SKRIPSI - ME141501

ANALISA KINERJA DAN KARAKTERISTIK EUTECTIC WATER-SALT PHASE CHANGE MATERIAL (PCM) UNTUK MENGURANGI KONSUMSI ENERGI COLD STORAGE

Mochammad Soleh
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Dosen Pembimbing :
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FINAL PROJECT – ME141501

PERFORMANCE ANALYSIS OF EUTECTIC WATER-SALT PHASE CHANGE MATERIAL (PCM) FOR COLD STORAGE TO REDUCE ENERGY CONSUMPTION

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DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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BACHELOR THESIS – ME141501

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2018

APPROVAL SHEET

PERFORMANCE ANALYSIS OF EUTECTIC WATER-SALT PHASE CHANGE MATERIAL (PCM) FOR COLD STORAGE TO REDUCE ENERGY CONSUMPTION

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain
Bachelor of Engineering Degree In
Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember (ITS)
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SURABAYA
July, 2018

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SURABAYA
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DECLARATION OF HONOUR

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Name	: Mochammad Soleh
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Title	: Performance Analysis of Eutectic Water-Salt Phase Change Material (Pcm) For Cold Storage To Reduce Energy Consumption
Department	: Marine Engineering

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ABSTRACT

Name : **Mochammad Soleh**
NRP : **04211440000085**
Supervisor 1 : **Sutopo Purwono F, ST., M.Eng., Ph.D**
Supervisor 2 : **Ede Mehta Wardhana ST., MT.**

The increasing number of perishable product distribution leads to the increasing number of the use of cold storage/container vessels. It is needed to keep the temperature suitable for meat, fish, fruits and vegetables. In the cold chain industry, some steps and long time needed in the storing and distribution process cause the expense of storing products large. That is of course is caused by operational of cold storage which consume massive energy to supply the electricity. In this study, Salt-Water Solutions of Phase Change Materials are implemented as one of the method to reduce energy consumption by hybrid the cold storage and run the cold storage in off/on mode.

Maintain the temperatures of fruits or meat in a certain condition is aimed to keep the product in the best quality. To maintain temperature in a good condition is necessary to choose proper cold storage. But mostly of Cold Storages are using HCFC (Hydro Chloro Flouro Carbon), HFC (Hydro Flouro Carbon), NH3 (Ammonia), air and carbon dioxide for the refrigerant. Despite it is natural refrigerant types, but HCFC, HFC and NH3 have toxic, corrosive and flammable impact (Ratiko, 2006). Knowing those refrigerants are dangerous, implementation of advance technology which reduce the use of such products is needed. One of advance technology that can be implemented to solve the problems are using Phase Change Material (PCM) for the substitution of conventional refrigerant. This material makes refrigerants do not need to work in continuous state because the ability of materials to store heat energy or release it. Besides, these organic materials are not toxic. Selected material in this study is salt PCM, it's properties to sustain temperature in the lower degrees and the ease to obtain the materials make the materials become priority to choose as refrigerant support.

In this study, concentration of the salt chosen as a variable to determine which composition is the most effective composition to keep the temperature in particular state. Several test can be done to know the properties of PCM is *bomb calorimeter to know the energy contained by materials and to determine the amount of PCM needed by system and the second test is performance test using cold storage which attached thermocouple inside cold storage to know the change of temperature when cold storage in off/on mode for counting the length of time*. The tests will be conducted in Fundamental Laboratory in Chemistry Department for bomb calorimeter and Marine Machinery and System Laboratory in Marine Engineering ITS.

Keywords: *Perishable product, Phase Change Materials (PCM), Cold Storage, Thermocouple, Bomb Calorimeter, Performance Test*

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CHAPTER I
INTRODUCTION

1.1. Background of the Study

The increasing number of perishable product distribution leads to the increasing number of the use of cold storage/container vessels. It is needed to keep the temperature suitable for meat, fish, fruits and vegetables. In the cold chain industry, some steps and long time needed in the storing and distribution process cause the expense of storing products large. For example storaging the meat in low temperature is highly recommended to keep the meet in the best condition befor it's consumed, and the best temperature of the meat is -12^{o}C to avoid Microbes growing. And the best temperature to inhibit cellular metabolism inside animals body is -18^{o}C (Puspita, 2012).

Maintain the temperatures of fruits, vegetables or meats in a certain condition is aimed to keep the product in the best quality. To maintain temperature in a good condition is necessary to choose proper cold storage. But mostly of Cold Storages are using HCFC (Hydro Chloro Flouro Carbon), HFC (Hydro Flouro Carbon), NH3 (Ammonia), air and carbon dioxide for the refrigerant. Despite it is natural refrigerant types, but HCFC, HFC and NH3 have toxic, corrosive and flammable impact (Ratiko, 2006). Knowing those refrigerants are dangerous, implementation of advance technology which reduce the use of such products is needed. One of advance technology that can be implemented to solve the problems are using Phase Change Material (PCM) for the substitution of conventional refrigerant. This material makes refrigerants do not need to work in continuous state because the ability of materials to store heat energy or release it. Besides, these organic materials are not toxic. Selected material in this study is salt PCM, it's properties to sustain temperature in the lower degrees and the ease to obtain the materials make the materials become priority to choose as refrigerant support.

Conventional cold storage using vapour compression needs continuous energy supply. The average power consumed by cold storage is 3,6 kW/TEU. 20 feet cold storage tend to consume 4 kW, and cold storage with dimension 40 feet tend to consume 7 kW (Yves Wild, 2017). In fulfilling the need of PCM which has already packed and ready to use in Indonesia are not easy. Indonesia needs to import the materials from the countries which produce PCM, and the cost of shipments are not cheap enough or sometime it can exeeding the price of PCM itself. This thesis is designed to create PCM that can be produced by Indonesian theirself. Chosen PCM in this thesis is eutectic PCM which is combined organic and inorganic materials.

1.2. Research Problems

According to the background of the study, determined the research problems are :

1. How is the performance of PCM with Natrium Chloride (NaCl) as solute and water as solvent?
2. How is the performance of PCM with Natrium Chloride (NaCl) as solute and water as solvent if it is added Propylene Glycol?
3. How is the effect of different mixture compositions to the properties of PCM?

1.3. Scope of the Study

According to the research problem and working on focus topic this final project has the following scopes.

1. The study will only focus to the salt-water solutions Phase Change Materials
2. Data will only be analyzed in Cold Storage in general use
3. Operation temperature is in range -10 ^{o}C to -20 ^{o}C based on cooling temperature of meats, fishes, fruits and products of vegetables
4. Data collections will be collected based on cold storage model using cool box

1.4. Research Objectives

In accordance with the background of the study, this final project has these following objectives.

1. To know the performance of PCM with Natrium Chloride (NaCl) as solute and water as solvent
2. To know the performance of PCM with Natrium Chloride (NaCl) as solute and water as solvent if it is added Propylene Glycol
3. To know the effect of different mixture compositions to the properties of PCM

1.5. Research Benefits

This research topic was chosen regarding to the need of reducing energy consumption to make a better world, so some points of this benefit are:

1. Implementation of PCM Technology for storing field in Indonesia
2. Advance technology implementation
3. Providing addition experimental data and reference for Phase Change Materials as new technology
4. Reduce energy consumption caused by refrigeration

1.6. Test Location

The places take for this bachelor thesis data collection are:

1. Laboratory of MMS (Marine Machinery System), Marine Engineering Department – Faculty of Marine Technology - ITS
2. Chemistry Department

CHAPTER II
THEORITICAL FRAMEWORK

2.1. Heat Transfer

Heat transfer is the science that seeks to predict the energy transfer that may take place between material bodies as a result of a temperature difference. Thermodynamics is defined as heat, the science of heat transfer seeks not merely to explain how heat energy may be transferred, but also to predict the rate at which the exchange will take place under certain specified conditions. The fact that a heat-transfer rate is the desired objective of an analysis points out the difference between heat transfer and thermodynamics. Thermodynamics deals with systems in equilibrium; it may be used to predict the amount of energy required to change a system from one equilibrium state to another; it may not be used to predict how fast a change will take place since the system is not in equilibrium during the process. Heat transfer supplements the first and second principles of thermodynamics by providing additional experimental rules that may be used to establish energy-transfer rates. As in the science of thermodynamics, the experimental rules used as a basis of the subject of heat transfer are rather simple and easily expanded to encompass a variety of practical situations.

As an example of the different kinds of problems that are treated by thermodynamics and heat transfer, consider the cooling of a hot steel bar that is placed in a pail of water. Thermodynamics may be used to predict the final equilibrium temperature of the steel bar–water combination. Thermodynamics will not tell us how long it takes to reach this equilibrium condition or what the temperature of the bar will be after a certain length of time before the equilibrium condition is attained. Heat transfer may be used to predict the temperature of both the bar and the water as a function of time.

There are three ways heat can be transferred:

2.1.1. Conduction

Conduction is defined as the heat by the direct collision of molecules. An area of higher kinetic energy transfers thermal energy towards the lower kinetic energy area. High-speed particles clash with particles moving at slow speed, as a result slow speed particle increase their kinetic energy. This is a typical form of heat transfer and takes place by physical contact. For example, place a metal over an open flame.

Which material transfers heat better can be determined by physical property? The coefficient of thermal conductivity shows that a metal body conducts heat better when it comes to conduction. The rate of conduction can be calculated by the following equation.

$$\mathbf{Q = [k \cdot A \cdot (T_{hot} - T_{cold})]/d} \qquad \ldots 2.1$$

Where,

Q is the transfer of heat per unit time.
K is the thermal conductivity of the body.
A is the area of heat transfer

T_{hot} is the temperature of hot region
T_{cold} is the temperature of the cold region.
d is the thickness of the body.

2.1.2. Convection

When fluid is heated, it carries thermal energy along with it and moves away from the source. This kind of heat transfer is known as convection. The liquid over the hot surface expands and rises up. A natural example is in the atmosphere. The earth's surface gets warmed by the sun and the warm air moves up and cool air comes in.

As the temperature of the liquid increases, the liquid's volume also has to increase by the same factor and this effect is known as displacement. The equation to calculate the rate of convection is as follows.

$$\mathbf{Q = h_c \cdot A \cdot (T_s - T_f)} \qquad \ldots 2.2$$

Where,

Q is the heat transferred per unit time.
Hc is the coefficient of convective heat transfer
A is the area of heat transfer
Ts is the surface temperature.
Tf is the fluid temperature.

2.1.3. Radiation

Thermal radiation is generated by the emission of electromagnetic waves. These waves carry away the energy from the emitting body. Radiation takes place through a vacuum or transparent medium which can be either solid or liquid. Thermal radiation is the result of the random motion of molecules in the matter. Movement of charged electrons and protons is responsible for the emission of electromagnetic radiation.

As temperature rises, the wavelengths in the spectra of the radiation emitted decreases and shorter wavelengths radiations are emitted. Thermal radiation can be calculated by Stefan-Boltzmann law:

$$\mathbf{P = e \cdot \sigma \cdot A \cdot (T_r - T_c)^4} \qquad \ldots 2.3$$

Where,

P is the net power of radiation
A is the area of radiation
T_r is the radiator temperature
T_c is the surrounding temperature
e is emissivity and σ is Stefan's constant.

2.2. Cold Storage

Cold storage is a space used to save perishable products, such as meats, fishes fruits, vegetables, and other products. By cooling down the temperature of a product, the activity of enzimes and microbes within the products will be reduced, so that damage and deterioration can be inhibited. Controlling the cooling process of fruits and vegetables is a critical factor because it can cause chilling injury when it is below a certain temperature (Pratama, 2018).

Cold storage can be described as a large structure of building that has a function as a refrigerator. This low temperature building can certainly be used properly if the room is closed. This means that there is no air circulation (air in and out) and using refrigeration equipment (refrigerator) emits cold air to keep the temperature low.

There are insulating panels in the structure of a reefer storage, as follows:

Table 2.1 Insulation Panel Materials

Panel Type	U value, W/m² °C	Weight, kg/m²	Water Adsorption Possibility
Polystirene	0.34	11.2	1.00%
Styrofoam	0.24	13.3	0.50%
Polyurethane	0.3	13.3	2%
Mineral Wool	0.38	19	50%

Source: (Pratama, 2018)

Reefer Storage has these following major compenents.

1. Evaporator
2. Compressor
3. Condenser
4. Expansion Device

2.3. Cold Storage Working Principle

In its system, the cooling system has four steps of cooling process. Refrigerant is circulated repeatedly with changes to support the cooling process. Four changes in the refrigerant are compression, condensation, expansion, and evaporation (liquid, vapor, gas, and liquid back) (Purnomo, 2018)

2.3.1. Compression

In the process of compression, refrigerant is pressed in the compressor until it becomes liquid at high temperature. The refrigerant gas sucked by the compressor will make the pressure remain low in the evaporator. To make a refrigerant liquid into a gas dynamically at low temperatures (0°C), the refrigerant gas is pressed in the cylinder, and turned into high, so the temperature and pressure rise, and will easily become a liquid refrigerant although the cooling process is in higher temperatures. And the compressed refrigerant gas is supplied to the next component which is cooled in a condenser.

2.3.2. Condensation

In the process of condensation, refrigerant is changed from a gas to a liquid and cooled down from high temperature in the condenser into lower temperature. A refrigerant that has high temperature and pressure is emitted into fluid in the condenser and transmitted to the receiver dryer to be filtered. It is also called heat condensation process. High heat from the refrigerant can be released by the condenser so that refrigerant is cooled down.

2.3.3. Expansion

In the process of expansion, the pressure of the refrigerant's liquid is lowered by the expansion valve. It is called expansion process, in which the pressurized gas is easily atomized in the evaporator so that refrigerant turns into gas, and the expansion valve regulates the flow of refrigerant's liquid while lowering its pressure. In the evaporator, this atomized refrigerant's liquid is regulated by the cooling rate which should be done under temperature carburetion. Therefore, it is important to control the amount of refrigerant needed by performing proper checks.

2.3.4. Evaporation

In the process of evaporation, refrigerant is changed from liquid to gas in the evaporator. Refrigerant's liquid is atomized by its suction during the process of evaporation which needs latent heat from the air around the. The air released heat to be cooled down, and flowed into the space in the cold storage by the cooling fan while lowering the temperature of the room. The refrigerant's liquid is supplied from the expansion valve in the evaporator and then once turned into refrigerant vapor, and the change occurs repeatedly from liquid to gas. The pressure and the temperature in the change are always related, if the pressure is set then the temperature will also be set. For carburetion which is done when the temperature is lower than the change (liquid to gas), in the condition as above, the pressure in the evaporator must also be made low. Therefore, the atomized refrigerant gas should be reduced continuously out of evaporator by the compressor suction.

2.4. Thermal Energy Storage

Thermal energy storage (TES) is one of the key technologies for energy conservation, and therefore, it is of great practical importance. One of its main advantages is that it is best suited for heating and cooling thermal applications. TES is perhaps as old as civilization itself. Since recorded time, people have harvested ice and stored it for later use. Large TES systems have been employed in more recent history for numerous applications, ranging from solar hot water storage to building air conditioning systems. The TES technology has only recently been developed to a point where it can have a significant impact on modern technology. In general, a coordinated set of actions has to be taken in several sectors of the energy system for the maximum potential benefits of thermal storage to be realized. TES appears to be an important solution to correcting the mismatch between the supply and demand of energy. TES can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use. TES is a key component of many successful thermal systems, and a good TES should allow little thermal losses, leading to energy savings, while permitting the highest reasonable extraction efficiency of the stored thermal energy. There are mainly two types of TES systems, that is, sensible (e.g., water and rock) and latent (e.g., water/ice and salt hydrates). For each storage medium, there is a wide variety of choices depending on the temperature range and application. TES via latent heat has received a great deal of interest. Perhaps, the most obvious example of latent TES is the conversion of water to ice. Cooling systems incorporating ice storage have a distinct size advantage over equivalent capacity chilled water units because of the ability to store large amount of energy as latent heat. TES deals with the storing of energy, usually by cooling, heating, melting, solidifying, or vaporizing a substance, and the energy becomes available as heat when the process is reversed. The selection of a TES is mainly dependent on the storage period required, that is, diurnal or seasonal, economic viability, operating conditions, and so on. In practice, many research and development activities related to energy have concentrated on efficient energy use and energy savings, leading to energy conservation. In this regard, TES appears to be an attractive thermal application. Furthermore, exergy analysis is an important tool for analyzing TES performance. We begin this chapter with a summary of fundamental definitions, physical quantities, and their units, dimensions, and interrelations. We consider introductory aspects of thermodynamics, fluid flow, heat transfer, energy, entropy, and exergy (Holman, 2008).

Latent heat is the energy absorbed by or released from a substance during a phase change from a gas to a liquid or a solid or vice versa. If a substance is changing from a solid to a liquid, for example, the substance needs to absorb energy from the surrounding environment in order to spread out the molecules into a larger, more fluid volume. If the substance is changing from something with lower density, like a gas, to a phase with higher density like a liquid, the substance gives off energy as the molecules come closer together and lose energy from motion and vibration.

For example, when water is boiled over a stove, energy is absorbed from the heating element and goes into expanding the water molecules into a gas, known as water vapor. When liquid water is put into ice cube trays and placed in the freezer, the water gives off energy as the water becomes solid ice. This energy is removed by the freezer system to keep the freezer cold.

Water vapor is a greenhouse gas located in the atmosphere and a very important component for cloud formation. If the air is dry, or unsaturated, clouds are not likely to form because there is minimal water vapor in the air. If the air is moist, or saturated, the water vapor will condense to form clouds. When these gas molecules condense into liquid drops, latent heat is released into the atmosphere which warms the air surrounding the molecule. This helps to add instability in the atmosphere and this warm air surrounding the molecule will want to rise. Warm air is less dense than cold air because molecules in warm air move around much faster and move further apart.

