Performance Evaluation of Coil Heat Exchanger inside PCM Bed

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Abstract— *An energy converting system has been designed to study the heat transfer from one medium to another with the help of various fluids like castor oil and paraffin wax. Recovery and reuse of this energy through converting can be useful in conservation of energy. Heat exchanger is an energy converting device that captures energy using coil heat exchanger inside pcm bed. It can be used later by latent heat. This paper deals with the feasibility of PCM as storage medium in heat exchanger and also to study heat transfer properties of various fluids and latent heat storage of PCM.*

Keywords— *Paraffin wax, castor oil, water, latent heat, heat exchanger.*

I. Introduction

Now a days the engineers are in deep research of recycling and reusing the wasted energy to contribute the energy need of society. Many forums and energy management groups have been formed to emphasize the storage of energy in both industrial and domestic sectors, in any possible form. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists.

The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications.

The project includes testing of a small heat exchanger, in order to establish the effectiveness of using paraffin wax as a suitable phase change material. The paraffin wax is incorporated in the heat exchanger, which acts as thermal energy storage device. This device will then be tested on a test rig for oil heating and other applications.

II. Literature Survey

Thirugnanam.C,Marimuthu.P"ExperimentalAnalysis of Latent Heat Thermal Energy Storage using Paraffin Wax as Phase Change Material"(2013) Recovery and reuse of this energy through storage can be useful in conservation of energy. In the present study, a double pipe type heat exchanger has been designed and fabricated for low temperature industrial waste heat recovery using phase change material (PCM) paraffin wax (PW).[1]

Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi , "Review on thermal energy storage with phase change materials and applications"(2009) PCMs have been widely used in latent heat thermal- storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications.[2]

Stella P.Jesumathy, M.Udayakumar and S. Suresh "Heat transfer characteristics in latent heat storage system using paraffin wax" the thermal characteristics of the paraffin wax, which includes total melting and total solidification times, the nature of heat transfer phenomena in melted and solidified PCM and the effect of Reynolds number as inlet heat transfer fluid (HTF) conditions on the heat transfer parameters. Experiment has been performed for different water flow rates at constant inlet temperature of heat transfer fluid for recovery and use of heat. Time- based variations of the temperature distributions were explained from the results of observations of melting and solidification curves.[3]

K.Kavitha S.Arumugam "A Study on Phase Change Material (PCM) For Insitu Solar Thermal Energy Collection and Storage" The PCM was loaded in GI (Galvanized iron) pipes and arranged in a criss cross manner to form a grid shape and the whole setup was laid one over the other and was used as a heat storage unit. Water is pooled as heat transfer fluid (HTF) surrounding the GI pipe, to collect the heat from the heat exchangers.[4]

Prabhu M, P.L. Ramalingam, R. Manivannan, G. Naveen, and Balasubramanian.k "Design and Fabrication of Alternate Energy Storage Device using PCM" The project focuses on the temperature distribution pattern of the phase change material during the process of charging and discharging.[5]

Travis John Gaskill "Heat Transfer of a Multiple Helical Coil Heat Exchanger Using a

Microencapsulated Phase Change Material Slurry" An experimental study was conducted using a counter flow CHE consisting of 3 helical coils. Two separate tests were conducted, one where water was used as heat transfer fluid (HTF) on the coil and shell sides, respectively.[6]

Vinay R. Patel1, Gerard G. Dumancas, Lakshmi C. Kasi Viswanath, Randall Maples and Bryan John J. Subong"Castor Oil: Properties, Uses, and Optimization of Processing Parameters in Commercial Production" Castor oil, produced from castor beans, has long been considered to be of important commercial value primarily for the manufacturing of soaps, lubricants, and coatings, among others.[7]

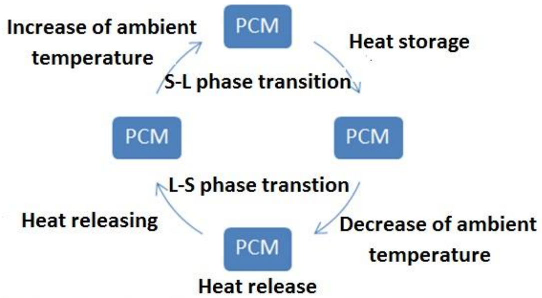
P. Sundaram, Rahul Kumar Tiwari, Sanat Kumar "Experimental Performance Study of Helical Coil Thermal Storage Unit Filled with PCM "Paraffin is considered as a storage material. An experimental testis conducted in order to study the characteristic of PCM during charging and discharging process at various parameters such as inlet heat transfer fluid temperature and volume flow rate of heat transfer fluid (HTF) as water. [8]

III.REVIEW OF WORKING FLUIDS

A. *Phase Change Material*

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa.PCM temperature remains constant during the phase change, which is useful for keeping the subject at a uniform temperature. And Paraffin waxes are safe and non-reactive.

