ENHANCEMENT OF HEAT TRANSFER USING PHASE CHANGE MATERIAL WITH WATER MIXTURE

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The present study deals with the Convective heat transfer performance of Phase Change Material (PCM) / Water mixture less than 0.4% volume concentration were tested using double pipe circular tube heat exchanger. We choose Erythritol as a phase change material, it has robust effect of cooling or optimistic heat of solution and latent heat of fusion is nearly equal to ice. The result shows that the addition of small amount of Erythritol powder to the base fluid water enhance the heat transfer coefficient considerably. The enhancement was about average of 2.3% increase in heat transfer coefficient was observed with 0.1% volume of PCM/Water mixture and average of 50.3% increase in heat transfer coefficient was observed with 0.3% volume of PCM/Water mixture.

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1. Introduction

Nowadays, the demand for cooling system increased greatly during the last decade, large demands of electrical power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demands by the industrial and commercial and residential activities. Most of the researches are trying to find the alternative energy efficient cooling system renewable energy sources. Efficient and economical technology that can be used to store large amount of heat or cold in definite volume, thermal energy storage plays an important role in all industries. Devices which store heat during peak power operation, release the same amount of heat during reduced power operation. Phase change material is one of the thermal energy storage devices. At present, a lot of materials are always selected as PCM for thermal storage system, including Water and Barium hydroxide, but these thermal storage systems are limited in heat storage density, safety and phase change temperature. The organic PCM can solve the potential problem, meanwhile in order to improve its low thermal conductivity, and different kinds of metal additives have to be added in the thermal storage material [1–5].As organic material, erythritol provides much higher storage density and a small temperature differential between storing and releasing heat. But in order to improve its low thermal conductivity, some metal matrix or high conductivity particle should be added. Teppei Oya [6] developed, a new phase change composites using erythritol as a phase change material ,and graphite and nickel particles are added as highly thermal conductive fillers, leading to 6.4 times of higher thermal conductivity of pure erythritol. Besides above, there are also numerous researches that reported that the preparation and characterization of encapsulated PCMs. Agyenim [7] reviewed the development of latent heat thermal energy storage systems, studied various phase change materials (PCM) investigated over the last three decades, and examined the geometry and configurations of PCM containers. A series of numerical and experimental tests were undertaken to assess the effects of parameters such as the inlet temperature and the mass flow rate of the heat transfer fluid. Sharma et al., [8] summarized the investigation and analysis of the

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available thermal energy storage systems incorporating PCMs for use in different application. Designing a suitable heat exchanger is equally important as material investigation. Two types of heat exchangers are primarily used for LHTS, namely, direct-contact heat exchanger and indirect-contact heat exchanger. For the indirect-contact heat exchanger, the plate, shell-and-tube, and packed-bed types are typically used because other complicated forms of heat exchangers can be developed from these types. Shell-and-tube heat exchanger is commonly employed in LHTS because of its simple structure and relatively small heat loss. Considerable research on the melting/solidification behavior and thermal performance of shell-and-tube LHTS [9-13], including theoretical, numerical, and experimental studies, has been conducted.

In the past decades, heat transfer enhancement technology has been developed and extensively fit in heat exchangers. Numerous efforts have been made to shrink the size, cost of heat exchanger and energy consumption. In general, the taxonomy of enhancement of heat transfer techniques can be scattered into three types namely; active, passive and compound techniques. The thermal conductivity enhancement has been used to enhance the thermal storage and release. The technical feasibility of a heat accumulator containing an advanced PCM material (Erythritol), which is a sugar alcohol, can be characterized as a high-temperature PCM, because it has a melting point of 120^{o}C and a large latent heat. In addition, it is regarded as a promising PCM because it is environmentally friendly, non-toxic, and non-flammable [14,15]. Even though the above mentioned properties of erythritol make it suitable for PCM-based applications, it has a very low thermal conductivity, and PCMs tend to lose energy during the repeated cycles of melting and solidification. Karthik et al., [16] discovered that Erythritol–graphite foam composite PCM can be considered as a potential material for various TES applications such as building and vehicle heating and cooling, solar thermal harvesting, and thermal management of electrochemical energy storage and electronic devices. Moreover, the inexpensive raw materials and the simple preparation method ensure the implementation of this process in large-scale applications. Erythritol possesses a high fusion heat of 340 J/g at a melting point of about 119^{o}C. It is always used for recovering waste heat. Agyenim et al., [17-19] conducted experimental studies on thermal storage using Erythritol as the PCM in a horizontal shell-and-tube unit. The heat transfer enhancement methods that use multi-tubes, circular fins and longitudinal fins were compared with those using plain inner tube forms, where natural convection still plays an important role during melting. However, no study on the vertically placed shell-and-tube type LHTS has been conducted with Erythritol as the PCM, where the effect of natural convection on the flow and heat transfer may be different from that on the horizontal type. In addition, the effect of natural convection when HTF flows from top to bottom needs to be studied further. Thus, detailed experimental and theoretical studies must be carried out to reveal the physical phenomena and design of vertical shell and- tube heat storage unit with Erythritol as storage media. Wang et al., [20] conducted an experimental study on a vertical shell tube latent heat thermal energy storage element with erythritol as storage material and air as heat transfer fluid was conducted to evaluate the heat transfer performance and the thermal behavior of the storage unit. While increasing the mass flow rate and inlet temperature of the HTF during charging obviously enhances the heat transfer in the PCM and reduces the charging time. During discharging time, the increasing the mass flow rate of the HTF helps to enhance the heat transfer rate. Increasing the pressure of the HTF with the same mass flow rate shows slight effect on the heat transfer in the PCM.

