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THERMAL ANALYSIS AND EVALUTION PHASE CHANGE MATERIALS AND THEIR BLENDS BY USING COUNTER FLOW HEAT EXCHANGER

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ABSTRACT

Industrial processes often encompass a wide range of temperature and different heat cold fluxes in any one particular production site. If supply and demand exist simultaneously, heat exchanger can be used very efficiently. In many cases however supply and demand vary in time and quantity. Instead of using energy efficiently, electricity is often used to generate heat and cold on the spot, just where and when it is needed. This is convenient, but inefficient in economical and ecological terms. Heat and cold stores can fill this gap and match supply and demand with respect to availability in time and power.

The concept of using PCM for the application for the thermal energy storage in industrial process is not new, PCM is the substance with a high heat of fusion with which melting and solidifying at certain temperature, is capable of storing and releasing large amount of energy. In PCM organic materials like paraffins are cheap and have moderate thermal energy storage density but low thermal conductivity and hence require large surface area. Hydrated salts have a larger energy storage density and higher thermal conductivity. In response to increasing electrical energy cost and desire for better led management, thermal storage technology has recently been developed. The storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management with emphasis on efficient use and conservation of waste heat and solar energy in industry.

This paper presents a simplified methodology for analyzing the effectiveness of heat exchanger using three PCM fluids from different groups.

Paraffin liquid- organic

Calcium chloride – Hydrated salt

Water – conventional fluid.

KEYWORDS: Phase change materials, Counter flow Heat exchanger, Effectiveness, storage system.

Nomenclature

ma= mass flow rate of air through tube (kg/s)
mf= mass flow rate of working fluid through shell (kg/s)
Va= velocity of air (m/s)
Vf = velocity of fluid (m/s)
At= C/s area of tube (m^2)
As= C/s area of shell (m^2)
Cv= co-efficient of velocity
dp= inner diameter of pipe (mm)
U= overall heat transfer co=efficient (W/m^2K)
h= convection heat transfer co-efficient
(W/m^2 K)
k= thermal conductivity (W/m)
Cpa= specific heat of air (Kj/kg-K)
Cpf= Specific heat of fluid (Kj/kg-K)
Tm= bulk mean temperature (K)
Tc1= Temperature of air at inlet of tube (K)
Tc2= Temperature of air at outlet of tube (K)

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Th1= Temperature of fluid at inlet of shell
Th2= Temperature of fluid at outlet of shell
Q= Heat gain or absorbed by air (W/m^2K)
Cmax, Cmin = heat capacity rate,
qmax= maximum heat transfer between two fluids (W/m^2K)
ρ – Density of the air, (kg/m^3)

Dimensionless Numbers:
Re= Reynolds number
Pr= prendtl number
Nu= nusselt number
F= friction factor
NTU= No. of transfer units
E= effectiveness

I. INTRODUCTION

Thermal energy storage (TES) is an advanced energy technology that has recently attached increasing interest for thermal application such as space and water heating, cooling and air conditioning. TES system has enormous potential to facilitate more effective use of thermal equipment and large-scale energy substitutions that are economic. Thermal energy may be stored by elevating or lowering the temperature of a substance (i.e. altering its sensible heat) or by changing the phase of a substance (i.e. altering its latent heat) or by combination of two .phase change material is one of the materials can be used as TES for storing the energy when required and supplied it to the demand when required Phase Change Materials are those materials when melts or vaporizes, absorbs heat, .when it changes to a solid (crystallize) or to a liquid (condense),it releases this heat. Typical PCMs are

- water/ice
- salt hydrates
- certain polymers

Since energy densities for latent TES (Thermal energy storage).smaller and lighter storage devices like ice and water, eutectic salts have been used as storage media form many decades, perhaps the oldest application of a PCM for TES was the use of seat warmer rail road cars in late 1800. During cold winter days, a PCM Sodium Thiosulphate Pentahydrate which melts and freezes at 44.4ºC was used. The PCM was filled into metal or rubber bags.