Fig 1: Solid - liquid phase change transition as an example of phase change transition cycle



Phase change materials are substances characterized by ability to phase transition at certain temperature range. Scheme of the phase change transition is presented on figure 1. During phase transition there is always heat emission or heat absorption which is called latent heat of fusion. Temperature of transition and amount of latent heat of fusion are distinctive for each material. PCMs are capable to store thermal energy for short or long time.

Table I: Thermo-Physical Properties of Commercial Grade Paraffin Wax

Melting temperature of the PCM	54.32 °C
Latent heat of fusion	184.48 kJ/kg
Density of the PCM (liquid phase)	775 kg/m^3
Density of the PCM (solid phase)	833.60 kg/m^3
Specific heat of the PCM (solid phase)	2.384 kJ/kg °C
Specific heat of the PCM (liquid phase)	2.44k J/kg °C
Thermal Conductivity	0.15 W/m°K
Viscosity	6.3 X10^{-3}
Kinematic Viscosity	8.31 X10-5 m^2/sec
Prandtl Number	1001.23
Thermal Expansion Coefficient	7.14 X 10-3 /°C

B. *Castor Oil*

Castor Oil is extracted from castor seeds (Ricinus Communis). It is a very pale yellow liquid that has a thick, sticky feel. Castor oil is one of the vegetable oils that have higher viscosity and density in comparison with fossil fuel. To lower the viscosity and density of the renewable oil, preheating is necessary prior to using. Castor oil is a vegetable oil obtained by pressing the seeds of the castor oil plant.

And the properties of castor oil is given, Boiling point (313°c), Density (0.959g/ml), Flashpoint (145°c) Colour- max (Pale Yellow).

C. *Latent Heat*

When a solid turns into a liquid (melts) or a liquid turns into a gas (evaporate), the loosening of attractions among the molecules requires energy. this energy is called latent heat.

$$Q = m L$$

Where,
Q – Energy (J)
M – Mass (g)
L – Specific latent heat (J/g)

The amount of latent heat per gram required to effect a phase change is called either the latent heat of fusion (melting) or else the latent heat of vaporization.

D. *Heat Exchanger*

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperature while keeping them from mixing with each other. Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix. The heat transfer rate across a heat exchanger is usually expressed in the form

$$Q = UA\Delta Tm$$

Where:
Q = heat transfer rate
U = overall heat transfer coefficient
A = heat exchanger area
ΔTm = average temperature difference between the fluids.

Fig 2: Experimental Setup

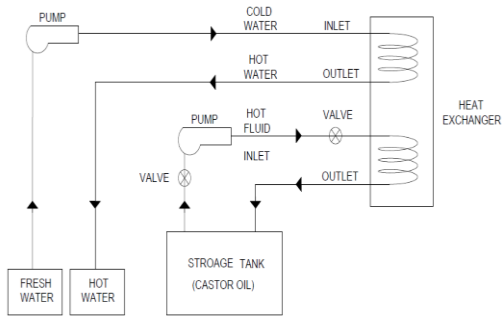
IV. Experimental Setup

Fig. 2 shows the experimental setup and the Fig. 3 shows the Schematic diagram of the outline of PCM heat exchanger. The heat exchanger is made up of GI sheet metal (Galvanized iron). Couples of copper coils are mounted inside the heat exchanger. And then the box is filled with pcm (Paraffin wax 68). The wax is made to fill the space between the coils. Once the pcm is filled, the heat exchanger is closed with a cover. Then the heat exchanger is completely surrounded with a rope for prevently the heat loss by convection. Inlet and outlet tubes are attached with the copper coil inside the heat exchanger. Through this the hot and cold fluids are made to flow. Two brass valves are attached to the inlet and outlet tubes for controlling the fluid flow. The fluids pass through the coils with the help of electrically powered pump.

V. Working Procedure

The working procedures are detailed in given below. Initially the heat exchanger is entirely filled with the pcm (Paraffin 68) and then it is closed. Hot fluid is made to flow through the copper coil at the top of heat exchanger. Copper coil act as conductor and transfer the heat from hot fluid to the pcm. This heat transfer through copper coil melts the pcm to melt completely. After melting the pcm attains complete liquid state. Then the heat from pcm transfer to the copper coil at bottom. Cold fluid is allowed to pass through the bottom coil. Due to heat transfer the temperature of cold fluid is increased. When the cold fluid passes through no. of turns in a coil the temperature gradually increases and turns it into a hot fluid with high temperature. Once the hot fluid flow is stopped the pcm liberates heat and starts turning into solid state. By this heat liberation we can get hot fluid from cold fluid. The pcm takes nearly 6 hours to attain complete solid state. Hence temperature of the fluid can be increased by passing it through the coil due to the liberation of heat from pcm. After attaining the complete solid state, that process is repeated again.

