UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF DIFFERENT THERMAL INSULATOR MATERIALS ON THERMAL ENERGY STORAGE (TES) HEAT LOSS

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering Technology (Refrigeration and Air-conditioning System) with Honours.

by

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I hereby, declared this report entitled “Effect of different thermal insulator materials on thermal energy storage (TES) heat loss” is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning system) with Honors. The member of the supervisory is as follow:

……

(Project Supervisor)

ABSTRAK

Kajian ini menggambarkan penghasilan papan penebat haba ketumpatan rendah yang diperbuat daripada sekam padi dan sabut kelapa sebagai bahan organik. Sementara itu, polistirena digunakan sebagai penebat terma bukan organik. Tujuan kajian ini adalah untuk mencipta penebat haba yang boleh digunakan dalam penggunaan sebenar tangki penyimpanan tenaga haba berbanding daripada bahan konvensional. Kaedah penekanan panas telah digunakan dalam kajian ini dan kesan ketumpatan papan dan komposisi pengikat pada sifat-sifat penebat, papan akan dicatatkan. Di samping itu, semua parameter yang digunakan dalam kaedah penekanan panas untuk penebat organik adalah sama. Kekonduksian haba sekam padi, sabut kelapa dan polistirena telah diukur untuk dibuat perbandingan dengan sistem penebat semasa yang digunakan di tangki TES. Ianya telah ditemui bahawa semua papan penebat termal yang digunakan dalam kajian ini menunjukkan konduktiviti termal yang rendah berserta dengan ketumpatan papan yang rendah yang mana ianya hamper sama dengan bahan penebat TES konvensional seperti bulu mineral dan busa poliuretana. Untuk peratusan penyerapan air, polistirena memberi nilai terendah yang mana ianya sangat baik untuk digunakan sebagai jenis penebat haba yang kalis air. Walau bagaimanapun, bagi kedua-dua jenis penebat haba jenis organik, peratusan penyerapan air agak tinggi yang mana ianya dapat mengurangkan kecekapan sistem sesuatu penebat.

ABSTRACT

This study describes the development of low density thermal insulation boards made from rice husk and coconut coir as organic materials. Meanwhile, polystyrene is used as non-organic type of thermal insulator. The aim of this study was to develop a thermal insulation that can be applied in the real application of thermal energy storage (TES) tank. The hot pressing method was used to make the thermal insulator boards from organic materials. In addition, all the parameters used in hot pressing method for rice husk and coconut coir are same. This research is reported based on the effect of board densities and their binder composition on the properties of the insulation boards. The thermal conductivity of rice husk, coconut coir and polystyrene boards were measured in order to do the comparison with current insulation system used in TES tank. It was found that all the thermal insulation boards in this study achieved low thermal conductivity with low board density which was close to those conventional TES insulation materials such as mineral wool and polyurethane foam. For the percentage of water absorption, polystyrene gives the lowest value which is good to be used as water resistance type of thermal insulators. However, for both organic types of thermal insulators, the percentages of water absorption are quite high which can reduce the efficiency of insulating system.

DEDICATION

Dedicated to my beloved parents,
My father, Mohd Razali Bin Din
My mother, Fatimah Wati Binti Tahir
and all my family, lecturers and friends
for their immeasurable support and love

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

A	-	Area
AC	-	Air-conditioning
CTES	-	Cold Thermal Energy Storage
CWS	-	Chilled Water system
EPS	-	Expanded Polystyrene
HVAC	-	Heating, Ventilation and Air-conditioning
h	-	Convection heat transfer coefficient
ITC	-	Iced Thermal Storage
K	-	Thermal conductivity
PCM	-	Phase Change Material
PU	-	Polyurethane
Q	-	Heat flux
TES	-	Thermal Energy Storage
TNB	-	Tenaga Nasional Berhad
XPS	-	Extruded Polystyrene
ϵ	-	Emissivity
σ	-	Stefan – Boltzmann constant

CHAPTER 1
INTRODUCTION

1.1 Electrical energy demand

Demand for electricity energy has become critical now than ever before. Most of the developing countries recorded energy growth by more than 10 % annually (Lusoh, 1996). Besides, the hot and dry weather is prolonged to this day resulting in increased electricity consumption. In Malaysia, this condition of weather has affected the electrical consumption habit as the air-conditioner (AC) consumed more electricity compared to other equipment in daily routine. Other than that, according to Tenaga Nasional Berhad (TNB), the use of old electrical appliances that are not properly maintained also can result in increased electricity consumption.

