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Production of Cost effective cooling using Eco-cooler

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Abstract: Thermal comfort is defined as "that condition of mind which expresses satisfaction with the environment". This condition is also sometimes called as "neutral condition". A living human body may be likened to a heat engine in which the chemical energy contained in the food consumes continuously converted into work and heat. The rate at which the chemical energy is converted into heat and work is called as "metabolic rate". A human body is very sensitive to temperature. The body temperature must be maintained with a narrow range to avoid discomfort, and within a somewhat wider range, to avoid danger from heat stress.

Present project deals with providing cost effective cooling using eco-cooler. Eco-cooler works on the principle of Latent Heat Storage (LHS) technique which is provided by using PCM (Phase Change Material).The reason for adoption of eco-cooler to provide cost effective cooling is drawbacks of passive cooling system like high initial building cost, requires more planning to reduce glare, require engineering expertise. In eco-cooler reduction of air temperature is achieved using PCM based evaporative cooling system.

Eco-cooler is best suited to hot and dry climatic regions like Anantapuramu. Basically anantapuramu is backward region, where rural population is high compared to urban population. Majority of this population cannot afford conventional Air conditioning system. So an effort is made to test and implement the proposed eco-cooler which has yielded a cost effective solution to the cooling problem. In the present project comparison of temperatures with dry and wet basis is performed. The room temperature is found to be reduced by 1 to 2℃ less than ambient temperature.

Key words: PCM, Fin, Converging section, Encapsulation, Thermal Conductivity, Lessing Rings

1. INTRODUCTION

Energy plays a major role in achieving economic prosperity and technologicalcompetitiveness of a nation. If the requirement of the energy is fulfilled, then any nationcan be considered as developed nation. This requires that a developing/underdevelopedcountry should concentrate on the energy technologies to ensure energy security, efficiency and environmental quality. Increasing energy costs impact everyone withrespect to ability to maintain a decent standard of living. Further, as climatic changesbecome erratic, energy has become all the more important to sustain the standard ofliving. Currently, the world is looking at renewable energy to replace conventional fuels in areas like electricity generation, space cooling and water heating.Hence it is necessary not only to develop economic energyusage patterns but also conserve the available energy. Thus focus is now slowly shiftingto greener and sustainable methods that have the ability to capture waste or free thermalenergy.

Phase change materials (PCMs) are suitable for storing thermal energy in the formof latent heat and release when required by changing its phase from solid to liquid andvice versa. They absorb or release large quantities of heat at a constant temperaturethereby maintaining desirable ambient conditions. Studies conducted tocompare phasechange (latent heat) and sensible heat storages have shown that a significant reduction in storage volume can be achieved by using PCM as compared to sensible heat storage. Phase change materials find their application in cold storage, temperature controlledfood transportation, pharmaceutical preservation, air conditioning, solar applications,thermal wear, building cooling and heating and in fact any industry looking to exploitoff peak electricity tariffs for heating or cooling or capturing freely available energy.Thus the Thermal Energy Storage (TES) systems which make use of PCM's facilitateuse of thermal energy equipment for large scale energy substitution economically.

2. DESIGN AND FABRICETION OF PCM STORAGE SYSTEM

(A) Methods to improve Thermal conductivity of PCM:

All non-metallic liquids, including PCM have a low thermal conductivity. SincePCM store large amounts of heat or cold in a small volume, and because it is necessaryto transfer this heat to the outside of the storage to use it, the low thermal conductivitycan be a problem. In the liquid phase, convection can significantly enhance heat transfer,however often this is not sufficient. In the solid phase, there is no convection. When fastheat transfer is necessary, one possibility to increase the thermal conductivity of thePCM is to add materials with larger thermal conductivity. This can be done at amacroscopic scale, for example by adding metallic pieces, or on a sub mm scale asmentioned before with composite materials.

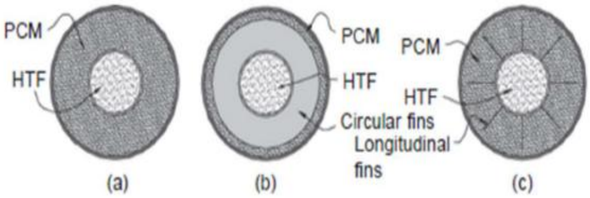


Fig.1.Cross-sectional views of the (a) control, (b) circular finned and (c) longitudinal Finned PCM systems

Velraj performed three types of heat enhancement techniques on analuminium cylindrical tube filled with paraffin wax. The three heat enhancementtechniques were internal longitudinal aluminium fins with a cross-shaped cross-section, Lessing rings of 1 cm diameter distributed in the tube and water/vapour bubbles that randomly appeared in the tube. It was found that the utilisation of Lessing rings had thebest enhancement results of the reduction of the solidification times by a factor of 9, while the internal fins was the next better enhancement technique. However, the thirdtechnique did not have any remarkable results. It was also found that with the additionof Lessing rings in the paraffin, the thermal conductivity was increased by 10 times. The Lessing rings are made of steel and have a thin-walled hollow cylindrical structure with a partition. Without partition, these rings are known as Raschig rings. Thermal conductivity enhancement techniques using carbon fibres wereinvestigated in a tube-in-tank system. Carbon fibres have a higher thermal conductivitythan copper and also minimise the space they occupy within the storage system. Thefibres were randomly distributed in the PCMs in the first technique. The second technique employed a fibre brush such that the directions of the fibres coincided withthe heat flow. The brush type technique significantly enhanced the effective thermalconductivity in the direction of the fibre orientation. Carbon fibre brushes were furtherinvestigated by arranging the brush along with the tubes as shown in above figure. Theresult of this experiment showed that the transient thermal responses in the composite improved as the length of the brush increased.

