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Thermal Analysis of Double Pipe Heat Exchanger Using Various PCM

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Abstract:
In this paper the use of a latent heat storage system using phase change materials (PCMs) is analyzed using two types of phase changing materials in a double tube heat exchanger. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. These materials are used in applications where it is necessary to store energy due to the temporary phase shift between the offer and demand of thermal energy. The aim of this project is to analyze the thermal behavior of various PCM materials in Double pipe heat exchanger. In this system the PCM of Lauric acid, Myristic acid and Palmitic acid having the melting point range from 36 ^{O}C - 50^{O}C is used. The PCM are place in the outer tube and water is used as working fluid medium in the outer tube.

Keywords: Lauric acid, Myristic acid, Palmitic acid, Double pipe heat exchanger

1. INTRODUCTION

The continuous increase in the level of greenhouse gas emissions and the climb in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. The scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. Heat exchangers with phase change material (PCM) are a solution to store energy [3]. Thermal energy storage improves the efficiency and eliminates the mismatch between the energy supply and energy demand of solar thermal energy applications. Among the different types of thermal energy storage, a phase change material (PCM) thermal energy storage exhibits superior efficiency and dependability due to its high storage capacity and nearly constant thermal energy [1]. The transient forced convective heat transfer between the heat transfer fluid (HTF) with moderate Prandtl numbers and the tube wall, heat conduction through the wall and solid–liquid phase change of the phase change material , based on the enthalpy formulation [2]. The heat transfer process during melting (charge) and solidification (discharge) of five small heat exchangers working as latent heat thermal storage systems. Commercial paraffin RT35 is used as PCM filling one side of the heat exchanger and water circulates through the other side as heat transfer fluid. Average thermal power values are evaluated for various operating conditions and compared among the heat exchangers studied. When the comparison is done for average power per unit area and per average temperature gradient, results show that the double pipe heat exchanger is the one with higher values in the range of 700–800 W/m^{2}K [5]. Volumetric expansion of PCM inside a container is a critical problem that exists in reality due to a large density difference in the solid and liquid PCM, and needs to be considered during the thermal storage process. Further, natural convection is caused by the density variation inside the liquid due to the temperature differences. Latent heat thermal energy storage (LHTES) has become a particularly attractive technique in energy saving using the melting enthalpy of phase change materials. Latent heat thermal energy storage (LHTES) requires a relatively smaller container volume for a given energy compared with a conventional sensible heat energy storage system [6]. The research on fatty acids as PCMs is mainly on the phase change temperature and latent heat, thermal conductivity, heat transfer behavior of saturated acids with the carbon number of 10–18 [7]. It is concluded that most of the phase change problems have been carried out at temperature ranges between 0ºC and 60ºC suitable for domestic heating applications. In terms of problem formulation, the common approach has been the use of enthalpy formulation. Heat transfer in the phase change problem was previously formulated using pure conduction approach but the problem has moved to a different level of complexity with added convection in the melt.[4] Free-cooling and temperature maintenance in rooms with special requirements possess high potential for PCM application in different countries according to their climate. The overall objective here is to apply methodologies to study PCM-air heat exchangers that allow the development of applications with technical and economical viability [9]. Different PCM materials, with and without enhancement of the thermal conductivity, were used, and their performance concerning the resulting charge/discharge power of a storage tank [8].

2. SELECTION OF PCM

Three different types of PCM were selected, namely Lauric acid, Myristic acid and Palmitic acid. The physical properties of the PCM are shown in the table 1. The various fatty acid composition of PCM properties are listed given below in Table.2 [7].

Table.1. Properties of PCM

Fatty Acid	Melting Temp(°C)	Thermal Conductivity (W/mK)	Enthalpy (J/kg)	
			Melting	Freezing
lauric acid	42	0.147	190	192
myristic acid	51	0.15	204	180
Palimitic acid	58	0.162	188	216

Table.2. Composition of PCM properties

Fatty Acid	Proportion	Melting Temperature (°C)	Enthalpy (J/kg)	
			Melting	Freezing
LA: MA	58: 42	36	162.27	168
LA:PA	69:31	35	166.3	168.3
MA: PA	58:42	43	169.7	185.6

2.1 Selection of Heat Exchanger

Heat exchangers with phase change material (PCM) are a solution to store energy. Such storage unit can be used both for free cooling and peak load shaving in winter and in summer. The heat exchanger is a device which transferred the heat from hot medium to cold medium without mixed both of medium since both mediums are separated with a solid wall generally. There are many types of heat exchanger that used based on the application. For example, double pipe heat exchanger is used in chemical process like condensing the vapor to the liquid.