2.4.1. Latent Heat

Latent heat, energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature. The latent heat associated with melting a solid or freezing a liquid is called the heat of fusion; that associated with vaporizing a liquid or a solid or condensing a vapour is called the heat of vaporization. The latent heat is normally expressed as the amount of heat (in units of joules or calories) per mole or unit mass of the substance undergoing a change of state.

The formula uses to express Latent Heat is

$$\mathbf{Q = m.h_1} \quad \text{...2.4}$$

Where:

Q : Energy Releases (J)
m : Mass (kg)
h_1 : Latent Heat (kJ/kg)

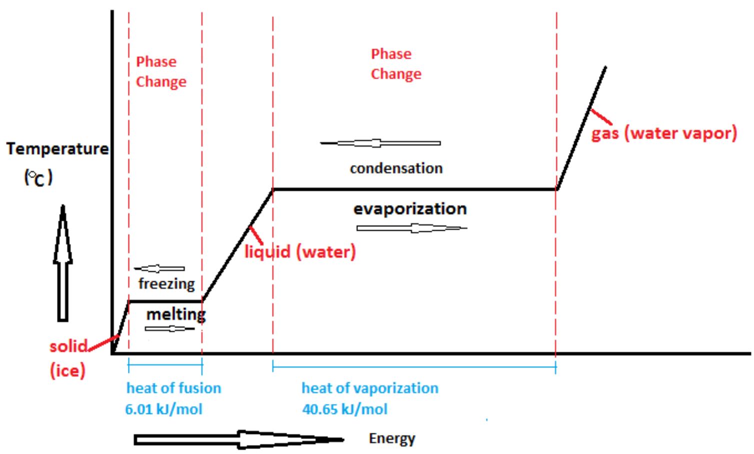


Figure 2.1 Phase Change

Source: http://energyeducation.ca/encyclopedia/Sensible_heat

2.4.2. Sensible Heat

Sensible heat is literally the heat that can be felt. It is the energy moving from one system to another that changes the temperature rather than changing its phase. For example, it warms water rather than melting ice. In other words, it is the heat that can be felt standing near a fire or standing outside on a [[sunny day. Sensible heat is used in contrast to latent heat (the heat needed to change from one form of matter to another, which doesn't change temperature), as the two are essentially opposite.

For example, in a cooling system condensation forms due to removal of latent heat, and the refrigerant (cooling liquid) changes temperature due to sensible heat. The sensible heat capacity then describes the capacity required to lower the temperature whereas latent heat capacity is the capacity to remove the moisture from the air.

The formula uses to express Latent Heat is

$$\mathbf{Q = m.C_p.}\Delta T \qquad \textbf{...2.5}$$

Where:

Q : Energy Releases (J)
m : Mass (kg)
C_p : Specific Heat (J/kg.K)
ΔT : Change of Temperature (K)

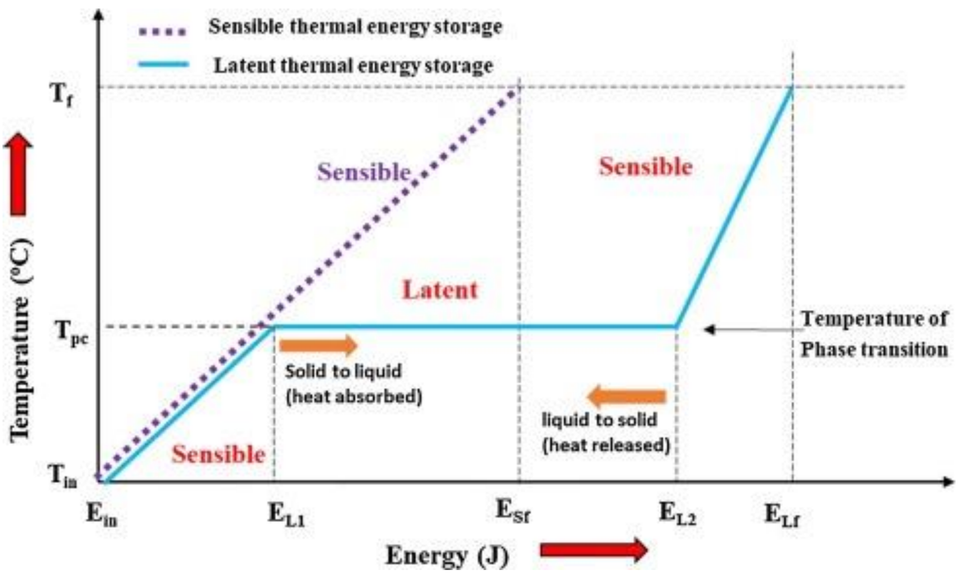


Figure 2.2 Sensible and latent heat
Source: http://en.stonkcash.com/what-is-latent-heat-energy/

2.4.3. The overall Heat-transfer coefficient

The overall heat transfer coefficient is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The larger the coefficient, the easier heat is transferred from its source to the product being heated. In a heat exchanger, the relationship between the overall heat transfer coefficient (U) and the heat transfer rate (Q) can be demonstrated by the following equation (Holman, 2008):

$$q = U\ A\ \Delta T_{LM}$$ ...2.6

Where,

Q is heat transfer rate, W=J/s [btu/hr]
A is heat transfer surface area, m^2 [ft^2]
U is overall heat transfer coefficient, W/(m^2°C) [Btu/(hr-ft^2°F)]
ΔT_{LM} is logarithmic mean temperature difference, °C [°F]

From this equation we can see that the U value is directly proportional to Q, the heat transfer rate. Assuming the heat transfer surface and temperature difference remain unchanged, the greater the U value, the greater the heat transfer rate. In other words, this means that for a same kettle and product, a higher U value could lead to shorter batch times.

Several equations can be used to determine the U value, one of which is:

$$U = \frac{1}{\frac{1}{h_1} + \frac{\Delta x}{k} + \frac{1}{h_2}}$$ ...2.7

Where

h is convective heat transfer coefficient, W/(m^2°C) [Btu/(hr-ft^2°F)]
L is thickness of the wall, m [ft]
λ is thermal conductivity, W/(m°C) [Btu/(hr-ft°F)]

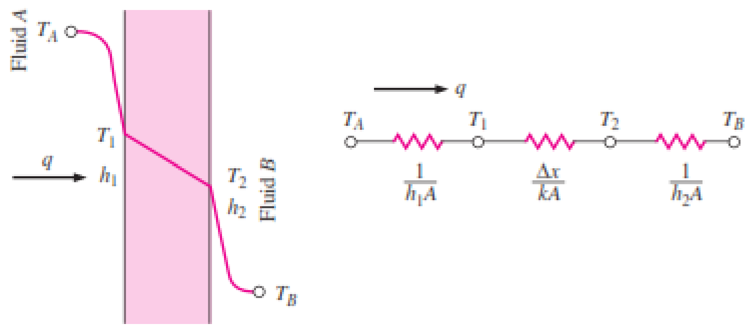


Figure 2.3 Overall heat transfer through a plane wall
Source: Heat Transfer Tenth Edition, J.P Holman

2.4.4. Specific Heat

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

$$\mathbf{Q = m.C_p.}\Delta T \qquad \textbf{...2.8}$$

From the above formula, specific heat is Cp. The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is higher than any other common substance. As a result, water plays a very important role in temperature regulation. The specific heat per gram for water is much higher than that for a metal, as described in the water-metal example. For most purposes, it is more meaningful to compare the molar specific heats of substances.

The molar specific heats of most solids at room temperature and above are nearly constant, in agreement with the Law of Dulong and Petit. At lower temperatures the specific heats drop as quantum processes become significant. The low temperature behavior is described by the Einstein-Debye model of specific heat.

Table 2.2 Specific Heat

Food	Specific Heat - Liquids (**above freezing**)			Specific Heat - Solids (**below freezing**)		
	(btu/(lb°F))	(kJ/(kg°C))	(kcal/(kg°C))	(btu/(lb°F))	(kJ/(kg°C))	(kcal/(kg°C))
Apples	0.87	3.64	0.87	0.42	1.76	0.42
Avocados	0.72	3.01	0.72	0.37	1.55	0.37
Bananas	0.8	3.35	0.8	0.4	1.67	0.4
Beef, round	0.74	3.1	0.74	0.38	1.59	0.38
Beef, rump	0.62	2.6	0.62	0.34	1.42	0.34
Beef, shanks	0.76	3.18	0.76	0.39	1.63	0.39
Blackberry	0.87	3.64	0.87	0.42	1.76	0.42
Blueberries	0.87	3.64	0.87	0.42	1.76	0.42
Broccoli	0.92	3.85	0.92	0.44	1.84	0.44
Chicken, broilers	0.77	3.22	0.77	0.38	1.59	0.38
Chicken, fryers	0.74	3.1	0.74	0.35	1.47	0.35
Chicken, hens	0.65	2.72	0.65	0.44	1.84	0.44
Codfish	0.86	3.6	0.86	0.39	1.63	0.39
Crabs	0.84	3.52	0.84	0.41	1.72	0.41
Eggs	0.76	3.18	0.76	0.4	1.67	0.4
Fish, fresh		3.6				
Nuts	0.28	1.17	0.28	0.24	1	0.24

Onions	0.9	3.77	0.9	0.43	1.8	0.43
Potatoes	0.82	3.43	0.82	0.41	1.72	0.41
Sardines	0.77	3.22	0.77	0.39	1.63	0.39
Shrimp	0.83	3.48	0.83	0.41	1.72	0.41
Strawberries	0.95	3.98	0.95	0.45	1.88	0.45
Tomatoes, red	0.95	3.98	0.95	0.45	1.88	0.45
Tomatoes, green	0.96	4.02	0.96	0.45	1.88	0.45
Watermelon	0.94	3.94	0.94	0.45	1.88	0.45

(Source: https://www.engineeringtoolbox.com)

2.5. Phase Change Materials

Phase change materials (PCM) are substances that absorb and release thermal energy during the process of melting and freezing. It can be also defined that PCM is one from three component which has to owned by Latent Heat Storage (LHS). Latent Heat Storage working with changing the phase of materials from solid to liquid by storing the heat whenever the heat having contact with the PCM. When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs recharge as ambient temperatures fluctuate, making them ideal for a variety of everyday applications that require temperature control.

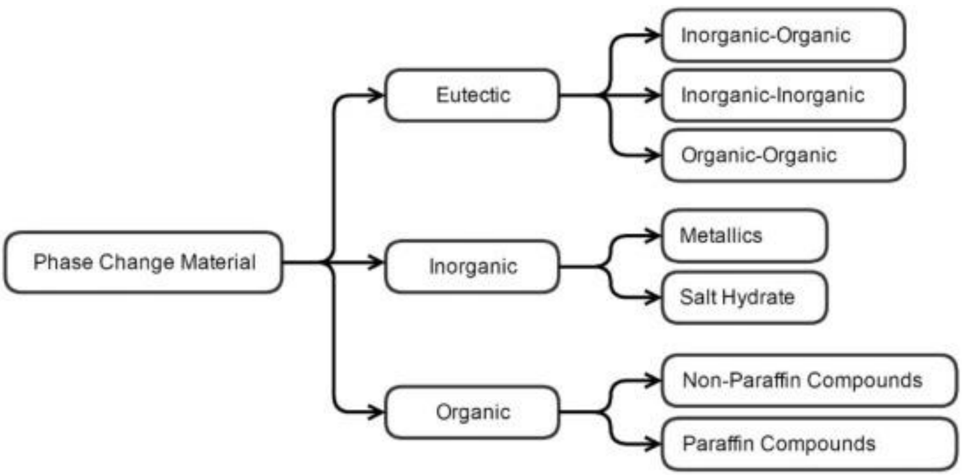


Figure 2.4 Phase Change Materials Classification

Source: https ://ars.els-cdn.com/content/image/1-s2.0-S0360128515300149-jpecs676-fig-0010.jpg

A suitable phase change temperature and a large melting enthalpy are two obvious requirements on a phase change material. They have to be fulfilled in order to store and release heat at all. However, there are more requirements for most, but not all applications. These requirements can be grouped into physical, technical, and economic requirements (Mehling, H; Cabeza, L.F, 2008).

Physical requirements, regarding the storage and release of heat:

- ✓ Suitable phase change temperature Tpc ⇒ to assure storage and release of heat in an application with given temperatures for heat source and heat sink.
- ✓ Large phase change enthalpy $\Delta_{pc}h$ ⇒ to achieve high storage density compared to sensible heat storage.
- ✓ Reproducible phase change, also called cycling stability ⇒ to use the storage material as many times for storage and release of heat as required by an application.

  The number of cycles varies from only one, when the PCM is used for heat protection in the case of a fire, to several thousand cycles when used for heating or cooling of buildings. One of the main problems of cycling stability is phase separation. When a PCM consists of several components, phases with different compositions can form upon cycling. Phase separation is the effect that phases with different composition are separated from each other macroscopically. The phases with a composition different from the correct initial composition optimized for heat storage then show a significantly lower capacity to
  Store heat.
- ✓ Little subcooling ⇒ to assure that melting and solidification can proceed in a narrow temperature range.

  Subcooling (also called supercooling) is the effect that a temperature significantly below the melting temperature has to be reached, until a material begins to solidify and release heat. If that temperature is not reached, the PCM will not solidify at all and thus only store sensible heat.

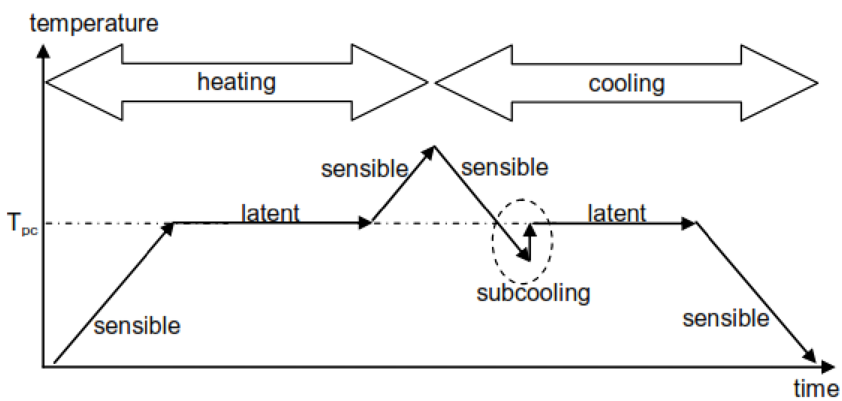


Figure 2.5 Schematic temperature change during heating (melting) and cooling (solidification) of a PCM with subcooling.

Source: Heat and Cold Storage with PCM, Mehling H

- ✓ Good thermal conductivity ⇒ to be able to store or release the latent heat in a given volume of the storage material in a short time, that is with sufficient heating or cooling power.
  If a good thermal conductivity is necessary strongly depends on the application and the design of the storage.

Technical requirements, regarding the construction of a storage:

- ✓ Low vapor pressure ⇒ to reduce requirements of mechanical stability and tightness on a vessel containing the PCM
- ✓ Small volume change ⇒ to reduce requirements of mechanical stability on a vessel containing the PCM
- ✓ Chemical stability of the PCM ⇒ to assure long lifetime of the PCM if it is exposed to higher temperatures, radiation, gases, …
- ✓ Compatibility of the PCM with other materials ⇒ to assure long lifetime of the vessel that contains the PCM, and of the surrounding materials in the case of leakage of the PCM
- ✓ This includes destructive effects as for example the corrosivity of the PCM with respect to other materials, but also other effects that significantly reduce or stop important functions of another material.
- ✓ Safety constraints ⇒ the construction of a storage can be restricted by laws that require the use of non-toxic, non-flammable materials. Other environmental and safety consideration can apply additionally.

Economic requirements, regarding the development of a marketable product:

- ✓ Low price ⇒ to be competitive with other options for heat and cold storage, and to be competitive with methods of heat and cold supply without storage at all
- ✓ Good recyclability ⇒ for environmental and economic reasons

2.6. Classes of Materials

Because the two most important criteria, the melting temperature and the melting enthalpy, depend on molecular effects, it is not surprising that materials within a material class behave similar. Figure below shows the typical range of melting enthalpy and melting temperature of common material classes used as PCM (Mehling, H; Cabeza, L.F, 2008).

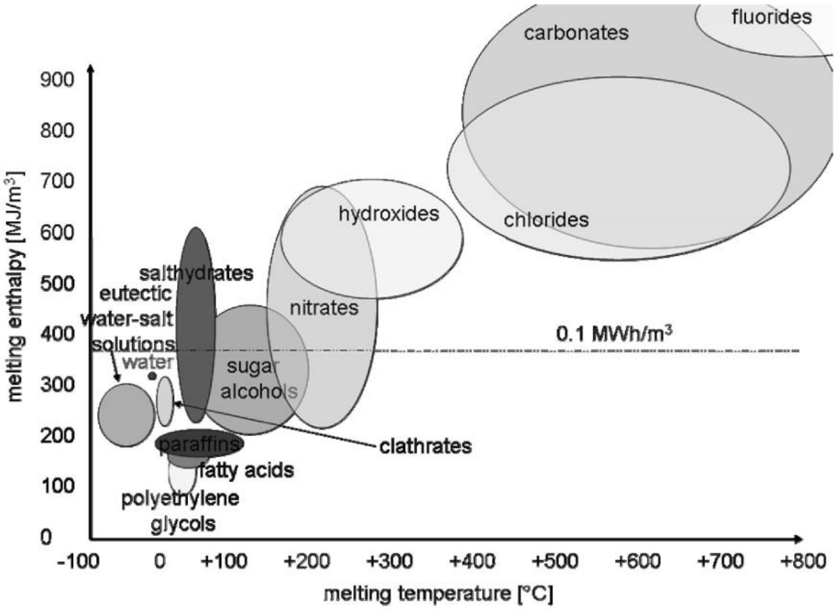


Figure 2.6 Classes of materials that can be used as PCM and their typical range of melting temperature and melting enthalpy
Source: ZAE Bayern

By far the best-known PCM is water. It has been used for cold storage for more than 2000 years. Today, cold storage with ice is state of the art and even cooling with natural ice and snow is used again. For temperatures below 0 °C, usually water-salt Solutions with eutectic compositions are used. Several material classes cover the temperature range from 0 °C to about 130 °C. Paraffins, fatty acids, and sugar alcohols are organic materials. Salt hydrates are salts with a large and defined Amount of crystal water. Clathrates are crystalline structures in which molecules of one type are enclosed in the crystal lattice of another. When The enclosed molecule is from a gas and the surrounding crystal structure is water, the clathrate is also called a gas hydrate. They cover a temperature range from about 0 °C to 30 °C. At temperatures above 150 °C, different salts and their mixtures can be applied.

