

EXPERIMENTAL EVALUATION OF SHELL & TUBE HEAT EXCHANGER WITH P – TOLUIDINE (PCM)

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Abstract - Thermal energy storage using phase change material proved to be promising technology because of its relative advantages over the other types of energy storage methods. Along with thermo physical properties of PCM, the performance of latent heat based thermal energy storage system depends on the design of heat exchangers. The heat exchanger is major element as far as heat transfer & energy conservation is concern. In this present work the experimental study carried out to evaluate the effect of phase change material in a shell & tube heat exchanger using water as working fluid and p-Toluidine as PCM. The melting temperature of p-Toluidine (PCM) is 44°C. The experimentally evaluated the temperature differences in shell & tube heat exchanger with variation of mass flow rate. The result was indicating the effectiveness is high when PCM is melted.

Key Words: shell & tube heat exchanger, PCM, Melting temperature, NTU method, effectiveness

1. INTRODUCTION

It is well understood that the implementation of energy storage technologies is an effective method to help to correct the mismatch between the energy demand and supply. Among the different energy storage technologies, latent heat thermal energy storage (LHTES) systems have gained relevance during the last decades because of their high energy storage densities and almost isothermal operating conditions (Zalba B 2018). The use of latent heat of Phase Change Materials (PCM) in the energy storage systems has attracted a lot the attention of researchers interested in renewable energies field. Usually, the PCM can be encapsulated in containers of cylindrical or spherical geometries. In literature, a large number of available works present experimental, numerical and analytical research investigating the PCM melting within a cylindrical tube. The PCM can be filled in open or closed containers that can be placed in vertical, horizontal or inclined position. Some researchers have been inspected the effects of the rotating shell on the phase change process (Mohammed Bechiri, Kacem Mansouri 2019).

Jaume Gasia, N.H. Steven Tay (2017) was presented the Experimental investigation of the effect of dynamic melting in a cylindrical shell-and-tube heat exchanger using water as

PCM, Results from the experimental analysis showed enhancements up to 65.3% on the melting period, up to 56.4% on the effectiveness, and 66% on the heat transfer rates when the PCM flow rate was twice the HTF flow rate. From these experiments, it can be concluded that dynamic melting is an effective technique for enhancing heat transfer during melting of PCM. Mohammed Bechiri (2019) Study of heat and fluid flow during melting of PCM inside vertical cylindrical tube, the results show that all parameters of the problem can really affect the phase change phenomena and consequently, affect the melting time. Ashish Agarwal (2015) was presented An experimental investigation of shell and tube latent heat storage for solar dryer using paraffin wax as heat storage material, Experimental results show that the LHS is suitable to supply the hot air for drying of food product during no sunshine hours or when the intensity of solar energy is very low. Temperature gain of air in the range of 17°C to 5°C for approximately 10 hrs duration was achieved during discharging of LHS. M. Rahimi (2018) was investigated Effect of Helical Diameter on the Performance of Shell and Helical Tube Heat Exchanger: An Experimental Approach, Results show that by increasing of Stefan number melting process accelerates and total melting time decreases. Results also indicate that increasing coil diameter causes a decrease in total melting time and also an increment in final average temperature of PCM. Absorbed energy by PCM is increased by increasing helical diameter of HTF tube.

Lokesh Kalapala (2018) was determined a Influence of operational and design parameters on the performance of a PCM based heat exchanger for thermal energy storage – A review, This review presents the in-depth analysis of various operating conditions and design parameters that need to be considered in the design of a PCM based heat exchanger. Shell and tube type, triple concentric tube type heat exchangers are discussed along with the various heat transfer techniques employed in both the types of heat exchangers. In each enhancement technique, the influencing geometric parameters are summarized, and the recommended values of those parameters are provided.

The present article is expected to be a helpful reference for the researchers working in the field of thermal energy storage. In this present work, p-Toluidine as a phase change material (PCM) for shell and tube heat exchanger for better

heat transfer coefficient. The experimental results have been presented here with p-Toluidine as PCM.

2. METHODOLOGY

2.1 Statement of Problem

Geometry configurations of shell and tube heat exchanger filled in Phase change material. The hot and cold water outlet temperatures recorded with respect to variation of inlet hot & cold temperature and mass flow rate.

2.2 Selection of materials

There are several factors that need to be considered when selecting a phase change material. An ideal PCM will have high heat of fusion, high thermal conductivity and density, long term reliability during repeated cycle and dependable freezing behavior. The PCM melts and absorbs part of the heat gain through the melting process and solidifies then releases the stored heat. The net effect is increased the heat transfer coefficient. PCM should be selected based on the melting temperature, cost and availability. The organic type of PCM is selected. The selected PCM is P-Toluidine. The PCM act as a good thermal resistor at a variation of Mass Flow Rate.