The temperature gradient or the differences in temperature facilitate this transfer of heat. Transfer of heat happens by three principle means of radiation, conduction and convection. In the use of heat exchangers radiation does take place. However, in comparison to conduction and convection, radiation does not play a major role. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall. To maximize the heat transfer, the wall should be thin and made of a very conductive material. The biggest contribution to heat transfer in a heat exchanger is made through convection

Figure.1. Double pipe copper tube heat exchanger

A simple Double pipe copper tube heat exchanger with the PCM in the annular space is used. The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. This is a concentric tube construction. In all cases water was used as the heat transfer fluid, passing through the inner side of the heat exchanger. The PCM used in the heat exchanger is about 0.5 kg.

3. METHODOLOGY FOR DESIGN

In order to analyze the thermal performance of the PCM by considering volume expansion of the PCM was developed with the heat exchanger could be represented as a double pipe heat exchanger.

Under these conditions one of the fluids in the heat exchanger undergoes a phase change process and the rate of heat transfer is expressed as equation given below.

$$Q = m.hfg$$

In this equation the useful rate of heat transfer (Q) is represented by a function mass of the PCM (m), melting latent heat of PCM (hfg).

According to the first law of thermodynamics the rate of heat transfers from the hot fluid to be equal to the rate of heat transfer to the PCM.

$$Q = mCp\Delta T$$

Thermal power given to the PCM with respect to the time is given by following equation.

$$Q = \frac{EPCM}{t}\left[\frac{\left[MC_{pcms}\left(T_{pcmlow} - T_{pcminitial}\right) + MCH_{pcm} + MC_{pcm}\left(T_{p\ cmend} - T_{p\ cmhigh}\right)\right]}{t}\right]$$

In above equation thermal energy given to the PCM (EPCM), time of the charging process until complete melting (t), (M) is the weight of PCM, cp_{PCMs} and cp_{PCMl} are specific heats for solid and liquid PCM, $T_{PCM\ low}$ and $T_{PCM\ high}$ are the lower and upper values of the PCM phase change interval, T_{PCM}, initial and T_{PCM}, end are the PCM temperatures at the start and end of the process, respectively, and HPC is the PCM phase change enthalpy. Thermal energy given or gained by water is evaluated by integrating the energy balance in the water side for every time interval during the phase change process. For a charging process this integration can be expressed by

$$E_{H2O} = m.\sum_{Tin}^{Tout}(h_{in} - h_{out})$$

Where EH_2O is the energy given by water to PCM, m is the water mass flow rate, and $\_h_{in}$ and $\_h_{out}$ the average enthalpies of water inlet and outlet for each time interval, respectively. Contrary to the common use rule in steady state heat exchangers, in this transient process E_{H2O} and E_{PCM} are not equal, as part of the heat is exchanged by the materials of the empty heat exchanger. In most of the heat storage systems studied, this difference is relatively small, around 20–30%, with the exception of the plate heat exchanger, where differences above 100% are reached, due to the much larger thermal capacity of this heat exchanger.

4. RESULTS AND DISCUSSION

4.1 THEORETICAL EVALUATION

The design calculation of double pipe heat exchanger with various PCM as working fluid. All the three PCM have been compared with their melting enthalpy and temperature difference.

4.1.1 Variation of Temp Diff with respect to Mass Flow Rate for Myristic Acid.

The effect of mass flow rate with respect to temperature difference between inlet and outlet temperature for myristic acid is shown in figure.2. As mass flow rate increases the temperature difference between inlet and outlet temperature is decreased. At a mass flow rate of 0.11 kg/sec the temperature difference was found to be 0.23ᵒC.

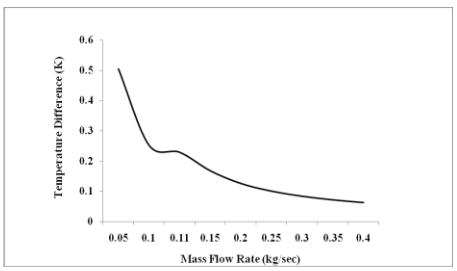

Figure.2. Variation of Temperature Difference with respect to Mass Flow Rate for Myristic Acid.