The energy density is roughly proportional to the melting temperature in K. This can be understood from thermodynamics according to the Theory of Richards. The theory of Richards shows that the melting enthalpy per volume is proportional to the melting temperature, the number of bonds per molecule, and the density divided by the molar mass that relates to the packing density of the Molecules or atoms (Linder, 1984).

Besides of need to choose the right PCM with design temperature, LHS system need a good material which can keep the temperature in a good state.

2.6.1. Organic PCM

Organic PCM is more stable than other PCM, there is no phase differences in the same composition between the density of solid materials and density of liquid materials.

There is also no undercooling condition occur to this material and the most important thing is no corrosion will occur in this material. It is suitable for food storage (*Food Grade Level*)

Paraffin

Paraffin consists of a mixture of alkane bonds that are included in a non-polar saturated hydrocarbon. Paraffins are produced from consecutive CH2 repeatedly. The simplest example of paraffin is methane (CH4) which is the starting point for increasing the length of the chain. One carbon and two hydrogens are then added to the existing molecule to form longer molecule. Most commonly, additional CH2 is added to form a straight chain paraffin. Paraffin shape depends on the amount of chain content C. Liquid paraffins have C chain of 5-15 to form liquid at room temperature. Paraffin wax has a C chain of more than 15 to form solids at room temperature.

Non-paraffin

Non-paraffin organic material often called as fatty acids is PCM with the greatest number of variations. Each of these materials has its own properties, unlike paraffin which on average has almost the same properties. This type of material is the most commonly used as heat storage material. Some of these non-paraffinic organic materials have the following properties:

- *Has high latent heat*
- *Low Flash point*
- *Low thermal conductivity*
- *Inflammable*
- *Not dangerous*

2.6.2. Inorganic PCM

Inorganic PCM can be classified to two type as follows:

Salt Hydrates

Salt Hydrates has several properties that can be categorized into Phase Change Materials ie:

- Has high latent heat per unit volume.
- Has high thermal conductivity.
- Small volume changes when melted.
- Not corrosive, small toxic level and does not react with plastic.

Metallics

Metal categories which is included in metallics are metals with low melting point and eutectic metals. This metallic material is still rarely used as PCM because of the loss on the amount / weight of the required material. As known, the amount of thermal energy that can be stored is directly proportional to the volume. The difference with other PCMs is that metallics has high thermal conductivity.

2.6.3. Eutectic PCM

Eutectic PCM is PCM with a minimum melt composition derived from two or more substances that each melt and freeze and form a crystal component during the crystallization process. The combination of eutectic PCM composition can be organic, inorganic-inorganic, and organic-inorganic.

2.7. Eutectic Water-Salt PCM

Eutectic water-salt solutions have melting temperatures below 0 ºC, because the addition of the salt reduces the melting temperature, and usually good storage density. In the book “Heat and Cold Storage with PCM” by Mehling, H and Cabeza, L.F it was mentioned that NaCl is one of water salt PCM which has freezing point between 0ºC to -30ºC. So, using NaCl is the best choice while the necessary temperature of cooling some product such as vegetables, meat or even fish is in range between 0ºC to -30ºC. Tabel below shows a selection of typical examples.

Table 2.3 Example of Eutectic water-salt solutions that have been investigated as PCM

Material	Melting temperature (°C)	Melting enthalpy (kJ/kg)	Thermal conductivity (W/m·K)	Density (kg/m^3)
$Al(NO_3)_3$ (30.5 wt.%) / H_2O	-30.6	131	-	1283 (liquid)
			-	1251 (solid)
NaCl (22.4 wt.%) / H_2O	-21.2	222	-	1165 (liquid)
			-	1108 (solid)
KCl (19.5 wt.%) / H_2O	-10.7	283	-	1126 (liquid)
			-	1105 (solid)
H_2O	0	333	0.6 (liquid, 20 °C)	998 (liquid, 20°C)
			2.2 (solid)	917 (solid, 0 °C)

Source: (Schroder, 1985)

And in research paper with title “Review on phase change materials (PCMs) for cold thermal energy storage applications” by E. Oró, it is also mentioned that the lowest temperature can be reached by water salt PCM with composition 22% Salt and 88% water. But it still cannot be concluded that the PCM with that composition is the most efficient PCM because the data about Thermal properties beside freezing/melting point aren’t provided. So, Performance test needs to be done to provide the necessary data before it can be used as PCM.

Table 2.4 Freezing-melting temperature range and subcooling for aqueous NaCl and KCL Solutions

Solutions	Subcooling (°C)	Freezing temperature (°C)	Melting temperature (°C)	ΔT (free
5% NaCl	3.87	−3.87/−4.27	−4.87/−3.18	3.04
10% NaCl	6.28	−7.60/−7.70	−7.80/−6.10	6.56
15% NaCl	5.30	−15.19/−15.29	−10.40/−9.20	10.88
20% NaCl	2.79	−18.22/−17.92	−18.92/−14.62	16.45
21% NaCl	2.20	−18.46/−18.36	−18.86/−18.26	17.77
22% NaCl	1.60	−21.95/−21.85	−20.15/−19.65	19.17
23% NaCl	0.20	−20.89/−21.39	−22.39/−20.89	20.66
24% NaCl	0.30	−20.19/−19.79	−22.08/−19.59	–
5% KCl	1.59	−3.38/−3.58	−3.28/−2.08	2.32
10% KCl	7.48	−6.60/−7.10	−11.79/−6.00	4.80
15% KCl	4.40	−12.80/−13.20	−11.40/−9.60	–
20% KCl	5.59	−12.93/−13.13	−10.23/−9.43	–
21% KCl	4.80	−10.35/−10.65	−10.15/−9.65	–
22% KCl	6.90	−10.45/−11.25	−10.95/−9.15	–
23% KCl	7.48	−12.12/−12.82	−12.32/−9.83	–
24% KCl	5.10	−10.80/−11.10	−11.10/−9.10	–

Source: (H Kumano, T Osaka, A saito, S Okawa., 2009)

2.8. Chosen Eutectic Water-Salt PCM

PCM Chosen in this Thesis is NaCl (22 wt.%) / H2O. This material has good properties in cooling (-21.2ºC) based on Schroder in 1985, but of course each material has its own flaws. For this water-salt solution, the problem is phase differences while it is cooling down, salt and water have different freezing point and melting point, then it is possible to occur solid phase to water but liquid phase in salt on the mixture.

Table 2.5 NaCl as PCM

Material	Melting temperature (°C)	Melting enthalpy (kJ/kg)	Thermal conductivity (W/m·K)	Density (kg/m^3)
$Al(NO_3)_3$ (30.5 wt.%) / H_2O	-30.6	131	- -	1283 (liquid) 1251 (solid)
NaCl (22.4 wt.%) / H_2O	-21.2	222	- -	1165 (liquid) 1108 (solid)
KCl (19.5 wt.%) / H_2O	-10.7	283	- -	1126 (liquid) 1105 (solid)
H_2O	0	333	0.6 (liquid, 20 °C) 2.2 (solid)	998 (liquid, 20°C) 917 (solid, 0 °C)

Source: (Schroder, 1985)

2.9. Previous Research

2.9.1. Febriana. Surabaya. 2016. Performance and Characteristic Analysis Of Phase Change Material With Paraffin And Linoleic Acid Substance As Cooling System In Cold Storage

(Febriana, 2016)

This study aims to create and determine the performance characteristics of PCM for food grade level. The method that is used is PCM experiment to analyse the results of the experiment. PCM that is made based paraffin and linoleic acid, it is because both of these materials are included in the type of organic materials of PCM. PCM is made by mixing the volume percentage of paraffin wax and white paraffin oil and the additional volume percentage of linoleic acid with 20ml: 70ml and 10ml: 80ml and 2%, 4% and 6% sequentially. Characteristics of mixing paraffin and linoleic acid as PCM can be obtained by using FTIR testing and bomb calorimeter.

FTIR testing results cluster function which is formed from tested materials that consists of aliphatic chain that is indicated by the peak at 3000 - 2800cm-1, the cluster of (CH2) n> 3 is indicated by the peak at 730-720 cm-1, CH3 and C = O each of them is indicated by the peak at 1490 - 1150cm-1 and 1870 - 1550cm-1 that indicating linoleic acid in the sample mixture with linoleic acid. While the bomb calorimeter test result show that the additional of linoleic acid can lowers the value of the specific heat of PCM. Based on the results of data analysis, it can be concluded that the PCM has the maximum performance is PCM with composition of 10 ml of paraffin wax, 80 ml paraffin white oil, and 2% of linoleic acid compared with other PCM. It also supported by the off time of refrigeration machine compressor that took time of 23 minutes and 14 minutes for the on time of engines refrigeration compressor.

2.9.2. Taufiqurrahman. Surabaya. 2016. Performance Analysis of Organic Phase Change Material as Cooling Alternative Cold Storage

(Taufiqurrahman, 2016)

The abundance of these production capabilities is not comparable with the availability of the cold storage in Indonesia. The ability of cold storage capacity in Indonesia in 2014 only amounted to 7.2 million tons per year, meanwhile the production had reached 14 million tons per year (www.industri.kontan.co.id, 2014). Nowadays, the type of cold storage used in Indonesia is still a conventional cold storage that uses the refrigeration machine with a refrigerant such as CFC and Freon in a certain degree. In addition, to the problem of environmentally unfriendly refrigerants, the conventional cold storage also has another problem in which it needs a quite large power to produce lower temperature.

Now, the most significant discussion regarding to the energy storage is the use of Phase Change Material (PCM) for thermal energy storage. PCMs are able to absorb and release large amounts of latent heat in accordance to the increment and reduction of the ambient temperature. The use of Phase change Material and modification of the air flow inside the cold storage is expected to keep the temperature of the storage fit in with the needs of storage duration. This reason makes the writer interested to do some research to perform PCM hybrid system in a conventional cold storage.

Based on the experimental data, it can be found that the more PCM used, the longer the low temperatures can be persisted or in other words the rise of temperature can be held. The experimental data shows the durations of the compressor to stop for the experiment without PCM, 0.5 kg PCM, 1 Kg PCM, 2 Kg PCM respectively are 17 minutes, 31 minutes, 40 minutes, and 70 minutes. Based on these data, it can be calculated the cost saving caused by the use of 2 Kg PCM is 237.830,91 rupiahs per month.

2.9.3. Herdito. Surabaya. 2016. Technical and Economic Review Design of Reefer Container Based on Phase Change Technology Material for Applications on Ship

(Herdito, 2016)

This research was conducted in 2017 by Herdito Haryowidagdo, undergraduate student of Department of Shipping System Engineering, FTK - ITS. The existing conventional reefer containers use a vapor compression refrigerant with an environmentally unfriendly refrigerant. On the other hand, this reefer container requires the supply of electrical energy both from the ship and from the dock continuously to continue working.

Currently the use of thermal energy storage technology that is widely used is PCM. This study analyses the calculation of reefer container performance with a PCM hybrid system with a focus on performance comparison or COP, technical calculations for refrigeration system components, and comparison of economic and operational costs compared to conventional reefer containers. As a result, the hybrid system can save the compressor power consumption of 57.7 kW per day per container or equivalent to 9.65 litres of fuel savings for diesel generator needs on the ship per day. From the economic side, the payback period was reached in the third years amounting to Rp34,290,519.96. While the cumulative cash flow for this hybrid system can go beyond the conventional system in the fifth to the tenth year.

CHAPTER III
RESEARCH METHODOLOGY

Experimental research was used as the research design of this study. In order to support the success of this research, it is necessary to choose a research methodology that can be used as a reference in the implementation of the research. This methodology contains some steps performed in the process of problems resolution contained in the research, starting from problem identification to preparing this final report. The stages that will be done to support this study are as follows.

3.1. Research Problem Analysis

In this step, writer will be specified the problems exist in Latent Thermal Energy Storage (LTES) to get the best solution of it. The problem analysis will be altered how to solve the problems with better technology implementations of PCM and refer to the recent journal about Latent Thermal Energy Storage.

3.2. Study of Literature

The second stage to do is study of literature by collecting and learning the supporting sources about Heat Transfer, Phase Change Materials, Salt properties (NaCl), and the composition obtained from the library of Marine Machinery and System Laboratory of Marine Engineering Department; the library of Marine Technology Faculty; the central library of Sepuluh Nopember Institute of Technology; and e-paper provided in internet.

3.3. Design and preparation of Apparatus

This step explain how the experiment will be conducted regarding to the objectives of this research. Additional information regarding to different types of experimental research design will be enrich the validation of advance technology refer to the use of Phase Change Materials. The objectives of this research are to find materials properties that could help improving the use of advance technology in order to reduce energy consumption with more effective materials.

PCM which will be tested to this thesis is NaCl (Natrium Chloride / Common Salt) and the solvent is water.

- The specifications of cool box are :

Length	: 0,515 m
Width	: 0,31 m
Height	: 0,31 m
Thickness	: 0,025 m

The design of Apparatus as follows

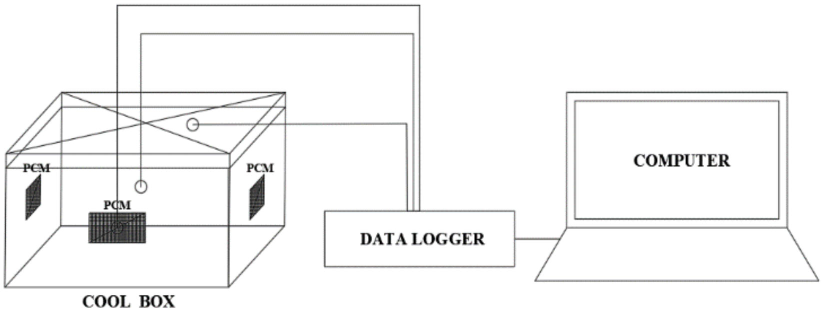


Figure 2.7 Design of Apparatus in the experiments

The first step before determining the PCM Performance is determining the thermocouples spot inside the cool box. There is no right or research which is specify thermocouples place inside the cool box, but as assumed by the writer to efficiently analysed the air distribution inside the cool box, it's placed side by side on the wall of the cool box.

Necessary thermocouple to analyse the air distribution is 3 thermocouples inside the cool box with some determinations:

- ✓ Two thermocouples placed to analyse the air distribution only
- ✓ Another thermocouple placed to show the change of temperature of PCM

- Material Specification

Physical state and appearance	: Solid. (Solid crystalline powder.)
Odor	: Slight.
Taste	: Saline
Product Name	: Sodium chloride
Catalog Codes	: SLS3262, SLS1045, SLS3889, SLS1669, SLS3091
Chemical Formula	: NaCl
Molecular Weight	: 58.44 g/mole
Colour	: White.
pH (1% soln/water)	: 7 [Neutral.]
Boiling Point	: 1413°C (2575.4°F)
Melting Point	: 801°C (1473.8°F)
Critical Temperature	: Not available.
Specific Gravity	: 2.165 (Water = 1)

***The data based on Material Safety Data Sheet**

- Thermocouple

Thermocouple is used to read the decline and rise in temperature in the cool box and cold storage.

3.4. Load Calculations

In this stage the heat load transmitted by outside cool box and product will be analysed. The air ambient temperature outside will be continuously transferred through the wall and also heat produced by the product.

3.5. Preparing salt PCM

The water salt solutions PCM is made in Laboratory of Materials and Energy, Chemistry Department, FMIPA – ITS. It is intended to know the compositions (Percentage) of Salt inside the water

3.6. Properties Test

It is conducted for knowing if there is the change of characteristics of PCM after mixed one another both physically and food grade level.

Several tests that will be done are :

- ✓ Bomb Calorimeter

  The output from this test is to know the calories / energy conceived by chosen material. Specific heat will be known from this test. But it has to be tested in Chemistry Laboratory

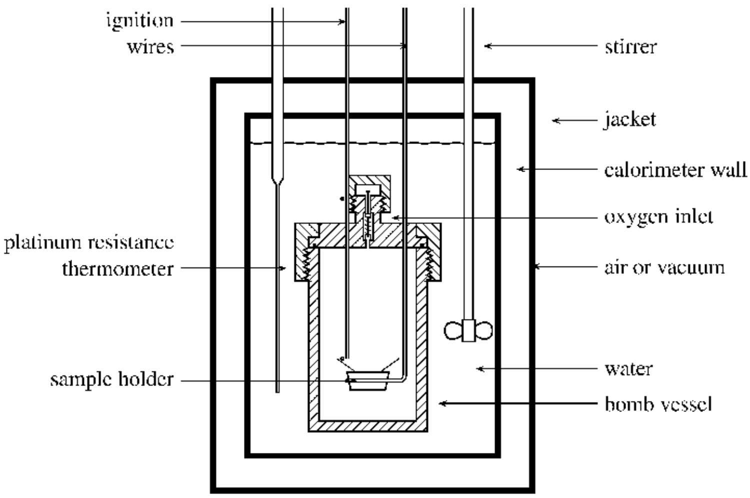


Figure 2.8 Section view of a bomb calorimeter.
Source: https://chem.libretexts.org

3.7. Experiments and Hypothesis

On this stage, the collections of main data would be carried out. After Heat Load has been known, the next step is showing the PCM performance by using the apparatus such as cool box and using ice cube as the sample product for the load. Temperature range which will be using to these experiments is between -18°C to -14°C. From this step some hypothesis might be occured by the researcher. The hypothesis should be based on science and technology knowledge to support the data accuration. The test will be done in 5 hours, started while the temperature inside cool box reaching -18°C.