Fig -1: P-Toluidine (PCM)

2.3 Thermo Physical Properties of PCM and Heat Exchanger

Table - 1: Thermo physical properties of PCM & Heat exchanger

Material	Thermal conductivity	Specific heat	Melting point	Density
PCM (p-toluidine)	0.3 w.m ⁻¹ .k ⁻¹	1.46 kg ⁻¹ .k ⁻¹	44° C	1.05g/cm ³
Copper	385 mK	0.386 J/gmK		8.96 g/cm ³
Aluminium	205W/mK	0.900 J/gmK		2.7 g/cm ³

2.4 Methodology for experimental calculation

Heat exchanger analysis is the determination of the heat transfer rate and the outlet temperatures of the hot and cold

fluids for prescribed fluid mass flow rate and the inlet temperatures when the type and size of the heat exchanger are specified []. From Text book of Heat & Mass Transfer by cengel the following equations to be find.

$$\epsilon = \frac{Q}{Q_{max}} = \frac{\text{actual heat transfer rate}}{\text{maximum possible heat transfer rate}} \quad (1)$$

The actual heat transfer rate in a heat exchanger can be determined from an energy balance on the hot or cold fluids and can be expressed as

$$\dot{Q} = C_c (T_{c, out} - T_{c, in}) = C_h (T_{c, in} - T_{c, out}) \quad (2)$$

Where $C_c = \dot{m}_c c_{p, h}$ and $C_h = \dot{m}_c c_{p, h}$ are the heat capacity rates of the cold and hot fluids, respectively. To determine the maximum possible heat transfer rate in a heat exchanger, we first recognize that the maximum temperature difference in a heat exchanger is the difference between the inlet temperatures of the hot and cold fluids. That is,

$$\Delta T_{Max} = T_{h, in} - T_{c, in} \quad (3)$$

The heat transfer in a heat exchanger will reach its maximum value when (1) the cold fluid is heated to the inlet temperature of the hot fluid or (2) the hot fluid is cooled to the inlet temperature of the cold fluid. These two limiting conditions will not be reached simultaneously unless the heat capacity rates of the hot and cold fluids are identical (i.e., $C_c = C_h$). When $C_c \neq C_h$, which is usually the case, the fluid with the smaller heat capacity rate will experience a larger temperature change, and thus it will be the first to experience the maximum temperature, at which point the heat transfer will come to a halt. Therefore the maximum possible heat transfer rate in a heat exchanger is

$$\dot{Q}_{Max} = C_{min} (T_{h, in} - T_{c, in}) \quad (4)$$

Where C_{min} is the smaller of C_h and C_c . The determination of \dot{Q}_{max} requires the availability of the inlet temperature of the hot and cold fluids and their mass flow rates, which are usually specified. Then, once the effectiveness of the heat exchanger is known, the actual heat transfer rate \dot{Q} can be determined from

$$\dot{Q} = \epsilon \dot{Q}_{max} = \epsilon C_{min} (T_{h, in} - T_{c, in}) \quad (5)$$

Where,

$$\text{If } C_c = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{C_c (T_{c, out} - T_{c, in})}{C_c (T_{h, in} - T_{c, in})} = \frac{T_{c, out} - T_{c, in}}{T_{h, in} - T_{c, in}} \quad (6)$$

$$\text{If } C_h = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{C_h (T_{h, in} - T_{h, out})}{C_h (T_{h, in} - T_{c, in})} = \frac{T_{h, in} - T_{h, out}}{T_{h, in} - T_{c, in}} \quad (7)$$

Therefore, the effectiveness of a heat exchanger enables us to determine the heat transfer rate without knowing the

outlet temperatures of the fluids. The effectiveness of a heat exchanger depends on the geometry of the heat exchanger as well as the flow arrangement. Therefore, different types of heat exchangers have different effectiveness relations. Effectiveness relations of the heat exchangers typically involve the dimensionless group UA_s/C_{min} . This quantity is called the number of transfer units NTU and is expressed as

$$NTU = \frac{UA_s}{C_{min}} = \frac{UA_s}{(mC_p)_{min}} \quad (8)$$

Where U is the overall heat transfer coefficient and A_s is the heat transfer surface area of the heat exchanger. Note that NTU is proportional to A_s . Therefore for specified values of U and C_{min} , the value of NTU is the measure of heat transfer surface area A_s . Thus the larger the NTU, the larger the heat exchanger. In heat exchanger analysis, it is also convenient to define another dimensionless quantity called the capacity ratio, c as

$$C = \frac{C_{min}}{C_{max}} \quad (9)$$

It can be shown that the effectiveness of a heat exchanger is a function of the number of transfer units NTU and the capacity ratio c . That is,

$$\epsilon = \text{function} (UA_s / C_{min}, C_{min} / C_{max}) = \text{function} (NTU, c) \quad (10)$$

3. EXPERIMENTAL EVALUATION

The experimental setup consisting of the 10 tubes such as 3/8 inch and 1 inch. 2m thickness aluminium plate is used as a shell. The 3/8 inch aluminium rod is filled with P - Toluidine (PCM). The hot water is passed through the 1 inch aluminium pipe and cold water is passed through the shell. Starting temperature of hot water is 35°C and cold water is 22°C. The hot & cold water temperatures are increased slightly and outlet temperatures of hot & cold water temperatures are recorded with use of temperature sensor.



