



## Experimental Study of the Phase Change Process for Energy Storage by Using PCMs

M. S. B. Jahromina, V. A. Kalantaro\*, M. B. Sefidey, M. S. Iranman

Yazd University, Mechanical Engineering, Yazd, Iran

Accepted 23 December 2022

### Abstract

Paraffin is one of the phase change materials, the reason for which can be mentioned is phase change at different temperatures as well as high latent heat. Paraffin is the most used by solar systems, for example, it is used in collectors and solar dryers. The experimental equipment was designed and manufactured using paraffin as the phase change material and copper and iron foam (iron wool) as the filler. Pure paraffin with and without copper and iron foam as well as the addition of copper absorbers plate to the copper and iron foam were the two conditions used in experiments delving into the heat charging process. Under various circumstances, the collected temperature's time course was recorded, and the findings were reviewed. From the obtained results, it can be pointed out that the porous plate can increase heat transfer. Also, the use of PCM material inside the porous plate makes the temperature distribution more uniform. The best case is when the copper absorber plate is connected to copper foam and reduces the charging time compared to pure PCM by 600s and saves 75% of energy while pure PCM stores 66.66% of energy.

Keywords: Phase change process; Energy storage; Phase change materials (PCMs)

### 1. Introduction

Energy consumption has significantly increased in recent years as a result of the swift development of human civilization and the economy. Research and studies, energy consumption in the world is doubling every 20 years. Because of this problem, less renewable energy is used than fossil fuels. However, in recent years, there has been a growth in the usage of renewable energy, particularly solar energy. [1-2]. Thermal energy storage systems (TES) are utilized in a range of climatic circumstances as temporary thermal energy storage or store preservatives. For many engineering applications, thermal energy storage is essential [3]. The word "TES" is not considered a new term; it has been applied for centuries in numerous industrial and agricultural endeavors, including drying procedures and building heating. Energy storage helps power systems operate more efficiently by regulating supplies and boosting dependability [4]. TES plays an important role in saving thermal energy by reducing the degree of time or uncertainty between supply and demand. Thermal energy can be stored in a liquid or solid with sufficient thermal insulation by changing the internal

energy of the material, such as sensible heat or latent heat, or a combination thereof [5-15].

Sensible heat, latent heat, and chemical energy are the three basic subtypes of TES. Depending on the material's thermo-physical characteristics, applications may vary [6]. Sensible heat storage (SHS) uses a solid or liquid's heat capacity to raise its temperature while changing the material's temperature during charging and discharging to store heat energy. The environment, temperature swings, and the value of the heat storage material all affect how much heat is stored [7-8]. When a material section transitions from a base state to another state, latent heat storage (LHS) depends on the thermal energy absorption or desorption during that transition (liquid to gas, solid to liquid, or vice versa) [6,9]. Due to the latent heat in the PCM material, the heat storage process takes place at a temperature close to the melting point of the PCM, which increases the density of energy storage in two units of mass and volume in a cycle of approximately the same temperature [3,10].

---

\* Corresponding author:

Email: [vkalantaro@yazd.ac.ir](mailto:vkalantaro@yazd.ac.ir)

PCMs use chemical bonds to store and unleash heat. When the PCM materials regenerate from solid to liquid or from liquid to solid, the chemical connections are disrupted, and heat transmission occurs. [11]. Therefore, storing thermal energy in the latent heat of PCM is an exclusive benefit of increasing the value of thermal energy in the system. PCM materials fall into three main categories: organic, inorganic, and eutectic. The required temperature range is 0-150°C, which is very suitable for solar applications [5,12]. For many applications, the PCM needs to have higher latent heat, higher thermal conductivity, and lower volume expansion [7]. The thermal conductivity of PCM materials, which ranges from 0.1 to 0.3 W/m.K, is quite low but has a significant latent heat value. If the thermal conductivity is low, the heat transfer coefficient when releasing the stored heat will decrease.