4.1.2 Variation of Temperature Difference with respect to Mass Flow Rate

The effect of mass flow rate with respect to temperature difference between inlet and outlet temperature for various PCMs such as caprylic acid, capric acid, palimitic acid, lauric acid, myristic acid and steatric acid has been illustrated in figure.3. It was found that mass flow rate increases with the temperature difference between inlet and outlet temperature of the heat exchanger reduces drastically. Maximum temperature difference is found for myristic acid and minimum temperature difference is found for capric acid under same condition.

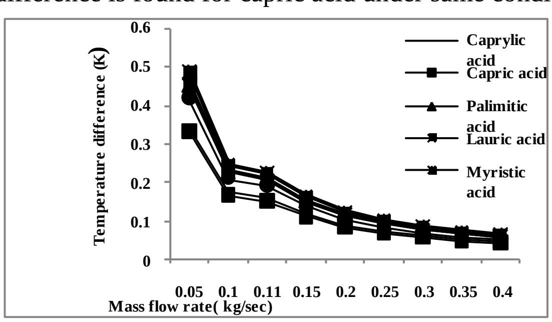

Figure.3. Variation of Temperature Difference with respect to Mass Flow Rate for Various PCM.

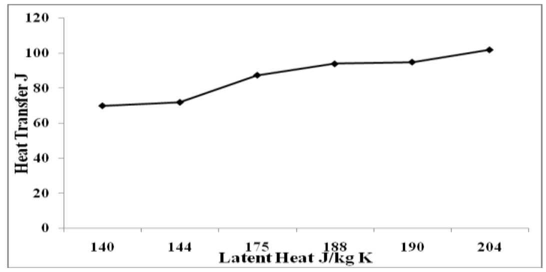

Figure.4. Heat transfer with respect latent heat.

4.1.3 Variation of Heat Transfer with respect to Latent Heat for Various PCM

The effect of heat transfer with respect to latent heat of the PCM is shown in figure.4 it was found that latent heat increases with the heat transfer in the heat exchanger increases drastically. For phase change process the heat transfer of the system is directly proportional to the latent heat of the phase change material.

4.2 EXPERIMENTAL EVALUATION

The experimental evaluation of double pipe heat exchanger with PCM was done and results are discussed in this section. The effect of mass flow rate and PCM were investigated.

4.2.1 Lauric Acid as Working Fluid

The temperature distributions of HTF and the lauric acid in the PCM tank for two different mass flow rates are recorded during charging and discharging processes. The experiment was conducted with flow rate of 20lph and 15lph. The inlet temperature of the hot water was kept 60-70°C for charging and the atmospheric temperature of 28°C for discharging. During the charging and discharging process the HTF is circulated through the PCM tank continuously.

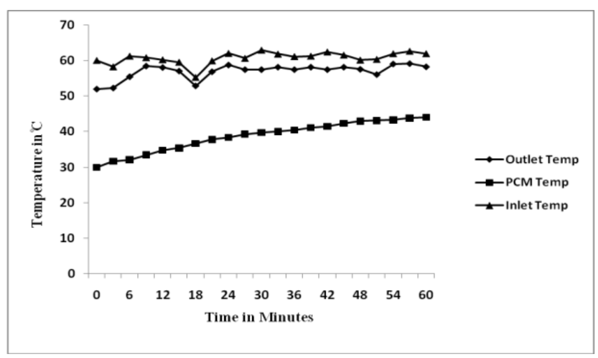

Figure.5. Charging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Lauric acid

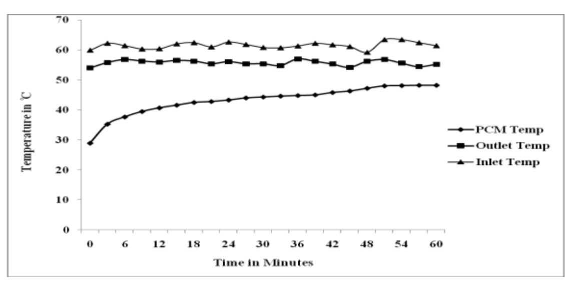

Figure.6. Charging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Lauric acid

4.2.1.1 Charging of Lauric Acid

The experimental results for charging process are shown in figure.5 and figure.6. From figure.5 it is observed that for the flow rate of 20lph, PCM temperature increasing gradually and takes 60 minutes to reach 49˚C. Also from figure.6 it is observed that for the flow rate of 15lph, PCM temperature increasing gradually and after 60 minutes it reaches 44˚C. From figure.6 it is observed that the energy stored during flow rate 20lph is lesser than 15lph.

