

Experimental Investigation and Performance Enhancement of Phase Change Material with Al_2O_3 Micro Particles

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ABSTRACT: Latent Heat Energy Storage system (LHESS) stores the thermal energy from solar, exhaust gases and waste heat from industries. To achieve this energy storage, the medium adopted is Phase Change Materials (PCM). PCM is preferred because of their higher storage density, with less volume. The disadvantage of PCM for using LHESS is that, thermal conductivity of PCM is less and this requires more time period and surface area of contact, for loading and unloading of thermal energy. To overcome this problem, an attempt was made to incorporate Alumina Micro-particles in the paraffin PCM to improve its thermal conductivity. The heat transfer rate of LHESS is determined experimentally. Incorporating Micro Particles in the PCM have improved the thermal conductivity of LHESS so the heat transfer rate is increased. In this project am going to determine the heat transfer when paraffin used with Micro particle and without Micro particle of Al_2O_3 . The results of heat transfer efficiency are tabulated and compared to get a conclusion using graphical representation. The heat transfer efficiency of PCM determined by concentric pipe heat exchanger is used to find charging and discharging heat on PCM with or without Micro particle experimentally.

KEYWORDS: LHESS, PCM, Al_2O_3 Micro particles, concentric pipe heat exchanger.

I. INTRODUCTION

Energy demands in the commercial, industrial, and utility sectors vary on daily, weekly, and seasonal bases. These demands can be matched with the help of thermal energy storage (TES) systems that operate synergistically. A variety of TES techniques have developed over the past four or five decades as industrial countries have become highly electrified. Such TES systems have an enormous potential to make the use of thermal energy equipment more effective and for facilitating large-scale energy substitutions from an economic perspective. Demirbas M F et al [1]. One of the most efficient ways to conserve thermal energy is latent heat storage. Latent heat thermal energy storage technique has proved to be a better engineering option primarily due to its advantage of providing higher energy storage density with the smaller temperature difference between storage and retrieval. Thermal energy can be stored in the form of sensible heat in which the energy is stored by raising the temperature of the storage material solid or liquid this technique driven by Zalba B et al. [2] and Abhat A. et al. [3]. Phase Change Materials (PCM) can be absorb/release high latent heat during the melting/solidifying process; they have received a great interest in many application. The thermal conductivity of paraffin wax can also be enhanced by employing high conductivity materials E. Choi et al. [4]. Thermal conductivity enhancement can be done in a number of ways including the use of micro particles. Alumina (Al_2O_3) is one of the most common and inexpensive micro particles used by in their experimental investigation By Miqdam T Chaichan et al. [5], and Wu.S et al. [6]. In my work experimental analysis has been carried out to investigate the

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performance enhancement due to the addition of micro alumina (Al_2O_3) particles in paraffin wax in a concentric double pipe heat exchanger by the cyclic as well as individual charging and discharging. Seeniraj R.V et al. [7] and Henze RH et.al [8]. The concept of which I have taken forced convection and constant heat flux in a pipe with micro encapsulated PCM slurries by Xianxu Hu et al. [9], and P. Charunyakorn et al. [10].

II. SYSTEM STUDY

Sensible heat storage

When an object is heated, its temperature rises as heat is added. The increase in heat is called sensible heat. Similarly, when heat is removed from an object and its temperature falls, the heat removed is also called sensible heat. Heat that causes a change in temperature in an object is called sensible heat. The amount of thermal energy stored in the form of sensible heat can be calculated by,

$$Q = m \times Cp \times dT \quad (2.1)$$

Where,

Q = the amount of thermal energy stored or released in the form of sensible heat (kJ),

T1 = initial temperature ($^{\circ}C$),

T2 = final temperature ($^{\circ}C$),

m = mass of material used to store thermal energy (kg),

Cp = specific heat of the material used to store thermal energy (kJ/kg $^{\circ}C$).

Latent heat storage

All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapour) but changes such as these require the addition or removal of heat. The heat that causes these changes is called latent heat. Latent heat however, does not affect the temperature of a substance - for example, water remains at $100^{\circ}C$ while boiling. The heat added to keep the water boiling is latent heat. Heat that causes a change of state with no change in temperature is called latent heat. The amount of thermal energy stored in the form of latent heat in a material is calculated by,

$$Q = m \times LH \quad (2.2)$$

Where,

Q = the amount of thermal energy stored or released in the form of latent heat (kJ),

m = mass of material used to store thermal energy (kg),

LH = latent heat of fusion or vaporization (kJ/kg).