(B) Encapsulation of PCM:

Encapsulations are classified according to their size as macro- andmicroencapsulation. Macro encapsulation is by far the most widely used type ofencapsulation, however also microencapsulated PCM are produced on an industrialscale nowadays. When encapsulating PCM, it is necessary to take into account severalaspects. First, the material of the container wall must be compatible with the PCM. Then, taking into account the selected wall material, the container wall has to be sufficientlythick to assure the necessary diffusion tightness. Finally, the encapsulation must bedesigned in a way that it is able to cope with the mechanical stress on the container wallscaused by the volume change of the PCM.

Properties of PCM	Climsel (C24)
Phase change temperature (Solid)	24°C
Phase change temperature (Liquid)	27°C
Latent heat of Fusion	140 kJ/kg
Thermal conductivity (Solid)	0.74 W/mK
Thermal conductivity (Liquid)	0.93 W/mK

Table 1:Thermal Properties of PCM

(C) Governing Equations of the Solidification Problem:

The physical model of the solidification problem to be investigated in this subsection is shown in Fig.2, where a liquid PCM with a uniform initial temperatureTi , which exceeds the melting point Tm , is in a half-space x > 0. At time t = 0, thetemperature at the boundary x = 0 is suddenly decreased to a temperature T0, which isbelow the melting point of the PCM. Solidification occurs from the time t = 0. This is atwo-region solidification problem as the temperatures of both the liquid and solid phasesare unknown and must be determined. It is assumed that the densities of the PCM forboth phases are the same. Natural convection in the liquid phase is neglected, andtherefore the heat transfer mechanism in both phases is pure conduction.

The temperature in the solid phase must satisfy

$$\frac{\partial^2 T_1}{\partial x^2} = \frac{\partial T_1}{\partial t}(\frac{1}{\alpha 1}) 0 < x < s(t), t > 0$$

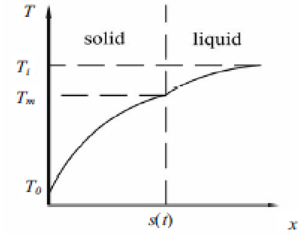


Fig. 2 Solidification($T_0 < T_m < T_i$)

$$T_1(x,t) = T_0 \, x = 0, t > 0$$

For the liquid phase, governing equations are,

$$\frac{\partial^2 T_2}{\partial x^2} = \left(\frac{1}{\alpha_2}\right)\frac{\partial T_2}{\partial t} s(t) < x < \infty, t > 0$$

$$T_2(x,t) \rightarrow T_i x \rightarrow \infty, t > 0$$

$$T_2(x,t) \rightarrow T_i \qquad x>0,\ t=0$$

The boundary conditions at the interface are

$$T_1(x,t) = T_2(x.t) = T_m x = s(t), t>0$$

$$k_1 \frac{\partial T_1}{\partial x} = k_2 \frac{\partial T_2}{\partial x} = \rho h_{sl} \frac{\partial s}{\partial t} x = s(t), t>0$$

$$\frac{\partial T_1}{\partial x} \sim \frac{T_m - T_0}{S}$$

$$\frac{\partial T_2}{\partial x} \sim \frac{T_i - T_m}{S}$$

The interface velocity is,

$$\frac{ds}{dt} \sim \frac{s}{t}$$

$$K_1 \frac{T_{m-T_0}}{S} - K_2 \frac{T_i - T_m}{S} \sim \rho h_{sl} \frac{S}{t}$$

$$\frac{S^2}{\propto t} \sim Ste\left(1 - \frac{K_2}{K_1}\frac{T_i - T_m}{T_m - T_0}\right)$$

$$\text{Ste} = \frac{C_{pl}(T_m - T_0)}{h_{sl}}$$

3. EXPERIMENTAL SETUP

Experimental set up consists of two modules.
1) Converging section
2) PCM section

Fig.3.Converging Section

In converging section air from the back side of cooler is drawn into the chamber by fan of cooler. In converging section as air is passed through reduced cross section of conduit, the velocity of air is increased with the reduction of pressure energy.

Fig.4.Aluminium metal chamber

Above Diagram shows metal chamber in which PCM pouch(Climsel C24) is placed which acts as thermal mass.PCM has high latent heat storage capacity with short temperature difference.But The general problem that encountered with the use of PCM is low thermal conductivity ,which further reduces thermal diffusivity.Thermal diffusivity is defind as the ratio between Thermal conductivity(K) and Heat storage capacity(ρC_p) .