During the late 1970 and 1980s, several organizations offered Phase Change Products for solar heat storage. For instance, Dow chemical proved a technically successful product that melts and freezes at 27.2ºC, whose market presence declined with the solar industry. In general PCM latent heat storage can be achieved through solid-solid, solid-liquid, solid-gas and liquid-gas phase change. However, the only phase change used for PCM is the solid-liquid change, liquid-gas phase are not practical for use as thermal storage due to large volumes or high pressure required to store the material when in gas phase.

Liquid gas transitions do have a higher heat of transformation than solid-liquid transition solid –solid phase changes are typically very slow and have a rather low heat of transformation. Initially the solid liquid PCMs behave like sensible (SHS) materials their temperature ,at which they change phase absorb large amount of heat at an almost const temperature .The PCM continue to absorb heat without significant raise in temperature until all the material is transformed to the liquid phase .when the ambient temperature around a liquid materials fall, the PCM solidifies, releasing its stored latent heat. A large number of PCM are available in any required temperature range from -5ºC to 190ºC.within the human comfort range of 2ºCto30ºC, some PCM are very effective. they store 5 to 14 times more heat per unit volume then conventional storage material such as water masonry or rock..

II. LITERATURE SURVEY

According to J E Van Dorp (1) in his paper “PCM Thermal properties in one dimensional heat transfer experiment” The temperature - and cooling or heating rate - dependency of PCM thermal properties is the cause of Hysteresis during normal operation of the PCM. Hysteresis means that the PCM temperature will rise or fall

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while in the phase change temperature range, but against expectation based on PCM temperature: phase change does not occur. This means that the PCM works only like a normal, sensible heat storage material during Hysteresis. If this effect is not understood and accounted for in mathematical modeling of the PCM, then large, unacceptable errors will occur, leading to exaggerated expectations of PCM performance.

According to M.Ravikumar & Dr PSS Srinivasan (2) in his paper "Phase change material as thermal storage material for cooling of buildings. PCM are one of the latent heat materials having low temperature range and high energy density of melting, solidification compared to the sensible heat storage. The tests on transient heat transmissions across different roof structures were conducted. It was found that when installing PCM in the withering course (WC-mixture of broken bricks and lime mortar) region nearly uniform roof bottom surface temperature was maintained.

According to M Faith Demirbas (5) Energy storage in PCM has a lot of advantages over sensible systems because of the lower mass and volume of the system and the energy is stored at a relatively constant temperature and energy losses to the surroundings are lower than with conventional systems.

Gong and Mujumdar (7) carried out an exergetic analysis for thermal storage systems using multiple PCMs. They analyzed the relative increase in the energy output for a system using two, three, five, as wel1 as an infinite number of PCMs, over that using a single PCM and obtained for the first time the theoretical limit of the energy output increase when using an infinite number of PCMs. However, their work was limited to only the storage process. In this article a thermodynamic analysis of the combined energy charge/discharge process in a latent heat thermal storage system using multiple PCMs is developed. Analysis is carried out for a system using two, three, as wel1 five PCMs. Illustrative examples are presented and discussed.

III. PRESENT WORK

The present experiment has the purpose of finding best suitable PCM, among the three category fluids by using regenerative counter current heat exchanger. The Set up consist:

Counter flow heat exchanger with specifications
Shell: material- mild steel
OD=80mm, ID= 70mm, L= 210mm.
Tubes: material – Stainless steel (IS-12933)
Profile diameter= 50mm,
Internal tubes: OD=10mm, ID= 8mm
L=120mm, tube no=8
Insulation: Asbestos
Blower: 0.25 HP, N= 2850 rpm, water manometer
head= 300mm,
Pump : 0.25 Hp, N=14000 rpm, mono-block type
Connecting pipes: material GI, OD=12.5mm
ID= 10mm, coated with
insulation.
Thermocouple: Thermo ZA 9020-FS Nicr-Ni Type K of range - 20 to 350 C.
Valves: Ball type brass valve of nozzle 1/2" dia

IV. EXPERIMENTAL SET UP AND PROCEDURE

Fig. 1 C/S view of heat exchanger inner tubes.