The use of Air condition AC system has been widely used around the world especially in hot and humid countries including Malaysia, as it located near the Equator. Like any other developing country, Malaysia has experienced a rapid economic growth since the past decade. Thus, the residential electricity consumption has increased drastically when people start to use AC system in the house. It is predicted that the amount of AC system use for residential and industrial will be reached around 1.5 million units by year 2020 (Rismanchi et al. 2012). Meanwhile, (Dinçer & Rosen 2010) already predicted that the energy consumption of AC systems tend to reach to 3055 GW-hr by year 2015 approximately However, by letting the AC system to be used all the time without any occupant in the room or building is very inefficient practice as it caused higher energy consumption. In addition, it also will damage the AC system as well and reduce for the lifetime of the system.

1.2 Thermal energy storage

Normally, the AC systems operate only for a few hours each day. The electricity consumption pattern of the AC systems can be divided in two operating periods, which are daytime (peak hours) and night time (off peak hours). Particularly the electricity for off peak hours is much cheaper than peak hours. Therefore, many researchers tried to invent new technology for heating, ventilation and cooling (HVAC) system in order to reduce the electricity consumption. As the result, thermal energy storage (TES) has been invented as a solution for this problem. Nowadays, there are many types of thermal energy storage existed such as solar energy and thermal energy storage, sensible thermal energy storage, latent thermal energy storage, cold thermal energy storage and seasonal thermal energy storage. These types of TES are specified based on their working principal and storage method.

Generally in Malaysia, cold thermal energy storage (CTES) is the most preferable technology used in this country since the weather is hot and humid throughout the year. CTES is a technology whereby cool energy is stored in a thermal reservoir during off peak periods and released during periods of peak demand. As the result, it can improve the system performance and reduced total cost for electricity bills effectively (ASHRAE Handbook). Based on the storage medium, CTES systems are categorized in three major types including ice thermal storage (ITS), chilled water storage (CWS) and eutectic salt phase change material (PCM) thermal energy storage systems.

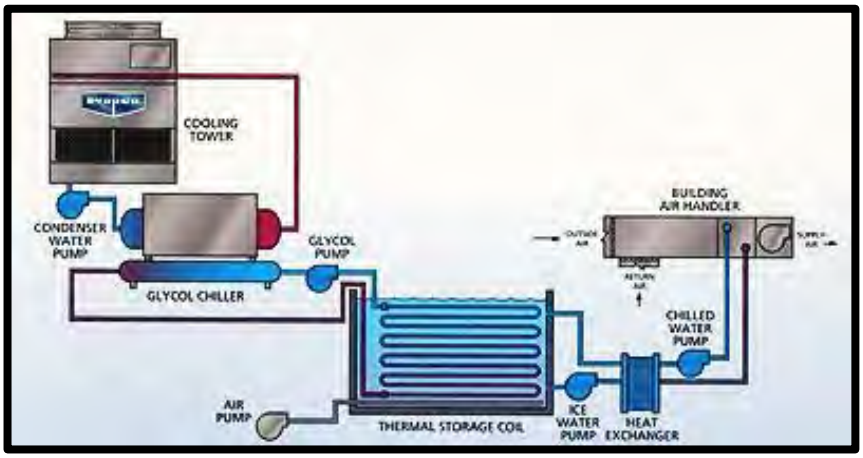

Figure 1.1: Cold thermal energy storage CTES schematic diagram

For ITS system, it can be very economical because it require less space compared to the CWS. Usually this system use smaller tank and it can operate at low temperature air system, but at the same time it requires more complex chiller system. Next, CWS system may require the largest storage tank, but it can easily interface with existing chiller systems. It used the sensible heat capacity of water to store cooling capacity. However, it has the most complex charge and discharge equipment because of the storage size and capacity. Meanwhile, eutectic salt also can use existing chiller but usually it can only operate at warmer temperature than ITS and CWS. This system also uses a combination of inorganic salts, water and other elements to create a mixture that freeze at a desired temperature.