III. METHODOLOGY

Selection of PCM

Paraffin is waxes. They are readily available, inexpensive and melt at different temperatures relating to their carbon chain length with the general formula C_nH_{2n+2} . They are chemically stable; their volume increase upon melting is in the order of 10% of their volume. Paraffin is safe and non-reactive. They do not react with most common chemical agents. They are economical, having a high heat of fusion, a low vapour pressure in the melt, exhibit negligible super cooling and no phase segregation, and are chemically stable and inert. Commercially available paraffin's from Rubitherm RT21 and RT27 were used in this investigation. It has Low thermal conductivity, Non compatible with the plastic container and moderately flammable.

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Table (1) Thermo physical properties of commercial grade paraffin wax

Melting temperature of the PCM	58-60 °C
Latent heat of fusion	216 kg/m ³
Density of the PCM (liquid phase)	760 kg/m ³
Density of the PCM (solid phase)	900 kg/m ³
Specific heat of the PCM (solid phase)	2.95 kJ/kg k
Specific heat of the PCM (liquid phase)	2.51 kJ/kg k
Thermal conductivity	0.24 w/m K
Viscosity	6.3 x 10 ⁻³
Kinematic viscosity	8.31 x 10 ⁻⁵ m ² /sec
Thermal expansion co-efficient	7.14 x 10 ⁻³ / °C

Selection of Micro Particle

Micro particles are particles between 0.1 and 100 μm in size. Has implication in all scientific disciplines including biology, chemistry, physics and engineering. Application may be in medicine, civil engineering and manufacturing, electronics Micro technology will result in the incorporation of 50 % of all new technology products. Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al₂O₃. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. It is commonly called alumina; it has High thermal conductivity, inexpensive. The overall performance of both melting and solidification process of paraffin wax is better for lower concentration of micro particles the usage of Al₂O₃ with paraffin wax having high energy storage capacity and less cost in lower volumetric concentration of the double pipe heat exchanger.

Table (2) Thermo physical properties of Micro particle Al₂O₃

Specific heat capacity of Al ₂ O ₃	0.880 KJ/Kg.K
Thermal conductivity of Al ₂ O ₃	30 W/m.K
Density of Al ₂ O ₃	3950–4100 kg/m ³
Diameter of Al ₂ O ₃	30-40μm
Weight of Al ₂ O ₃	6gm

Volumetric concentration of Al₂O₃ Micro particle

The volume concentration for micro particle is calculated by (Φ)

$$\Phi = \frac{\text{Weight of Al}_2\text{O}_3 / \text{Density of Al}_2\text{O}_3}{\text{Weight of Al}_2\text{O}_3 / \text{Density of Al}_2\text{O}_3 + \text{Weight of PCM} / \text{Density of PCM}}$$

$$\Phi = \frac{0.006 / 3950}{(0.006 / 3950) + (0.180 / 900)} = 0.753\%$$

Preparation methods of micro/ PCM mixture

Initially, Al₂O₃ micro particle of 30 gm are divided approximately 6 gm each needed for the addition to the paraffin wax of 180gm. Then the paraffin wax of 180 gm is filled in a small tank. The tank with paraffin wax immersed in another tank in which the water is maintained at 85 °C. By the convection process the heat from the hot water is transferred to the paraffin wax material. As the temperature increase, the paraffin wax starts changing its phase from the normal. Once the paraffin wax increases above 45 °C, Al₂O₃ micro particles of 6 gm are added to the paraffin wax

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of 180gm, before its melting temperature. After preparing it, the tank with micro PCM is cooled by water to get micro PCM in liquid phase which is further poured to the annulus side of concentric pipe heat exchanger.

IV. EXPERIMENTATION

Experimental set up

To enhance the effective thermal conductivity of the system fig (1) shows the inner pipe is made of copper. The outer pipe is made of galvanized iron (GI). The outside of the outer pipe was insulated with 3 mm thick rope to reduce the heat loss during charging and discharging process of the PCM. The outer pipe inner side was filled with 230gms commercial grade paraffin wax being used as latent heat storage media. Resistant Temperature Detectors (RTDs) (T1, T2, T3, T4) were used for measuring the inlet and outlet temperature of heat transfer fluid (HTF) and the PCM temperature at two locations in the PCM tank. A two tank systems are used for maintaining a constant pressure head for inlet water to maintain nearly constant flow rate. Heaters with RTDs were also provided in the water tanks for constant inlet water temperature during charging mode. Flowing hot water through inner pipe started the energy charging test, and the stored energy was extracted by passing cold water in the inner pipe. The temperature of water at inlet and outlet of the heat exchanger at four axial locations were measured simultaneously at an interval of 10 min.

