

ENHANCEMENT OF LATENT HEAT THERMAL ENERGY STORAGE USING EMBEDDED HEAT PIPE

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Abstract - An idea of novel concept of combine effect of heat pipes with thermal energy storage for solar power applications is investigate. The low thermal conductivity of phase change materials used in LHTES presents a challenge due to slow heat transfer rates during heating and cooling of the material. Heat pipes act to reduces the thermal resistance in phase change materials, increasing the overall heat transfer rate used for solar power. A laboratory scale experiment is presented to validate the concept of using heat pipes in LHTES to lower thermal resistance in phase change materials. Commercial scale LHTES with gravity assisted heat pipes is modeled and a cost analysis is conducted to determine competitiveness with other forms of thermal energy storage currently used in the solar power industry. LHTES utilizing heat pipes is explore experimentally. Photographic Result, melting and solidifying rates, and phase change materials energy storage quantities are to measure. Heat pipe effectiveness, is defined and used to quantify the relative performance of heat pipe-assisted configurations to process involving neither heat pipes. For the experimental conditions of this study, inclusion of heat pipes increases phase change materials melting rates by approx. 60%, while the fins are not as effective. Secondly, an economic evaluation of a LHTES system for large scale Solar power applications is conducted. A new design is proposed for charging and discharging a large-scale LHTES system.

Key Words: Solar Power, Latent Heat Thermal Energy Storage, Heat Pipe, Phase Change Material

1. INTRODUCTION

Nowadays, due to increase in energy consumption, a very large amount of fossil fuels is being used. This latter is a consequence of the present environmental problems, such as global warming, acid rain, etc. So to decrease these problems, the use of renewable energy sources is being promoted. But the renewable energy sources, Especially solar energy, present the drawback that there is a mismatch between the energy demand and supply. To cover this, the use of thermal energy storage systems is required.

Thermal energy storage proves to be an attractive and alternative for large-scale use. Energy is accumulated in a storage medium, and the storage mechanism can be

classified as sensible heat, latent heat. The most popular sensible thermal storage systems use molten salts. Thermal energy storage systems provide the potential to attain energy savings, which is used to reduce the environment impact of energy use. Phase change materials can store relatively large amounts of energy in small volumes, and thus have some of the lowest storage material costs. Most Phase change material operate between solid-liquid transitions, therefore most suitable as an indirect storage concept.

The largest barrier to the development of large scale LHTES is the low thermal conductivity of most phase change materials and much of the last research regarding LHTES has focused on reducing the thermal resistance posed by the phase change material. For example, Velraj et al. (1999) incorporated Lessing rings within phase change material and observed increased heat transfer rates from the phase change material to a coolant, making the technique suitable for reducing solidification times. The investigators also considered use of extended surfaces to increase heat transfer, concluding that fins also reduce total solidification times by approximately 75% based upon the predictions of a numerical model. Similar results for LHTES charging experiments utilizing a finned heat transfer fluid tube have been reported by Balikowski and Mollendorf (2007). Sparrow et al. (1981) showed that small fins can triple the amount of phase change material that freezes about a cold tube. Although the preceding approaches increase heat transfer rates in LHTES systems, they all occupy volume within the phase change material storage vessel. Ideally, any strategy to increase heat transfer rates would also occupy little space in order to maximize energy storage capacity.

1.1 Heat pipe

Heat pipe heat is exchanger device which is used to transfer heat from one point to another point, using condensation and evaporation cycle. One end of the tube is heated and the other is cooled. The heat source (the evaporator) causes the fluid to boil and turn to vapor. When that happens, the liquid picks up the latent heat of vaporization. The gas, which then has a higher pressure, moves inside the sealed container to a colder location where it condenses. Once the vapor reaches the cold end of the tube

(the condenser), the fluid changes phase again from vapor back to a liquid. Heat pipes have an extremely effective high thermal conductivity. While solid conductors such as aluminum, copper, graphite and diamond have thermal conductivities ranging from 250 W/m•K to 1,500 W/m•K, heat pipes have effective thermal conductivities that range from 5,000 W/m•K to 200,000 W/m•K. Heat pipes transfer heat from the heat source (evaporator) to the heat sink (condenser) over relatively long distances through the latent heat of vaporization of a working fluid. Heat pipes typically have 3 sections: an evaporator section (heat input/source), adiabatic (or transport) section and a condenser section (heat output/sink).