In the applications of energy storage and increasing heat transfer, the copper porous plate should be used because it has a high thermal conductivity coefficient and also has a higher volume than the volume of the material filled in the porous plate. Research has been done on the melting variation of the phase change material in copper and iron foams. Zhang et al [6], investigated the phase transition properties of a composite material comprised of metal porous plate and paraffin. The findings demonstrate that the unbalanced thermal effect on the heat transmission between the paraffin and the copper porous plate causes a significant temperature difference between the copper ligaments and the paraffin porous plate. The use of the two-temperature energy method makes it correctly answers the characteristics related to heat transfer because, in the research of most researchers, the experimental and simulation results have a low percentage of error. The findings demonstrate that as compared to the cylinder system, the conical shell system boosts natural convection. The frustum tube arrangement, however, boosts convection as well as conduction. The performance of the composite metal/PCM porous plate in terms of heat transfer is largely unaffected by variations in geometry.

The results showed that the heatsink based on copper porous plate at 5 to 6 °C showed a lower base temperature compared to nickel iron porous plate. When examining the effect of porous plate porosity, copper porous plate with less porosity (95%) at the end of the charge cycle showed 11% lower base

temperature. The findings indicate that the porosity performs better than heatsink settings with uniform porosity and PPI density in terms of time to reach the set point temperature by 28 and 45%, respectively. It is clear from the numerical simulations that the convection velocity cells are dramatically altered by the PCM melt percentage, which has an impact on the PCM melting dynamics.

The examined literature indicates that the melting of PCM material in two copper and iron foams (iron wool) connected to the copper absorber plate has not been studied. Due to the low thermal conductivity of paraffin as a phase change material, copper and iron foams (iron wool) were used, and the charging and discharging process of PCM and the effect of the implementation of the copper absorber plate on the charging and discharging process of PCM materials were investigated and the results were compared to each other. This new study can be widely used for solar applications, especially solar panels, types of solar collectors (FPSC, ETSC, and PTSC), solar air heaters (SAH), and solar desalination systems, which are capable of using porous foams. The obtained results have been done with the solar simulation device, which will greatly help scientists in the field of renewable energy in future research.

## 2. Experimental setup

As shown in Figure 1a, the sample preparation steps include: (1) calculating the weight of PCM material and porous foams, (2) melting PCM material with an electric heater, (3) filling copper and iron porous plates with PCM material and (4) placing samples in Teflon insulated box. The next step, shown in Figure 2b, is to place the copper plate using solder on copper and iron foams and then fill it with PCM. The melting temperature fluctuations of PCM material have been investigated using some pre-calibrating K-type thermocouples. K-type thermocouples are affixed to the paraffin-filled inside of the foam, and a 16-channel data logger is used to capture temperature data. Therefore, by analyzing the collected data, it is possible to determine the melting rate of PCM materials and their heat storage capability. A sample of pure paraffin core was examined for comparison in order to investigate the increase in heat transmission caused by copper and iron foams. Additionally, the impact of the structure (porosity) of porous foams on the transfer of heat from solid to liquid was examined.

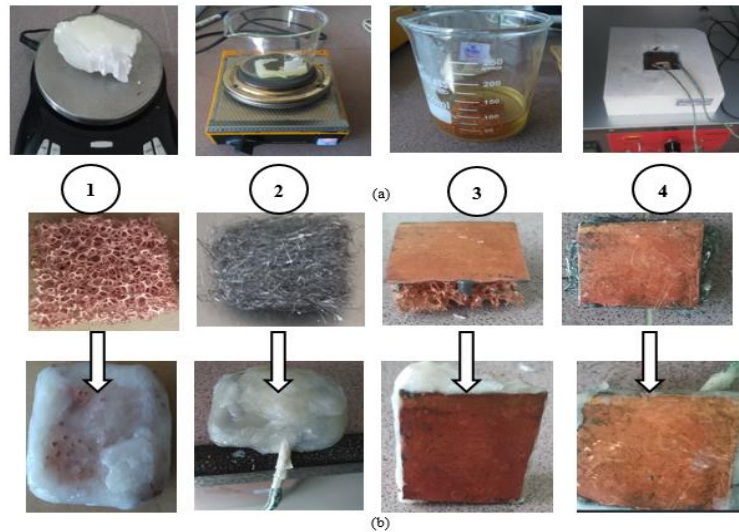


Figure 1. (A) Samples preparation steps, (b) Paraffin filling in cases with copper foam, iron foam, copper foam with copper absorber, and iron foam with copper absorber

