Investigation of potential waste material insulating properties at different temperature for thermal storage application

To cite this article: T Z S Ali *et al* 2013 *IOP Conf. Ser.: Mater. Sci. Eng.* **50** 012049

View the article online for updates and enhancements.

Related content

- A Comparison between Passive Regenerative and Active Fluidized Bed Thermal Energy Storage Systems
  M Haider, K Schwaiger, F Holzleithner et al.

- Heat exchangers and thermal energy storage concepts for the off-gas heat of steelmaking devices
  T Steinparzer, M Haider, A Fleischanderl et al.

- Sustainable manufacturing: Effect of material selection and design on the environmental impact in the manufacturing process
  Mohd Hazwan Syafiq Harun, Zahari Taha and Hadi Abdul Salaam

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Investigation of potential waste material insulating properties at different temperature for thermal storage application

T Z S Ali[1], A B Rosli, L M Gan, A S Billy and Z Farid
 Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang. Malaysia

E-mail: [a] tanty.ali@gmail.com

Abstract. Thermal energy storage system (TES) is developed to extend the operation of power generation. TES system is a key component in a solar energy power generation plant, but the main issue in designing the TES system is its thermal capacity of storage materials, e.g. insulator. This study is focusing on the potential waste material acts as an insulator for thermal energy storage applications. As the insulator is used to absorb heat, it is needed to find suitable material for energy conversion and at the same time reduce the waste generation. Thus, a small-scale experimental testing of natural cooling process of an insulated tank within a confined room is conducted. The experiment is repeated by changing the insulator from the potential waste material and also by changing the heat transfer fluid (HTF). The analysis presented the relationship between heat loss and the reserved period by the insulator. The results show the percentage of period of the insulated tank withstands compared to tank insulated by foam, e.g. newspaper reserved the period of 84.6% as much as foam insulated tank to withstand the heat transfer of cooking oil to the surrounding. The paper finally justifies the most potential waste material as an insulator for different temperature range of heat transfer fluid.

1. Introduction
In a solar energy power plant, four elements are required to have which are concentrator, receiver, transport/storage media system and power conversion device. Of all the components, thermal storage is a key component. However, it is also the less developed. Only a few plants in the world have tested high temperature thermal energy storage systems [1].

Energy storage systems in commercial use today can broadly categorised as showed in Figure 1. Energy storage became a dominant factor in economic development to make electrical generation power plant reliable. Thermal energy storage can be divided into three main categories: sensible heat storage, latent heat storage and chemical storage [2].
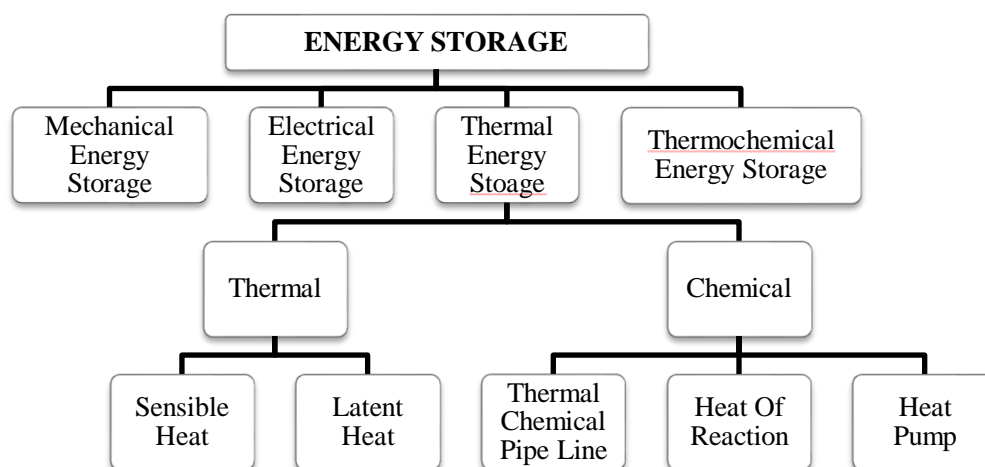
Figure 1. Classifications of energy storage

Today, the development of the energy storage system is growing as to fulfil the demand of users. An energy storage design needs to consider a lot of criteria (applicable laws, standards, technology and cost) in order to establish the system. Researches have been conducted in proposing not only a safe and efficient energy storage system but also an economic and green environment configuration.