4.2.1.2 Discharging of Lauric Acid

The discharging process was conducted with flow rate 20 lph and the inlet temperature of the cold water kept at the atmospheric temperature that is 32˚C. During the discharging process the cold water is circulated through the PCM tank now the heat energy stored in PCM is transferred to the cold water so the cold water temperature is increased. Temperature of the PCM and HTF are recorded at intervals of 15 minutes. The discharging process is continued until the PCM temperature reduces to atmospheric temperature. The temperatures of the HTF at inlet and outlet are recorded. Also the temperatures of the PCM at two locations are recorded. Like that the flow rate changed to 15lph and the PCM and HTF temperatures are recorded. The experimental results for discharging process are shown in figure.7 and figure.8.

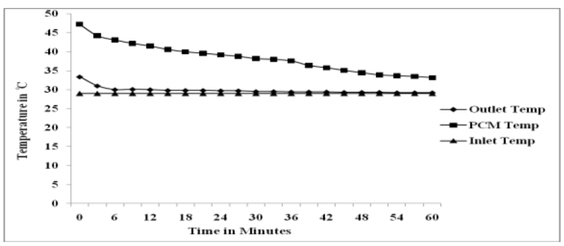

Figure.7. Discharging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Lauric acid

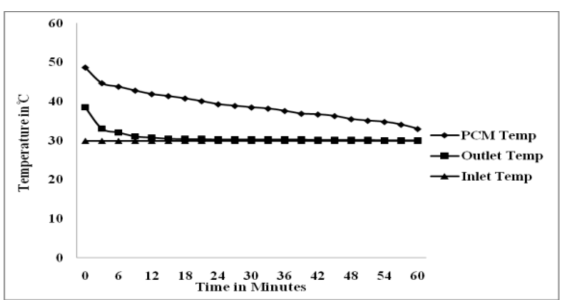

Figure.8. Discharging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Lauric acid

Figure.7 shows the variation of inlet and outlet temperatures and PCM temperatures during discharging process for flow rate 20lph and Figure.8 shows the variation of inlet and outlet temperatures and PCM temperatures during discharging process for flow rate 15lph.From Figure.7 it is observed that for the flow rate of 20lph PCM temperature decreasing gradually and takes 60 minute to reach 33˚C temperature. Also figure.6 shows the same for the flow rate of 15lph and it shows that after 60 minutes it reaches only 30˚C.

4.2.2 Myristic Acid as Working Fluid

The temperature distributions of HTF and the myristic acid in the PCM tank for two different mass flow rates are recorded during charging and discharging processes. The experiment was conducted with flow rate of 20lph and 15lph. The inlet temperature of the hot water was kept 60-70°C for charging and the atmospheric temperature of 28°C for discharging. During the charging and discharging process the HTF is circulated through the PCM tank continuously.

4.2.2.1 Charging of MyristicAcid

The experimental results for charging process are shown in figure.9 and figure.10. From figure.9 it is observed that for the flow rate of 20lph, PCM temperature increasing gradually and takes 60 minutes to reach 55˚C. Also from figure.10 it is observed that for the flow rate of 15lph, PCM temperature increasing gradually and after 60 minutes it reach 49˚C. Figure.9 shows the same for the flow rate of 15lph.From figure.10 it is observed that the energy stored during flow rate 20lph is lesser than 15lph.