### 3. Results and discussions

Figure 2 shows the melting curve of paraffin from DSC measurement. Figure 3 depicts the outcome for the PCM sample when two pieces of foam made of copper and iron were present. The wall temperature rises steadily at the same rate as paraffin throughout the charging process. In 2400s, pure PCM reaches 67.3°C, ie above the melting point, respectively, copper foam reaches 73.27°C and iron foam reaches 72.5°C, respectively. The increase in heat transfer via copper foam is due to the metal foams' excellent heat conduction. The

temperature line experiences a significant drop after the pure PCM successfully undergoes the transition from solid to liquid. The increase in heat transmission brought on by the liquid phase's inherent convection effect can be the cause of it. The use of foam can make the temperature distribution more homogeneous in the discharge process. The heat from the PCM can be efficiently dissipated via a foam structure, resulting in a reduction process, for copper and iron foams. Therefore, the usage of metal foams significantly improves the PCM heat transfer efficiency, much like the charging process.

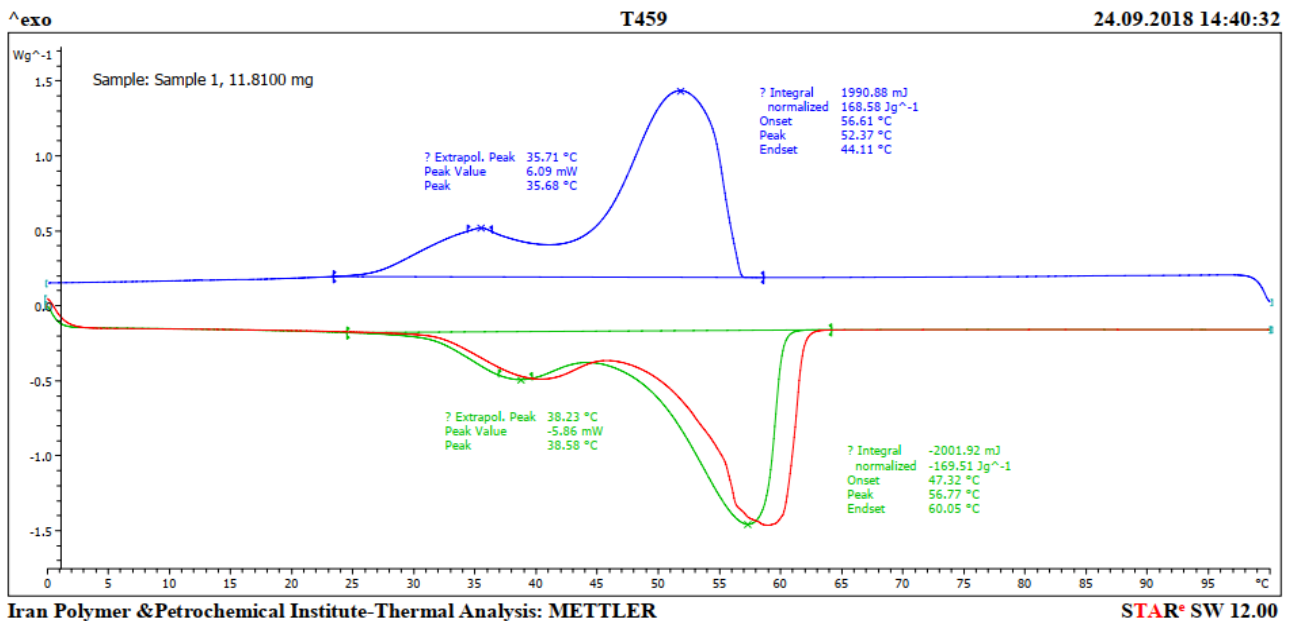


Figure 2. The melting curve of paraffin from DSC.