3.8. Data Analysis

Data analysis lends itself to a variety of statistical analyses. It happens because the data is analysed regarding to the actual data which has been collected during the experiments. In this stage, some step of analysation can be done by :

- Data recorded by Data Logger (Labjack) will be converted to
    1. Graphics comparison in PCM temperature with how long it will take time for operating the cold storage
    2. The difference of hybrid time while PCM installed inside Cold Storage

3.9. Method Comparison

The objectives of this step are providing the necessary informations regarding to the objectives which is deterimend on this Thesis and proofing which one is more efficient in the use of conventional structure used in storage field nowadays or advance technology supported by Phase Change Materials.

3.10. Conclusion

After finishing all stages and making methods comparison, the conclusion of this thesis was drawn. This conclusion was expected to answer the purposes of the analysis that had been carried out. Then, there are also some suggestions that will be useful for the further similar studies.

The Flow Chart of the Research Methodology

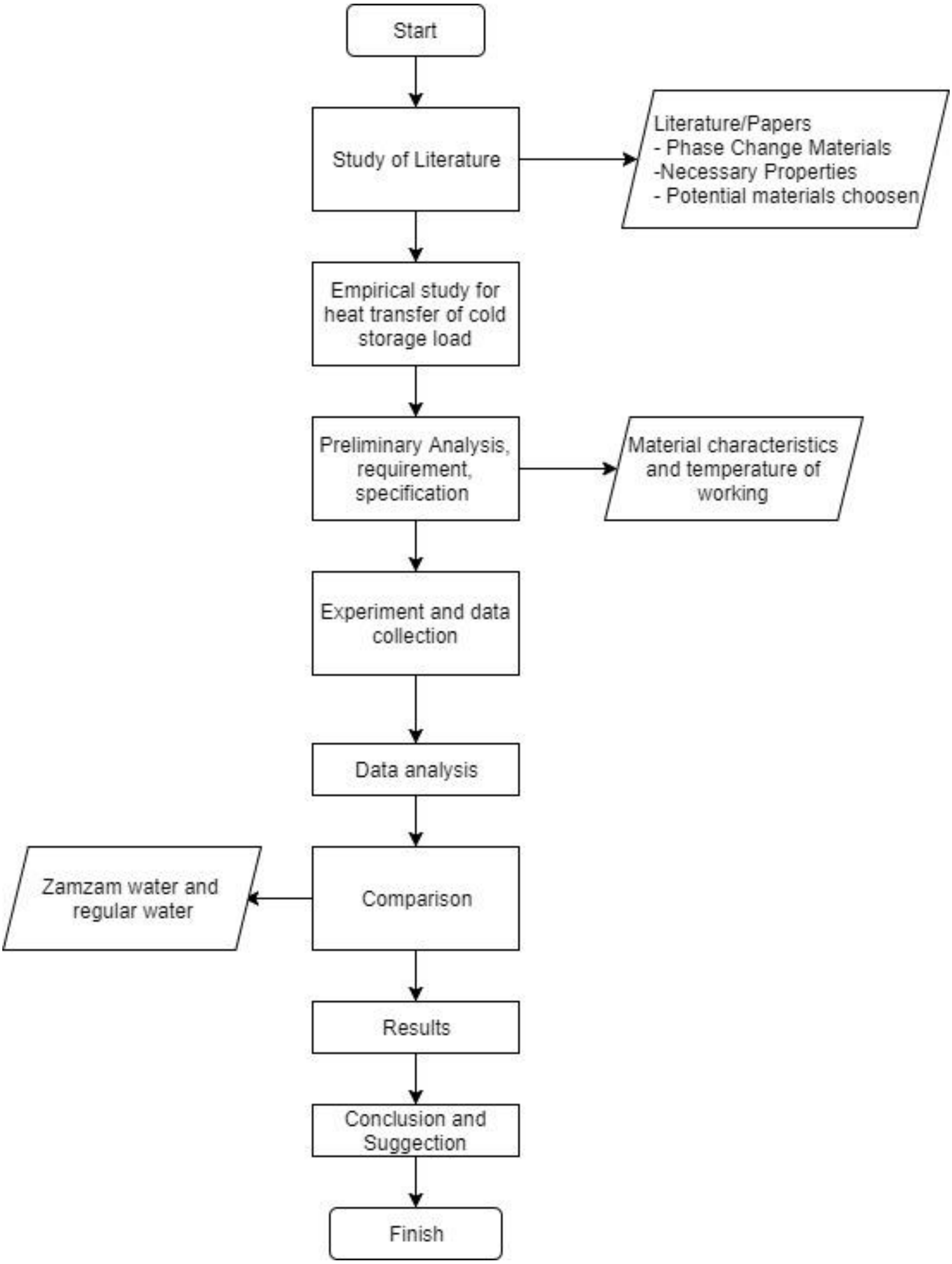


Figure 2.9 The Flow Chart of the Research Methodology

3.11. Experiment Procedure

In this experiment, there will be some steps have to be done. And each step has to be in sequence because it has its own procedure. Here some steps which has to be done.

- **Hot plate operation Procedure (Laboratory of Fundamental, Chemistry Department, FMIPA, ITS)**

  a. Procedure to turn on Hot Plate
     1. Plug in the electric socket in proper condition to let the electricity flowing to hot plate and then there will be occurred OFF on hotplate's LCD

Figure 2.10 The Flow Chart of the Research Methodology

     2. Set appropriate temperature in 'HEAT' Panel and the number will be shown in the LCD
     3. Set the rotation speed of magnetic stirring bar in 'STIR' panel in certain speed

  b. Procedure to turn off the hot plate
     1. Slow down the rotation speed of magnetic stirrer on 'STIR' Panel slowly until it is reach 0/OFF
     2. Cool down the temperature of the hot plate on panel 'HEAT' slowly until the number reach 0/OFF
     3. Release the electric socket

➢ **Eutectic PCM preparation**

1. Prepare the hot plate to mix the salt and water to avoid phase differences and set the necessary temperature for mixing the PCM (Celcius). It depends to the melting point of the salt for making good mixture
2. Prepare PCM (Water-Salt)
    a. Fresh water
    b. Salt water (Sea water)
    c. Propylene Glycol
3. Pour some amount of water (ml) to the measuring cup, each kind of liquid with certain concentration as determined objective to make a good comparation between one and another
4. Pour some amount of salt in determined concentration to the beaker
5. Put the beaker on the top of hot plate (which containing salt)
6. Mix salt and water in one beaker which has been prepared
7. Put magnetic stirring and set the rpm of the hot plate in purpose of mixing (Stirring process)
8. For the PCM which is contain Propylene Glycol, put some amount of Propylene Glycol carefully

➢ **Data Logger preparation and validation**

1. Plug in thermocouple to data logger labjack T7-Pro screw terminals (AIN0-3)
2. Open Kipling program from PC (It is necessary to install it first)
3. Open Device Selector, there is a picture of Labjack T7-Pro, connect it
4. After connected to data logger, open Analog Inputs on the left ribbon and indication of thermocouple that it has connected or not will be known by change of signals, press +

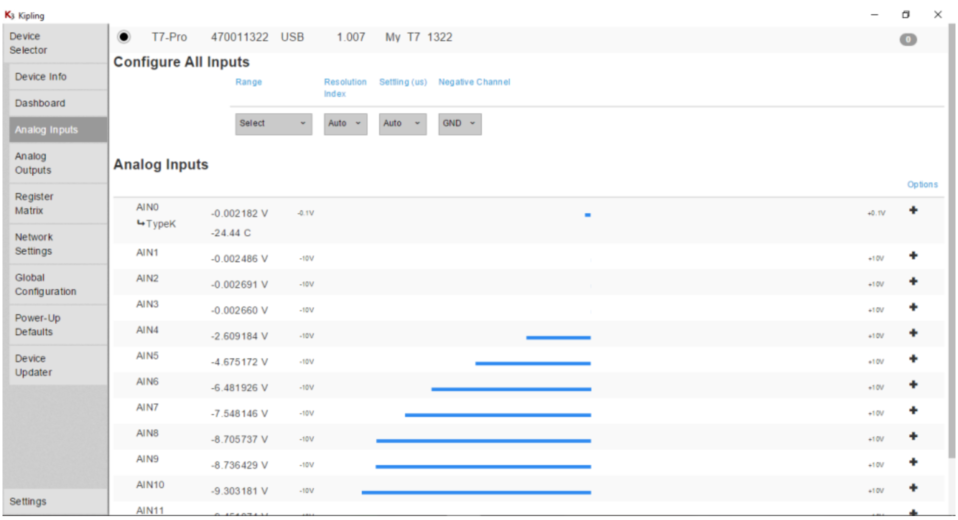


Figure 2.11 Software Kipling

5. In Extension Feature, choose Type K thermocouple

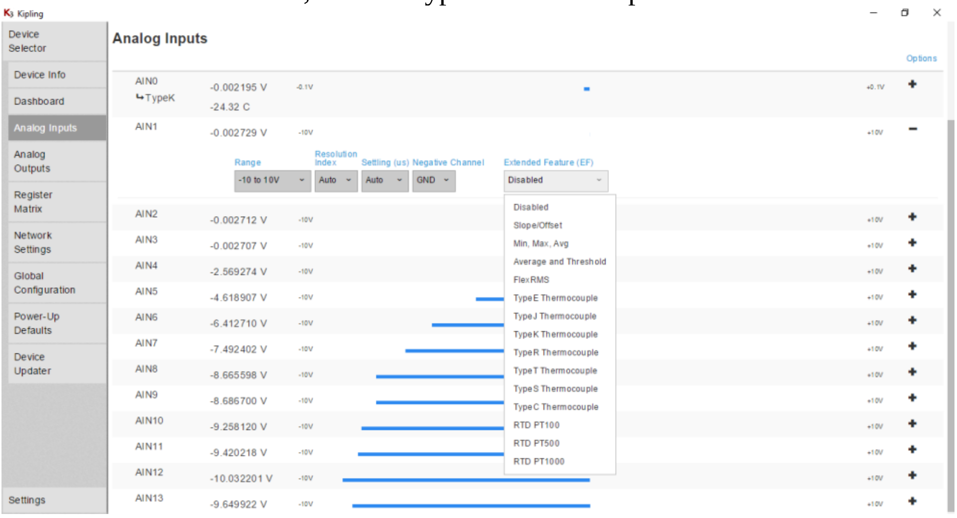


Figure 2.12 Software Kipling

6. And change the metric from Kelvin (K) to Celcius (C)

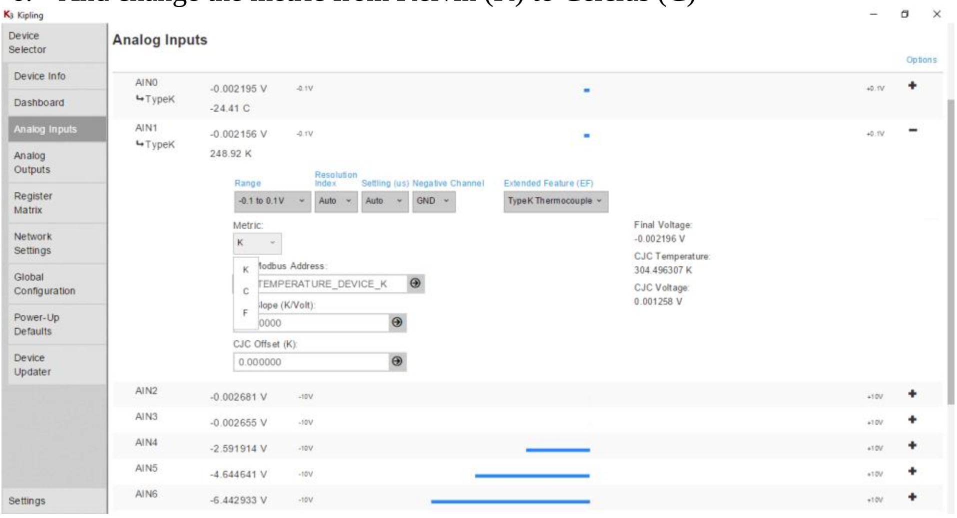


Figure 2.13 Software Kipling

7. In CJC Modbus Address, choose T7 Screw Terminals (AIN0-3) or if it is necessary to use extension, choose CB37 Screw Terminals (AIN0-13)

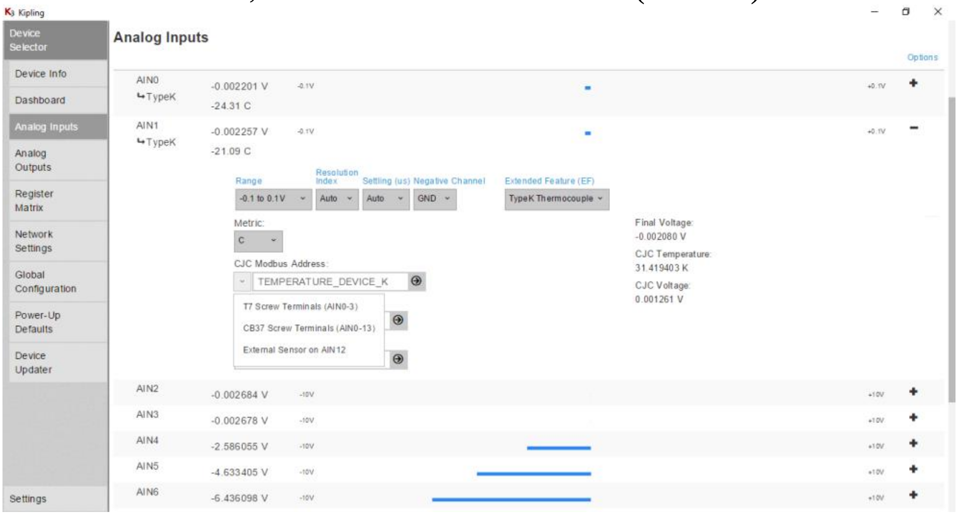


Figure 2.14 Software Kipling

- **PCM Experiment Procedure**

1. Put 1 kg ice cube inside the cool box
2. 3 pack of PCM (1 Litre for Each) on 3 side of cool box

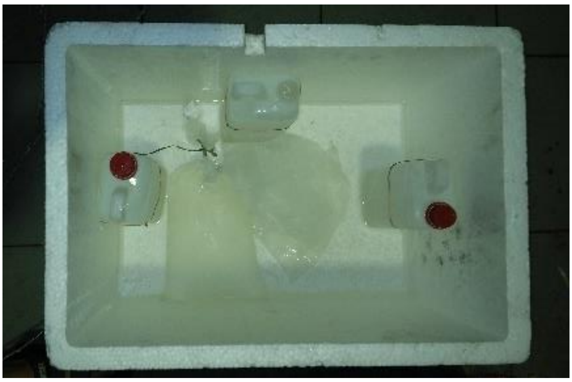


Figure 2.15 Design of Apparatus inside cool box

3. Install thermocouple inside cool box in certain point inside cold storage

Figure 2.16 Thermocouple positioning

4. Install one thermocouple inside the PCM to know the PCM's temperature and connect cool box to Cold Storage thermocouple by putting extension (Pipe) from cool box cover to cold storage thermocouple

Figure 2.17 Modified Cool box

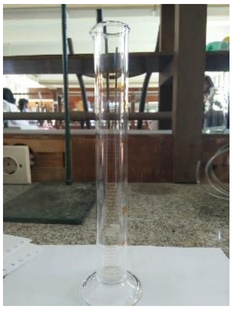
5. Set the sensor with certain range (About -18 C to -14 C). Cold storage will be turned off in the lowest temperature and turned on again in highest temperature which has determined. To do this action, press and hold "set" button until CB code appears, press "set" one more time and it will appear dif code, press set again and change dif temperature. After it finishes, press fnc.

Figure 2.18 Panel setting

6. Data collection can be collected with data logger labjack T7-Pro within 3 hours since it started

Table 2.6 Tools and Materials

No.	Equipment/Materials	Pict.	Inf.
1.	NaCl		PCM Solute
2.	Water		PCM Solvent
3.	Propylene Glycol		PCM Solvent
4.	Hot Plate		Brand: Cimarec To ease the process of mixing PCM

5.	Magnetic Stirring Bar		Stirring materials inside beaker using magnetic working principal
6.	Measuring Cup		Brand: Pyrex Class A in 20^{o} C ISO Capacity: 100 ml
7.	Beaker Cup		Brand: GG – 17 Capacity: 100 ml
8.	Pipette		Move liquid materials

9.	Cool Box		Materials: Styrofoam Dimension. Length : cm Width : cm Height : cm Thick. : cm
10.	Cold Storage		Brand:… Dimension. Length : 2,4 m Width : 1,26 m Height : 2,5 m
11.	Thermocouple		PT100 T/C type K To measure the temperature of Cool box
12.	Data Logger		14 input analog. Analog input range: 10 to 0.001 V Current output: 200µA

13.	Computer		Store the data from data logger
14.	Glue		Glue to avoid leakage and seal

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CHAPTER IV
EMPIRICAL STUDY

Empirical study on this Bachelor Thesis is to explain the experimental process and some experiments that will be done to find the properties of chosen PCM.

4.1. PCM Composition

Refer to the previous research about organic PCM, for making PCM can be processed by mixing fatty acid such as capric acid and lauric acid with variated concentrations, 55:45; 60:40; 65:35; 70:30; 75:25 and 80:20 (Wang, 2013). To make effective PCM in certain temperature, added another additive substance to lowered the temperature. The additive substance has to work in the nearest working temperature with materials solutions of Paraffin wax.

Another research written by Febriana, 2016 using different concentration 70:20 and 80:10 and added linoleic acid with concentration 2%, 4%, and 6%, it was objected to reach freezing point in range between 0°C to -30°C.