Key Components of a Heat Pipe

The three major components of a heat pipe include:

- A vacuum tight, sealed containment shell or vessel
- Working fluid
- Capillary wick structure

They all work together to transfer heat more efficiently and evenly. The wick structure lines the inner surface of the heat pipe shell and is saturated with the working fluid. The wick provides the structure to develop the capillary action for the liquid returning from the condenser (heat output/sink) to the evaporator (heat input/source). Water, for instance, will boil at just above 273° K (0°C) and start to effectively transfer latent heat at this low temperature.

1.2 Phase change material (PCM)

Phase change materials provide an effective way of accumulating thermal energy, due to their high capacity to store heat at a constant. The gap between a Thermal Paste and Solid filler pad a phase change material is an ideal material. At room temperature it is a solid filler pad but when its transition temperature is reached it softens or melts and behaves more like a paste. There are two types of materials, waxed based type and elastomer type. The wax based material has good wetting characteristics and low viscosity the material is ideal to fill any microscopic surface irregularities resulting in very low thermal resistance. It does not dry out, separate or settle. The elastomer type has good compressibility, and is available with single sided adhesive. It is also ideal where re-workability is required. Due to the physical characteristics of phase change material it is easier to handle and process than paste/grease and yet still offer good thermal conductivity with low thermal resistance.

The application of phase change material can have two different goals.

- Using natural heat and cold sources, that is solar energy for heating or night cold for cooling.

- Using manmade heat or cold sources.

1.3 Latent heat thermal energy storage

Latent heat thermal energy storage involves the storage of energy in Phase-Change Materials. Thermal energy is stored and released with changes in the materials phase. The most common phase change to exploit is the solid-liquid transition, as the liquid –gas transition is impractical and crystalline structure transitions usually have too low an energy density to be useful. When a phase change material is heated initially it behaves like sensible heat energy storage and the materials temperature is increased. However, once the transition temperature is reached the material will continue to absorb heat at a constant temperature while it changes state. This heat absorbed at constant temperature is known as the latent heat of the transition. To retrieve the energy the phase change material can be changed back from the liquid to the solid phase and the energy stored as latent heat is released. Latent heat thermal energy storage in phase change material offer an increase in energy density and a decrease in losses. Due to this higher energy density phase change material are the subject of much research, especially concerned with the integration of phase change material into building materials for both heat and cool storage. Phase change material can be split into organic and inorganic. Most organic Phase change material, exhibit little or no sub-cooling, are compatible with most building materials and have a high latent heat per unit weight and low vapour pressure. Their disadvantages are low thermal conductivity, high changes in volume on phase change and flammability. Inorganic compounds have a high latent heat per unit volume and high thermal conductivity and are non-flammable and low in cost in comparison to organic compounds. However, they are corrosive to most metals and suffer from decomposition and subcooling, which can affect their phase change properties.

2. OBJECTIVES OF WORK ON ENHANCEMENT OF LATENT HEAT THERMAL ENERGY STORAGE USING EMBEDDED HEAT PIPE

In this study, combination of heat pipes with LHTES is interesting. Heat pipes is used to increase heat transfer rates to the phase change material, while maintaining small temperature differences between the phase change material. Experimentally, Lee et al. developed a low temperature LHTES system operating with a various phase change material that utilized a two-phase thermo syphon operating with ethyl alcohol as the working fluid. Paraffin LHTES, with copper–water heat pipes embedded within a rectangular phase change material enclosure was developed and tested by Liu et al. Recently, Shabgard et al. modeled a large scale heat pipe-assisted LHTES and reported predictions showing improvement in both melting and solidification rates. Thus,

the objective of this study is to establish the effectiveness of heat pipes in potentially increasing heat transfer rates in a LHTES system by directly comparing measured performance with a system with heat pipes.