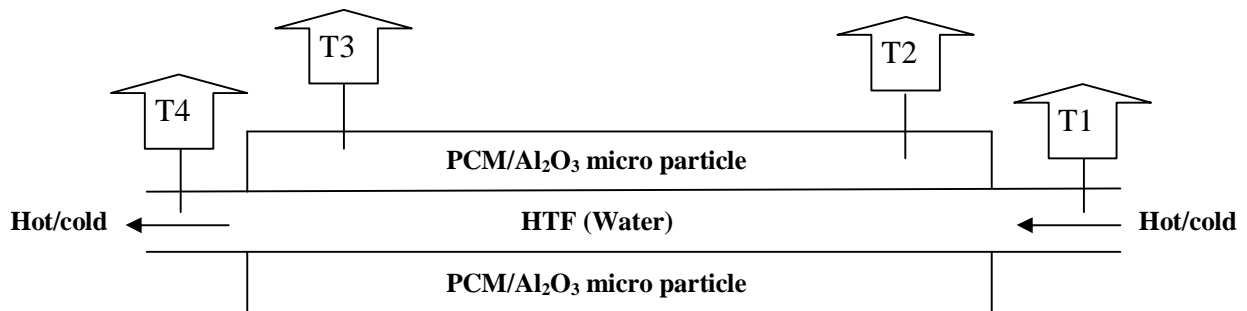


Fig (1)

Table (3) Technical specifications of the concentric double pipe heat exchanger

Components	Materials	Outer diameter (mm)	Length (mm)	Thickness (mm)	Density (Kg/m ³)	Thermal conductivity (w/m K)	Specific heat capacity (KJ/kg k)
PCM	Paraffin wax	-	-	-	900	0.24	2.1
Inner pipe	Copper	25.6	625	1	8954	386	0.3830
Outer pipe	Galvanized iron	38	410	3	7850	71.8	0.452
Insulation case	Asbestos ropes	-	-	3	470	0.1105	0.816
Micro particle	Al ₂ O ₃	-	-	40-30µm	3950	30	0.880

Loading calculation of PCM

$$\begin{aligned}
 V_{\text{outer pipe}} &= [(\pi/4) \times (0.038)^2] \times 0.320 = 3.629 \times 10^{-4} \text{ m}^3 \\
 V_{\text{inner pipe}} &= [(\pi/4) \times (0.0256)^2] \times 0.320 = 1.647 \times 10^{-4} \text{ m}^3 \\
 M_{\text{PCM}} &= (V_{\text{outer pipe}} - V_{\text{inner pipe}}) \times \rho_{\text{PCM}}
 \end{aligned}$$

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$$M_{PCM} = (3.629 \times 10^{-4} - 1.647 \times 10^{-4}) \times 900 = 0.180 \text{ Kg}$$

Where,

$$M_{PCM} = \text{Mass of phase change material (kg)}$$

$$\rho_{PCM} = \text{Density of phase change material (Kg/m}^3\text{)}$$

Performance during Charging Process

In charging process, the HTF entered LHSS at high temperature. It cause melting of PCM

$$\text{Heat stored } Q_S = M_W \times C_{p_w} \times (T_{hi} - T_{ho}) \times t$$

$$\text{Heat available } Q_A = M_W \times C_{p_w} \times (T_{hi} - T_{ci}) \times t$$

$$\text{Charging Efficiency } \eta = (Q_S / Q_A) \times 100$$

Performance during Discharging Process

In discharge process, the HTF entered at low temperature to the LHTESS. It cause solidification of PCM

$$\text{Heat Released } Q_R = M_W \times C_{p_w} \times (T_{co} - T_{ci}) \times t$$

$$\text{Heat available } Q_A = M_{pcm} \times C_{p_{pcm}} \times (T_{pcm} - T_{ci}) + (M_{pcm} \times L_{pcm})$$