Concentration of PCM used in this research for the salt solutions also altered in certain point refer to the previous research. Based on the research which has done by E. Oro, 2012, the lowest temperature can be reach with composition of Salt within water is 22% with freezing point -21,95°C/21,85 °C and melting point -20,15 °C /-19°C. But it has to be remembered that salt water PCM has subcooling effect, for this

In this research, the following table shows the concentration and of Salt and concentration of Water.

Table 2.7 Variated Concentration between Salt Water and Propylene Glycol

No	PCM	Concentration		
		Water	Salt	Propylene Glycol
1	PCM A	78% Water	22% NaCl	-
2	PCM A1	83% Water	17% NaCl	-
3	PCM A2	88% Water	12 % NaCl	-
4	PCM B	78% Water	22% NaCl	10 ml
5	PCM B1	83% Water	17% NaCl	10 ml
6	PCM B2	88% Water	12% NaCl	10 ml

4.2. Laboratory Tests to determine PCM Performance

Some tests need to be done to identify the performance of PCM before it can be used in industry. Process of mixing the solvent and solute can be done in Chemistry Laboratory to avoid inaccurate data collection. Some tests that has been chosen by writer can be shown below:

4.3. Bomb Calorimeter

A calorimeter is an object used for calorimetry, or the process of measuring the heat of chemical reactions or physical changes as well as heat capacity. A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The change in temperature of the water allows for calculating calorie content of the fuel.

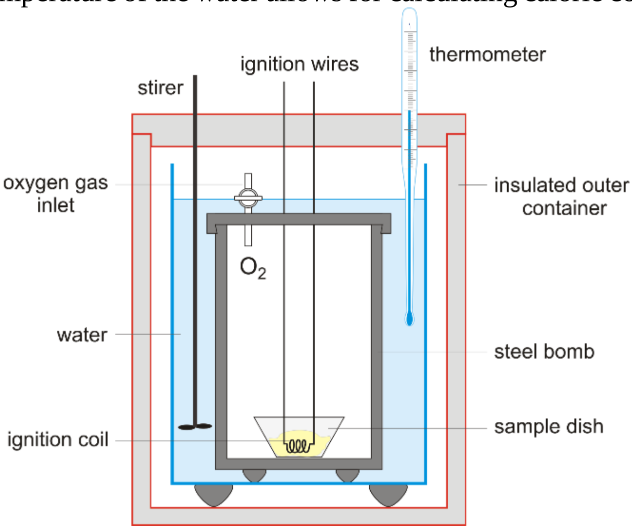

Figure 2.19 Bomb Calorimeter
Source: Croatian-English Chemistry Dictionary & Glossary

Necessary tools for operating Bomb Calorimeter are:

a. Thermometer for measuring temperature
b. Stirrer for stirring cold water
c. Valve to alter oxygen flow
d. Tube for the place of the sample
e. Wire for firing the sample
f. Bomb which is used to burn the sample

Operating Procedure of Bomb Calorimeter

1. Substance which is going to be tested placed in bomb
2. The wire installed directly contacted to the sample
3. Close the bomb tightly, then fill the room with oxygen until it is reach 25 atm.
4. Bomb which filled by oxygen then placed inside the tube that before has filled with water
5. Let the electricity flowing to the wire until it gets burned and the rising temperature can be measured

4.4. Another Test with DSC (Differential Scanning Calorimeter)

The Differential Scanning Calorimeter (DSC) technique was used for the thermal characterization of both damaged and nondamaged PCMs. The DSC technique is useful for the determination of several thermodynamic properties of a material such as the melting and freezing temperatures, the specific heat, the phase change enthalpies etc. In this study, the experiments were performed using a DSC 204 F1 Phoenix from Netzsch under a nitrogen atmosphere by considering different masses and dynamic rates. Typical heating rates of about 5–10 K/min are often used in standard calorimetric methods. However, it shall be pointed out that these rates could not be compatible with PCMs due to their low thermal conductivity (Sara Drissi, Anissa Eddhahak, Sabine Care, Jamel Neji, 2015).

Accordingly, in order to optimize the experimental parameters governing the DSC test, many investigations were performed using various dynamic rates and sample masses. For the first series of experiments, the mass was maintained constant (12 mg) and several dynamic rates ranging between 0.5 and 20 K/min were tested. Whereas, in the second series of experiments, the dynamic rate was kept constant (0.5 K/min) and three different sample masses were tested (8 mg, 10 mg and 12 mg). For the two experimental configurations, three tests were performed and the average result is considered. The temperature ranges considered for this study were chosen such as to be close to the natural climate temperatures expected in building applications.

The DSC technique allows the direct knowledge of the heat fluxes per unit mass of the material managed by the DSC machine in order to maintain the same temperature between the reference and the sample

$$\Phi = \Phi_r - \Phi_s = k.(T_r - T_s)$$

…2.9

Because of the thermal inertia of the sample being tested, T_s is deviated from T_r. The latter is prescribed by the thermal program
as

$$T_r = T_{(t=0)} + \beta t$$

…2.10

Eq. (1) can be expressed in terms of the specific heats as following:

$$\Phi = \beta\,(Cp_r - Cp_s)$$

…2.11

Where Cp_r and Cp_s denote respectively the specific heats of the total reference cell and the total sample cell.

Note that Eq. 3 is available when no thermal event occurs during the test i.e. when a thermodynamic equilibrium is reached within the sample. In the opposite case for which a phase change occurs, the heat flux is no longer constant since a higher heat flux shall be supplied or subtracted to the sample cell in order to keep it at the same temperature as the reference one.

For the measurement of the specific heat (Cp), three DSC tests were conducted: a measurement of the base line, the standard (sapphire) and the sample. Then the ratio method was used in order to deduce the specific heat. For further details regarding the methodology of the Cp measurement, the readers could consult the work of.

4.5. PCM experiment

Refer to the previous research conducted by (Wang, 2013), to see the performance of Charging and Discharging PCM using Storage ball. PCM placed inside the storage ball and to know the temperature of PCM while Charging and Discharging, placed 4 Thermometer inside Storage ball in certain distance from the nearest with the centre of storage ball and then sequence 0 mm, 10 mm, 20 mm and 30 mm. After the storage ball has been closed, then sink the storage ball to the HTF (Heat Transfer Fluid) homo thermal circulator to stimulate charging and discharging process. The beginning temperature of storage ball is 25°C and then it was cooled down by HTF homo thermal circulator until the temperature reach 13°C and then it was heated until 21°C. The temperature of the storage ball continuously recorded.

The results of the analysis are variation of the temperature in 4 position of Thermometer showed rapid depression in the first 10 minutes when sensible heat period still in liquid phase. The temperature reach 13°C gradually until the phase change to solid. The process discharging showed increasing of temperature bit by bit until it was melted.

For this bachelor Thesis, the first step has to be determined is to design the appropriate apparatus for the experiment for cold storage and determine where PCM shall be placed to get the most efficient results and proper experiment regarding to the objectives that this PCM is purposed to support the performance of inefficient wall as a conventional Cold Storage Component.

Based on the research conducted by Febriana 2016, the design of experiment as following picture:

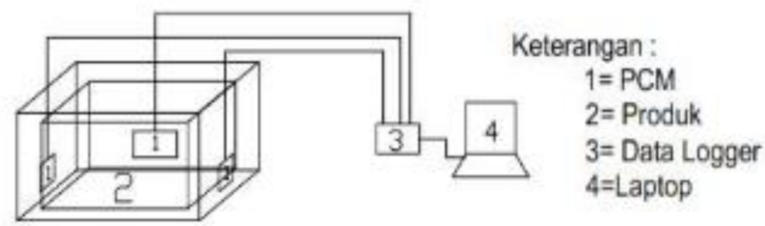

Figure 2.20 Design of Apparatus

As mentioned before, the Chosen PCM in this experiment is NaCl / H2O and also Water-Salt solution PCM mixed with Propylene Glycol.

To know the impact of PCM to the air distribution inside cool box, and also the performance of PCM, some Thermocouples have to be installed in certain position. Some conditions refer to the capacity of cold storage which is too big and also the possibility to provide big amount of PCM, it is used small scale which is using Cool Box as the reference to calculate the need of one certain room in cooling instead of Cold Storage.

CHAPTER V
DATA ANALYSIS

5.1. Several Main Instruments

5.1.1. Cold Storage

In this Experiments Cold Storage is used to determine necessary time for compressor in on mode or off mode. Inside of the cold storage will be placed cool box which have been modified with PCM on its side and the temperature is set until -18^{o}C to reach the freezing point of Salt Phase Change Materials

Dimension of Cold Storage Are:

Length	: 2400 mm
Width	: 1260 mm
Height	: 2500 mm
Refrigerant	: R404 A
Compressor	: Bitzer 2HC – 1.2 – 40 S 220 – 240 V 50 Hz Displacement 6.5 m^3/h, 1450 rpm
Evaporator	: Muller MLT 013 Capacity 1345 watt, 4 Coil Rows 1 Fan Flow Rate 1224 m^3/h, 240 V 50 Hz

Figure 2.21 Cold Storage

5.1.2. Cool box

Cool box is an insulated box used to keep food or drink cool. Cool Box is a tool used in the storage of fresh food items such as vegetables, fruits, fish, and meat. These materials are vulnerable to decomposition. Therefore, in the process of removal and storage required a temperature sufficient to prevent the process of decay. Ice cubes are most commonly placed in it to help the contents inside stay cool. Ice packs are sometimes used, as they either contain the melting water inside, or have a gel sealed inside that stays cold longer than plain ice (absorbing heat as it changes phase).

The Selection of PCM Shall be determined as following the need to cool the product as the substation of Cold Storage for Experiments. Basic material of the cool box is from Styrofoam. Cool box for this type is easy to get because it is used by people for personal utilities to store certain product such as food or drink.

Modification of Cool box by making frames for Packed PCM inside of the cool box. And also makes thermocouple to get through the wall by making holes in certain point. This modification is also aimed to regulate air distribution inside of the cool box.

Figure 2.22 Cool box

5.1.3. Data Logger

A data logger (also datalogger or data recorder) is an electronic device that records data over time or in relation to location either with a built in the instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer). They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Some data logger interface with personal computer and use software to activate the data logger and view and analyse the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

Data loggers vary between general purpose types for a range of measurement applications to very specific devices for measuring in one environment or application type only. It is common for general purpose types to be programmable; however, many remain as static machines with only a limited number or no changeable parameters. Electronic data loggers have replaced chart recorders in many applications.

One of the primary benefits of using data loggers is the ability to automatically collect data on a 24-hour basis. Upon activation, data loggers are typically deployed and left unattended to measure and record information for the duration of the monitoring period. This allows for a comprehensive, accurate picture of the environmental conditions being monitored, such as air temperature and relative humidity.

Data Logger Specification

Brand	: Labjack
Type	: T7-Pro
Analog	: 14 analog
Range	: 10 s/d 0.001 V
Current Output	: 200µA.

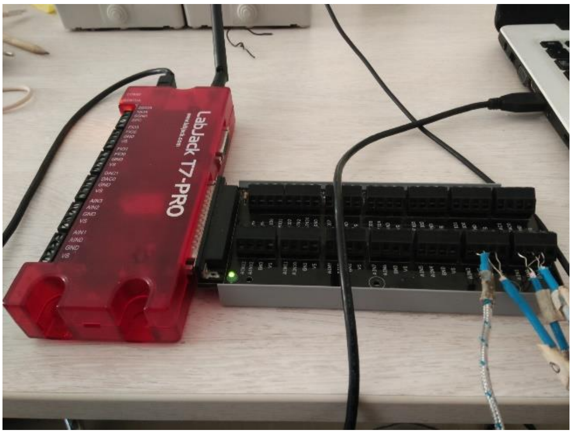

Figure 2.23 Data Logger

5.1.4. Thermocouple

Thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor.

Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Thermocouples are widely used in science and industry. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered appliances.

Figure 2.24 Thermocouple

5.1.5. Phase Change Materials (PCM)

Phase change materials (PCM) are substances that absorb and release thermal energy during the process of melting and freezing. When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs recharge as ambient temperatures fluctuate, making them ideal for a variety of everyday applications that require temperature control.

The most commonly used PCM is water/ice. Ice is an excellent PCM for maintaining temperatures at 0°C. But water's freezing point is fixed at 0°C (32°F), which makes it unsuitable for most thermal energy storage applications.

To address that limitation, PCMs have been developed for use across a broad range of temperatures, from -40°C to more than 150°C. They typically store 5 to 14 times more heat per unit volume than materials such as water, masonry or rock. Among various heat storage options, PCMs are particularly attractive because they offer high-density energy storage and store heat within a narrow temperature range.

In this Research chosen PCM has specification:

Physical state and appearance	: Solid. (Solid crystalline powder.)
Odor	: Slight.
Taste	: Saline
Product Name	: Sodium chloride
Catalog Codes	: SLS3262, SLS1045, SLS3889, SLS1669, SLS3091
Chemical Formula	: $NaCl$
Molecular Weight	: 58.44 g/mole
Color	: White.
pH (1% soln/water)	: 7 [Neutral.]

Boiling Point : 1413°C (2575.4°F)
Melting Point : 801°C (1473.8°F)
Critical Temperature : Not available.
Specific Gravity : 2.165 (Water = 1)

***The data based on Material Safety Data Sheet (MSDS)**

Figure 2.25 Phase Change Materials

5.2. Calculations of heat load

5.2.1. Load calculation of Product

Product Name = Meat, Beef
Mass = 3 Kg
T1 = 27 ^oC
T2 = -18 ^oC (EngineeringToolbox, 2018)
C = 3180 J/Kg ^oC (EngineeringToolbox, 2018)

Calculation:

$$\begin{aligned} Q_{Load} &= m\ Cp.\ \Delta T \\ &= 3 \times 3180 \times (27^oC - (-18^oC)) \\ &= 3 \times 3180 \times 55 \\ &= 524700 \text{ Joule} \end{aligned}$$

5.2.2. Calculation of heat load inside the Cool box

Some conditions have to applied

Materials : Styrofoam
$K_{styrofoam}$: 0.02579536 Kcal/jam $m^{2o}C$
h : 0.024 Kcal/jam $m^{2o}C$
T1 : 30 ^oC`
T2 : -18 ^oC
Δx : 0,025 m
Δt : 1 hour ~ 3600 second

(Necessary time to transfer the heat from outside to the system)

Table 2.8 Dimension of Cool Box

No	Wall	Length (m)	Width (m)	Area (m2)
1	Wall 1	0,515	0,31	0,160
2	Wall 2	0,515	0,31	0,160
3	Wall 3	0,37	0,31	0,115
4	Wall 4	0,37	0,31	0,115
5	Floor	0,515	0,31	0,160
6	Ceil	0,515	0,31	0,160

Calculations:

- Wall 1 and 2

$$\boldsymbol{U = \frac{1}{\frac{1}{h_1} + \frac{\Delta x}{k} + \frac{1}{h_2}}}$$

$$U = \frac{1}{\frac{1}{0{,}024} + \frac{0{,}025}{0.02579536} + \frac{1}{0{,}024}}$$

= 0,01186 Kcal/hour m^{2o}C

q = *U* A ΔT

= 0,01186 x 0,16 x (30 – (-18))

= 0,01186 x 0,16 x 48

= 0,0910848 kcal/hour

= 381,0988032 Joule/hour

So, the heat transmission in wall 1 and wall 2 is 2 x 381,0988032 Joule/hour

= 762,19760664 Joule/hour

- Wall 1 and 2

$$\boldsymbol{U = \frac{1}{\frac{1}{h_1} + \frac{\Delta x}{k} + \frac{1}{h_2}}}$$

$$U = \frac{1}{\frac{1}{0{,}024} + \frac{0{,}025}{0.02579536} + \frac{1}{0{,}024}}$$

= 0,01186 Kcal/hour m^{2o}C

q = $\boldsymbol{U}$ A ΔT

= 0,01186 x 0,115 x (30 – (-18))

= 0,01186 x 0,115 x 48

= 0,0654672 kcal/hour

= 273,9147648 Joule/hour

So, the heat transmission in wall 3 and wall 4 is 2 x 273,9147648 Joule/hour

= 547,8295296 Joule/hour

- Floor and Ceil

$$\boldsymbol{U = \frac{1}{\frac{1}{h_1} + \frac{\Delta x}{k} + \frac{1}{h_2}}}$$

$$U = \frac{1}{\frac{1}{0{,}024} + \frac{0{,}025}{0.02579536} + \frac{1}{0{,}024}}$$

= 0,01186 Kcal/hour m^{2o}C

q = $\boldsymbol{U}$ A ΔT

= 0,01186 x 0,16 x (30 – (-18))

= 0,01186 x 0,16 x 48

= 0,0910848 kcal/hour

= 381,0988032 Joule/hour

So, the heat transmission in floor and ceil is 2 x 381,0988032 Joule/hour

$= 762,19760664$ Joule/hour

And calculate the total heat transmission which is transmitted through the cool box's wall

$$q_{total} = 762,19760664\ J/hr + 547,8295296\ J/hr + 762,19760664\ J/hr$$
$$= 2072,2247429\ Joule/hour$$

And then the Energy enter the system (cool box) in 1 hour is

$$Q_{CB} = q.\ \Delta T$$
$$Q_{CB} = 2072,2247429\ Joule/hour \times 1\ jam$$
$$Q_{CB} = 2072,2247429\ Joule$$

Refer to the calculation above, total Q produced by the system (cool box and the product) is

$$Qts = Q_{Product} + Q_{CB}$$
$$= 2072,2247429 + 524700$$
$$= 526772,22\ Joule$$
$$= 526,77\ kJ$$

5.3. Salt PCM Compositions

PCM is made by mixing Salt, Propylene Glycol and water. The mixing process will have two stages as below

1. Mixing salt and water
   Because melting point of salt is too high 809°C, the process of making the solution has to be in high temperature. Table below shows the concentration of salt in the water:
2. Adding Propylene Glycol to the solution
   The purpose of adding Propylene Glycol to the PCM is increase the performance of PCM. The properties of Propylene Glycol are known from MSDS with freezing point -59°C. Writer assumed that the more Propylene Glycol added to the PCM, the lower freezing point of the PCM while the capability of Cold Storage is maximum -25°C.

