Abstract

The productivity of any industry depends highly on the efficient utilization of energy through energy-efficient systems and devices. Heat exchangers are devices that can be used to recover thermal energy and convert waste heat into useful energy using different heat transfer fluids (HTF). Most heat exchangers involve a single-phase HTF that can only absorb energy in the form of sensible heat - making the system less efficient compared to the amount of pumping power exerted on the fluid. However, phase change material (PCM) based HTF can be utilized to enhance the heat transfer performance of the working fluid to absorb energy in both sensible and latent heat form to increase the overall efficiency of the system.

PCM has received tremendous attention from fundamental research to industrial applications due to its excellent thermal energy storage and thermal management capabilities. However, PCMs have a few limitations, including thermal instability, low thermal conductivity, and supercooling, which affect the thermal efficiency of the system. Thus, encapsulation of PCM has been used to overcome the shortcomings and to facilitate an easy dispersion into a liquid fluid to form a mixture of two-phase slurry. The advantage of microencapsulated phase change material (m-PCM) slurry is that the phase change latent heat is involved in the flow to increase its effective specific heat capacity. In this regard, m-PCM slurry as a working fluid was numerically investigated as a thermal energy conservation solution. A mathematical model based on the Eulerian-Eulerian two-phase flow was adopted to conduct the numerical analysis. The accuracy of the model was first validated with experimental data for the flow and heat transfer characteristics of the m-PCM slurry flow.

The results showed that particle concentration significantly affects the heat transfer performance of m-PCM slurry and promotes pressure drop due to increased viscosity. The study on the ratio of $h_{avg}/\Delta P$ found that a 10% volume concentration showed better performance as an HTF. Analysis was made to study the effects of the temperature difference between the pipe inlet to outlet and volume concentrations of m-PCM particles. Accordingly, it is found that water exhibits the highest pumping power demand over PCM-based HTFs to transport the corresponding thermal energy. The increase in temperature variation improves the energy capacity of both water and m-PCM slurry but affects the influence of the latent heat of the PCM. Furthermore, it is observed that a flow of m-PCM slurry with a low Reynolds number achieves a better value of Q/Wp under turbulent flow conditions.

It is commonly accepted practice to improve a thermal-fluid device by adopting surface enhancement techniques for heat transfer. On the other hand, Microencapsulated phase change material (m-PCM) slurry can be used as an HTF due to its improved heat capacity. A study was conducted to combine the two enhancement methods in a double-pipe heat exchanger. The result found that the groove-cut models demonstrate enhanced flow mixing, manifested by an improved heat transfer and facilitating a uniform melting of m-PCM particles. Similarly, the Q/Wp ratio indicates that the groove cut models transport more heat than the pumping power requirement for m-PCM slurry. An experimental investigation was conducted to assess the performance of the m-PCM slurry during the charging and discharging process. The study compared the performance of m-PCM with plain water, a commonly used working fluid in heat exchangers. The comparative performance factor exhibits that m-PCM slurry has a value of around 1.65 times higher than plain water during the heating cycle at a Reynolds number of 5,100. On the other hand, it has a performance factor increment of 22% for the discharge cycle. The study findings indicate that the overall performance of m-PCM slurry depends highly on flow parameters but exhibits favourable characteristics as a heat transfer fluid (HTF) for both charging and discharging cycles.

Keywords: Phase change material, Microencapsulated PCM slurry, Double pipe heat exchanger, Heat transfer fluid, Heat capacity, Waste heat recovery, Thermal Efficiency

---