2. MATERIALS

2.1 Waste Materials

Waste refineries focusing on various outputs of material resources, energy carriers, and nutrients may potentially provide more sustainable utilization of waste resources than traditional waste technologies. On the basis of research, it is recommended that a narrow focus on global warming aspects should be avoided as most waste technologies may provide comparable performance.

Presently the environmental permits will include necessary regulations on wastes and reduction of their quantity and harmfulness. Table 1 explained the problems associated upon waste and alternatives to land disposal for different waste type. This information is taken from Trash Management Guide 1992.

Table 1. Waste type problems and alternatives.

Waste Type	Problems	Alternatives
Paper	Litter. Fuel source for uncontrolled fires	Ask stores to reuse packaging for other purposes.
Leather & rubber	Minimal concerns	Set up salvage area
Metals	Corrosion slowly releases metals and causes landfill area	Recycle
Yard wastes/wood	Shelters rodents and other animals	Compost yard waste

In addition, efficiency in the use of materials must be taken into account as required. Thus, in TES development, there are a form of materials can be used as an insulator in order to absorb heat. The insulator ability is measured by its R-value, which was the resistance to heat flow. The higher the number, the more blocking capacity or insulating it provides. Table 2 summarized the insulating capabilities, densities and thermal conductivities of materials used in this study.

Table 2. Thermal properties of natural materials.

Material	Insulating Capability (R-value) K.m²/W	Density, ρ kg/m³	Thermal conductivity, k W/m.K
Foam	1.23-1.41	30-150	0.025-0.035
Sand	1.11	1515	0.2-1.0
Rubber	1.23	1100	0.13
Newspaper	0.52-0.7	930	0.18
Wire mesh	3.8-4.1	7850-7950	0.22-0.65

Gil suggested to used a material that is low cost, good thermal conductivities, comfort during handling and have good structural strength [1]. Hence using the waste materials as insulators, it is not only reducing the price but also reduce the pollution.

2.2. Heat Transfer Fluid (HTF)

Fluid which flows neither through nor around a device to prevent overheats, transfer the heat produced to other devices that use or disperse it is known as coolant. The term coolant commonly used in automotive applications, in industrial processing, heat transfer fluid (HTF) is one technical term more commonly used, in high temperature as well as low temperature manufacturing applications. HTF can either maintain its form or undergo a phase transition with the latent heat add to the cooling efficiency.

The most common HTF for low temperature is water. It contained high heat capacity and low cost makes it a proper heat-transfer medium. Water appears to be the best liquid available because it is inexpensive and has a high specific heat. However for temperature above 100℃, oils, molten salts and liquid metals, etc. are used.

Oils are used for applications where water is incompatible. Oil can be raised to a higher temperature above 100℃ without introducing high pressures within the container. Oil has higher boiling points than water. Other than that mineral oils serve as both coolants and lubricants in various mechanical gears. Castor oil is also used. Due to their high boiling points, mineral oils are used in portable electric radiator-style space heaters in residential applications and in closed-loop systems for industrial process heating and cooling.

For example, Mawire [3] has been using oil in the glass tube TES system and its thermal performance is evaluated. In his study, he presented the results of energy and exergy charging rates during the experiments at temperatures of 200⁰C, 250⁰C, and 300⁰C. The results indicate an optimal charging temperature when exceeded the usage and the thermal performance due to increased heat losses.

3. Thermal study of materials

Insulating capability is measured with thermal conductivity, k. Low thermal conductivity is equivalent to high insulating capability, R-value. Thermal conductivity, k represents how well a material conducts heat.