The potential of CTES as a system that can change the pattern of electricity consumer have gained a lot of recognition especially from electricity supplier. The reason is CTES technology able to give great impact on the economic strategies. The use of CTES systems in building applications can decrease energy costs and also reduce the total energy consumption. When the electricity consumption at a low level, thus it will reduce the risk against the environmental impact.

1.3 Disposal of organic waste product

Malaysians are generating waste at an alarming rate, much faster than the natural degradation process and they are using up landfill space. Some of this waste is even dumped into drains, on the roadsides and at illegal dumpsite. Most of waste generated in this country is from organic and food waste which is the wet type of waste. The source of these organic waste include coconut shell and fibre, kitchen waste, sugarcane fibre, rice husk paddy, unwanted vegetables and many more.

Agricultural combustion occurs as an activity to eliminate agricultural waste such as rice husk. This activity is still practiced by farmers, who cultivate rice traditionally especially in Kedah. Combustion of rice husk is usually carried out during the harvesting season, after the paddy was cultivated for 120 days to be composted or fertilized.

This activity is also intended to increase soil fertility after the rice is harvested because it will kill the remaining rice seeds that can interfere with the cultivation and growth of paddy that will be replanted afterwards. However, when the combustion of rice husk was not managed properly, it will cause an air quality problem to the environment due to the fire that easily spread and take a long time to extinguish it. Otherwise, the uncontrolled fire also tends to become great burning that will cause damage especially during relatively dry and hot seasons throughout the day. In addition, the air pollution that occur due to the open burning also will effect human health and cause serious diseases such as asthma, lung cancer, skin irritation and many more.

Next, the industrial and agricultural sectors are the most main sectors in Malaysia that contribute to the destruction of the environment especially the water pollution. The main causes for this problem including the use of chemical fertilizers, and discharge and disposal of organic and toxic waste illegally to the water. Disposal of organic and non-organic waste through the agriculture activities to the rivers such as hazardous metals and organic bagasses is very endanger to the aquatic life. Furthermore, there are several diseases that caused by drinking contaminated or dirty water. Contaminated water can cause many types of diarrheal diseases, including Cholera, and other serious illnesses such as Guinea worm disease, Typhoid, and Dysentery which can cause death to human.

1.4 Problem statement

Several studies have been proved that TES is one of HVAC innovation that able to save great amount of electricity bills during peak hours. It uses off peak night time energy to provide cold storage which is basically ice that is used to run up the systems throughout the day.

However, there is still a possibility that the heat may be loss to surrounding especially in the tank during the day due to the environmental factors such as weather, ambient temperature and radiant heat. These factors may contribute to the phase change of ice inside the tank and cause it to melt rapidly. Therefore, this situation will reduce the TES system performance as the amount of ice supplied is not operates based on its operating temperature range, thus it cannot support enough load in the whole building.

Thermal insulation is one of the effective methods that can reduce heat loss in the TES tank because it can act as a heat flow resistor in the system. In addition, it has been widely used for building insulation, ductworks, clothing and many more. Commonly, the effectiveness of thermal insulation depends on type of material used in the system. The use of renewable sources like organic material in making the thermal insulation has been widely used in many applications. The reason is peoples tend to find ways to save the environment by inventing product that is high biodegradability, with low cost and reduce energy consumption. In contrast, synthetic materials also have been selected for thermal insulation in industrial application because it has a lot of advantages on the material strength and hardness which is very good for a long term usage.