$$\text{Discharging Efficiency } \eta = (Q_R / Q_A) \times 100$$

Where,

$$M_W = \text{Mass of water flow (kg/min)}$$

$$C_{p_w} = \text{specific heat of water (KJ/Kg K)}$$

$$T_{hp} = \text{hot water outlet temperature (}^\circ\text{C)}$$

$$T_{hi} = \text{hot water inlet temperature (}^\circ\text{C)}$$

$$T_{ci} = \text{cold water inlet temperature (}^\circ\text{C) or atmospheric temperature}$$

$$T_{cp} = \text{cold water outlet temperature (}^\circ\text{C)}$$

$$t = \text{time taken for charging (min)}$$

$$L_{pcm} = \text{latent heat of phase change material (KJ/Kg)}$$

V. EXPERIMENTAL PROCEDURE & RESULTS

Charging process for the flow rate of (5L/hr) – PCM without Al₂O₃ micro particle

The first charging process of PCM without Al₂O₃ micro particle was conducted with flow rate 5lt/hr and the inlet temperature of the hot water was kept 75°C and the atmospheric temperature is 32°C during the charging process, the HTF is circulated through the TES tank continuously. Initially, temperature of PCM is 32°C and as HTF exchanges its heat energy to PCM, the PCM gets heated up to melting temperature (storing the energy as sensible heat). Later heat is stored as latent heat once the PCM melts and becomes liquid. The energy is then stored as sensible heat in liquid PCM. The temperature of PCM and HTF are recorded at interval of 10 min. The charging process is continued until the PCM temperature reaches maximum temperature. The readings are noted and efficiency were calculated and tabulated (4) below.

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Table (4) Charging process for PCM only

HTF flow rate	Charging time	Hot water inlet temp	PCM temp right position	PCM temp left position	Hot water outlet temp	Heat available	Heat stored	Charging efficiency
M_w (L/hr)	T(min)	$T_1(^{\circ}C)$	$T_2(^{\circ}C)$	$T_3(^{\circ}C)$	$T_4(^{\circ}C)$	$Q_A(KJ)$	$Q_S(KJ)$	η (%)
5	10	75	48	42	73	149.99	6.97	4.64
	20	75	49	44	72	216.27	20.93	9.69
	30	75	53	50	71	261.62	41.86	16
	40	75	55	54	70	293.02	69.76	23.8
	50	75	57	56	69	331.39	104.65	31.5
	60	75	61	58	70	355.81	104.65	29.4

Discharging process for the flow rate of (5L/hr) – PCM without micro particle

The discharging process of PCM without Al_2O_3 micro particle was conducted with flow rate of 5lt/hr and the inlet temperature of the cold water kept at the atmospheric temperature is $32^{\circ}C$. During the discharging process the cold water is circulated through the TES tank continuously. Now that heat energy stored in PCM is transferred to the cold water, so the cold water temperature is increased. The temperature of the PCM and cold water outlet temperature are recorded at intervals of 10 min. The discharging process is continued until the PCM temperature reduced to atmospheric temperature. The readings are noted and efficiency were calculated and tabulated (5) below.

Table (5) Discharging process for PCM only

HTF flow rate	Discharging time	Cold water inlet temp	PCM temp right position	PCM temp left position	Cold water outlet temp	Heat available	Heat released	Discharging efficiency
M_w (L/hr)	T(min)	$T_1(^{\circ}C)$	$T_2(^{\circ}C)$	$T_3(^{\circ}C)$	$T_4(^{\circ}C)$	$Q_A(KJ)$	$Q_R(KJ)$	η (%)
5	10	32	60	59	34	53.48	6.97	13.03
	20	32	50	51	34	48.7	13.95	28.64
	30	32	46	47	35	46.57	31.395	67.41
	40	32	44	45	34	45.51	27.90	61.30
	50	32	42	42	34	44.19	34.88	78.93
	60	32	39	40	34	42.86	41.86	97.66

Charging process for the flow rate of (5L/hr) – PCM with Al_2O_3 micro particle

The charging process of micro PCM was conducted with flow rate 5lt/hr for micro PCM and the inlet temperature of the hot water was kept $75^{\circ}C$ and the atmospheric temperature is $32^{\circ}C$. During the charging process, the HTF is circulated through the TES tank continuously. Initially the temperature of the micro PCM is $32^{\circ}C$ and as the HTF exchanges its heat energy to micro PCM, The micro PCM gets heated up to melting temperature (storing the energy as sensible heat). Later heat is stored as latent heat once the micro PCM melts and becomes liquid. The energy is then stored as sensible heat in liquid micro PCM. The temperature of micro PCM and HTF are recorded at intervals of 10 min; the charging process is continued until the Micro PCM temperature reaches maximum temperature. The readings are noted and efficiency were calculated and tabulated (6) below.