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Fig. 2 Side view of the inner tubes

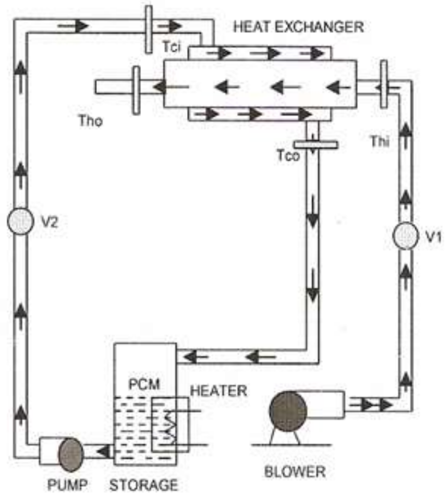

Fig. 3 Schematic of Experimental Set up

Experimental set up consist of counter flow exchanger connected with a blower to the tubes and shell with storage tank. Valves are used to control the mass flow rate of air and PCM fluids.

Whole set up is placed on flat surface PCM fluid is filled in storage tank, a heater coil is fitted in storage tank immersed in PCM fluid connected with the dimmerstat, all the electrical connections are made properly.

Set dimmerstat at the constant voltage and valves at specific mass flow rate. Start the set up, and wait till the steady state (with in 10-15 mins) is reached, note down the thermocouples reading and velocity of the fluids. For air velocity measurement digital anemometer is used and for PCM fluid velocity measurement pitot tube with water tube manometer is used.

V. CALCULATION ANALYSIS

For the experimental result and properties of PCM at bulk mean temperature effectiveness of heat exchanger is calculated.

$q_{max} = C_{min}(T_{hi}-T_{ci})$

qmax is the maximum heat which could transfer between the fluids.

According to above equation to experience maximum heat could be transfer, the heat capacity should be minimize. Since we are using maximum possible difference, justifies the reason of using Cmin.

Effectiveness E(E) is the ratio between actual heat transfer rate and maximum heat transfer rate. Velocity V(V)= $C_v\sqrt{2gh}$

Where, $C_v = 0.98$

Mass flow rate $m = \rho AV$

ρ at bulk mean temperature

$E = q/q_{max}$

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q= Ch(Thi-Tho)
= Cc(Tco-Tci)
qmax= Cmin (Thi-Tho)
N= NTU= UA/ Cmin
C= Cmin/Cmax
Cmin= (m Cp)min
Cmax= (m Cp)max

Counter flow heat exchanger effectiveness:

$$E = \frac{1-\exp[-N(1-C)]}{1-C\exp[-N(1-C)]}$$

VI. RESULT ANALYSIS

Supplied power= 230 V
Valves opening (Air + PCM fluids)=60°

PCM	E	NTU	q	mf	Q
Water	**0.5**	**0.7**	**0.86**	**0.078**	**0.984**
$CaCl_2$ (10%)	**0.69**	**1.5**	**1.98**	**0.086**	**0.725**
$CaCl_2$ (20%)	**0.7**	**1.51**	**2.17**	**0.088**	**0.925**
$CaCl_2$ (30%)	**0.72**	**1.53**	**2.66**	**0.091**	**1.320**
Paraffin	**0.25**	**0.49**	**0.347**	**0.066**	**0.191**
Paraffin(10%)	**0.28**	**0.50**	**0.719**	**0.067**	**0.289**
Paraffin(20%)	**0.30**	**0.51**	**1.23**	**0.068**	**0.307**
Paraffin(30%)	**0.33**	**0.52**	**0.97**	**0.069**	**0.505**

VII. RESULT AND DISCUSSION

From the experiment conducted by using three different groups it is found that effectiveness of heat exchanger using calcium chlorides is apxomately 70% and that of water is 50% effetive than the organic compounds.