A useful; material is the one that reasonable, have good thermal capacity and the rate for heat to be released and extracted (thermal diffusivity). Thermal diffusivity measures on how fast the heat diffuses through a material. Thermal energy can be stored in solid or liquid materials. The ratio of the thermal conductivity and heat capacity defined the thermal diffusivity.

$$\alpha = \frac{k}{\rho c} \tag{1}$$

High values of thermal conductivity indicate that the material is a potential heat conductor, and a low value indicates that the material is an insulator.By considering steady heat conduction,

$$\dot{Q} = -kA\frac{dT}{dx} \tag{2}$$

Here, dT/dx is the temperature gradient, which is the slope of the temperature curve on T-x diagram (the rate of change of T with x, e.g. time), at location x [4]. Therefore, the amount of thermal energy stored in a mass of material can be calculated as:

$$Q = \rho . \bar{c}_p . V . \Delta T \tag{3}$$

where, Q : amount heat stored (J)

ρ : density of the storage material (kg/L)

$\bar{c}_p$: specific heat over the temperature range of operation (J/(kg.K))

ΔT : temperature range of operation (℃)

4. Experimental testing setup

A small-scale storage tank undergoes natural cooling process in a confined room without any force cooling system, e.g. fan. In the end, the experiments will justify the most potential waste material as an insulator in different HTF based on the comparison.

Firstly, a cylindrical container, Tank A, is filled with the insulator material with thickness of 40mm compactly. Thermocouples (T1 and T2) are placed at the position illustrated in Figure 2. Then a litre of HTF; water or cooking oil, is prepared in a cylindrical container, Tank B. The HTF is heated and maintained at 100^0C for water and 300^0C for cooking oil. Then Tank B is placed in the Tank A.
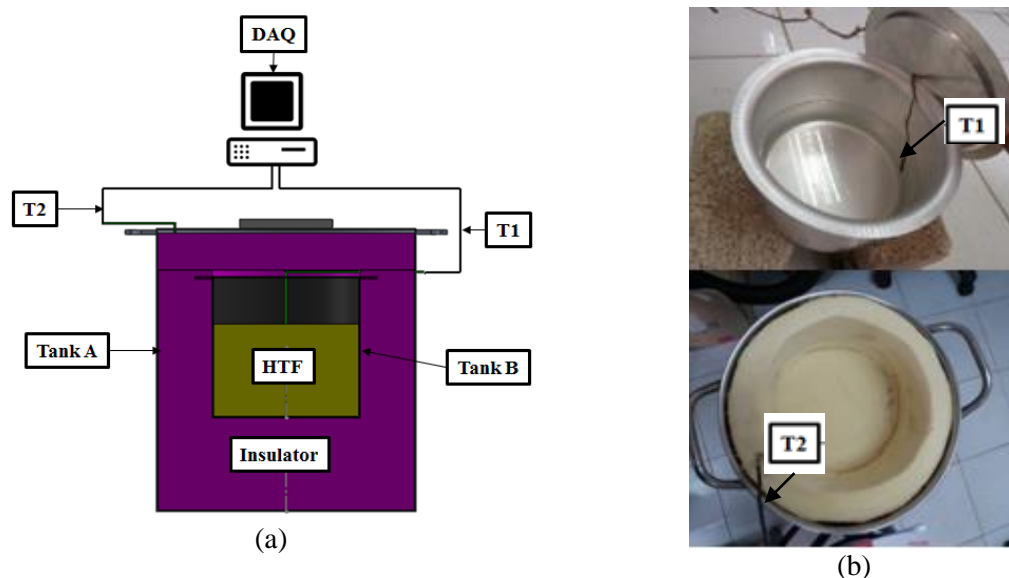

Figure 2. Experimental setup (a)section view and (b)actual conditions.

Data acquisition system was setup to measure the temperatures and collect data. T1, measurement point was set in the middle of the container, Tank B, and T2, was set at a point between Tank A and Tank B. The process of testing the storage materials was based on monitoring the temperature and

time of the experimental period. The testing is measured until T1 reached 40^{0}C and reported in plotted graphs.