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Table (6) Charging process for PCM with Al₂O₃ micro particle

HTF flow rate	Charging time	Hot water inlet temp	PCM temp right position	PCM temp left position	Hot water outlet temp	Heat available	Heat stored	Charging efficiency
M _w (L/hr)	T(min)	T ₁ (°c)	T ₂ (°c)	T ₃ (°c)	T ₄ (°c)	Q _A (KJ)	Q _S (KJ)	η (%)
5	10	75	44	43	74	111.62	3.488	3.214
	20	75	47	46	72	202.32	20.93	10.34
	30	75	48	47	70	293.02	52.32	17.85
	40	75	51	49	68	362.78	97.67	26.92
	50	75	53	51	65	418.6	174.41	41.66
	60	75	56	53	62	460.46	272.09	59.09

Discharging process for the flow rate of (5L/hr) – PCM with Al₂O₃ micro particle

The discharging process of micro PCM was conducted with flow rate 5lt/hr and the inlet temperature of the cold water kept at the atmospheric temperature is 32 °C. During the discharging process the cold water is circulated through the TES tank continuously. Now the heat energy stored in micro PCM is transferred to the cold water, so the cold water temperature is increased. Temperature of the micro PCM and cold water temperature (HTF) are recorded at intervals of 10 min. The discharging process is continued until the micro PCM temperature reduced to atmospheric temperature. The readings are noted and efficiency were calculated and tabulated (7) below.

Table (7) Discharging process for PCM with Al₂O₃ micro particle

HTF flow rate	Discharging time	Cold water inlet temp	PCM temp right position	PCM temp left position	Cold water outlet temp	Heat available	Heat Released	Discharging efficiency
M _w (L/hr)	T(min)	T ₁ (°c)	T ₂ (°c)	T ₃ (°c)	T ₄ (°c)	Q _A (KJ)	Q _R (KJ)	η (%)
5	10	32	51	50	35	48.70	10.465	21.4
	20	32	48	47	35	47.11	20.93	44.44
	30	32	45	44	34	45.51	20.93	45.98
	40	32	42	41	34	43.92	27.90	63.52
	50	32	38	37	34	41.80	34.88	83.44
	60	32	35	35	32	40.47	0	0

Model Calculations:

Performance during Charging Process (PCM)

$$\begin{aligned} \text{Heat stored } Q_s &= M_w \times C_p \times (T_{hi} - T_{ho}) \times t \\ &= 5 \times 4.186 \times (75 - 65) \times (50/60) \\ &= 174.41 \text{ KJ} \end{aligned}$$

$$\begin{aligned} \text{Heat available } Q_A &= M_w \times C_p \times (T_{hi} - T_{ci}) \times t \\ &= 5 \times 4.186 \times (75 - 51) \times (50/60) \\ &= 418.6 \text{ KJ} \end{aligned}$$

$$\begin{aligned} \text{Charging Efficiency } \eta &= (Q_s / Q_A) \times 100 \\ &= (174.41/418.6) \times 100 \end{aligned}$$

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$$\begin{aligned}
 &= 41.66\% \\
 \text{Performance during Discharging Process (Micro Al}_2\text{O}_3\text{/ PCM)} \\
 \text{Heat Released } Q_R &= M_w \times C_{p_w} \times (T_{co} - T_{ci}) \times t \\
 &= 5 \times 4.186 \times (34 - 32) \times (50/60) \\
 &= 34.88 \text{ KJ} \\
 \text{Heat available } Q_A &= M_{pcm} \times C_{p_{pcm}} \times (T_{pcm} - T_{ci}) + (M_{pcm} \times L_{pcm}) \\
 &= 0.180 \times 2.95 \times (37.5 - 32) + (0.180 \times 216) \\
 &= 41.80 \text{ KJ} \\
 \text{Discharging Efficiency } \eta &= (Q_R / Q_A) \times 100 \\
 &= (34.88 / 41.8) \times 100 \\
 &= 83.45\%
 \end{aligned}$$

Graphical Representation

The graph represented the values of efficiency of charging and discharging process of PCM with micro particle and without micro particle to temperature with respect to time compared and concluded.