Fig 3: Schematic of PCM Heat Exchanger



VI. COMPONENTS OF HEAT EXCHANGER

There are several parts are to be used in heat exchanger. It's given below.

A. *Energy storage unit*

The heat transfer fluid flows from the inner copper pipe. After that the wax should be melted.

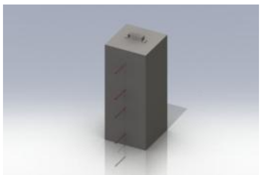


Fig 4: Energy storage unit

B. *Copper coil*

Copper is one of the best conducting material. When the hot fluid is allowed to pass through the coil, it transfer heat from coil to pcm and made it to melt. When cold fluid is passed inside the coil it conducts heat from pcm to coil.

Fig 5: copper coil

C. *Pump*

The purpose of the pump is to create a circulation in the circuit. The pump used in the circuit is a non-submersible water pump with a head of 1 feet.

Fig 6: pump

D. *Flow control valve*

The purpose of flow control valve is to regulate the mass flow rate of the heat transfer fluid through the circuit.

Fig 7: Flow control valve

VII. EXPERIMENTS CONDUCTED

A. *Boiling Of PCM By External Heat*

The heat exchanger is boiled externally through fire. The internal paraffin wax gets heated and melts into liquid. At that time fresh water will inserted into the heat exchanger. The fresh water obtained from the heat from the wax and the hot water will come out. The temperature of the hot water come from heat exchanger is

Below the graph is plotted for the heat exchanger water heating process. The table is plotted with time and temperature.

TIME	PCM TEMP(^{o} C)	STATE	EXTERNAL HEAT
10.00	34	SOLID	HEAT APPLIED
10.30	65.3	LIQUID/ SOLID	HEAT APPLIED
11.00	112.1	LIQUID/ SOLID	HEAT APPLIED
11.30	120.4	LIQUID	HEAT STOPPED
12.00	112.3	LIQUID	HEAT STOPPED
12.30	104	LIQUID	HEAT STOPPED
1.00	96.7	LIQUID	HEAT STOPPED
1.30	82.5	LIQUID/ SOLID	HEAT STOPPED
2.00	66.8	LIQUID/ SOLID	HEAT STOPPED
2.30	42.6	SOLID	HEAT STOPPED
3.00	36	SOLID	HEAT STOPPED

B. *Upper Coil Steam With Lower Coil Water*

Through the upper coil hot steam is inserted. The inside wax get melted and the balance steam condensed the water came out through next coil. At this time through the lower coil fresh water is inserted so by absorbing hot from the wax the fresh water convert into hot water and came out.

TIME	LOWER COIL		UPPER COIL	
IN (30 MINS)	STEAM IN TEMP (^{0} C)	STEAM OUT TEMP (^{0} C)	WATER IN TEMP (^{0} C)	WATER OUT TEMP (^{0} C)

10.00	110.2	106.5	30.3	33.7
10.30	110.2	101.8	30.3	38.3
11.00	110.2	98.2	30.3	42.3
11.30	110.2	91	30.3	49.5
12.00	110.2	83.4	30.3	57
12.30	110.2	76.4	30.3	64.1
1.00	110.2	69.9	30.3	70.6

C. Hot Fluid(castor oil) through lower coil with Upper Coil Water

Through lower coil hot fluid (castor oil) get inserted into the heat exchanger. By the help of hot fluid the wax get melted and converted into liquid state. Through another coil cool fluid will come out. This will be again heated and send into heat exchanger. This process is repeated again and again.

After this through the upper coil fresh water will inserted to the heat exchanger. The fresh water absorbs the hot from wax and converted into hot water. This hot water will come out through another coil. So we get hot water. Below the table and readings are plotted.

TIME	LOWER COIL		UPPER COIL	
IN (30 MINS)	CASTOR OIL IN TEMP (^{0} C)	CASTOR OIL OUT TEMP (^{0} C)	WATER IN TEMP (^{0} C)	WATER OUT TEMP (^{0} C)
10.00	170	163.1	30.3	36.9
10.30	170	155.6	30.3	44.5
11.00	170	140.2	30.3	60
11.30	170	127	30.3	72.9
12.00	170	117.2	30.3	83.1
12.30	170	104.2	30.3	95.6
1.00	170	91.9	30.3	108.2

VIII. CONCLUSIONS

Through the lower coil temperature of 110.2°c hot steam is passed. So the wax gets melted. At that time through the upper coil fresh water is passed and the hot water with 70.6°c is obtained. So the water with low temperature is obtained so it is not highly efficient.

To overcome this we are using Castor oil instead of steam. The Castrol oil of 170°c is passed through the lower coil. So the wax become melt fast at that time we passed fresh water through upper coil we get steam of 108.2°c.

This obtained steam can be used for industrial purpose. Like in generators etc. It can be also used for domestic purpose for hot water. With our paper concept we can efficiently use wasted energy for the good will of society.

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