In light of the above discussion, the purpose of this study was to prepare phase change composites using water to evaluate the comprehensive thermo physical properties such as convective heat transfer co-efficient of PCM and viscosity of erythritol at temperatures ranging from 15 to 160^{o}C are carried out, Moreover, the effects of inlet temperature, mass flow rate, and pressure of the HTF on thermal performance are studied.

2. Experimental setup

A heat exchanger is a heat transfer device whose purpose is transfer of energy from one moving fluid stream to another moving fluid stream. In heat transfer, conduction is the transfer of thermal energy between regions of matter due to a temperature gradient. Heat spontaneously flows from higher temperature region to lower temperature region; temperature differs over time to approach thermal equilibrium. The following criteria's are involved for selection a heat exchanger. Namely, suitable operating pressure, temperature, fluid-material compatibility, handling, extreme thermal conditions and estimating the cost of those which may be suitable. General considerations for tubes and cylinder in heat exchanger. Tubes and cylinders can with stand higher pressures than plate if exchangers can be built with a variety of materials, then it is more likely that you can find a metal which will cope with extreme temperatures or corrosive fluids. More specialist exchangers have fewer suppliers, longer delivery times and must be repaired by experts.

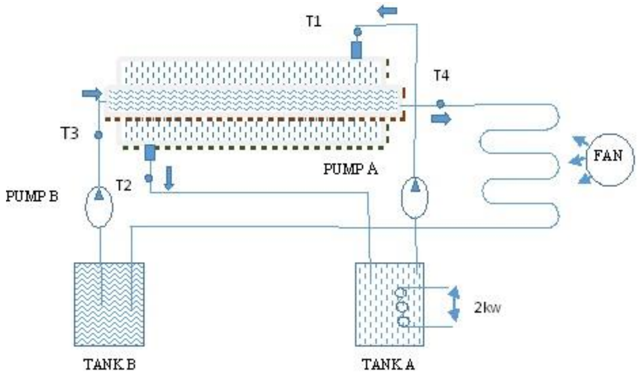

Fig. 1. Schematic diagram of experimental setup

Fig.1 illustrates the schematic diagram of the double pipe heat exchanger experimental system used to investigate the improvement in heat transfer of Erythritol. The setup consists of two tanks A & B of capacity 10 liters each and two ½ HP Centrifugal Pumps A & B and 2KW industrial heater is fitted to tank A.

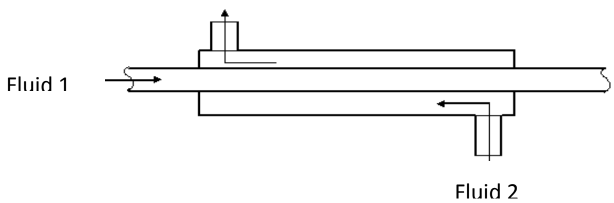

Fig.2. Double pipe heat exchanger

Fig. 2 shows double pipe heat exchanger schematic diagram. The double pipe setup consists of outer Galvanized Iron pipe of 1.5 inch diameter and 1.25 m length and inner Stainless Steel pipes of ½ inch diameter and 1.5 m length. Temperatures are measured using for thermocouples of K-type, they are located at the ends of outer and inner pipes of double pipe setup. Thermocouple DAQ card interface is used to measure the temperature using LABVIEW software. The properties are listed below.

