Performance Analysis Of A Heat Exchanger Using Phase Change Materials (Pcm)

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ABSTRACT

Thermal energy storage (TES) provides a unique way for thermal solutions to short-duration thermal load systems. TES system utilizes phase change material (PCM), wherein energy is stored in latent heat during the lean time and released during peak load. Conventionally, in a shell-and-tube PCM heat exchanger, PCM is stored in the shell, and heat transfer fluid (HTF) flows in the tube. Numerical modeling based on computational fluid dynamics (CFD) tools like FLUENT and COMSOL is computationally intensive. Most numerical research is based on the enthalpy porosity model for solidification/melting problems. Enthalpy-porosity model requires a mushy zone parameter constant which significantly affects analysis results. The constant has no theoretical basis and is chosen based on experience. Analytical models in literature cannot give reasonably good results, which can be directly utilized for engineering purposes. This paper establishes a mathematical model based on the effectiveness-NTU (e-NTU) technique for heat exchangers.

1. INTRODUCTION

Conventionally, for thermal management systems, heat transfer mediums are air and water. However, most of these systems are not operated continuously. The so-called “SWAP (size, weight, and power) reduction” of these conventional systems is the need of the hour, and an alternative approach of cooling via thermal energy storage (TES) based systems are being investigated worldwide. Thermal energy storage (TES) provides an innovative way to manage cyclic thermal management of systems like electronic cooling systems, solar thermal energy systems, furnace thermal management systems, and similar electrical & mechanical systems. In these systems, cold (cooling system) or hot (heating system) energy is initially stored in TES and later released during operational peak loads. While the conventional system operates at peak load capacity, the TES-based system operates at average load capacity, and hence TES is more efficient. This system reduces overall power requirement, and with some innovative engineering, system size and weight can be further optimized and reduced. In general, TES is beneficial where the peak load time to lean time ratio is a minimum of 1:3 to increase the system’s effective coefficient of performance (COP). An illustrative example of an electro-optic cooling system where TES based cooling system can be employed. The operation is shown in Fig. 1, wherein the peak thermal load is 7 kW for 10 min and the lean time load is only 1 kW for 50 min. Hence, TES recharging unit is designed for an average heat load of 2 kW only, while the system can cater to peak loads of 7 kW. In this situation, the TES chiller can have a lower SWAP than the conventional vapor compression chiller.

In the literature for TES, the primary focus has been on latent heat storage systems because of the high energy storage capacity and availability of phase change material (PCM) in wide temperature ranges. Solid-liquid transition PCM is mainly used because of the lower volume transition and high energy and mass density of PCM, resulting in a smaller PCM container size. Most PCM has limited applications due to low thermal conductivity, leading to low solidification/melting rates. Heat transfer enhancement techniques using fins, multi-tube passes, high conductivity particle dispersion, or PCM composites have been extensively investigated. Shell-tube configuration-based PCM heat exchangers are most commonly used. Improvement in heat transfer within PCM significantly depends on the PCM tank's geometry, fin configuration, and PCM properties An effective transient analysis technique is essential to capture the real-time behavior of the PCM heat exchanger. Further, the PCM heat exchanger needs to be optimized for maximum utilization of PCM.

2. MATERIALS AND METHODS

Conventionally, steady-state heat exchangers have been designed and analyzed using the logarithmic mean temperature difference technique (LMTD), effectiveness-number of transfer units technique (e-NTU), and other similar techniques. However, these steady-state approaches are not suitable for direct application in the rating of PCM heat exchangers. The temperature profile in the PCM keeps on changing (due to phase transformation) with time and the effective heat transfer boundary also varies.

2.1 Materials

Phase Change Materials (PCMs): The PCM is the key material in a heat exchanger using PCMs. Examples of commonly used PCMs include paraffin wax, stearic acid, and sodium sulfate dehydrate. The selection of the PCM depends on the desired melting temperature, the heat of fusion, and the thermal conductivity. Heat transfer fluid, The heat transfer fluid is used to transfer heat from the heat source to the PCM and from the PCM to the heat sink. The fluid must have high thermal conductivity and low viscosity to ensure efficient heat transfer. Examples of commonly used heat transfer fluids include water, ethylene glycol, and oil. Structural Components: The structural components of the heat exchanger include the pipes, fins, and housing that enclose the PCM and the heat transfer fluid. These components must be made of materials that are thermally conductive, durable, and resistant to corrosion and thermal expansion. Examples of commonly used materials for structural components include copper, aluminum, and stainless steel.