Heat transfer from PCM to air is calculated and form results it is seen the heat transfer by using CaCl2 is increased by 10% than paraffin and 4% than water

Materials and their properties. 27°C

Material	Density Kg/m^3	Specific Heat KJ/kg-K	Thermal Conductivity **(W/mK)**
Air	**1.1774**	**1.0057**	**0.026**
Water	**997.1**	**4.79**	**0.612**
CaCl2	**1090**	**3.580**	**0.815**
Paraffin	**800**	**2.09**	**0.156**

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GRAPHS

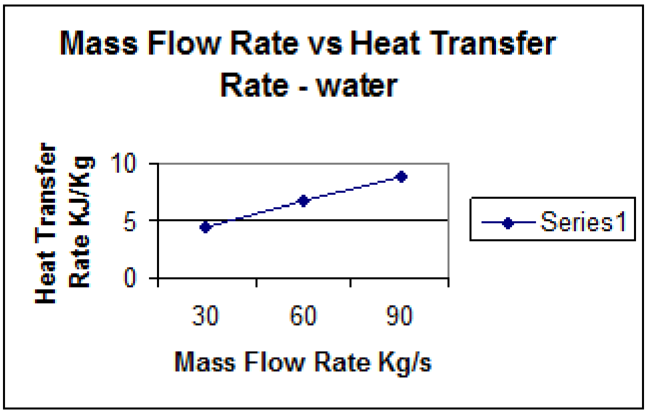

Fig.no:-04

Graph 4: It is seen that heat transfer rate from water to air increases by 0.0738 kj/kg as mass flow rate increases by 1˚

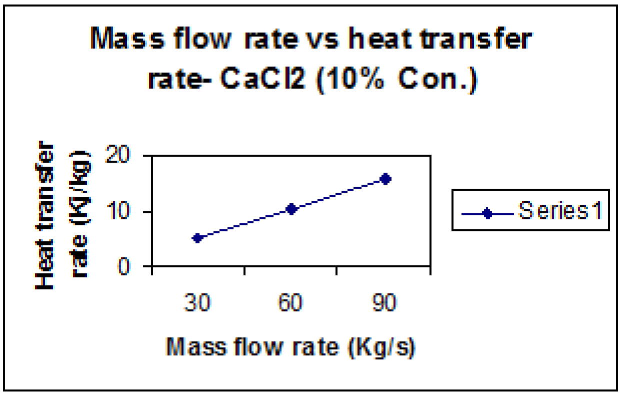

Fig no.05

Graph 5 Heat transfer rate from CaCl2 (10%conc) to air increases by 0.178 kj/kg as mass flow rate increases by 1º

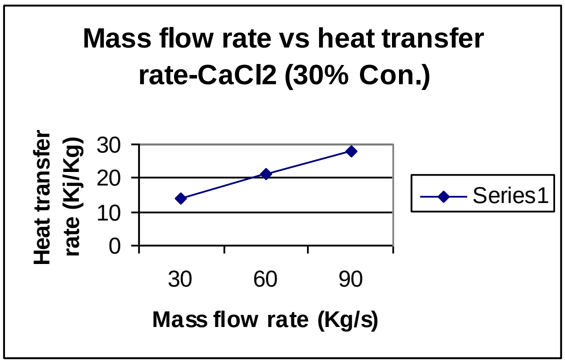

Fig no 06

Graph 6: Heat transfer rate from CaCl2 (30%conc) to air increases by 0.2 kj/kg as mass flow rate increases by 1˚.