This system is developed for the study on dispersal of materials act as an insulator in thermal storage system. This process was setup also based on the combination testing done by other researchers [5][6][7]. Visibly, the experiment was designed to validate the theoretical approach on heat losses and reserved period.
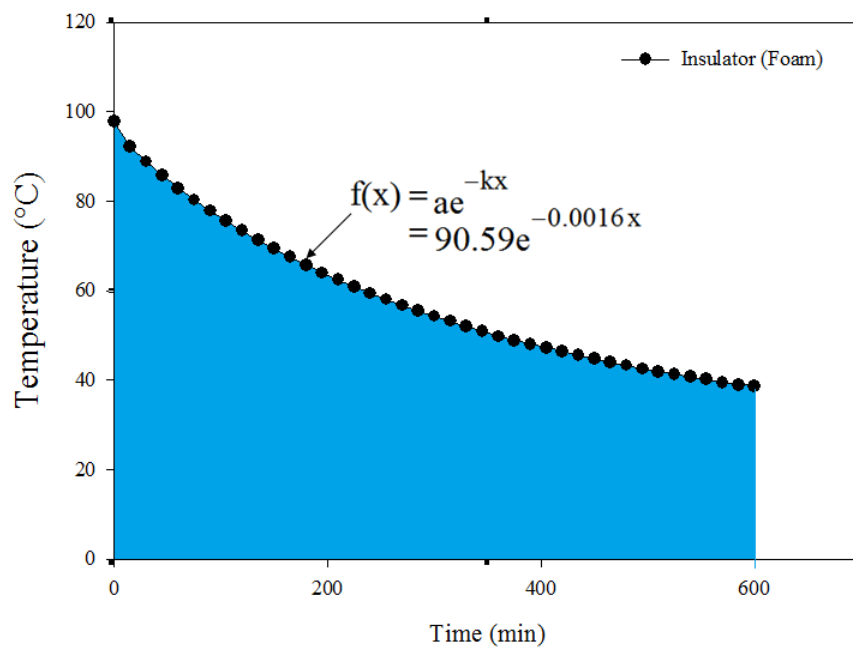
5. Results & discussion

Figure 3 shows exponential decay pattern graphs which are governed by the equation of:

$$f(x)=ae^{-kx} \tag{4}$$

where,

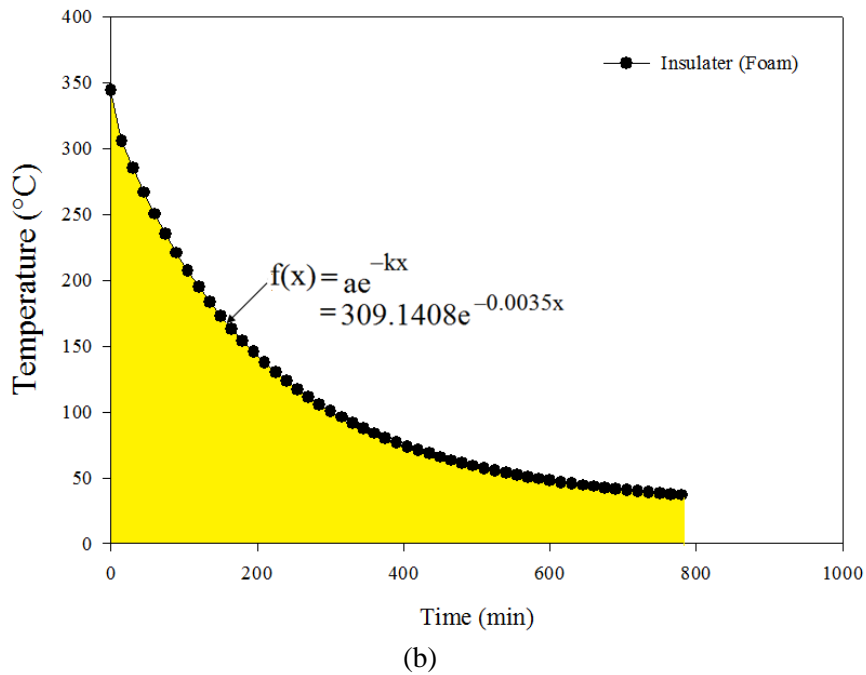|	
x:	time
k:	thermal conductivity(k = 0.0016 and 0.0035)
a:	mean temperature (a = 90.59 and 309.1408)
(-) sign:	cooling process

(a)

(b)

Figure 3. Effect of temperature at different time with (a)water HTF and (b)oil HTF.