1.5 Objectives

Based on introduction and problem study above, the objective of this study as follow:

i. To develop the thermal insulation board by using organic and non-inorganic materials
ii. To study the value of thermal conductivity for different type of thermal insulators
iii. To determine the percentage of water absorption for the thermal insulators after being immersed in water

1.6 Scopes

In order to achieve the objectives in this study, several scopes have been stated:

1. The raw material selection for organic and non-organic product to be used as thermal insulators. For organic material, rice husk and coconut coir has been selected, whereas polystyrene has been selected as non-organic material.
2. The prototype used in this study is steel cans which is filled with ice that will act as TES tank.
3. The machine used to make the particle board from organic materials is hot pressing machine which is located at Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malysia Melaka.
4. The experiment will be conducted in Heat Transfer Laboratory located at Fakulti Teknologi Kejuruteraan, Universiti Teknikal Malaysia Melaka by using Heat Flow Meter device.
5. The experimental assessment that will focus in this study are the thermal conductivity value and the percentage of water absorption

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter reviews related journals and researches on the description of variety concepts for TES in detail. Generally, the process of heat loss in thermal energy storage tank occurs by mechanisms of heat transfer which are conduction, convection and radiation. Therefore thermal insulation needs to be considered for the development of thermal energy storage tank to prevent more heat loss to surrounding. The material selection for thermal insulator also is the main focus that should be approached in order to determine the insulation ability against the thermal energy storage tank. Therefore, this chapter will describe on the findings from the investigation that have been carried out by several researchers which are targeted on medium of heat transfer, type of thermal insulation and the condition of heat loss in the thermal energy storage tank.

2.2 Thermal energy

Thermal energy is an energy which is produced from the heat and it involves the motion of molecules in the mass or surrounding. Heat is generated more when the movement of molecules in the mass is high. Figure 2.1 show the types of molecules motion involve in process of heat transfer such as rotation (circular motion), translation (motion in axis) and vibration (back and forth motion).

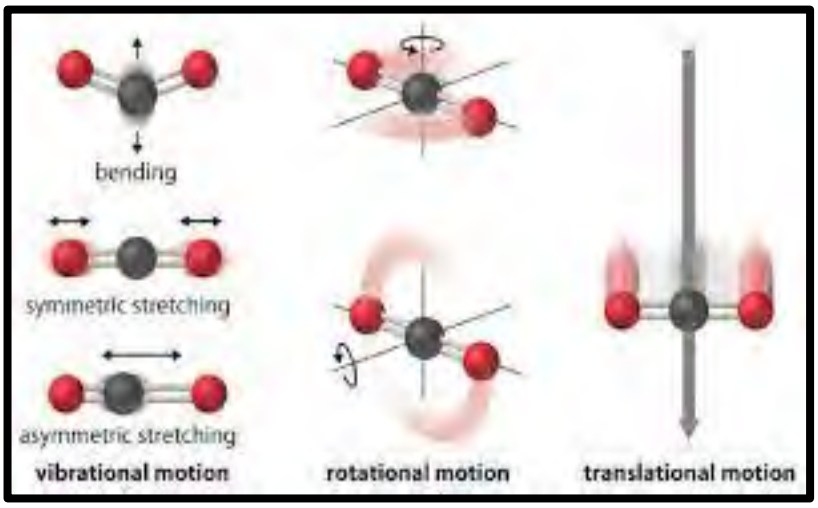

Figure 2.1: Motion of molecules in heat transfer

Next, temperature measures the average kinetic energy of molecules. Usually, the behaviour of molecules in hot object tends to has high kinetic energy compared to molecules in cool object. So, when the hot object is in contact directly with cold object, there would be a collision of molecule that occurs within both objects. Some of molecules in hot object will transfer their kinetic energy to the molecules in cold object. Thus, this transfer of kinetic energy of molecules can be related to the heat transfer method for conduction and convection (Hoboken, N.J.: Wiley, 2011).