The objective of this study was to design, build and test a phase change storage module. This characterized module will be used as a building block in a phase change storage system. The analysis objectives are to set up numerical models of the storage systems, both of the low temperature storage module to validate it with the experiments, as well as in a concentrated solar power plant test facility to determine its predicted performance.

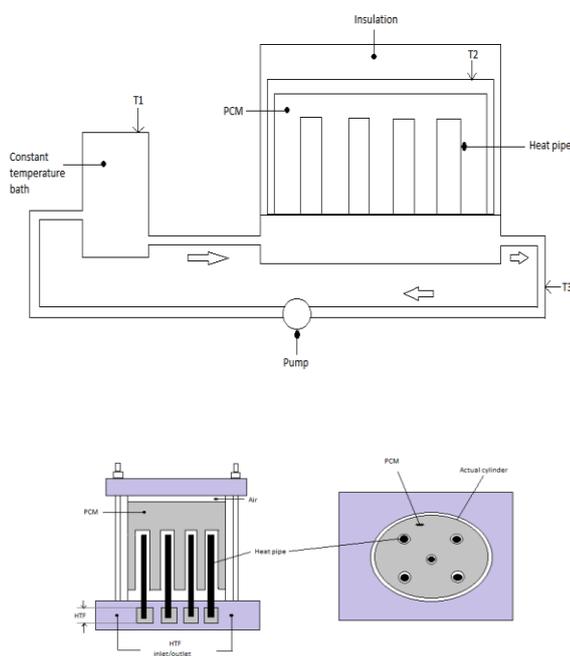


Fig -1: Experimental setup

3. LITERATURE REVIEW

Work is underway to investigate the inherent potential that phase change storage systems may hold for solar thermal energy storage systems [3]. Phase change material exhibit high energy densities during the phase change process between solid and liquid states and contain significant heat capacity during sensible heat up and cool down processes. The container may be kept at atmospheric pressures and this reduces containment cost compared to using high pressure steam as Phase change material. One of the main drawbacks of many of the Phase change materials is its low thermal conductivity. The adverse insulating effect is most noticeable during the heat removal phase when the Phase change material coagulates onto the heat exchanger surfaces. The only mode of heat transfer through the growing solid layer is by conduction. Therefore using such Phase change material as storage material results in long heat absorption and

especially long heat removal periods of a Phase change material storage container, because natural convection does not aid the solidification process [4]. An extensive research effort has been directed at shortening the heat absorption and heat removal periods of a Phase change material container and 28 references are noted by Agyenim et al. [5] that investigated heat transfer enhancement by either geometry adaptation or embedding highly conductive material in the Phase change material. The result of this research effort is that there are various design options available to increase the heat removal rates from a given mass of Phase change material to some extent, by using many small pipes in a shell and tube configuration at the cost of intricate welding and large pressure losses, or encapsulation of the Phase change material, or embedding the Phase change material in highly conductive foams or porous material such as graphite, or using heat pipes and fins. Various geometries of heat transfer enhancers have been investigated to heat or cool the Phase change material, but to reach some form of compromise between storage capacities of the resulting configuration per unit mass, cost of materials utilised and the shortened resulting heat absorption and heat removal rates from the formed mixture of Phase change material further analysis is required. In this study the heat transfer enhancing technique that was selected was to use heat pipes and fins. Robak et al. argues that small laboratory scale tests may be built and analysed with lower melting temperature Phase change material before larger systems are constructed and tested at higher temperatures for commercial viability [2 6]. This may aid initial design decisions and improve geometry layout for a particular application. Robak et al. tested three set-ups experimentally: One just with Phase change material in a cylindrical container heated from below, one with 5 added vertical rods, and one with 5 added heat pipes. The melting and solidification periods were significantly decreased when the heat pipes were incorporated into the Phase change material, compared to the metal rods and the Phase change material only test case. Unfortunately no tests were done with finned heat pipes to give an indication of how much the heat absorption and heat removal periods of such a system could be shortened. The low thermal conductivity of the Phase change material lends itself to finned surfaces to decrease the distance that heat needs to be transferred through the solid Phase change material. In further studies a decision was made to only use heat pipes to enhance heat transfer, without considering combining the two [1 5]. The results are still laboratory set-up specific.

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