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Analysis of Temperature Distribution and Phase Change Time Inside Iron-Nickel Foam Infiltrated with Paraffin

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ABSTRACT

Thermal performance of phase change materials (PCMs) have great importance in efficient thermal energy storage systems (TESS). Pure PCMs have high heat absorption capacity and latent heat. In this study temperature distribution inside the pure paraffin, pure iron-nickel foam, and Iron-nickel foam/paraffin PCM composite was experimentally investigated. Heat flux of 1000 W/m^2 was supplied through a flexible heater (100 mm × 100 mm × 1.3 mm) at the bottom of the paraffin, pure iron-nickel foam, and iron-nickel foam/paraffin wax composite. Phase change time of paraffin and iron-nickel foam/paraffin wax composite was also investigated. Experimental results show that temperature difference was lowered by 50% in case of new Iron-Nickel foam/paraffin PCM composite due to high effective thermal conductivity [2.08 W/m.K]. During the thermal storage process of pure paraffin, maximum temperature difference along the z-axis was found to be more (14%) as compared to that along the x-axis. Temperature difference was found 4ºC in case of paraffin while in pure iron-nickel foam it was 2ºC during the heating process. Phase transition time of pure paraffin was increased by 16.67% as compared to the composite PCM during the thermal storage process.

Keywords: *Heat Flux, Pure Paraffin, Iron-Nickel foam, Thermal storage, Phase Transition Time*

1. Introduction

Phase change materials (PCMs) can absorb or release large amount of energy during phase change phenomenon. PCMs can be categorized in two ways based on [1]: (a) chemical composition (organic and inorganic) and (b) melting temperatures (low temperature PCMs and high temperature PCMs). Organic PCMs have lower latent heat values and are non-corrosive in nature, while inorganic PCMs have high latent heat values [2]. Low temperature PCMs (below 200ºC) are used in buildings and waste heat recovery systems (WHRS) [3]. High temperatures PCMs, due to their large latent heat, are utilized in solar power plants (SPPs) and high thermal energy storage systems (TESS) [4].

PCMs are widely used for thermal management of electronic devices, computers, and other energy dissipating systems because of their excellent heat storage capacities [1, 5-7]. The only drawback associated with PCMs is their low thermal conductivity.

Development of composite PCMs can solve the dispute between the large heat storage capacity and low thermal conductivity. Metal foams with high thermal conductivity are popular choice to increase the thermal conductivity of PCMs, [5, 8, 9]. Metal foams have high porosity, are light weight and possess large surface area [10]. PCMs can either be infiltrated [5] or impregnated [10] inside the metal foam. There are various metal foams which are used with different PCMs for thermal enhancement like copper foam [11-12], nickel foam [13] and aluminum foam [14]. Hussain et al. [13] studied thermal performance and management of battery pack using nickel foam/PCM composite. They found that the temperature of the battery pack was lowered by 31% using nickel foam/PCM composite. R. Baby et al. [15] studied the behavior of copper foam/PCM based heat sink. They found that orientation does not influence the rate of heat transfer. Mahdi et al. analyzed the thermal management of the battery using aluminum/PCM composite [14]. In their study, they found the battery temperature reduction of 6 K at 9.2 W.

The studies on the heat storage properties of the composite PCMs are inadequate as previous studies have mainly focused on thermal management aspect using metal foam/PCM composite. In this paper, the heat storage properties of the composite PCMs were experimentally analyzed.

2. Experimental Setup

A heat cavity with dimensions of 100 mm x 100 mm x 26 mm was utilized to perform the experimental analysis. Aluminum heat sink was insulated with plexiglass of 3 mm thickness and 20 mm of cotton to achieve one-dimensional heat flow. A flexible silicon heating pad (dimensions 100 mm x 100 mm x 1.3 mm) was pasted at the sink bottom on external side. This heating pad is used as the heat generating element. Thermal resistance of the glue paste was insignificant because thermal conduction of glue is only 9 W/(m.K), and the thickness of the glue paste is less than 0.1 mm. 5 K-type (-50ºC to 1350ºC) thermocouples were positioned at different places of the heat sink to measure temperature distribution. Data acquisition (USB-34972A) was utilized to measure and scan the thermocouple's reading with a time interval of 5 Sec along the x- and z-axes. The required input power of 10 W was supplied to the heating element using power supply (A M10-QD & QR series). The experimental setup is shown in Fig. 1 and a schematic illustration of the setup with thermocouples positioning is shown in Fig. 2.