Table 2.9 PCM Compositions

NO	PCM	CONCENTRATION		
		Water	Salt	Propylene Glycol
1	PCM A	78% Water	22% NaCl	-
2	PCM A1	83% Water	17% NaCl	-
3	PCM A2	88% Water	12 % NaCl	-
4	PCM B	78% Water	22% NaCl	10 ml
5	PCM B1	83% Water	17% NaCl	10 ml
6	PCM B2	88% Water	12% NaCl	10 ml

5.4. Bomb Calorimeter Test

This test is conducted to know the calories contained by material in this case is the mixture of Salt and Propylene Glycol. In this research bomb calorimeter test will be determining the specific heat of material. The result of the test can show up how much PCM needed to cover heat load inside the system (Cool Box). This test took place in Laboratory of Chemical Fundamental – Chemistry Department. The table below shows the results of the test:

Table 2.10 Bomb Calorimeter Test Results

No	Materials	Heat Capacity	Unit	Test
1	1% NaCl + 99% Propylene Glycol	11064,81	Cal/gr	Bomb Calorimeter
2	3% NaCl + 97% Propylene Glycol	14974,50	Cal/gr	
3	5% NaCl + 95% Propylene Glycol	11733,74	Cal/gr	

**Note : 1 Cal is equal to 4,1858 Joule*

It can be seen on the table above calories for each salt concentration in propylene glycol as solvent. To know total mass and specific heat which can cover total Q in the system the formula can be used:

$$Q = m.Cp.\Delta T$$

Specific Heat Calculation:
To know the value of Cp, the formula of sensible heat can be used

$$Q/m = Cp.\ \Delta T$$

- Specific Heat of Water is 4,184 J/g°C
- Heat capacity of Calorimeter is 420 J/°C

- 0,5 g **PCM 1** (5% NaCl + 95% Propylene Glycol) is burned in bomb calorimeter which contained 650 g of water
  - T_1 = 26 ºC
  - T_2 = 34,8 ºC
  - ΔT = 8,8 ºC

Specific Heat of 5% NaCl + 95% Propylene Glycol

Q/m = 11733,74
Q/m = Cp. ΔT
11733,74 = Cp.8,8
Cp = 1333,38 Cal/gr ºC
= 5581,26 J/gr ºC

- 0,5 g **PCM 2** (3% NaCl + 97% Propylene Glycol) is burned in bomb calorimeter which contained 650 g of water
  - T1 = 26ºC
  - T2 = 34 ºC
  - ΔT = 8 ºC

Specific Heat of 3% NaCl + 97% Propylene Glycol

Q/m = 14974,50
Q/m = Cp. ΔT
14974,50 = Cp.8
Cp = 1871,81 Cal/gr ºC
= 7835,03 J/gr ºC

- 0,5 g **PCM 3** (1% NaCl + 99% Propylene Glycol) is burned in bomb calorimeter which contained 650 g of water
  - T1 = 26ºC
  - T2 = 33ºC
  - ΔT = 7 ºC

Specific Heat of 1% NaCl + 99% Propylene Glycol

Q/m = 11064,81
Q/m = Cp. ΔT
11064,81 = Cp.7
Cp = 1580,69 Cal/gr ºC
= 6616,44 J/gr ºC

Calculation of PCM Mass

In This step, the value of Cp can be determined using formula for sensible heat

$$m = \frac{Q}{Cp.\Delta T}$$

T1 = -18oC
T2 = -12oC
ΔT = 4 oC
Qtotal = 526772,22 J
Necessary mass of 5% NaCl + 95% Propylene Glycol is

$$526772{,}22\ J = m \times 5581{,}26\ J/gr\,^{o}C \times 4\,^{o}C$$

$$m = \frac{526772{,}22\ J}{5581{,}26\ J/grC \times 4C}$$

m = 23,60 gram

Necessary mass of 3% NaCl + 97% Propylene Glycol is

$$Q = m.Cp.\Delta T$$

$$526772{,}22\ J = m \times 7835{,}03\ J/gr\,^{o}C \times 4\,^{o}C$$

$$m = \frac{526772{,}22\ J}{7835{,}03\ J/grC \times 4C}$$

m = 16,8 gram

Necessary mass of 1% NaCl + 99% Propylene Glycol is

$$Q = m.Cp.\Delta T$$

$$526772{,}22\ J = m \times 6616{,}44\ J/gr\,^{o}C \times 4\,^{o}C$$

$$m = \frac{526772{,}22\ J}{6616{,}44\ J/grC \times 4C}$$

m = 19,9 gram

*The properties of PCM Materials can’t only be determined by the mass of PCM. But it is necessary to determine freezing point, thermal conductivity and congealing point of materials. In this case, the freezing point of Propylene Glycol can be seen in Material Safety Data Sheet (MSDS) it’s equal to -59oC and freezing point of Sodium Chloride (NaCl) is 809oC. The mixture or solution of both will have differential freezing point, and the mixture freezing point is below 30oC while the ability of Cold Storage can only able to reach 20-25oC.

*Reefer to that problems, so the mixture will be added some water in the solutions

5.5. Results of performance test

The analysis of PCM performance here will compare between Salt PCM without Propylene Glycol and with Propylene Glycol

The results of the performance test presented in curve and table

- Comparison of time on/off Cold Storage’s Compressor to know the performance of Each concentration of PCM

The purpose of this test is to know how long time needed by compressor in on or off mode correlated to operational cost. Table below shows the results of performance test in unit minutes. From the table, the comparison for each PCM can easily see.

1. **PCM A (22% Salt PCM without Propylene Glycol) and PCM B (22% salt PCM with Propylene Glycol)**

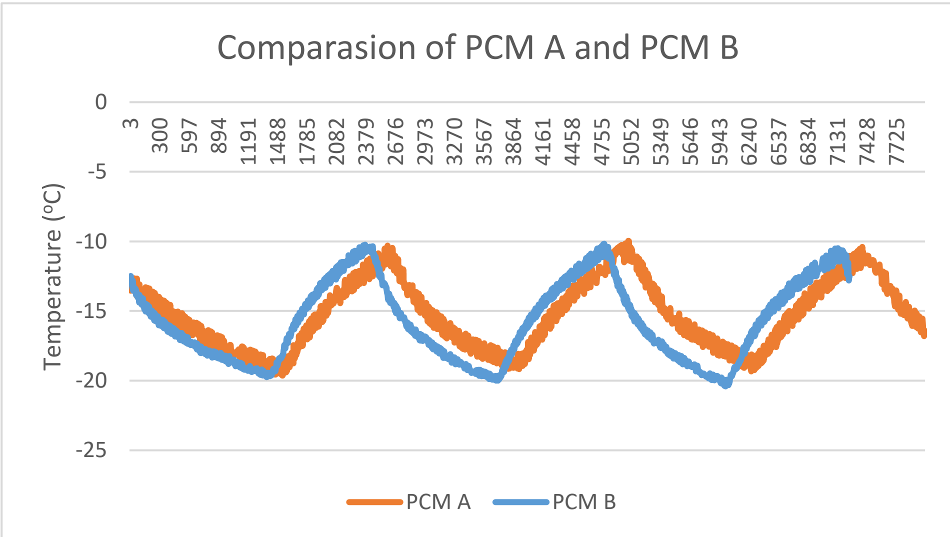

Figure 2.26 Comparison of PCM A and PCM B

Graphic above shows the results of first performance test. In this experiment the lowest temperature which can be reached is -20ºC with the highest temperature -10ºC. The experiment is done after reach about iteration 3000 and the data is recorded each 3 second. From -20ºC to -10ºC, it takes about 19 minutes for PCM A in off mode and 17 Minutes for PCM B with the same condition in the first iteration. This process of experiments is repeated several times in certain period of time (hours), and after reaching the highest temperature, compressor will be turned on automatically. It takes 21 minutes for compressor to lower temperature until reaching -20ºC again for PCM A and it takes 21,55 minutes for PCM B to reach -20ºC in the first iteration. table below shows the summary of time period for PCM change the temperature from -20ºC to -10ºC and to raise temperature from -10ºC to -20ºC.

Table 2.11 Time comparison of PCM A and PCM B

	Time (Minutes)	
	PCM A	PCM B
Off Compressor	19,1	17
On Compressor	21,6	21,55
Off Compressor	19,3	18,2
On Compressor	21,3	20,3
Off Compressor	18,75	18,35
% Off	47,23 %	45,68 %
% On	52,77 %	54,32 %

From the comparison table above, it can be known that PCM with composition A, with 22% salt without Propylene Glycol is more efficient than PCM B, there are almost 2% differences.

2. **PCM A1 (17% Salt PCM without Propylene Glycol) and PCM B1 (17% salt PCM with Propylene Glycol)**

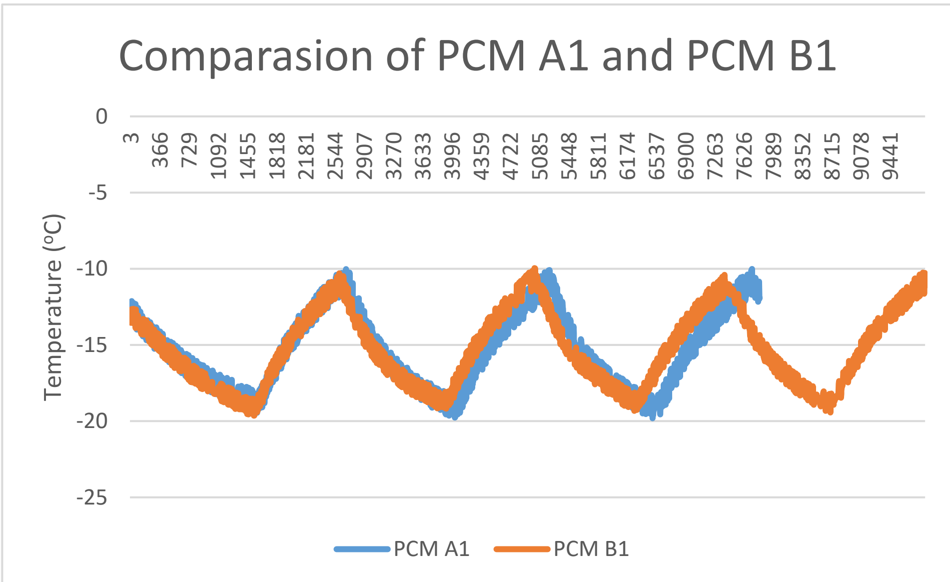

Figure 2.27 Comparison of PCM A1 and PCM B1

Graphic above shows the results of second performance test. In this experiment the lowest temperature which can be reached is -20°C with the highest temperature -10°C. The experiment is done after reach about iteration 3000 and the data is recorded each 3 second. From -20°C to -10°C, it takes about 17,05 minutes for PCM A1 in off mode and 17,85 Minutes for PCM B1 with the same condition in the first iteration. This process of experiments is repeated several times in certain period of time (hours), and after reaching the highest temperature, compressor will be turned on automatically as well as when it reaches the lowest temperature will be turned off automatically. It takes 23,9 minutes for compressor to lower temperature until reaching -20^{o}C again for PCM A1 and it takes 21,9 minutes for PCM B1 to reach -20^{o}C in the first iteration. Table below shows the summary of time period for PCM change the temperature from -20^{o}C to -10^{o}C and to raise temperature from -10^{o}C to -20^{o}C.

Table 2.12 Time comparison of PCM A1 and PCM B1

	Time (Minutes)	
	PCM A1	PCM B1
Off Compressor	17,05	17,85
On Compressor	23,9	21,9
Off Compressor	19,4	18,8
On Compressor	21,6	20,7
Off Compressor	20,5	18,6
On Compressor	-	21,5
Off Compressor	-	19,6
% Off	44,48 %	46,29 %
% On	55,52 %	53,71 %

From the comparison table above, it can be known that PCM with composition B1, with 17% salt with addition 10 ml Propylene Glycol is more efficient than PCM A1, 17% salt without propylene glycol, there are almost 2% differences.

3. PCM A2 (12% Salt PCM without Propylene Glycol) and PCM B (12% salt PCM with Propylene Glycol)

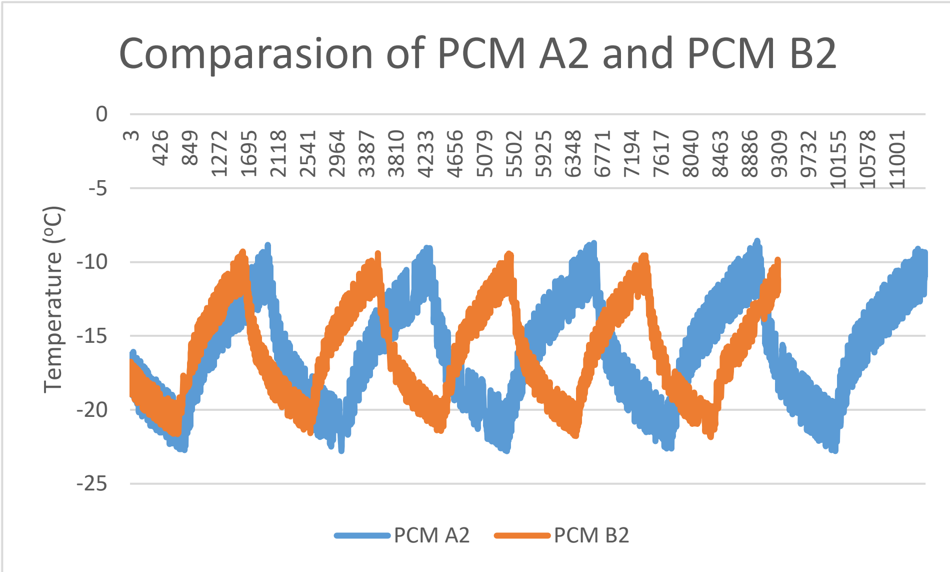

Figure 2.28 Comparison of PCM A2 and PCM B2

Graphic above shows the results of third performance test. In this experiment the lowest temperature which can be reached is -22°C - -23°C with the highest temperature -9°C. The experiment is done after reach about iteration 3000 and the data is recorded each 3 second. From -20°C to -10°C, it takes 19 minutes for PCM A2 in off mode and 16,1 Minutes for PCM B2 with the same condition in the first iteration. This process of experiments is repeated several times in certain period of time (hours), and after reaching the highest temperature, compressor will be turned on automatically as well as when it reaches the lowest temperature will be turned off automatically. It takes 17,3 minutes for compressor to lower temperature until reaching -23°C again for PCM A2 and it takes 15,4 minutes for PCM B2 to reach -20°C in the first iteration. Table below shows the summary of time period for PCM change the temperature from -20°C to -10°C and to raise temperature from -10°C to -20°C.

Table 2.13 Time comparison of PCM A2 and PCM B2

	Time (Minutes)	
	PCM A2	PCM B2
Off Compressor	19	16,1
On Compressor	17,3	15,4
Off Compressor	19,5	16,2
On Compressor	18,5	15,1
Off Compressor	19	16,85

On Compressor	18,75	15,45
Off Compressor	19,3	16,6
On Compressor	18,65	15,65
Off Compressor	19,8	16
% Off	51,2 %	51,63 %
% On	48,8 %	48,37 %

From the comparison table above, it can be known that PCM with composition B2, with 12% salt with addition 10 ml Propylene Glycol is more efficient than PCM A2, 12% salt without propylene glycol, there is only small differences.

4. Summary of time of compressor in off/on mode

Table 2.14 Summary of all PCM Performance Test

	PCM A	PCM A1	PCM A2	PCM B	PCM B1	PCM B2
Off Compressor	19,10	17,05	19	17,00	17,85	16,1
On Compressor	21,60	23,9	17,3	21,55	21,9	15,4
Off Compressor	19,3	19,4	19,5	18,20	18,8	16,2
On Compressor	21,30	21,6	18,5	20,30	20,7	15,1
Off Compressor	18,75	20,5	19	18,35	18,6	16,85
On Compressor	-	-	18,75	-	21,5	15,45
Off Compressor	-	-	19,3	-	19,6	16,6
On Compressor	-	-	18,65	-	-	15,65
Off Compressor	-	-	19,8	-	-	16
% Off	47,23 %	44,48 %	51,2 %	45,68 %	46,29 %	51,63 %
% On	52,77 %	55,52 %	48,8 %	54,32 %	53,71 %	48,37 %

Note :
Unit : Minutes
% *on/off* : To know the performance of PCM in Percentage

PCM A	: Mixture of 22% salt and water
PCM A1	: Mixture of 17% salt and water
PCM A2	: Mixture of 12% salt and water
PCM B	: Mixture of 22% salt with addition 10 ml Propylene Glycol in water
PCM B1	: Mixture of 17% salt with addition 10 ml Propylene Glycol in water
PCM B2	: Mixture of 12% salt with addition 10 ml Propylene Glycol in water

Refer to the results of the performance test above in the table, it shows that the system using PCM with addition 10 ml Propylene Glycol tend to have better efficiency than PCM without Propylene Glycol, it indicates the effect of adding propylene glycol can raise the freezing point of PCM because of freezing point of Propylene Glycol itself is about 50 – 60°C, and higher amount of salt added to water, the freezing point will also getting lower because of freezing point of salt itself.

Table shows that using PCM with 10 ml Propylene Glycol in certain concentration is more efficient than using PCM without propylene glycol, so it can be said that hybrid system using salt-water PCM with addition 10 ml Propylene Glycol is effective to reduce energy consumption in Cold Storage. The most effective concentration shows by the table is PCM B2 which was mixture of 12% salt and water with 10 ml Propylene Glycol. And in the second place for the most effective PCM to use in this case is PCM A2 which has Mixture of 12% salt without addition 10 ml Propylene Glycol in water. Thus, the more concentration of salt with the same amount of Propylene Glycol and water as the solvent affect to the increasing of freezing point and with the same operation temperature and it was also affected to the performance which lower the off time of Compressor. There is uncertainty within the graphic if it observe as the order of the amount of salt added, so the effectiveness of PCM can only be determined by using more sample data from experiments and addition properties test such as Differential Scanning Calorimeter.