As shown in Figure 3(a) and 3(b) are the distribution of temperature at the variation of time for foam insulated tank at different HTF. The figures show the heat of insulators decay decreased and cooling towards the temperature of 40^0C. The areas under the graphs are the reserved period of the insulated tank using a litre of water (Figure 3(a)) and oil (Figure 3(b)) as HTF respectively.

Based on the results from experiments, it is proved the experimental endured the process of cooling. The experiment is repeated using different waste materials as insulators, which were results in different k-values. Then, the k-values are pointed in Figure 4.
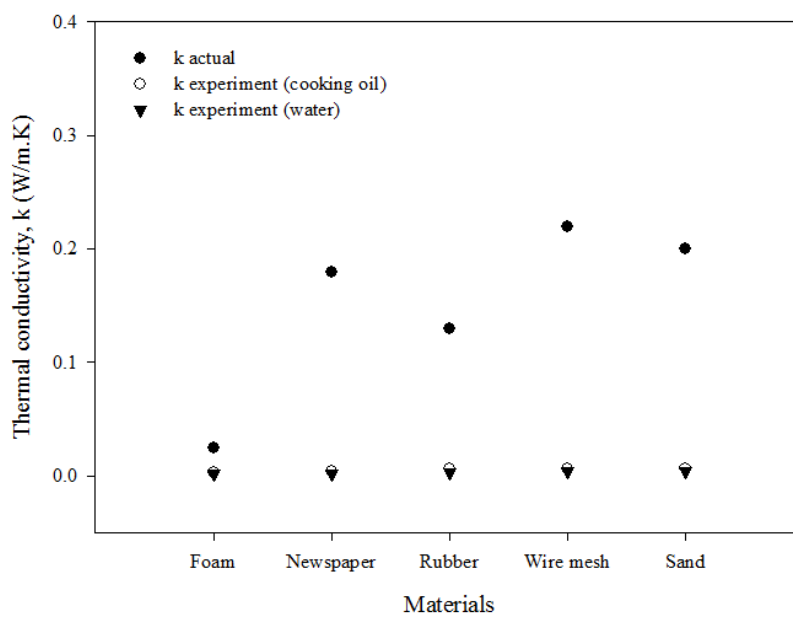

Figure 4. Effect of thermal conductivity, k at different materials.

From the Figure 4, the values for water and oil testing result almost the same, but there is a difference between the experimental and reference values are due to the experimental setup of the containers. It is occurred that containers did not reach the level of vacuum.

Subsequently, based on the results of time, the overall percentage of the reserved period of the insulator is calculated by:

$$\text{Percentage of Reserved Period} = \frac{t_{insulator}}{t_{insulator(foam)}} \times 100\% \tag{5}$$

The reserved period for the insulators is shown in Figure 5. The results show the percentage of the reserved period for potential waste insulating materials in water and oil testing. This figure also showed the value differences between an insulated tank and non-insulated tanks.
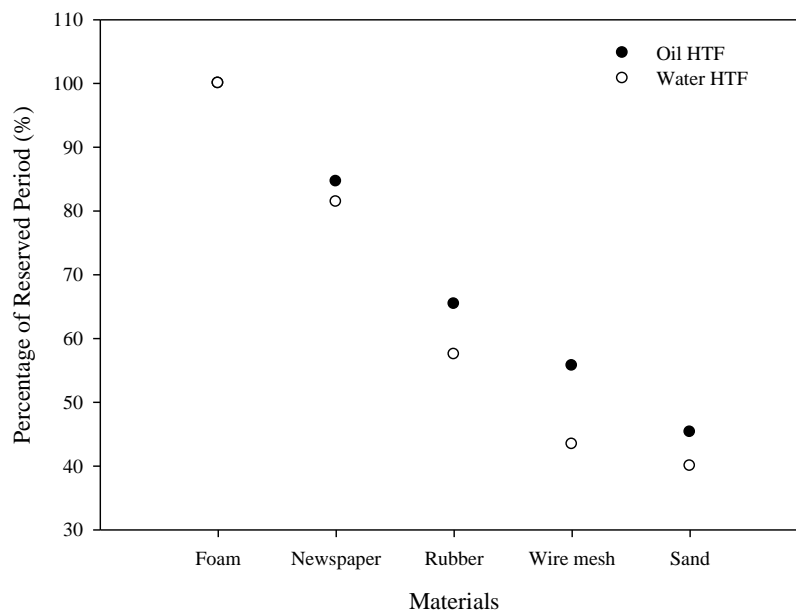

Figure 5. Effect of percentage of the reserved period at different potential waste materials.