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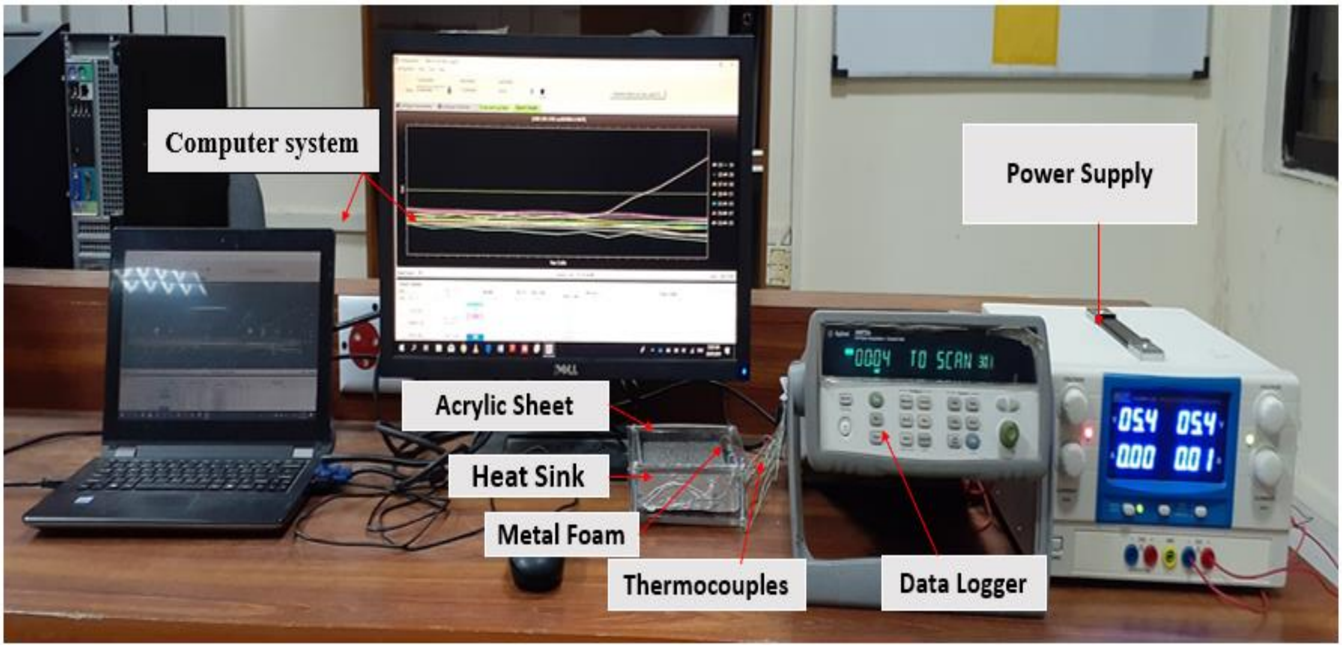

Fig. 1: Experimental Setup.