5.6. Freezing point calculation

5.6.1. PCM A (22% Salt)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f \quad = K_f m}$$

K_f of H_2O	: 1,86 °C/m
Freezing point of H2O	: 0 °C
NaCl Density (ρ)	: 2,16 g/cm³
	: 2160 gram/litre
Water Density (ρ)	: 1000 kg/m3

: 1000 gram/litre

- **Freezing point of PCM A**
  22% salt in 1 litre solutions
  220 grams salt in 1 litre solution
  Determine grams of water

Litre of NaCl $= \frac{\text{220 grams NaCl}}{\text{2160 grams/litre}}$

$= 0{,}102$ Litres of salt in 1 litre salt water solutions

Amount of water in the bottle is
Litre of H_2O = 1 Litre – 0,102 litres

= 0,898 litres of water in 1 litre salt water solutions

Density of water is 1000 gram/litre
So, gram of water is 898 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

Moles of solute $= 220 \text{ grams NaCl} \times \frac{\text{1 mol NaCl}}{58{,}4\ g\ NaCl} \times \frac{\text{2 mol particles of NaCl}}{1\ Mole\ NaCl}$

= 7,53 moles

2 moles particles refer to
NaCl → Na⁺ + Cl⁻

Molality $= \frac{\text{Moles of solute}}{Kg\ of\ solvent}$

$= \frac{\text{7,53 moles}}{0{,}898\ kg}$

= 8,385 m

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

$\Delta T_f \quad = K_f m$

$\Delta T_f \quad = (1{,}86\ ^{o}C/m).(8{,}385\ m)$

$= 15{,}59\ ^{o}C$

Freezing point of solution $= 0\ ^{o}C - 15{,}59\ ^{o}C$

$= -15{,}59\ ^{o}C$

5.6.2. PCM A1 (17% Salt)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f \quad = K_f m}$$

K_f of H_2O : 1,86 $^{o}C/m$
Freezing point of H2O : 0 ^{o}C
NaCl Density (ρ) : 2,16 g/cm^3
: 2160 gram/litre
Water Density (ρ) : 1000 kg/m^3
: 1000 gram/litre

- **Freezing point of PCM A1**
  17% salt in 1 litre solutions
  170 grams salt in 1 litre solution

Determine grams of water

Litre of NaCl $= \dfrac{170 \text{ grams NaCl}}{2160 \text{ grams/litre}}$

= 0,0787 Litres of salt in 1 litre salt water solutions

Amount of water in the bottle is

Litre of H_2O = 1 Litre – 0,0787 litres

= 0,921 litres of water in 1 litre salt water solutions

Density of water is 1000 gram/litre

So, gram of water is 921 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

$$\text{Moles of solute} = 170 \text{ grams NaCl} \times \frac{1 \text{ mol NaCl}}{58{,}4\ g\ NaCl} \times \frac{2 \text{ mol particles of NaCl}}{1\ Mole\ NaCl}$$

= 5,82 moles

2 moles particles refer to
NaCl → Na^+ + Cl^-

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

$$= \frac{5{,}82 \text{ moles}}{0{,}921\ kg}$$

= 6,319 m

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

$\Delta T_f = K_f m$

$\Delta T_f = (1{,}86\ ^oC/m).(6{,}319\ m)$

$= 11{,}75\ ^oC$

Freezing point of solution $= 0\ ^oC - 11{,}75\ ^oC$

$= -11{,}75\ ^oC$

5.6.3. PCM A2 (12% Salt)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f = K_f m}$$

K_f of H_2O : 1,86 $^oC/m$
Freezing point of H2O : 0 ^oC
NaCl Density (ρ) : 2,16 g/cm³
: 2160 gram/litre
Water Density (ρ) : 1000 kg/m^3
: 1000 gram/litre

- **Freezing point of PCM A2**
  12% salt in 1 litre solutions

120 grams salt in 1 litre solution

Determine grams of water

Litre of NaCl $= \frac{120 \text{ grams NaCl}}{2160 \text{ grams/litre}}$

$= 0{,}056$ Litres of salt in 1 litre salt water solutions

Amount of water in the bottle is

Litre of H_2O = 1 Litre – 0,056 litres

= 0,94 litres of water in 1 litre salt water solutions

Density of water is 1000 gram/litre

So, gram of water is 940 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

$$\text{Moles of solute} = 120 \text{ grams NaCl} \times \frac{1 \text{ mol NaCl}}{58{,}4\ g\ NaCl} \times \frac{2 \text{ mol particles of NaCl}}{1\ Mole\ NaCl}$$

= 4,11 moles

2 moles particles refer to
NaCl → Na⁺ + Cl⁻

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

$$= \frac{4{,}11 \text{ moles}}{0{,}94\ kg}$$

= 4,37 m

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

$\Delta T_f = K_f m$

$\Delta T_f = (1{,}86\ ^oC/m).(4{,}37\ m)$

= 8,13 ºC

Freezing point of solution = 0 ºC – 8,13 ºC

= -8,13 ºC

5.6.4. PCM B (22% Salt with addition 10 ml Propylene Glycol)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f \quad = K_f m}$$

K_f of H_2O	: 1,86 ºC/m
Freezing point of H2O	: 0 ºC
NaCl Density (ρ)	: 2,16 g/cm³
	: 2160 gram/litre
NaCl Molecular Weight	: 58,4 g/mol
Propylene Glycol Density (ρ)	: 1,035 – 1,037 g/ml
PG Molecular Weight	: 76,095 g/mol
Water Density (ρ)	: 1000 kg/m^3
	: 1000 gram/litre

- **Freezing point of PCM B**

22% salt in 1 litre solutions
220 grams salt in 1 litre solution

Determine grams of water

Litre of NaCl $= \dfrac{220 \text{ grams NaCl}}{2160 \text{ grams/litre}}$

= 0,102 Litres of salt in 1 litre solutions

Litre of PG = 10 ml

= 0,01 L Litres of Propylene Glycol in 1 litre solutions

Amount of water in the bottle is

Litre of H_2O = 1 Litre – 0,102 litres of NaCl – 0,01 litres of PG

= 0,888 litres of water in 1 litre solutions

Density of water is 1000 gram/litre

So, gram of water is 888 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

Moles of NaCl

$$\text{Moles of solute} = 220 \text{ grams NaCl x } \frac{1 \text{ mol NaCl}}{58{,}4\ g\ NaCl} \text{ x } \frac{2 \text{ mol particles of NaCl}}{1\ Mole\ NaCl}$$

$$= 7{,}53 \text{ moles}$$

***2 moles particles refer to**
NaCl → $Na^+ + Cl^-$

Moles of Propylene Glycol

PG mass is = 10 ml x 1,036 g/ml

= 10,36 grams

$$\text{Moles of solute} = 10 \text{ grams NaCl x } \frac{1 \text{ mol C3H8O2}}{76{,}095\ g \text{ C3H8O2}}$$

$$= 0{,}13 \text{ moles}$$

Total moles of solutions are

= 7,53 + 0,13

= 7,66 moles

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

$$= \frac{7{,}66 \text{ moles}}{0{,}888\ kg}$$

$$= 8{,}63 \text{ m}$$

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

$\Delta T_f = K_f m$

$\Delta T_f = (1{,}86\ ^oC/m).(8{,}63\ m)$

= 16,04 °C

Freezing point of solution = 0 °C – 16,04 °C

= -16,04 °C

5.6.5. PCM B (22% Salt with addition 10 ml Propylene Glycol)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f = K_f m}$$

K_f of H_2O	: 1,86 °C/m
Freezing point of H2O	: 0 °C
NaCl Density (ρ)	: 2,16 g/cm³
	: 2160 gram/litre
NaCl Molecular Weight	: 58,4 g/mol
Propylene Glycol Density (ρ)	: 1,035 – 1,037 g/ml
PG Molecular Weight	: 76,095 g/mol
Water Density (ρ)	: 1000 kg/m^3
	: 1000 gram/litre

- **Freezing point of PCM B1**

17% salt in 1 litre solutions

170 grams salt in 1 litre solution

Determine grams of water

Litre of NaCl $= \frac{170 \text{ grams NaCl}}{2160 \text{ grams/litre}}$

= 0,0787 Litres of salt in 1 litre solutions

Litre of PG = 10 ml

= 0,01 L Litres of Propylene Glycol in 1 litre solutions

Amount of water in the bottle is

Litre of H_2O = 1 Litre – 0,0787 litres of NaCl – 0,01 litres of PG

= 0,911 litres of water in 1 litre solutions

Density of water is 1000 gram/litre

So, gram of water is 911 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

Moles of NaCl

Moles of solute $= 170 \text{ grams NaCl x } \frac{1 \text{ mol NaCl}}{58{,}4\ g\ NaCl} \text{ x } \frac{2 \text{ mol particles of NaCl}}{1\ Mole\ NaCl}$

= 5,82 moles

***2 moles particles refer to**
NaCl → Na^+ + Cl^-

Moles of Propylene Glycol

PG mass is = 10 ml x 1,036 g/ml

= 10,36 grams

Moles of solute $= 10 \text{ grams NaCl x } \frac{1 \text{ mol C3H8O2}}{76{,}095\ g\ \text{C3H8O2}}$

= 0,13 moles

Total moles of solutions are

= 5,82 + 0,13

= 5,95 moles

Molality $= \frac{\text{Moles of solute}}{Kg\ of\ solvent}$

$= \frac{5{,}95 \text{ moles}}{0{,}931\ kg}$

= 6,53 m

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

ΔT_f $= K_f m$

ΔT_f = (1,86 °C/m).(6,53 m)

= 12,15 °C

Freezing point of solution = 0 ºC – 12,15 ºC

= -12,15 ºC

5.6.6. PCM B2 (12% Salt with addition 10 ml Propylene Glycol)

To determine freezing point of solutions, formula below can be used

$$\boxed{\Delta T_f = K_f m}$$

K_f of H_2O	: 1,86 ºC/m
Freezing point of H2O	: 0 ºC
NaCl Density (ρ)	: 2,16 g/cm³
	: 2160 gram/litre
NaCl Molecular Weight	: 58,4 g/mol
Propylene Glycol Density (ρ)	: 1,035 – 1,037 g/ml
PG Molecular Weight	: 76,095 g/mol
Water Density (ρ)	: 1000 kg/m^3
	: 1000 gram/litre

- **Freezing point of PCM B2**

12% salt in 1 litre solutions
120 grams salt in 1 litre solution

Determine grams of water

Litre of NaCl $= \dfrac{120 \text{ grams NaCl}}{2160 \text{ grams/litre}}$

= 0,056 Litres of salt in 1 litre solutions

Litre of PG = 10 ml

= 0,01 L Litres of Propylene Glycol in 1 litre solutions

Amount of water in the bottle is

Litre of H_2O = 1 Litre – 0,056 litres of NaCl – 0,01 litres of PG

= 0,934 litres of water in 1 litre solutions

Density of water is 1000 gram/litre

So, gram of water is 934 grams

To determine freezing point

Step 1. Determine the molality of the solution using formula below

$$\text{Molality} = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

Moles of solute can be determined

Moles of NaCl

$$\text{Moles of solute} \quad = 120 \text{ grams NaCl x } \frac{1 \text{ mol NaCl}}{58{,}4\ g\ NaCl} \text{ x } \frac{2 \text{ mol particles of NaCl}}{1\ Mole\ NaCl}$$

$$= 4{,}11 \text{ moles}$$

***2 moles particles refer to**
NaCl → Na^+ + Cl^-

Moles of Propylene Glycol

PG mass is = 10 ml x 1,036 g/ml

= 10,36 grams

$$\text{Moles of solute} \quad = 10 \text{ grams NaCl x } \frac{1 \text{ mol C3H8O2}}{76{,}095\ g\ \text{ C3H8O2}}$$

$$= 0{,}13 \text{ moles}$$

Total moles of solutions are

= 4,11 + 0,13

= 4,24 moles

$$\text{Molality} \quad = \frac{\text{Moles of solute}}{Kg\ of\ solvent}$$

$$= \frac{4{,}24 \text{ moles}}{0{,}934\ kg}$$

$$= 4{,}54 \text{ m}$$

Step 2. Use the molality and the molal freezing point depression constant to determine the decrease in freezing point

ΔT_f = $K_f m$

ΔT_f = (1,86 ^oC/m).(4,54 m)

= 8,44 ^oC

Freezing point of solution = 0 °C – 8,44 °C

= -8,44 °C

5.6.7. Freezing point summary of PCM

After calculating freezing point for each composition of PCM, it can by summarized by creating table to facilitate the analysis.

Table 2.15 Freezing point

No.	PCM	Freezing Point
1.	PCM A	-15,59 °C
2.	PCM A1	-11,75 °C
3.	PCM A2	-8,13 °C
4.	PCM B	-16,04 °C
5.	PCM B1	-12,15 °C
6.	PCM B2	-8,44 °C

PCM A : Mixture of 22% salt and water
PCM A1 : Mixture of 17% salt and water
PCM A2 : Mixture of 12% salt and water
PCM B : Mixture of 22% salt with addition 10 ml Propylene Glycol in water
PCM B1 : Mixture of 17% salt with addition 10 ml Propylene Glycol in water
PCM B2 : Mixture of 12% salt with addition 10 ml Propylene Glycol in water

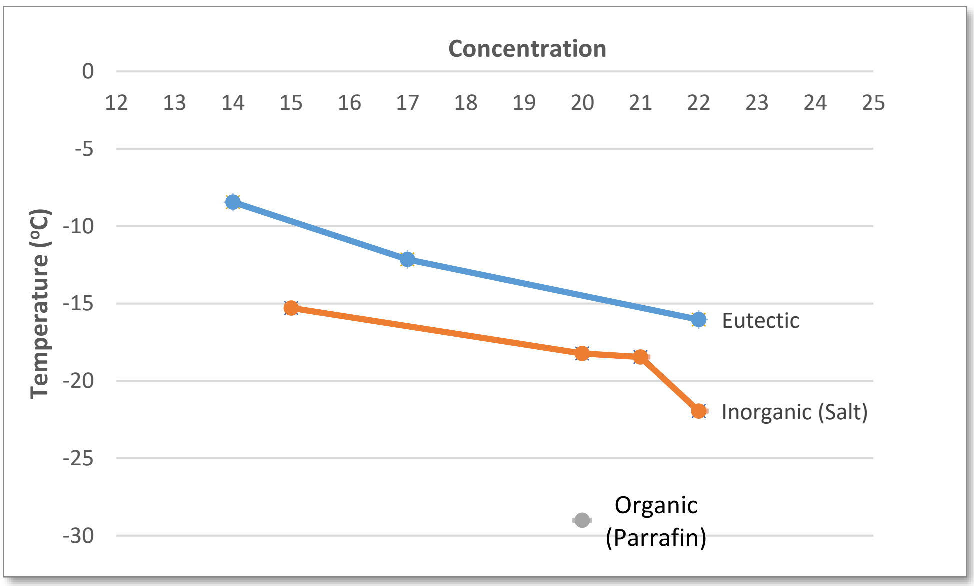

Figure 2.29 Freezing points of Organic, Inorganic and Eutectic PCM

From **Table 2.15**, it is known that adding 10 ml Propylene Glycol constantly affect the depression of freezing point. And it indicates that adding little amount of Propylene Glycol can change freezing point about -5ºC. And it works linearly for adding more PCM, it can considerably affect the change of material properties especially the freezing point.

Figure 2.29 shows 3 different behaviour of Organic, Inorganic and Eutectic PCM. It shows from several process of determining freezing point that Organic PCM (Paraffin) has lower Freezing point. It causes by Aliphatic chain of molecular structure. And in the second place is inorganic PCM. From the graphic, it can be known that salt PCM has low freezing point which depends on the solvent. But basically, salt has low freezing point, so there is only small change of depression or escalation after process of mixture.