Density of Solid	$\rho_s=$	8940	kg/m^3
Density of Water	$\rho_w=$	1000	kg/m^3
Specific heat of solid	$C_{ps}=$	0.385	KJ/Kg K
Specific heat of Water	$C_{pw}=$	4.186	KJ/Kg K
Thermal conductivity of copper	$K_s=$	401	W/mk
Thermal conductivity of Water	$K_w=$	0.58	W/mk

	β=	0.1	
Viscosity of water	μ_w=	0.0012	Pa-s
Density of PCM fluid	ρ_{pcm}=	3382	kg/m^3
Specific heat of PCM fluid	C_{ppcm}=	1.171724	KJ/Kg K
Thermal conductivity	$K_{pcm=}$	3.028884	W/mk
Flow velocity	V=	0.01	m/s
Viscosity of PCM fluid	μ_{pcm}=	0.0021	Pa-s
Inner pipe diameter	d_o=	21.3	mm
Inner pipe diameter	d_i=	12.7	mm
Length of the inner pipe	L=	1300	mm
Area of Outer pipe	A_o=	126.68	mm
Area of Inner pipe	A_i=	126.68	mm
Liquid contact surface	∏DL	86990.70	mm

Fig. 3. Experimental setup used to investigate the heat transfer of Erythritol.

Fig. 3 shows the experimental setup procedure for convective heat transfer co-efficient measurement in phase change material with water mixture. The tank A and B are filled with water and the water in the tank A is heated with the 2KW heater and after reaching certain temperature (below boiling point) the heater is turned off and then two pumps A & B are turned on simultaneously. Now water from the tank A was pumped by the pump A and flows through the outer tube of the double pipe setup, where the temperature T3 was measured at the inlet of the outer tube and the Temperature T2 is measured at the outlet of the outer tube and again the water flows into the tank A and the process continues. Simultaneously water from the tank B was pumped by the pump B and flows through the inner tube of the double pipe setup, where the temperature T3 was measured at the inlet of the inner tube and the temperature T4 is measured at the outlet of the inner tube and again the water flows into the tank B and the process continues. A data acquisition system (National Instruments Compact DAQ) with one NI9203 and one NI9213 series digital output and relay module on a computer was used to collect the flow rate, pressure, and temperature signals. The experimental data were recorded at 5 s intervals. The temperatures T1, T2, T3 and T4 are obtained from respective thermocouples which are connected to the Thermocouple DAQ card which is connected to the PC running LABVIEW through USB port. And the collected data are exported to the excel sheet through the option provided. Now water in tank B is replaced with Erythritol/Water mixture and the process is carried on to obtain the temperatures T1, T2, T3 and T4 from respective thermocouples which are connected to the Thermocouple DAQ card which is connected to the PC running LABVIEW through USB port. And the collected data are exported to the excel sheet through the option provided.

2.1. Estimation of thermo Physical properties

The convective heat transfer co-efficient of PCM fluid and Reynolds number and Nusselt number are calculated by the given equation:

The convective heat transfer co-efficient

$$\text{Hpcm} = \frac{\text{Cppcm} * \rho\text{pcm} * \text{V} * \text{Ain}(\text{Tco} - \text{Tci})}{\pi * \text{d0l}(\text{LMTD}) * 1000} \quad (1)$$

Where,h_{pcm} – Convective heat transfer coefficient, Cp_{pcm} – Specific heat of pcmfluid, ρ_{pcm} – Density of pcmfluid,V – Flow velocity, A_{in} – Area of Inner pipe, T_{co} – Cold outlet temperature, T_{ci} – Cold inlet temperature, $\pi d_0 l$ – Liquid contact surface.

Log Mean temperature difference (LMTD)

$$\text{LMTD} = \frac{(\Delta\text{T1} - \Delta\text{T2})}{\text{In}(\Delta\text{T1}/\Delta\text{T2})} \quad (2)$$

Where,$\Delta T_1 = T_{hi}$- T_{ci} and $\Delta T2 = T_{ho}$- $T_{co,}$ T_{hi}= Hot inlet temperatureT_{ho}= Hot outlet temperature

$$\text{Repcm} = \frac{\rho\text{pcm} * \text{V} * \text{di}}{\mu\text{pcm}} \quad (3)$$

Where, Repcm = Reynolds number, V = Flow velocity, di = inner pipe diameter, $\mu pcm_{=}$ Viscosity of pcm fluid

$$\text{Pr} = \frac{\mu\text{pcm}/\ \text{Cppcm}}{\text{Kpcm}} \quad (4)$$

$$\text{Kpcm} = \frac{(\text{Ks} + 2\text{Kw} + 2(\text{Ks} - \text{Kw})(1 + \beta)3\varphi)}{(\text{Ks} + 2\text{Kw} - (\text{Ks} - \text{Kw})(1 + \beta)3\varphi)} * \text{KW} \quad (5)$$

$$\text{Nupcm} = 0.021 * 0.5\ \text{Repcm}^{0.3} * \text{Prpcm}^{0.5} \quad (6)$$

Where, Pr = Prandtl Number, Nupcm = Nusselt Number.

3. Results and discussion

The convective heat transfer coefficient of pcm fluid are calculated by the given equation and the results are compared and discussed with the experimental results.Dilute PCM/water with different loading of 0%, 0.1%, 0.2% & 0.3% were used as working fluid. Reynolds number of flow varied between 1000 to 4500.