2.2 Conceptual design

Determine the heat source and heat sink: The first step in the conceptual design is to determine the heat source and heat sink for the heat exchanger. This may include identifying the type of fluid or material that will be heated or cooled and the desired temperature range.

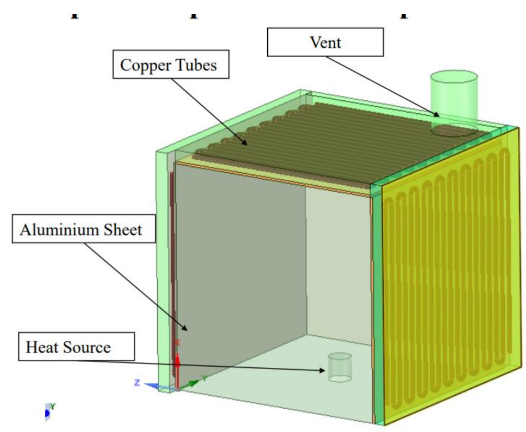

Fig.1 3D View

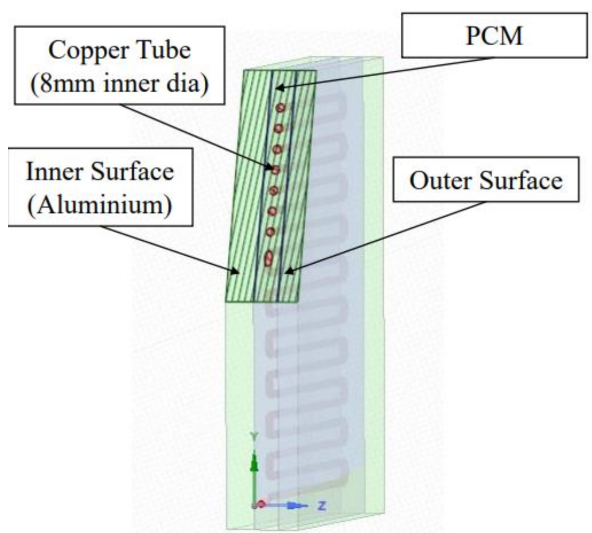

Fig.2 Side View

3. RESULTS AND DISCUSSION

3.1 Completed unit

The completed unit is shown in the below figure.