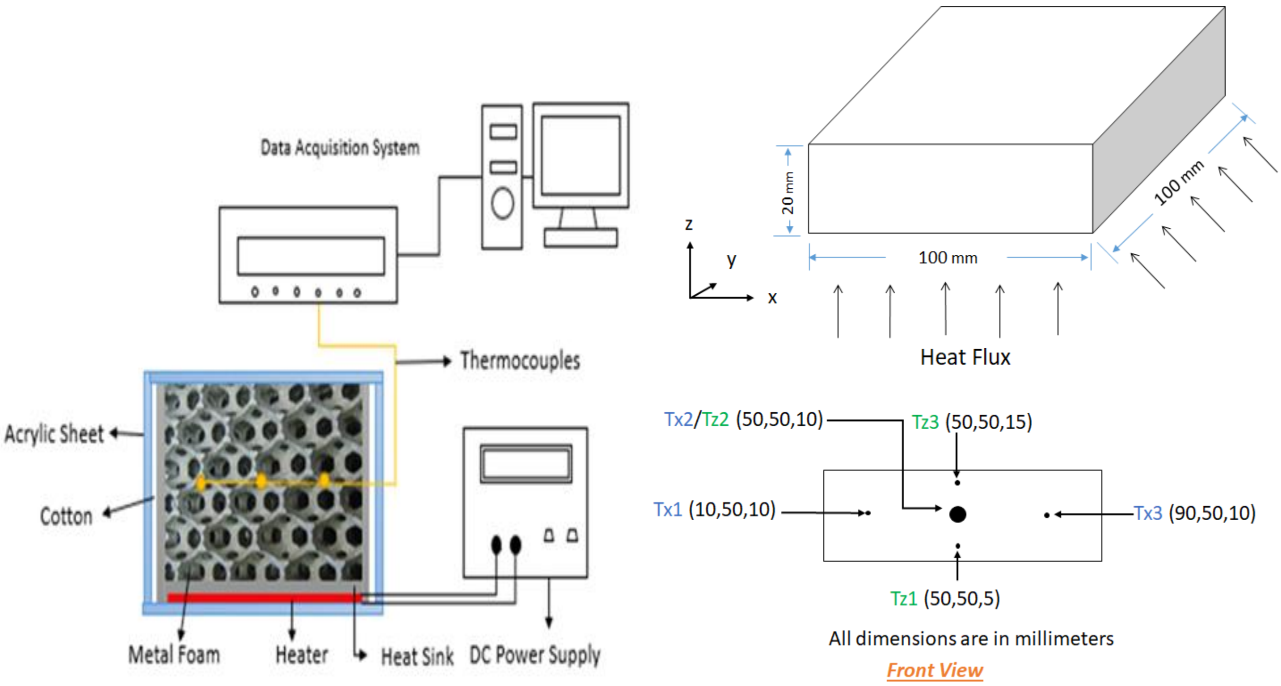

Fig. 2: Schematic view of the experimental setup and thermocouple positioning.

2.1 *Materials*

Paraffin wax is considered as one of the most widely used PCMs possessing excellent thermal storage properties such as uniform temperature distribution, high latent heat, and storage capacity. Metal foam (iron-nickel foam) was cut according to the desired dimensions. To investigate the internal storage properties of PCM inside the metal foam, PCM was infiltrated inside the metal foam. For infiltration purpose, the paraffin was heated up to its melting temperature. The metal foam was immersed in the melted PCM. The stainless-steel container was exposed to cold water at 25°C for about 110 minutes to gradually cool down the paraffin till it is solidified inside the metal foam. The images of iron-nickel foam and iron-nickel foam PCM composite are shown in Fig. 3 (a) and (b), respectively. Characteristics properties of the paraffin wax and iron-nickel foam are shown in table 1 and table 2, respectively.

Table 1: Characteristics properties of paraffin Wax

Thermal Conductivity	High Operating Point	Congealing Point	Melting Range	Heat Capacity	Density @15 ºC
0.15-0.3 W/m. K	72 ºC	42-38 ºC	38-42 ºC	2000 J/kg. K	880-900 kg/m^3