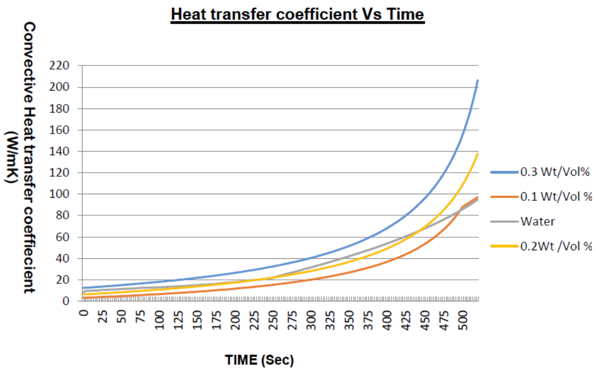

Fig. 4. Comparison between convective heat transfer coefficient of pcm fluid and time

The convective heat transfer coefficient of PCM has been calculated using equation 1 and the results are compared with the measured value.The fig.4 shows the heat transfer co-efficient of PCM with respect to time. The heat transfer coefficient is increased gradually when increasing the time period. It can be clearly seen that the convective heat transfer coefficient of the 0.1 vol% of PCM/water mixture is slightly higher than base fluid (water) at a given Reynolds number. Then the convective heat transfer coefficient of the 0.2 vol% of PCM/water mixture is higher than 0.1 vol% of PCM/water mixture at a given Reynolds number. And finally the convective heat transfer coefficient of the 0.3 vol% of PCM/water mixture is higher than 0.2 vol% of PCM/water mixture at a given Reynolds number.

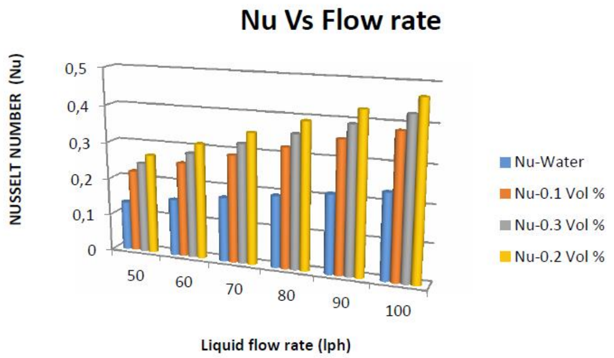

Fig. 5 Comparision between nusselt number and flow rate

The Nusselt number depends on the Prandtl number and Reynolds number where reynolds number depends on the velocity of the liquid. Thus, the nusselt number increases with increase in flow rate of the liquid.The Nusselt numbers are calculated from the given equation 6. The Nusselt nmbers with respect to liquid flow rate is shown in fig. 5. When increasing the liquid flow rate nusselt number is also increased gradually. The nusselt number of the 02 vol% of PCM/water mixture is higher than the 0.3 vol % and 0.3 vol % of PCM/water mixture.

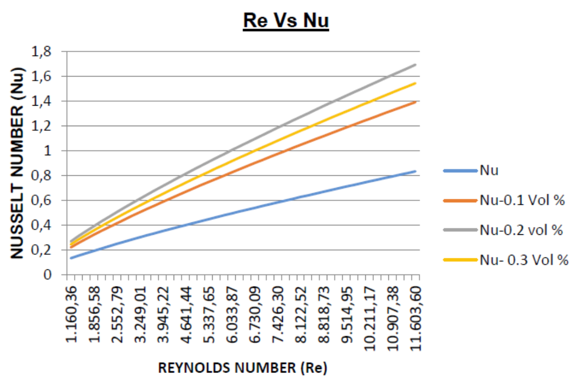

Fig. 6. Comparision between the reynolds number and nusselt number

Reynolds number is calculated by the formula in which all other parameters except velocity are constant. Thus, the Reynolds number changes with change in velocity of the fluid. Nusselt number depends on the Prandtl number and Reynolds number. Comparison between the Reynolds number and Nusselt number are shown in fig. 6. The result shows that the Nusselt number increases with the increase in Reynolds number.

4. Conclusions

A phase change material is proficient way of absorbing or releasing excessive amount of energy in a form of latent heat during phase transitions between or solid–liquid or solid–solid phases over a narrow temperature range. Latent heat storage in phase change material is very attractive because of its high storage density with small temperature variation. Many PCM has been studied and tested for different practical uses by many researchers. The enhancement of PCM heat transfer performance is still needs attention. The PCM/Water mixture fluid convective heat transfer inside a double pipe heat exchanger tubehas been built and studied experimentally to evaluate its heat transfer performance. The dilute PCM fluid with Erythritol volume fractions less than 0.4% were used. The heat transfer coefficient increased about 50.3% compared to water. Increase in PCM concentration shows some effect on heat transfer enhancement in the range of concentrations studied.

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