After the transfer of heat continues between two touching medium for a while, finally the molecules inside the medium will reach the equilibrium state. The temperature between two mediums also will become equal. Hence, this condition already follows the Zeroth Law of thermodynamic. This law states that when two different bodies with different temperature are stick together, the bodies will achieved the thermal equilibrium with same degree of warmth. In the equilibrium system, commonly the measurable properties such as the temperature, pressure and density will remain same and it does not involve with time except for some special case (H. Gould et al, 2009).

2.3 Heat transfer

Heat is a type of energy that can cause the increment and decrement of temperature in a substance. Heat transfer can be defined as the situation of the heat is being transferred from one medium to another medium. The condition of heat transfer can involve in many cases especially in daily life which are including process of heating, cooling, condensation, evaporation and many more.

Basically, the heat is moved from high temperature to lower temperature through the mediums existing. However, there must be one condition that needs to consider during the process of heat transfer, where the temperature difference should be exist between the two mediums related so that the heat can be moving through the medium by a driving force (Hoboken, N.J.: Wiley, 2011).

Generally, the mode of heat transfer can be divided into three main processes which are conduction, convection and radiation. In some situation, these three modes of heat transfer can be happen at the same time through a same medium. The process of heat transfer of conduction can occur when there is temperature gradient in the medium either in form of solid or fluid (consist of liquid and gas) which allow the heat to flow across the medium. Next, the convection process can take place when there is difference in temperature between a moving fluid and the surface of the medium. Meanwhile, radiation emits the heat directly in the form of electromagnetic waves.

2.3.1 Conduction

Thermal conduction of the substance can be simply defined as the heat transfer from one point to another point within same material, or from one material to another material by physical contact.

For example when there is a solid object is subjected to heat conduction, the molecules inside the substance will start to vibrate and transfer the heat due to the internal radiation. If the solid object is metal, the moving electrons inside a metal object tend to move from an atom to another through the substance. Then, the electrons redistribute energy in the metal object and this behaviour can be relates to the thermal conductivity in the materials.

Fourier's law of heat conduction states that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area. The equation below represents the heat conduction of Fourier's law

$$Q = -kA\,\frac{dT}{dx}$$

Here, the term k is thermal conductivity which measures the ability of material to conduct heat. Whereas, dT/dx represent the temperature gradient of the temperature curve on a T-x diagram. The negative sign in the equation is used to ensure the value of heat conduction is always positive, as heat is conducted in direction of decreasing temperature.

In the TES application, conduction and natural convection are the most important factors causing the heat transfer in the system especially in liquid phase (Cabeza & Mehling 2003). Meanwhile for pure substance of thermal energy storage, they consider that the heat transfer only occur in one-dimensional conduction where the heat flows in one direction only.

Besides, according to (Sharma et al. 2009) only conduction is considered during phase change material (PCM) for latent heat energy storage system. Normally the PCM in the system is originally in solid state and then it melts into liquid after conduction of heat take place.

2.3.1.1 Steady-state conduction

Conduction of heat can be divided into two different conditions which are steady-state heat conduction and unsteady-state (transient) heat conduction. Steady-state heat is the condition of heat transfer through the solid by electrical force fields among the molecules. When the temperature of the solid becomes high, the kinetic energy inside the molecules also will start to increase. In this situation, the heat flows does not involved with the change in time.

2.3.1.2 Unsteady-state conduction

For the unsteady-state heat conduction, the flow of heat at particular point of surface is not constant with the time. Sometimes, this type of heat of heat conduction also can be influenced by others mode of heat transfer such as forced convection, free convection and radiation. For instance, when an engine starts up, the heat start to flow in transient heat conduction as the system is not stable at the beginning. Then, after some moments, the system becomes stabilize and the heat conduction turns into steady-state condition (Tulwin 2016).

2.3.1.3 Thermal conductivity

Theoretically, thermal conductivity is the amount of heat flows per unit time through the thickness of surface area based on the given temperature. Usually, the unit used for conductivity is W/m.°C. Next, thermal conductivity also measures how fast or how easily the heat can flow through the metal.