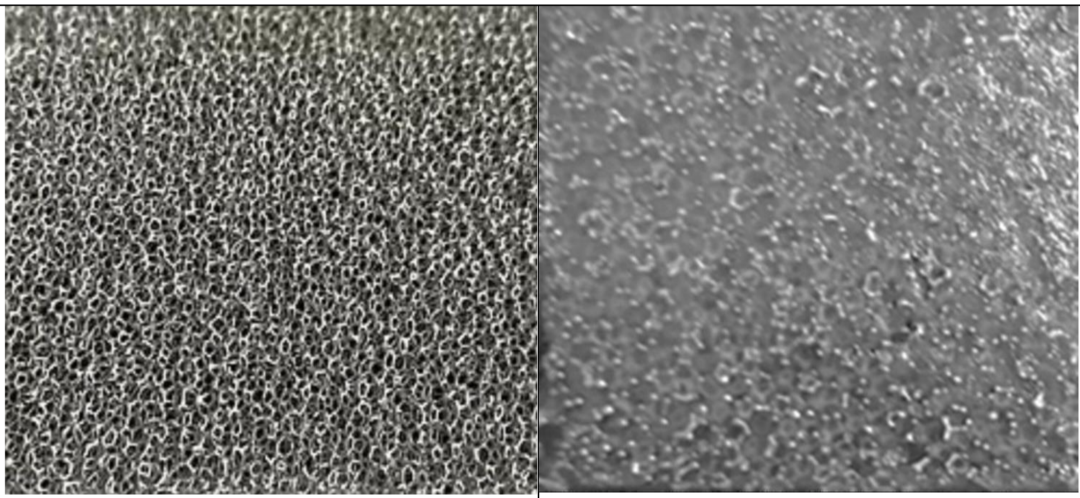

Fig. 3: Images of (a) Pure iron-nickel foam and (b) Iron-nickel foam PCM composite.

Table 2: Characteristic Properties of Iron-Nickel Metal Foam.

Thermal Conductivity	Density	Porosity	Pore density	Specific heat
83 W/m. K	273 Kg/m3	97%	35 PPI	0.426 kJ/kg.K

3. Results and Discussion

In this work, heat flux of 1000 W/m^2 was supplied along the z-direction to analyze the thermal storage properties of pure PCM, pure iron-nickel foam and composite PCM. Due to the uniform temperature distribution along x-axis and z-axis, the readings recorded were along these directions. Thermocouples were positioned at the heat sink bottom along the x-axis (10 mm, 50 mm, and 90 mm) and z-axis (5 mm, 10 mm, and 15 mm) as shown in Fig. 2. The ambient temperature for the current study was maintained at 30ºC. Three specimens 1) Pure paraffin, 2) Pure Iron-Nickel foam, 3) Iron-Nickel foam/paraffin composite was investigated and compared at different input powers for heating.

3.1 Thermal Storage Analysis

3.1.1 Temperature profile of Pure Paraffin

The heating pad was supplied a power of 10 W and thus it generated a flux of 1000 W/m^2. The observed temperature was maximum in the center, which shows uniform heat flux generated by the heater. The maximum temperature variation of 4ºC along the x-y plane (10, 50) to (90, 50) was observed. paraffin wax was started to melt at 38ºC and during the phase change process, the temperature almost remained constant. The sensible heating phase continued for 3246 Sec (54 min) before melting started. It was observed that pure PCM had more phase transition time because of its low thermal conductivity as shown in Fig. 4.

The maximum temperature variation along z-axis was found to be 8ºC at the same input power of 10 W as shown in Fig. 5. The maximum temperature difference was increased by 50% as compared with that along the x-axis. The phase change time (17 min) was reduced during the thermal storage process along the z-axis.