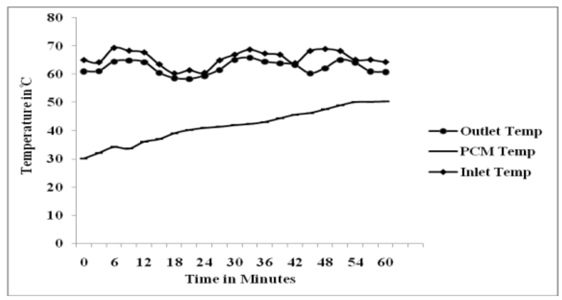

Figure.9. Charging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Myristic acid

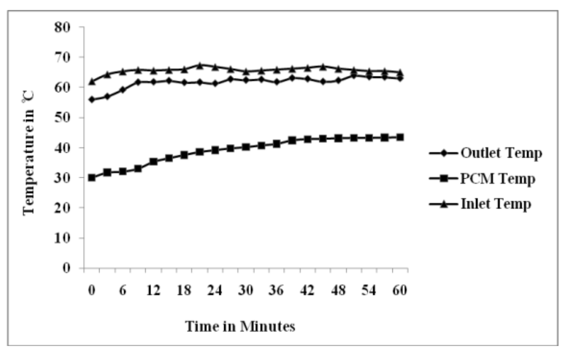

Figure.10. Charging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Myristic acid

4.2.2.2 Discharging of MyristicAcid

The discharging process was conducted with flow rate 20 lph and the inlet temperature of the cold water kept at the atmospheric temperature that is 32˚C. During the discharging process the cold water is circulated through the PCM tank now the heat energy stored in PCM is transferred to the cold water so the cold water temperature is increased. Temperature of the PCM and HTF are recorded at intervals of 15 minutes. The discharging process is continued until the PCM temperature reduces to atmospheric temperature. Like that the flow rate changed to 15lph and the PCM and HTF temperatures are recorded. The experimental results for charging process are shown in figure.11 and figure.12. From figure.11 it is observed that for the flow rate of 20lph PCM temperature decreasing gradually and takes 60 minute to reach 33˚C temperature. Also figure.12 shows the same for the flow rate of 15lph and it shows that after 60 minutes it reaches only 30˚C.

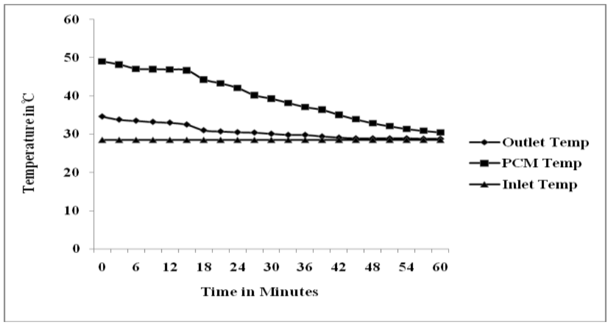

Figure.11. Discharging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Myristic acid

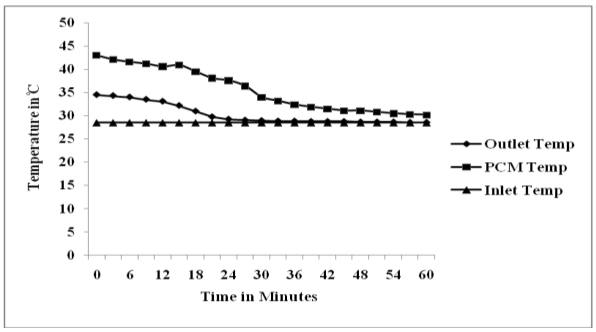

Figure.12. Discharging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Myristic acid

4.2.2.3 Palmitic Acid as Working Fluid

The temperature distributions of HTF and the palmitic acid in the PCM tank for two different mass flow rates are recorded during charging and discharging processes. The experiment was conducted with flow rate of 20lph and 15lph. The inlet temperature of the hot water was kept 60-70°C for charging and the atmospheric temperature of 28°C for discharging. During the charging and discharging process the HTF is circulated through the PCM tank continuously.

4.2.3.1 Charging of PalmiticAcid

The experimental results for charging process of palmitic acid are shown in figure.13 and figure.14. From figure.13 it is observed that for the flow rate of 20lph, PCM temperature increasing gradually and takes 60 minutes to reach 59˚C. Also from figure.14 it is observed that for the flow rate of 15lph, PCM temperature increasing gradually and takes 60 minutes to reach 54˚C.

