46.5
690	45.7	46.9	46.3
720	45.6	46.7	46.2
750	45.5	46.5	46.0
780	45.5	46.3	45.9
810	45.2	46.2	45.7
840	45.1	46.1	45.6
870	45	46	45.5
900	45	45.9	45.5
930	45	45.7	45.4
960	44.9	45.6	45.3
990	44.8	45.5	45.2
1020	44.7	45.4	45.1
1050	44.5	45.3	44.9
1080	44.4	45.1	44.8
1110	44.3	45	44.7
1140	44.1	45	44.6
1170	44.1	44.9	44.5
1200	44	44.7	44.4

Appendix 1dii

$PbBr_2$

1g	
Time (sec)	Temp °C
0	24
30	24
60	24
90	24
120	24
150	24
180	23.9
210	23.9
240	23.9
270	23.9
300	24
330	24
360	24
390	24.1
420	24.1
450	24.1
480	24.1
510	24.1
540	24.2
570	24.2
600	24.2
630	24.2
660	24.2
690	24.2
720	24.2
750	24.2
780	24.2
810	24.3
840	24.3
870	24.3
900	24.3
930	24.3
960	24.3
990	24.3
1020	24.4
1050	24.4
1080	24.4
1110	24.4
1140	24.4
1170	24.4
1200	24.4

5g	
Time (sec)	Temp °C
0	24
30	24
60	24
90	24
120	24
150	24
180	23.6
210	23.6
240	23.6
270	23.6
300	23.6
330	23.7
360	23.7
390	23.7
420	23.8
450	23.8
480	23.8
510	23.8
540	23.9
570	23.9
600	23.9
630	24
660	24
690	24
720	24
750	24
780	24.1
810	24.1
840	24.1
870	24.1
900	24.1
930	24.1
960	24.2
990	24.2
1020	24.2
1050	24.2
1080	24.3
1110	24.3
1140	24.3
1170	24.3
1200	24.3

10g	
Time (sec)	Temp °C
0	24.2
30	24
60	24
90	24
120	24
150	24
180	24
210	24
240	23.9
270	23.9
300	23.9
330	23.9
360	23.9
390	23.9
420	23.9
450	23.9
480	23.9
510	23.9
540	23.9
570	23.9
600	23.9
630	24.1
660	24.1
690	24.1
720	24.1
750	24.2
780	24.2
810	24.3
840	24.4
870	24.4
900	24.4
930	24.4
960	24.4
990	24.4
1020	24.4
1050	24.5
1080	24.6
1110	24.6
1140	24.6
1170	24.6
1200	24.6

Appendix 1eii

$NaClO_3$

15g	
Time (sec)	**Temp °C**
0	24
30	22.3
60	17.8
90	17.4
120	17.5
150	17.6
180	17.7
210	17.8
240	17.8
270	17.9
300	18
330	18.1
360	18.1
390	18.2
420	18.2
450	18.2
480	18.3
510	18.3
540	18.4
570	18.5
600	18.5
630	18.6
660	18.7
690	18.7
720	18.8
750	18.8
780	18.9
810	18.9
840	19
870	19
900	19.1
930	19.1
960	19.2
990	19.2
1020	19.3
1050	19.3
1080	19.4
1110	19.4
1140	19.5
1170	19.5
1200	19.5

30g	
Time (sec)	**Temp °C**
0	24
30	13
60	10.5
90	9.8
120	9.5
150	9.8
180	9.9
210	10.3
240	11.4
270	12
300	12.8
330	13
360	13.4
390	13.4
420	13.5
450	13.6
480	13.8
510	13.9
540	14
570	14
600	14.1
630	14.2
660	14.4
690	14.5
720	14.6
750	14.6
780	14.7
810	14.9
840	14.9
870	15
900	15
930	15.1
960	15.1
990	15.1
1020	15.2
1050	15.3
1080	15.4
1110	15.5
1140	15.6
1170	15.7
1200	15.8

60g	
Time (sec)	**Temp °C**
0	24
30	10.1
60	9.9
90	9.3
120	9.5
150	9.6
180	9.6
210	9.7
240	9.8
270	9.8
300	9.9
330	10
360	10.1
390	10.3
420	10.4
450	10.7
480	10.8
510	10.9
540	11
570	11
600	11.1
630	11.2
660	11.3
690	11.4
720	11.5
750	11.6
780	11.8
810	11.9
840	12
870	12.1
900	12.2
930	12.3
960	12.4
990	12.5
1020	12.6
1050	12.7
1080	12.7
1110	12.8
1140	12.8
1170	12.8
1200	12.8