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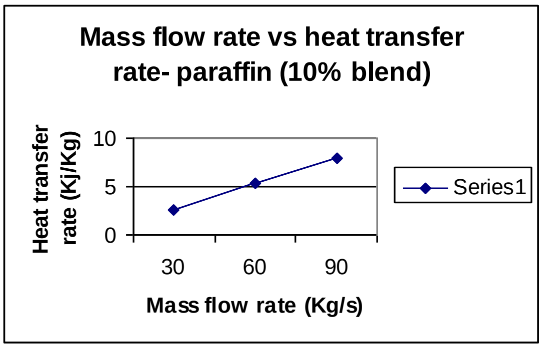

Fig.no.07

Graph 7 Heat transfer rate from paraffin to air increases by 0.088 kj/kg as mass flow rate increases by 1˚.

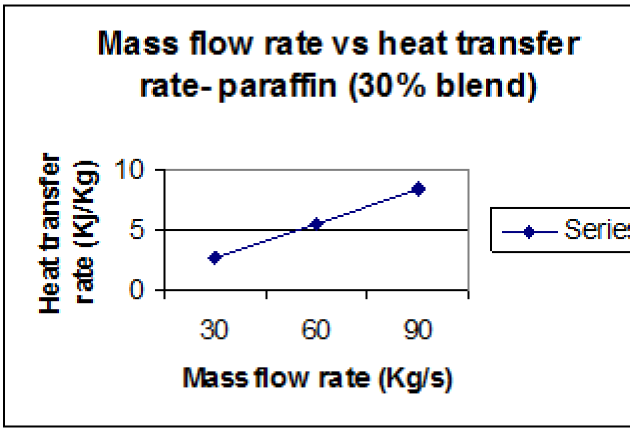

Fig no 08

Graph 8 : Heat transfer rate from paraffin (30% blend) to air increases by 0.093 kj/kg as mass flow rate increases by 1˚.

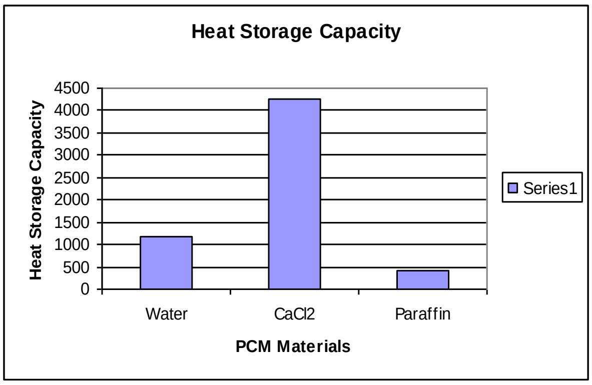

Fig no 09

Graph 9: From the graph it is seen that heat storage capacity of CaCl2 is 0.9847 which is greater than water 0.954 (3%more than water) and that of paraffin 0.1914 (8% than paraffin).

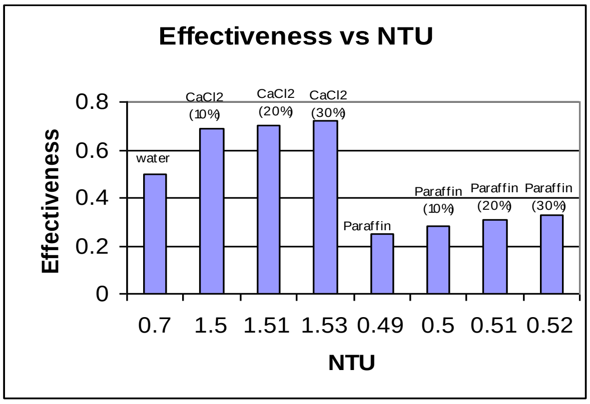

Fig no 10

Graph 10: The graph represent the comparative effectiveness of different PCM materials and their blends/concentration with respect to Number of Transfer Units.

VIII. CONCLUSION

The conclusion from the experiment is that for space heating, It is seen that effectiveness of heat exchanger using CaCl2 is 70% and by using water is 50% and by using paraffin is 30%. Maximum heat storage capacity of CaCl2 730 KJ/Kg and the minimum heat storage capacity 162.5 KJ/kg..

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