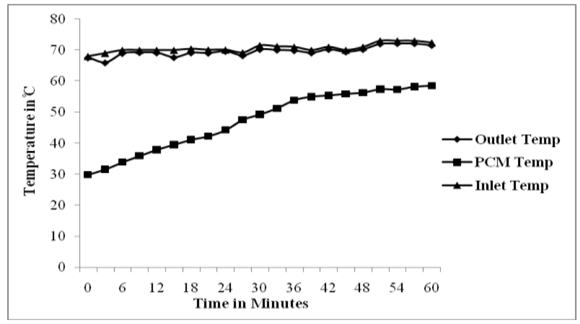

Figure.13. Charging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Palmitic acid

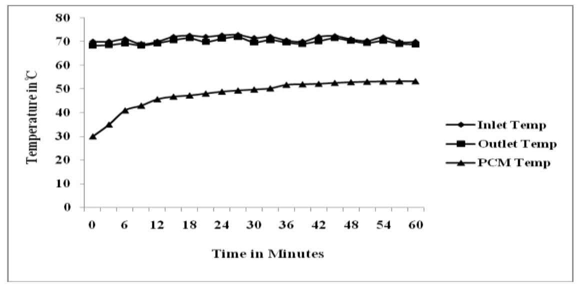

Figure.14. Charging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Palmitic acid

4.2.3.2 Discharging of PalmiticAcid

The experimental results for charging process are shown in figure.15 and figure.16. From figure.15 it is observed that for the flow rate of 15lph PCM temperature decreasing gradually and takes 60 minute to reach 30˚C temperature. Also figure.12 shows the same for the flow rate of 15lph and it shows that after 45 minutes it reaches only 30˚C.

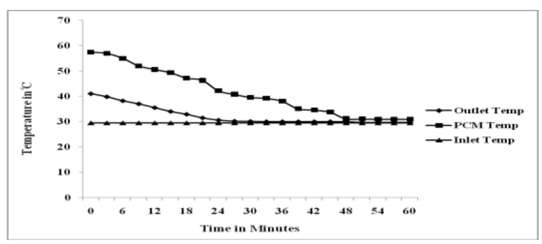

Figure.15. Discharging PCM Temperature with respect to Time for flow rate of 20 lit/hr of Palmitic acid

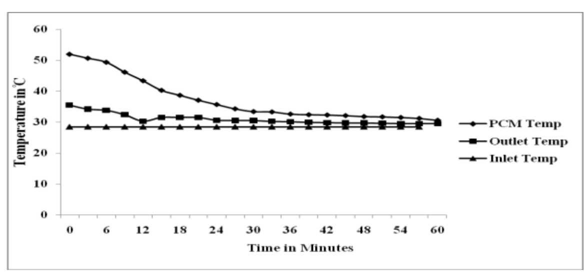

Figure.16. Discharging PCM Temperature with respect to Time for flow rate of 15 lit/hr of Palmitic acid

Table.3. Thermal Performance of the Heat Exchanger with various PCM

PCM	Energy Released by the Hot Water during Charging Mode (J)	Energy Gained by the Cold Water during Discharging Mode (J)	Heat Gain Efficiency of PCM (%)
Lauric Acid at 20 lph	1645.34	597.75	36
Lauric Acid at 15 lph	1978.26	584.71	29.5
Myristic Acid at 20 lph	1609.57	879.76	54.65
Myristic Acid at 15 lph	1863.30	881.58	47.31
Palmitic Acid at 20 lph	1456.86	654.2	44.9
Palmitic Acid at 15 lph	1625.63	658.49	40.5

Table.3 shows the performance of the heat exchanger with two different flow rates of various PCM. It shows that maximum heat gain efficiency is attain for myristic acid at 20lph of 54.65% and minimum heat gain efficiency is attain by the PCM of lauric acid at 15lph of 29.5%.

5. CONCLUSION

The PCM of Lauric acid, Myristic acid and Palmitic Acid having the melting point range from 36 ^{O}C - 50^{O}C is used .The thermal analysis for the suggested double pipe heat exchanger design has been carried out. The effect of three different PCM in the double pipe heat exchanger has been evaluated theoretically and experimentally. A Comparison has been made for different PCMs by changing latent heat of PCM. It is found that PCM having higher enthalpy is capability to absorb more temperature. By using Myristic acid having high enthalpy and attain a maximum temperature difference of 0.49 is achieved for the mass flow rate of 0.05 kg/sec.

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