(a)



(b)

Fig - 2: (a) Al Tubes filled PCM, (b) Shell & tube heat exchanger.

4. RESULTS AND DISCUSSION

Experiments were conducted in one day, the temperature of inlet, outlet were recorded at every 15 minute interval.

4.1 Experimental recorded temperature at counter flow condition.

Table 2 shows the experimental measured temperatures with respect to time.

Table - 2: Measured temperatures with respect to time

Time (min)	Hot water inlet temperature (°C)	Cold water inlet temperature (°C)	Hot water outlet temperature (°C)	Cold water outlet temperature (°C)
15	35	22	27	27
30	38	24	29	29
45	40	26	34	32
60	45	28	38	35
75	53	33	43	40
90	60	35	45	55

When the hot water temperature is reached 45°C at that time the PCM was start to melt and stored the heat and releases the stored heat to cold water and hot water outlet. Maximum heat transfer is occurred when hot water inlet temperature is 60°C.

Table - 3: Overall heat transfer & Effectiveness with respect to time

Time (min)	Overall Heat transfer Coefficient $W/(m^2 K)$	Effectiveness ϵ (%)
15	0.127	38
30	0.120	39

45	0.154	43
60	0.164	45
75	0.171	48
90	0.201	54

Table 3 shows the overall heat transfer and effectiveness with respect to time. The maximum effectiveness is 54% it occurred at when the hot water temperature is comes to 60°C.

4.2 Variation of temperatures with respect to time

Chart 1 represents the variation of inlet, outlet temperatures of hot & cold water. Initially the hot water temperature measured at 35°C circulated through the tubes. Every 15 minute the temperatures are recorded. When the temperature comes to 45°C the PCM absorbs the heat from the hot water inlet at that time the PCM is start to melt. The inlet temperature is increased the heat transfer also increased. The maximum heat is transferred in 90 minute and 60°C. And the same condition the hot water outlet temperature was decreased.

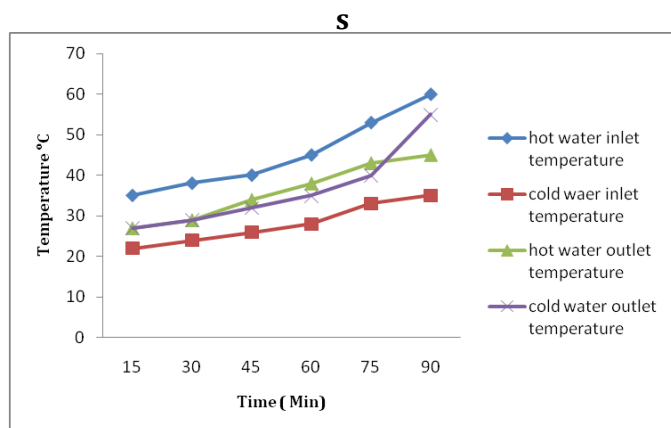


Chart -1: Temperature variations with respect to time

Chart 2 represents the variation of effectiveness with respect to time. Initially the effectiveness obtained in 38 % and it will increase in every 15 minutes. 54 % of effectiveness is obtained at maximum 90 minutes.

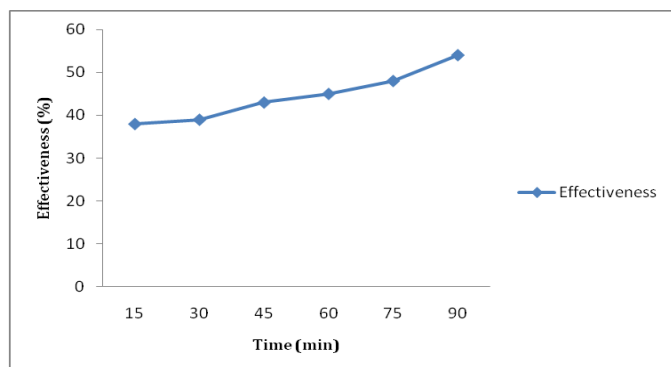


Chart -2: Effectiveness with respect to time

5. CONCLUSION

An experimental model of shell and tube heat exchanger was evaluated with phase change material. The PCM filled with tube inner side and HTF (water) circulated through the shell & tube side. Unsteady temperature distributions of heat transfer fluid, tube and phase change material have been obtained by experimentally and thermal behavior of latent heat storage unit during charging and discharging had been evaluated. The experimental results show that when the hot water inlet temperature increased, the effectiveness is increased and hot water outlet temperature is decreased. The PCM is P- Toluidine was found that having higher latent heat and effectiveness of 54%. The similar analysis may be considered by changing the parameters like influence of Various phase change materials,, nano-particle size, geometry, and change in flow as scope for future research.

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