The highest percentage of the reserved period for the insulated tank to withstand the heat as good as foam for water and oil as HTF is newspaper. It resulted as well as foam with just about 84.6% in water and 81.4% in oil testing.

This is followed by rubber, wire mesh and sand in both HTF tested. The percentages of the reserved period in water and oil for rubber are 65.4% and 57.5%, wire mesh are 55.7% and 43.4%, and sand are 45.3% and 40% respectively.

The experimental testing proven that the waste materials can be used as insulator which resulted as well as the common insulator used is foam. Based on other researchers [5][7], a suitable material is the one with a low thermal conductivity with low heat loss and high insulating capability.

6. Conclusion

Developing a storage system is an implementation of heat transfer knowledge. As the basis of designing TES is the insulator, selecting the insulator materials are also complicated and costly if based on the application. In this study, it shown that the waste materials could act as well as foam in

preserve period of the HTF. Based on the point of reference of the insulated tank by foam, the percentage of reserved period can be calculated for each waste materials calculated.

Thus for future improvement, the waste materials could be mix and organize surrounded the HTF tank for the insulation test. By conducting the testing could also prove that arrangement of variation insulators could increase the insulation system reserved period.

7. References

[1]   Gil A, Medrano M, Martorell I, Lazaro A, Dolado P, Zalba B and Cabeza L F 2009 State of the art on high temperature thermal energy storage for power generation. Part 1 – Concepts, materials and modellization. *Renewable and Sustainable Energy Reviews*. **14** 31-35

[2]   Barlev D, Vidu R And Stroeve P 2010 Innovation in concentrated solar power. *Solar Energy Materials and Solar Cells*. **95** 2703-2725

[3]   Mawire A, McPherson M and Heetkamp R R J 2009 Thermal performance of a small oil-in-glass tube thermal energy storage system during charging. *Energy* **34** 838-849

[4]   Cengel Y A 2006 Heat and Mass Transfer. New York: McGraw-Hill.

[5]   Canbazoglu S, Sahinaslan A, Ekmekyapar A, Aksoy Y G and Akarsu F 2005 Enhancement of solar thermal energy storage performance using sodium thiosulfate pentahydrate of a conventional solar water-heating system. *Energy and Buildings*. **37** 235-424

[6]   Adinberg R, Zvegilsky D and Epstein M 2010 Heat transfer efficient thermal energy storage for steam generation. *Energy Conversion and Management*. **51** 9-15

[7]   Royon L, Guiffant G and Flaud P 1997 Investigation of heat transfer in a polymeric phase change material for low level heat storage. *Energy Conversion and Management*. **38** 517-524

[8]   Arteconi A, Hewitt N J and Polonara F 2012 State of the art of thermal storage for demand-side management. *Applied Energy*. **93** 371-389

[9]   Bazmi A A, Zahedi G and Hashim H 2011 Progress and challenges in utilization of palm oil biomass as fuel for decentralized electricity generation. *Renewable and Sustainable Energy Reviews*. **15** 574-583

[10]   Greiner H and Bussick F 2000 Mechanical Sealing for Heat Transfer Fluids. *Lubrication Engineering*. **56** 17-24

[11]   Ng W P Q, Lam H L, Ng F Y, Kamal M and Lim J H E 2012 Waste-to-wealth: green potential from palm biomass in Malaysia. *Journal of Cleaner Production*. **34** 57-65

[12]   Solangi K H, Islam M R, Saidur R, Rahim N A and Fayaz H 2010 A review on global solar energy policy. *Renewable and Sustainable Energy Reviews*. **15** 2149-2163

Acknowledgement