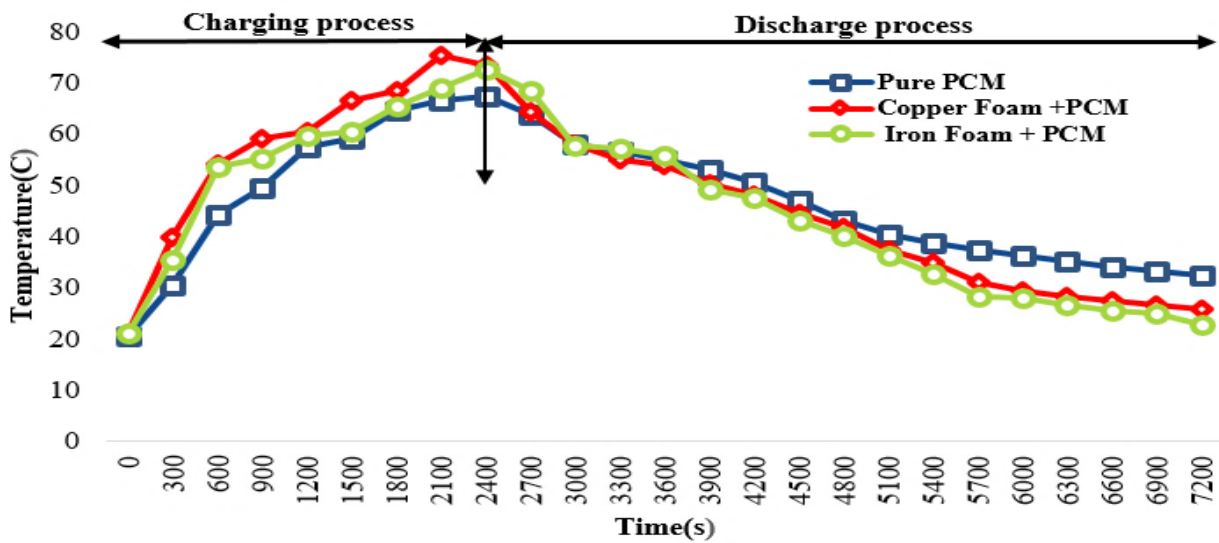


Figure 3. Comparison between three different modes of pure PCM, PCM with copper foam, and PCM with iron foam in the charging and discharging process.

In Figure 4, by adding a copper absorber plate to copper and iron foams, the melting process of PCM material and the effect of heat transfer are investigated. As can be seen, by adding the absorber plate, the heat transfer increases and the maximum value is 77.41°C for copper foam and 74.67°C for iron foam. The reason for this can be the effect of conductive heat transfer between the copper absorber plate and the foam's structure containing PCM. For

copper and iron foams, a foam structure can quickly dissipate heat from the PCM and reduce the discharge process. However, when the copper absorber plate is added to copper and iron foams, the process does not decrease during discharge, and the heat present in the copper absorber plate, which still transfers to the foam containing PCM, can explain the reason.

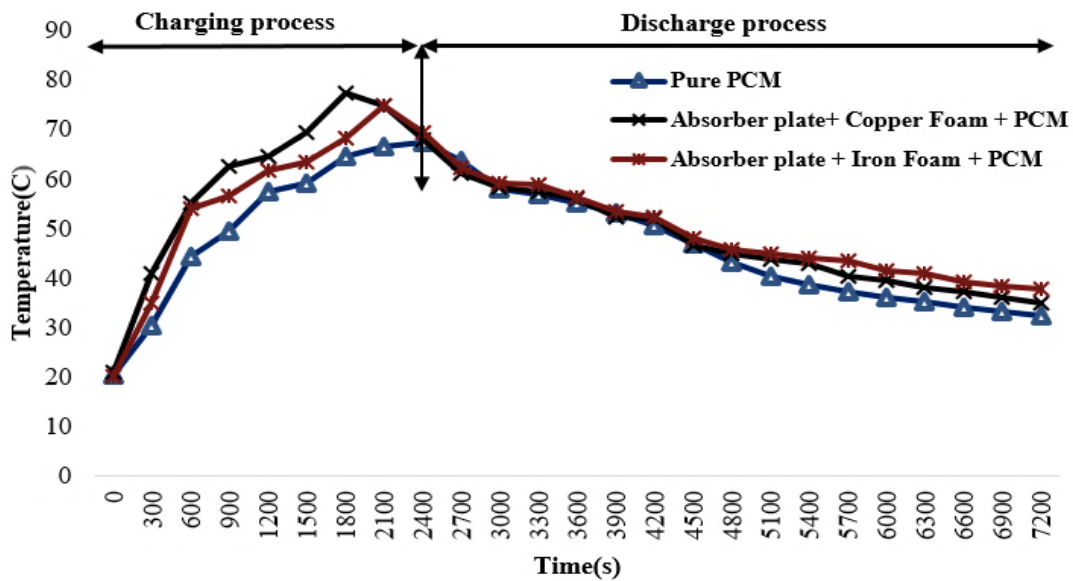


Figure 4. Comparison between pure PCM samples and copper and iron foam samples with copper absorber plate during the melting process.