5.7. Mass flow calculation

Calculation of refrigerant mass flow

Refrigerant specification

Type	: R 404 A
T (inlet comp)	: 0 ºC
T (outlet comp)	: 65 ºC
Low Pressure	: 2.06 bar
High Pressure	: 18.9 bar
T subcooling	: 20 ºC
Cooling capacity	: 1.345 KJ/s
T Freezer Room	: -15 ºC

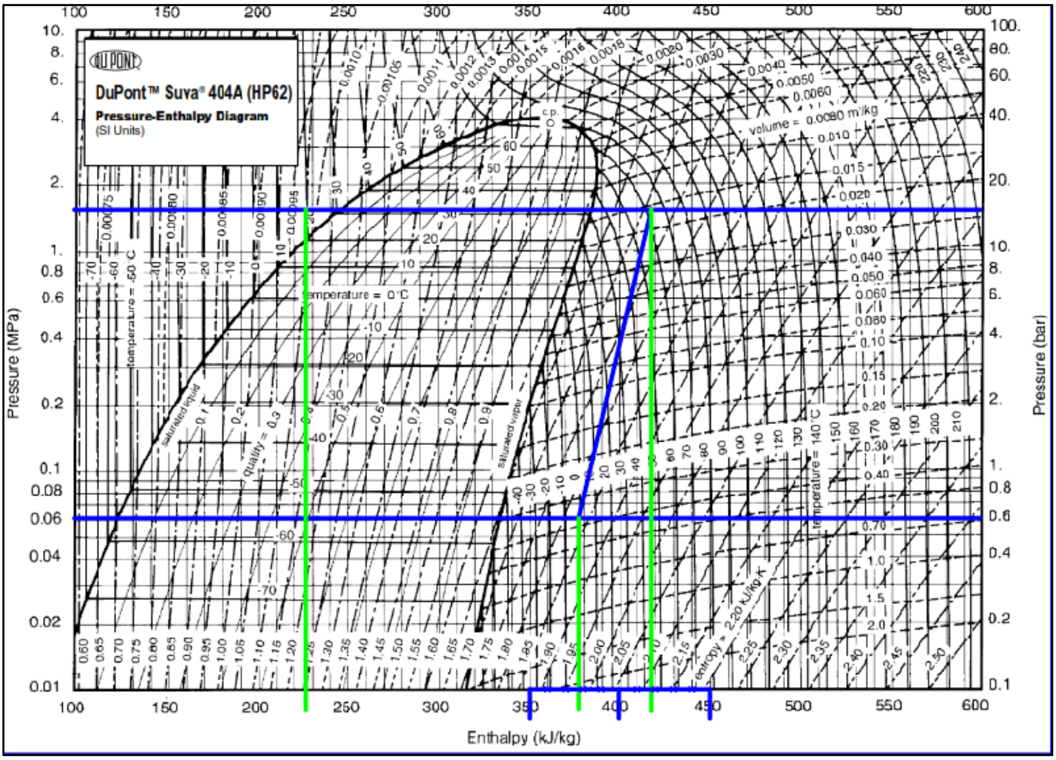

Figure 2.30 Refrigerant 404A P-h Diagram

Determine the amount of enthalpy from P-h diagram R404A refer to the diagram above. The enthalpy gained after reading the diagram above is:
h1 : 378 KJ/Kg
h2 : 419 KJ/Kg
h3 : 227,7 KJ/Kg
h4 : 227,7 KJ/Kg

From those data, refrigerant mass flow can be determined using the following formula:

$$Q_L = \dot{m}ref\ (h_1 - h_4)$$

$$\dot{m}ref = \frac{Q_L}{(h_1 - h_4)}$$

$$\dot{m}ref = \frac{1.345\ \frac{KJ}{s}}{378\frac{KJ}{Kg} - 227{,}7\frac{KJ}{Kg}}$$

$$\dot{m}ref = \frac{1{,}345 \ \frac{\cancel{KJ}}{s}}{150{,}3 \ \frac{\cancel{KJ}}{Kg}}$$

$$\dot{m}ref = 0{,}00895 \ Kg/s$$

5.8. Calculation of necessary energy to supply the compressor

After the value of mass flow of refrigerant has known, those data can be used to determine the energy consumed by refrigeration system. To do that, additional data of enthalpy in super heat vapor condition. Based on the experimental results and read P-h diagram by input the known data of refrigerant then calculation of the compressor energy as follows.

$$W_{comp} = \dot{m}ref \ (h_2 - h_1)$$

$$W_{comp} = 0.00895 \ Kg/s \ (419 \ KJ/Kg - 378 \ KJ/Kg)$$

$$W_{comp} = 0.367 \, KJ/s$$

$$W_{comp} = 1321{,}02 \ KJ/h$$

1 KJ/hour is equal to 0,000278

So,

$$W_{comp} = 0.367 \, KW$$

Based on the above calculation, it is found that the amount of energy required by the compressor to serve the system is 0.367 KW.

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CHAPTER VI
DATA ANALYSIS

6.1. Conclusions

Based on the experiments of Performance Test using thermocouple sensors in Cold storage and several calculations, the following conclusions were made.

1. Performance of Phase Change Materials can be known by observe behavior of performance graphics which is created based onto the experiments data in cold storage. The best performance of Salt-water solution Phase Change Materials (PCM) in these experiments showed that PCM B2 with 12% salt in the water with addition 10 ml Propylene Glycol has better efficiency to maintain temperature in temperature range -20 ^{o}C to -10 ^{o}C. it happened because freezing point of PCM B2 and A2 is higher than PCM A, PCM B, PCM A1 and PCM B1. So, the best performance showed up here is PCM B2 and the second best performance based on the experiments data is PCM A2.
2. The difference performance graphic and time difference showed by PCM with 10 ml addition of Propylene Glycol. PCM with addition 10 ml Propylene Glycol tend to have better performance than using PCM without Propylene Glycol. But within three sample for each data between addition 10 ml Propylene Glycol and without Propylene Glycol th ere is unstable graphic showed by PCM A and B. To determine the properties of the mixture, addition samples and another properties test such as DSC needed to be done to add more accuracy for the analysis.
3. The lowest freezing point of the mixture can be reached is -16,04 ^{o}C. That properties obtained by PCM B affected by large amount of Salt which made the temperature of freezing decrease and 10 ml addition of Propylene Glycol which has so much effect even in small amount. Small addition of propylene glycol to NaCl as Phase Change Materials may affect to the significant property changes such as a change in freezing point of about 1 ^{o}C and the performance of PCM to maintain temperature at a certain temperature. it is the result of the properties of propylene glycol which is quite influential in the cooling area which has normal freezing point about -59 ^{o}C

6.2. Suggestions

Based on the experiments conducted in cold storage using thermocouple sensors and Calorimeter Test , there are several suggestions as follows.

1. Process of making PCM shall be conducted refer to the procedure which referred to the related organizations
2. In the same time of cold storage, preparation of test needs to be pre-cooled in several hours longer than 3 hours to freeze the entire mixture so then the PCM can work optimally
3. Change of position of apparatus need to be prevented to avoid data error when the experiments are running

4. Additional tests need to be conducted to determine exact properties of materials such as Differential Scanning Calorimeter

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MSDS (Material Safety Data Sheet)

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Kepada Yth :
Moch. Soleh
T. Sistem Perkapalan ITS

LAPORAN ANALISIS Subyek : Garam (NaCl)	No	:382/IT2.VI.1.4/PM.05.02/2018
	Tanggal	: 22 Mei 2018
	Metode	: ---
	Diteliti Oleh	: Fataty K

Tanggal diterima sampel : 5 Mei 2018

No	Kode Sampel	Hasil Analisa (Kalori)	Metode
1	NaCl 1%	11064,81 Cal/gr	Bom Calorimeter
2	NaCl 3%	14974,50 Cal/gr	
3	NaCl 5%	11733,74 Cal/gr	

Catatan :

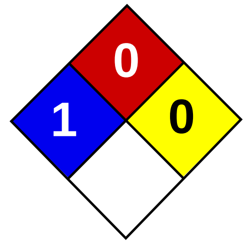
1. Hasil analisis ini mengacu pada sampel yang diterima laboratorium Kimia ITS dan tidak dapat digunakan sebagai alat bukti hukum
2. Pengambilan sampel tidak dilakukan oleh Laboratorium Kimia ITS

KEMENTERIAN RISET, TEKNOLOGI, DAN PENDIDIKAN TINGGI INSTITUT TEKNOLOGI SEPULUH NOPEMBER FAKULTAS ILMU ALAM DEPARTEMEN KIMIA

Hormat Kami,

Prof. Dr. Didik Prasetyoko, M.Sc
Ketua

Science Lab.com
Chemicals & Laboratory Equipment



Health	1
Fire	0
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Sodium chloride MSDS

Section 1: Chemical Product and Company Identification

Product Name: Sodium chloride

Catalog Codes: SLS3262, SLS1045, SLS3889, SLS1669, SLS3091

CAS#: 7647-14-5

RTECS: VZ4725000

TSCA: TSCA 8(b) inventory: Sodium chloride

CI#: Not applicable.

Synonym: Salt; Sea Salt

Chemical Name: Sodium chloride

Chemical Formula: NaCl

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Sodium chloride	7647-14-5	100

Toxicological Data on Ingredients: Sodium chloride: ORAL (LD50): Acute: 3000 mg/kg [Rat.]. 4000 mg/kg [Mouse]. DERMAL (LD50): Acute: >10000 mg/kg [Rabbit]. DUST (LC50): Acute: >42000 mg/m 1 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: When heated to decomposition it emits toxic fumes.

Special Remarks on Explosion Hazards:
Electrolysis of sodium chloride in presence of nitrogenous compounds to produce chlorine may lead to formation of explosive nitrogen trichloride. Potentially explosive reaction with dichloromaleic anhydride + urea.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Do not ingest. Do not breathe dust. Avoid contact with eyes. Wear suitable protective clothing. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Solid crystalline powder.)

Odor: Slight.

Taste: Saline.

Molecular Weight: 58.44 g/mole

Color: White.

pH (1% soln/water): 7 [Neutral.]

Boiling Point: 1413°C (2575.4°F)

Melting Point: 801°C (1473.8°F)

Critical Temperature: Not available.

Specific Gravity: 2.165 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility:
Easily soluble in cold water, hot water. Soluble in glycerol, and ammonia. Very slightly soluble in alcohol. Insoluble in Hydrochloric Acid.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, high temperatures.

Incompatibility with various substances: Reactive with oxidizing agents, metals, acids.

Corrosivity: Not considered to be corrosive for metals and glass.

Special Remarks on Reactivity:
Hygroscopic. Reacts with most nonnoble metals such as iron or steel, building materials (such as cement) Sodium chloride is rapidly attacked by bromine trifluoride. Violent reaction with lithium.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 3000 mg/kg [Rat.]. Acute dermal toxicity (LD50): >10000 mg/kg [Rabbit]. Acute toxicity of the dust (LC50): >42000 mg/m3 1 hours [Rat].

Chronic Effects on Humans: MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Lowest Published Lethal Dose (LDL) [Man] - Route: Oral; Dose: 1000 mg/kg

Special Remarks on Chronic Effects on Humans:
Causes adverse reproductive effects in humans (fetotoxicity, abortion,) by intraplacental route. High intake of sodium chloride, whether from occupational exposure or in the diet, may increase risk of TOXEMIA OF PREGNANCY in susceptible women (Bishop, 1978). Hypertonic sodium chloride solutions have been used to induce abortion in late pregnancy by direct infusion into the uterus (Brown et al, 1972), but this route of administration is not relevant to occupational exposures. May cause adverse reproductive effects and birth defects in animals, particularly rats and mice (fetotoxicity, abortion, musculoskeletal abnormalities, and maternal effects (effects on ovaries, fallopian tubes) by oral, intraperitoneal, intraplacental, intrauterine, parenteral, and subcutaneous routes. While sodium chloride has been used as a negative control n some reproductive studies, it has also been used as an example that almost any chemical can cause birth defects in experimental animals if studied under the right conditions (Nishimura & Miyamoto, 1969). In experimental animals, sodium chloride has caused delayed effects on newborns, has been fetotoxic, and has caused birth defects and abortions in rats and mice (RTECS, 1997). May affect genetic material (mutagenic)

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: May cause skin irritation. Eyes: Causes eye irritation. Ingestion: Ingestion of large quantities can irritate the stomach (as in overuse of salt tablets) with nausea and vomiting. May affect behavior (muscle spasicity/contraction, somnolence), sense organs, metabolism, and cardiovascular system. Continued exposure may produce dehydration, internal organ congestion, and coma. Inhalation: Material is irritating to mucous membranes and upper respiratory tract.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Sodium chloride

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
R40- Possible risks of irreversible effects. S24/25- Avoid contact with skin and eyes.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 0

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Splash goggles.

Section 16: Other Information

References:
-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II.

Other Special Considerations: Not available.

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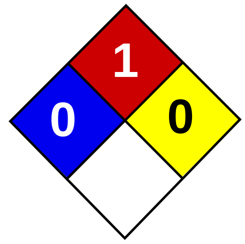
Last Updated: 05/21/2013 12:00 PM



Health	2
Fire	1
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Propylene glycol MSDS

Section 1: Chemical Product and Company Identification

Product Name: Propylene glycol

Catalog Codes: SLP1162, SLP2974

CAS#: 57-55-6

RTECS: TY2000000

TSCA: TSCA 8(b) inventory: Propylene glycol

CI#: Not applicable.

Synonym: 1,2,-propanediol, 1,2-dihydroxypropane

Chemical Name: Propylene Glycol

Chemical Formula: CH3CHOHCH2OH

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Propylene glycol	57-55-6	100

Toxicological Data on Ingredients: Propylene glycol: ORAL (LD50): Acute: 20000 mg/kg [Rat]. 22000 mg/kg [Mouse]. DERMAL (LD50): Acute: 20800 mg/kg [Rabbit].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of ingestion. Slightly hazardous in case of skin contact (irritant, permeator), of eye contact (irritant), of inhalation.

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (sensitizer). CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: 371°C (699.8°F)

Flash Points: CLOSED CUP: 99°C (210.2°F). OPEN CUP: 107°C (224.6°F) (Cleveland).

Flammable Limits: LOWER: 2.6% UPPER: 12.5%

Products of Combustion: These products are carbon oxides (CO, CO_2).

Fire Hazards in Presence of Various Substances: Slightly flammable to flammable in presence of heat.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: When heated to decomposition it emits acrid smoke and irritating fumes.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Absorb with an inert material and put the spilled material in an appropriate waste disposal. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, reducing agents, acids, alkalis, moisture.

Storage:
Hygroscopic. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 23°C (73.4°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 10 (mg/m3) from AIHA Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid. (Oily liquid.)

Odor: Practically Odorless.

Taste: Practically Tasteless.

Molecular Weight: 76.1g/mole

Color: Colorless. Clear

pH (1% soln/water): Not available.

Boiling Point: 188°C (370.4°F)

Melting Point: -59°C (-74.2°F)

Critical Temperature: Not available.

Specific Gravity: 1.036 (Water = 1)

Vapor Pressure:
0 kPa (@ 20°C) 0.08 mmHg at 20 C 0.129 mmHg at 25 C

Vapor Density: 2.62 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: The product is more soluble in water; log(oil/water) = -0.9

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, acetone.

Solubility: Soluble in cold water, hot water, acetone.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, excess heat, exposure to moist air or water

Incompatibility with various substances: Reactive with oxidizing agents, reducing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic; keep container tightly closed. Incompatible with chloroformates, strong acids (nitric acid, hydrofluloric acid), caustics, aliphatic amines, isocyanates, strong oxidizers, acid anhydrides, silver nitrate, reducing agents.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact.

Toxicity to Animals:
Acute oral toxicity (LD50): 18500 mg/kg [Rabbit]. Acute dermal toxicity (LD50): 20800 mg/kg [Rabbit].

Chronic Effects on Humans: May cause damage to the following organs: central nervous system (CNS).

Other Toxic Effects on Humans:
Hazardous in case of ingestion. Slightly hazardous in case of skin contact (irritant, permeator), of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May affect genetic material (mutagenic). May cause adverse reproductive effects and birth defects (teratogenic) based on animal test data.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: May cause mild skin irritation. It may be absorbed through the skin and cause systemic effects similar to those of ingestion. Eyes: May cause mild eye irritation with some immediate, transitory stinging, lacrimation, blepharospasm, and mild transient conjunctival hyperemia. There is no residual discomfort or injury once it is washed away. Inhalation: May cause respiratory tract irritation. Ingestion: It may cause gastrointestinal tract irritation. It may affect behavior/central nervous system(CNS depression, general anesthetic, convulsions, seizures, somnolence, stupor, muscle contraction or spasticity, coma), brain (changes in surface EEG), metabolism, blood (intravascular hemolysis, white blood cells - decreased neutrophil function), respiration (respiratory stimulation, chronic pulmonary edema, cyanosis), cardiovascular system(hypotension, bradycardia, arrhythmias, cardiac arrest), endocrine system (hypoglycemia), urinary system (kidneys), and liver. Chronic Potential Health Effects: Skin: Prolonged or repeated skin contact may cause allergic contact dermatitis. Ingestion: Prolonged or repeated ingestion may cause hyperglycemia and may affect behavior/CNS (symptoms similar to that of acute ingestion). Inhalation: Prolonged or repeated inhalation may affect behavior/CNS (with symptoms similar to ingestion), and spleen

Section 12: Ecological Information

Ecotoxicity:
Ecotoxicity in water (LC50): >5000 mg/l 24 hours [Goldfish]. >10000 mg/l 48 hours [guppy]. >10000 mg/l 48 hours [water flea].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations:
Pennsylvania RTK: Propylene glycol Minnesota: Propylene glycol TSCA 8(b) inventory: Propylene glycol

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
R21/22- Harmful in contact with skin and if swallowed. S24/25- Avoid contact with skin and eyes.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 1

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 0

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Splash goggles.

Section 16: Other Information

References:
-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II. -Supplier MSDS -LOLI -RTECS -HSDB

Other Special Considerations: Not available.

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BIOGRAPHY

Mochammad Soleh was born in Jember, East Java, on 09th July 1995. He is the third son of a father named Kuswandi Achmad Sulton and a mother named Sudarmi. Soleh spent six-year primary study at SDN 1 Kaliglagah. He entered elementary school in 2002 and graduated in 2008. Right after, he had his secondary level of study at SMPN 2p Jatiroto and graduated in 20011. He, then, continued his study to SMAN 1 Lumajang and graduated in 2014. In the same year, he continued studying to Sepuluh Nopember Institute of Technology majoring in Marine Engineering, Faculty of Marine Technology and graduated on September, 2018.

During his study at Sepuluh Nopember Institute of Technology, Soleh was a member of EPC Office project team which is working in Oil & Gas Fields for Several different projects in Remaining Life Assessment (RLA), Monitoring, Equipment Critical Analysis (ECA) and so on. He is also a member of Marine Machinery and System Laboratory and actively participated in some organizations and social communities, such as becoming head of division in Research and Technology Department (2014-2015) and Marine Engineering English Club in Marine Engineering Student's Union. Besides, he once chosen as Indonesian delegation to join Erasmus+ Student Mobility in Warsaw University of Technology 2017, Poland for one semester, ITS delegation in National Chung Hsing University (NCHU) Summer Internship Program 2018 in Taiwan and as one of three awardees of American Bureau Shipping Scholarship 2018.

He took two different months of internship program conducted in PT. DUMAS Tanjung Perak Shipyard Surabaya, and PT. Badak Natural Gas Liquefaction (NGL) Bontang, Kalimantan Timur.

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