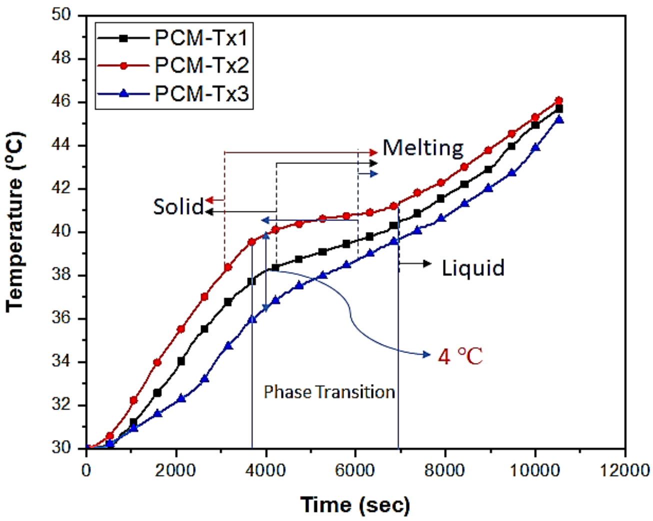

Fig. 4: Temperature profile of pure paraffin along x-axis

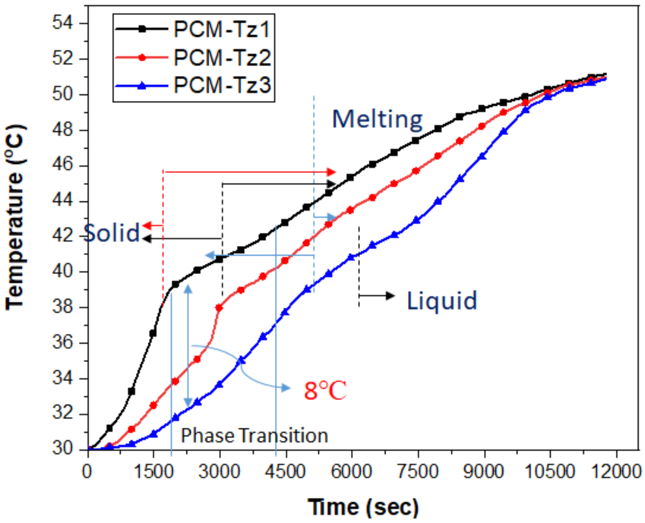

Fig. 5: Temperature profile of pure paraffin along z-axis

3.1.2 Temperature profile of pure Iron-Nickel

The temperature difference of 2 ºC along x-axis was observed in case of metal foam under the same heat flux of 1000 W/m^2 as shown in Fig. 6. The temperature variation was more inclined towards the lower side due to high thermal conductivity of pure iron-nickel foam. Similarly, along z-axis the temperature distribution showed a slight variation of 2.5ºC, which is 25% higher as compared to that of the x-axis as shown in Fig. 7.

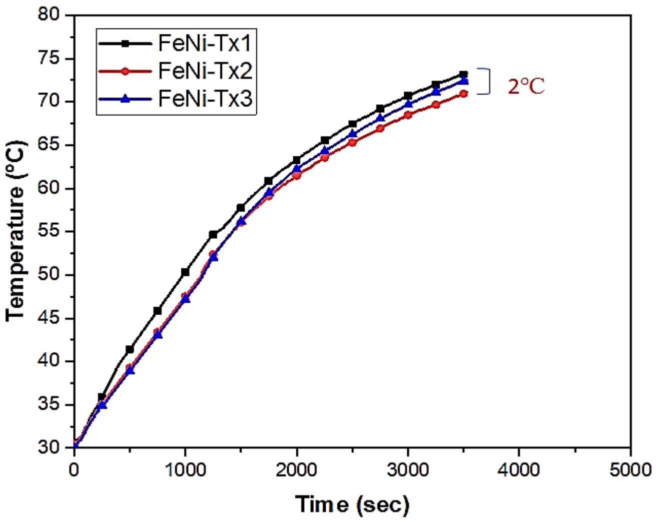

Fig. 6: Temperature profile of pure Iron-Nickel foam along x-axis

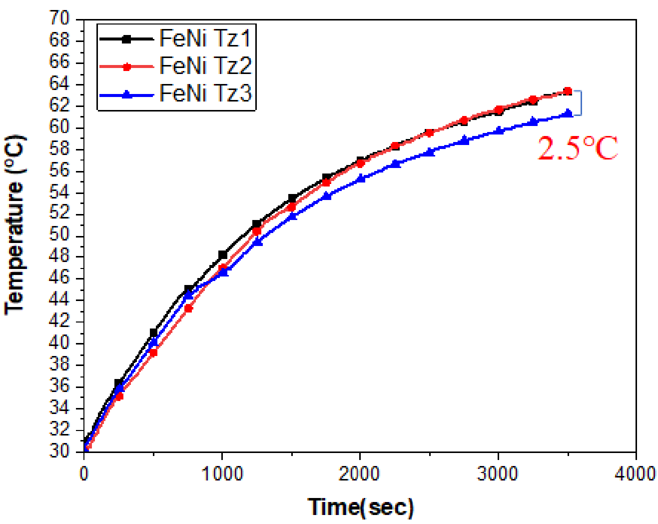

Fig. 7: Temperature profile of pure Iron-Nickel foam along z-axis

3.1.3 Temperature profile of Iron-Nickel foam/paraffin PCM composite

The Iron-Nickel foam/PCM composite was exposed to the same heat flux of 1000 W/m^2 to analyze the heat flow along the x-axis. The maximum temperature difference (2ºC) was observed at the center as shown in Fig. 8. It was observed that molten paraffin moved through the foam towards upper side due to the difference in density of pure paraffin in solid and liquid phases [16]. The temperature at center position was raised as molten pure paraffin with high temperature moved towards the central surface [17]. The conduction phenomenon played a pivotal role during the solid state of paraffin wax while convection heat transfer mode dominated during the melting and liquid phases [16].