#### 4. Conclusions

In this investigation, pure paraffin filled with and without copper and iron foams, as well as pure paraffin with the addition of a copper absorber plate to the copper and iron foams, were used to melt PCM. The findings demonstrate that the addition of metal foams can significantly increase the melting process's effective thermal conductivity. The heat transfer rate is increased by 14% when the copper foam is combined with a copper absorber plate.

#### References

- [1] Akgün, M., Aydın, O., Kaygusuz, K. Experimental study on melting/solidification characteristics of a paraffin as PCM. *Energy Convers Management*, 2007; 48: 669-678.
- [2] Jahromi, M.S.B., Kalantar, V., Akhijahani, HS., Kargarsharifabad, H. Recent progress on solar cabinet dryers for agricultural products equipped with energy storage using phase change materials. *Journal of Energy Storage*, 2022; 51: 104434.
- [3] Zhao, C.Y., Lu, W., Tian, Y. Heat transfer enhancement for thermal energy storage using metal foams embedded within phase change materials (PCMs). *Solar Energy* 2010; 84: 1402–1412.
- [4] Karaipekli, A.; Sarı, A.; Kaygusuz, K. Thermal conductivity improvement of stearic acid using expanded graphite and carbon fiber for energy storage applications. *Renewable Energy* 2007, 32, 2201.
- [5] Ali, HM., Janjua, MM., Sajjad, U., Yan, WM. A critical review on heat transfer augmentation of phase change materials embedded with porous materials/foams. *Int. J. Heat and Mass Transfer* 2019; 135: 649–673.
- [6] Zhang, P., ZN., et al., Melting heat transfer characteristics of a composite phase change material fabricated by paraffin and metal foam. *Appl. Energy* 2017; 185: 1971–1983.
- [7] Ibrahim, N et al., Heat transfer enhancement of phase change materials for thermal energy storage applications: A critical review. *Renew. Sustain. Energy Rev* 2017; 74: 26–50.
- [8] Dincer, I., Rosen, MA. *Thermal energy storage systems and applications*. John Wiley & Sons, 2021.
- [9] Robert A. Huggins. *Energy Storage*. Springer, New York, 2010.
- [10] Abhat, A. Low-temperature latent heat thermal energy storage: heat storage materials. *Solar Energy* 1983; 30: 313-332.
- [11] Kumar, N., Gupta, SK. Progress and application of phase change material in solar thermal energy: An overview. *Mater. Today Proc.*, 2021; 44: 271–281.
- [12] Usman, H., et al., An experimental study of PCM based finned and un-finned heat sinks for passive cooling of electronics. *Heat Mass Transfer* 2018; 54: 3587–3598.
- [13] Ebrahimi, H., Akhijahani, HS., Salami, P. Improving the thermal efficiency of a solar dryer using phase change materials at different position in the collector. *Solar Energy* 2021; 220: 535–551.
- [14] Shalaby, SM., Bek, MA. Drying oleander in an indirect solar dryer using phase change material as an energy storage medium. *J. Clean Energy Technol.* 2015; 3: 176–180.
- [15] Bhardwaj, AK et al., Energy and exergy analyses of drying medicinal herb in a novel forced convection solar dryer integrated with SHSM and PCM. *Sustain. Energy Technol. Assessments* 2021; 45: 101119.

Because of this, using metal foam with a copper absorber plate might hasten to melt and cut down on charging time. Natural convection can boost heat transfer efficiency and lower temperature discrepancy among the wall and the PCM when PCMs start to melt. Additionally, the iron foam performed admirably in terms of boosting heat transport and quickening the melting of PCM material.