Charging process for PCM vs. Micro Al₂O₃PCM (5L/hr)

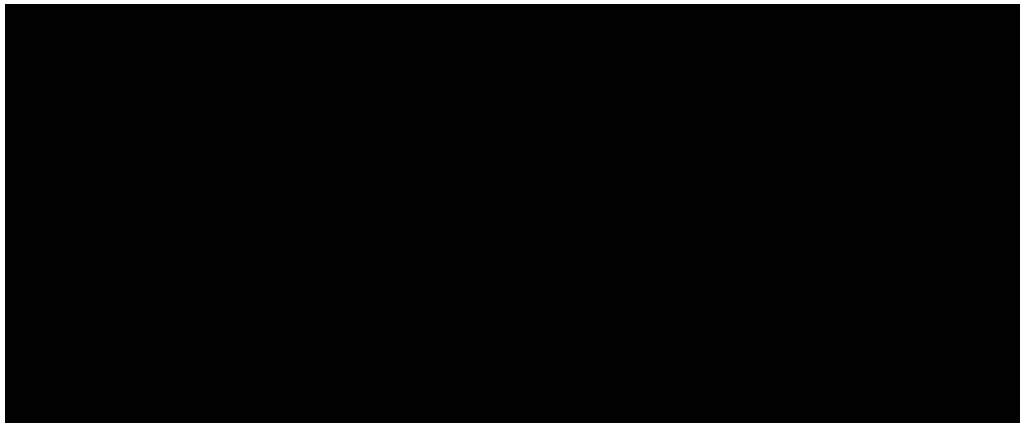


Fig (2)

This graph shows increase in charging efficiency of PCM used with micro particle with respect to time, when compare to efficiency of PCM without micro particle. There is reducing in time to charge the PCM with Al₂O₃ micro particle compare to PCM without Al₂O₃ micro particle.

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Discharging process for PCM vs. Micro Al₂O₃ PCM (5L/hr)

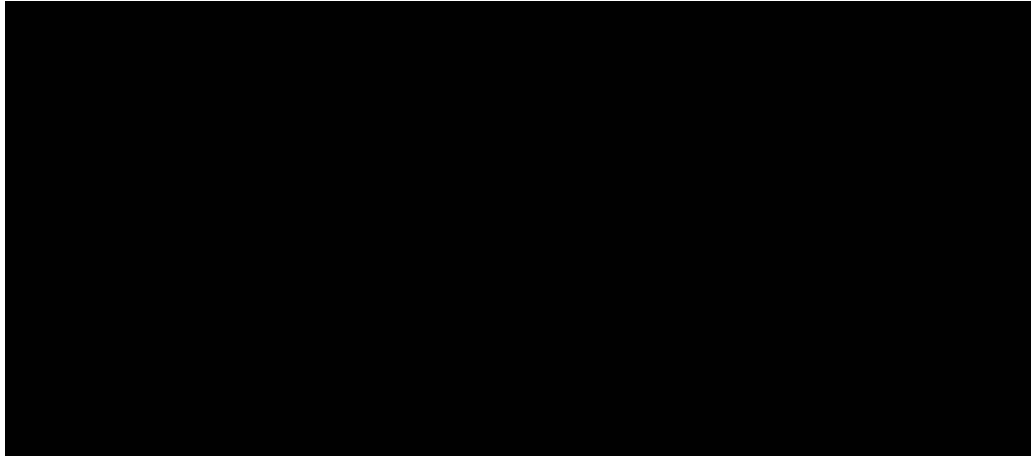


Fig (3)

This graph shows increase in average discharging efficiency of PCM used with micro particle with respect to time, when compare to efficiency of PCM without micro particle. There is reducing in time to discharge the PCM with Al₂O₃ micro particle compare to PCM without Al₂O₃ micro particle.

VI. CONCLUSION

Thus the experimental analysis on the latent heat thermal energy storage system has been done using Al₂O₃ micro particle. The effect of 0.75% volumetric concentration of micro particles on the melting and solidification performance is examined and compared between micro PCM and pure paraffin wax. The readings were tabulated for PCM as well as micro PCM. From the experimental results, it is found that the use of micro particles with paraffin wax increases the heat transfer and reduces the melting and solidification time compare with PCM without micro particle. It is also observed that there is almost 50% reduction in charging time and discharging time of the PCM for a volume concentration of 0.75%.

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