Maximum temperature difference was 2.2ºC (at 81.5 min) along the z-axis for the same input power as shown in Fig. 9. The transition time along z axis was 1800 sec (30 min) during the thermal storage process, which is significantly lower (35.13%) as compared to x-axis.

Comparing the temperature distribution of metal foam/ PCM composite with pure PCM, it can be observed that presence of PCM in the iron-nickel foam accelerated the melting process [14].

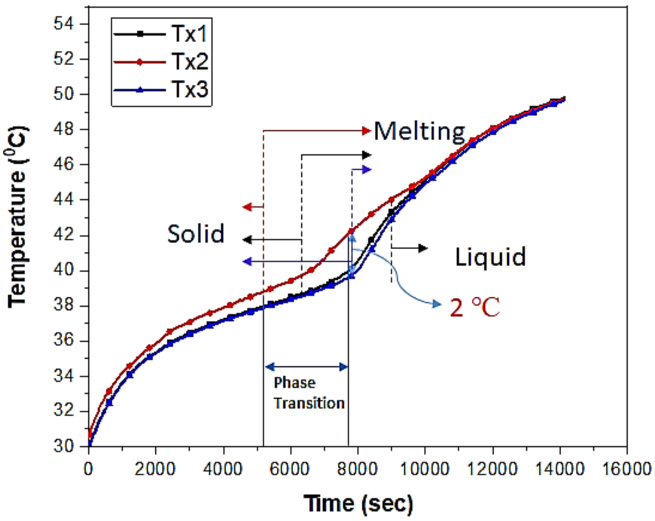

Fig. 8: Temperature profile of Iron-Nickel foam/paraffin composite along X-axis.

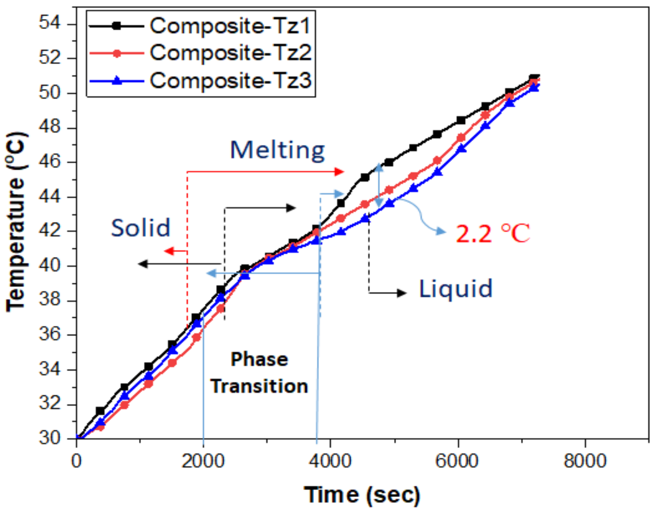

Fig. 9: Temperature profile of Iron-Nickel foam/paraffin composite along z-axis

4. Conclusion

In this study, thermal storage properties of pure paraffin, pure iron-nickel foam and iron-nickel foam/paraffin composite were analyzed and compared at heat flux of 1000

W/m^2. The temperature distribution inside these materials was monitored and compared along the longitudinal and thickness directions. The key findings of this work are summarized below.

- The phase transition time of pure paraffin was 16.67% more as compared to that of iron-nickel foam/paraffin composite.
- The addition of pure paraffin inside iron-nickel foam lowered the temperature difference by 50% and reduced the transition of melting time of PCM during the thermal storage process.
- Temperature uniformity inside iron-nickel foam/paraffin PCM was more as compared to that of the paraffin and pure iron-nickel foam.
- Along the z-axis, maximum temperature difference was reduced by 74%, when the metal foam was added in paraffin as compared to the x-axis.

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