Fig.3 Completed unit

3.2 Assembled 3D drawing

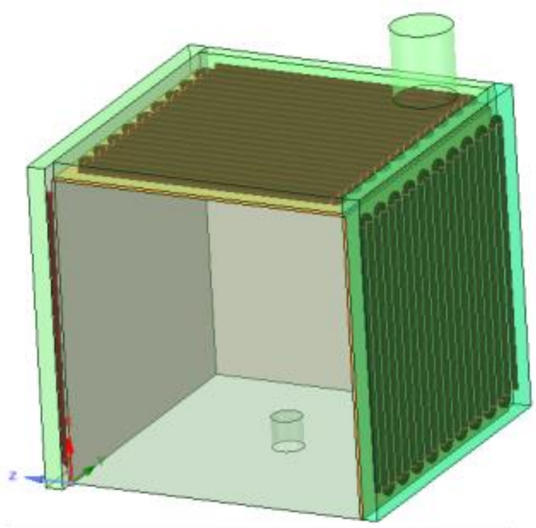

Fig.4 3D front view

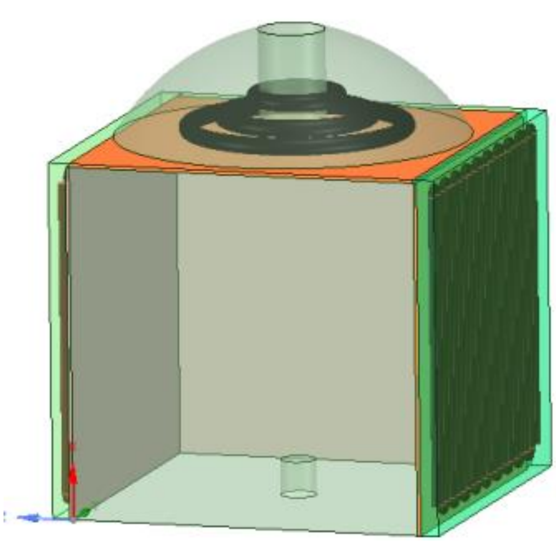

Fig.5 3D Interior view

3.2 PROPERTIES OF PCM

S. No.	Type of PCM	Melting Point (^{O}C)	Density (kg/m^3)	Latent heat of Fusion (kJ/kg)
1	Lauric Acid	44	1007	178
2	Capric Acid	32	878	152.7
3	Lauric Acid + Capric Acid	-	-	-

Fig.6.Properties

Melting Temperature: The temperature at which the PCM changes from solid to liquid state. Latent Heat of Fusion: The amount of heat required to melt the PCM. Thermal Conductivity: The ability of the PCM to conduct heat. Specific Heat Capacity: The amount of heat required to raise the temperature of the PCM by 1 degree Celsius. Density: The mass of the PCM per unit volume. Chemical Stability: The ability of the PCM to maintain its chemical properties over time. Compatibility with Heat Transfer Fluid: The PCM should be compatible with the heat transfer fluid to ensure efficient heat transfer.

PCMs in Buildings

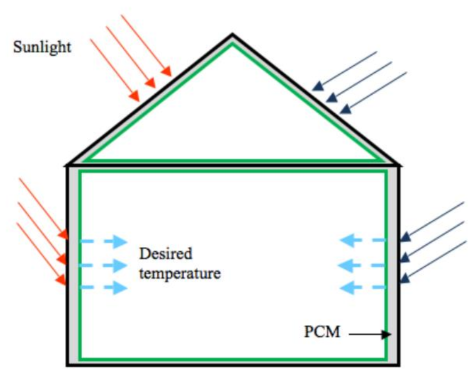

Fig.6 Building structure

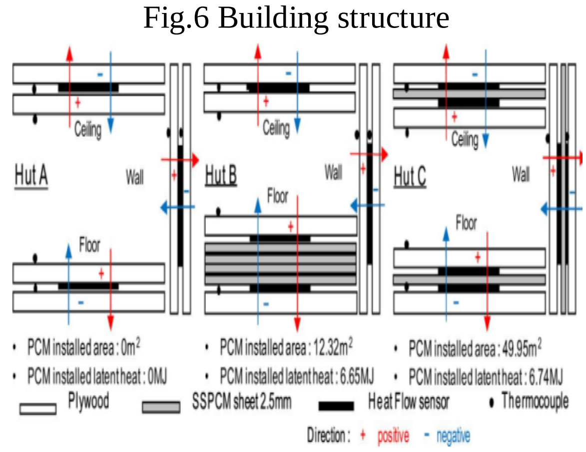

Fig 7 Analysis of PCM

4. INTRODUCTION OF THE RESEARCH:

In the household, more amount of heat from the kitchen portion is generated.

PCM materials are used to store the waste heat and that can be utilized for other applications, like water heating for kitchen vessel washing. • Nowadays most cooking is carried out by Gas stoves, and more amount of heat is released while cooking. The objective of the present work is to develop an experimental setup for storing and reusing the waste heat from the household.

5. CONCLUSION

A mathematical model has been presented for transient analysis/rating of the PCM heat exchanger, wherein heat exchanges between the heat-carrying fluid in the conduit and PCM in a shell surrounding the conduit have been considered. The model is based on the effectiveness-NTU technique and considers the system to be in a pseudo-steady state during the operation of the PCM heat exchanger. The model describes an innovative concept of zonal heat transfer boundaries (solid zone, melt zone, usable

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