Appendix 1fii

$Ba(NO_3)_2$

5g	
Time (sec)	Temp °C
0	23
30	22
60	21.9
90	21.7
120	21.6
150	21.5
180	21.5
210	21.4
240	21.4
270	21.4
300	21.3
330	21.3
360	21.3
390	21.3
420	21.3
450	21.3
480	21.3
510	21.5
540	21.5
570	21.5
600	21.6
630	21.6
660	21.7
690	21.7
720	21.7
750	21.8
780	21.9
810	21.9
840	22
870	22
900	22.1
930	22.1
960	22.2
990	22.2
1020	22.2
1050	22.3
1080	22.3
1110	22.4
1140	22.4
1170	22.4
1200	22.4

10g	
Time (sec)	Temp °C
0	23
30	22
60	21.8
90	21.2
120	20.9
150	20.8
180	20.5
210	20.2
240	20.2
270	20.2
300	20.1
330	20.1
360	20.1
390	20.1
420	20
450	20
480	20
510	20
540	20
570	20
600	20
630	20
660	20
690	20
720	20.5
750	20.5
780	20.7
810	20.7
840	20.7
870	20.8
900	20.8
930	20.9
960	20.9
990	21
1020	21
1050	21.1
1080	21.2
1110	21.5
1140	21.6
1170	21.7
1200	21.8

30g	
Time (sec)	Temp °C
0	23
30	20
60	19.8
90	19.7
120	19.6
150	19.8
180	19.8
210	19.9
240	19.9
270	19.9
300	19.9
330	20
360	20
390	20
420	20
450	20
480	20
510	20
540	20
570	20
600	20
630	20.1
660	20.1
690	20.1
720	20.1
750	20.2
780	20.2
810	20.3
840	20.4
870	20.4
900	20.4
930	20.5
960	20.6
990	20.6
1020	20.7
1050	20.7
1080	20.8
1110	20.8
1140	20.9
1170	20.9
1200	21

ppendix 1gii

NO_3

15g	
ime (sec)	Temp °C
0	24
30	20
60	18
90	17
120	16
150	15
180	14.3
210	13
240	12.8
270	12.9
300	13
330	13.1
360	13.6
390	13.9
420	14.1
450	14.3
480	14.5
510	14.6
540	14.7
570	14.8
600	14.9
630	15
660	15.1
690	15.1
720	15.1
750	15.2
780	15.2
810	15.3
840	15.4
870	15.5
900	15.6
930	15.7
960	15.8
990	15.9
1020	16
1050	16.1
1080	16.1
1110	16.2
1140	16.2
1170	16.2
1200	16.2

30g	
Time (sec)	Temp °C
0	24.3
30	17.5
60	13
90	11.8
120	11.2
150	11
180	10.7
210	10.8
240	10.9
270	11
300	11.1
330	11.2
360	11.3
390	11.4
420	11.5
450	11.7
480	11.8
510	11.9
540	11.9
570	12
600	12
630	12.1
660	12.1
690	12.2
720	12.3
750	12.4
780	12.4
810	12.4
840	12.5
870	12.6
900	12.8
930	12.9
960	12.9
990	13
1020	13
1050	13.1
1080	13.2
1110	13.3
1140	13.3
1170	13.4
1200	13.5

60g	
Time (sec)	Temp °C
0	24.5
30	11.6
60	11.3
90	11.2
120	10.9
150	11.3
180	11.5
210	11.2
240	11.5
270	11.6
300	11.8
330	11.9
360	12
390	12
420	12.1
450	12.2
480	12.3
510	12.4
540	12.5
570	12.6
600	12.7
630	12.8
660	12.9
690	13
720	13.1
750	13.1
780	13.2
810	13.3
840	13.4
870	13.4
900	13.4
930	13.5
960	13.6
990	13.6
1020	13.7
1050	13.8
1080	13.9
1110	14
1140	14.1
1170	14.1
1200	14.2

APPENDICES 3

Sample calculation

The result of 15g Aluminium Sulfate is taken as a sample calculation. The step calculation for heat of solution is as per below:

$$Specific\ heat\ capacity\ Cp_{H2O} = 4.184\frac{J}{g^oC}$$

$$\begin{aligned} m_{H2O} &= 98.89g \\ m_{solute} &= 15g \\ m_{solution} &= (98.89+15)g \\ &= 113.89g \end{aligned}$$

$$T_i = 24^oC \qquad T_f = 27^oC \qquad \begin{aligned} \Delta T &= T_f - T_i \\ &= 27-24 = 3^oC \end{aligned}$$

$$\begin{aligned} q_{rxn} &= -(mC_p\Delta T) \\ &= -\left(113.89g \times 4.184\frac{J}{g^oC} \times 3^oC\right) \\ &= -1429.547J \end{aligned}$$

$$\begin{aligned} mole\ of\ solute, n &= \frac{m}{MW} \\ &= \frac{15g}{630.39\,g/mole} \\ &= 0.0238\,mole \end{aligned}$$

$$\begin{aligned} \therefore \Delta H_{soln} &= \frac{q}{n} \\ &= \frac{-1429.547J}{0.0238\,mole} \times \frac{1KJ}{1000J} \\ &= -60.078\frac{kJ}{mole} \end{aligned}$$