Charged PCM is placed inside the Aluminium metal chamber and heat transfer is taken place between PCM pouch and metal surface. Air stream is allowed to converge using converging portion of Air cooler and is passed over the surface of Aluminium metal chamber which consists of extended surfaces. By using extended surfaces effective heat transfer takes place between air stream and metal surface which is cooled by charged PCM pouch.

The experiment is conducted at different speeds of air cooler fan with different chamber conditions like dry and wet condition. In dry condition ambient air is sucked by fan without changing specific humidity of air, it means without changing of moisture level in ambient air. In dry condition temperature of air decreased by 0.5℃ to 1℃.In wet condition the air is allowed to pass through converging portion of Air cooler, which increases velocity of air further. Charged PCM is placed inside Aluminium metal chamber and air comes to contact with extended metal surfaces. In wet condition the pads of air cooler is getting wetted by sprinkling of water which is supplied from sump of air cooler. In this condition air comes to contact with wetted pads so by evaporative cooling phenomena air DBT, WBT gets reduced. In wet condition air specific humidity gets changed. As the experiment is conducted in hot and dry climatic conditions changes in specific humidity of air is negligible.

Fig.5. Converging of air stream

Calculations: Energy stored by PCM = Energy gained by air

M_{PCM}*(Latent heat of fusion) = M_{air}*Cp_{air}*(ΔT)*time

$M_{PCM} = \frac{0.15 \times 1.005 \times 2 \times 1800}{140} = 2.58$ kg.

Mass flow rate of air = (density of air) x (area of fan) x (velocity of flow)

$= 1.2x\ (\frac{\pi}{4} \times 0.4^2)\ x1$

= 0.15 kg/sec

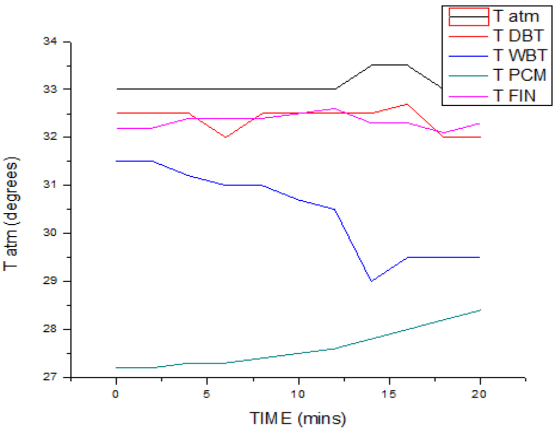
Energy absorbed by air = $m_{air} * C_{pair} * \Delta T * 120\ kJ$

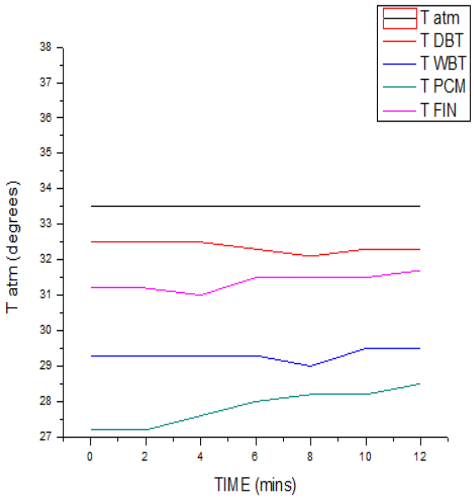
Where m_{air} is mass flow rate of air in kg/sec

C_{pair} is specific heat of air at constant pressure in kJ/kg K

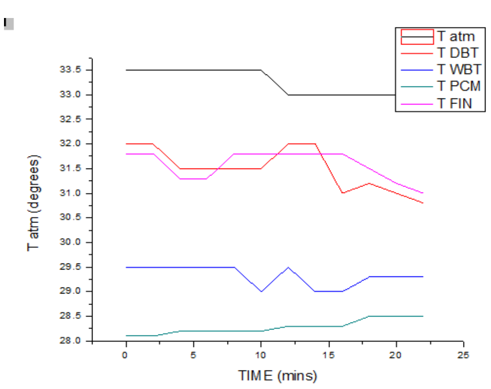
$\Delta T$is temperature difference between ambient and outlet temperature (DBT)

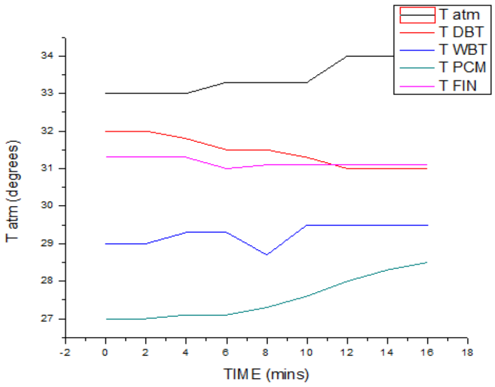
4. RESULTS



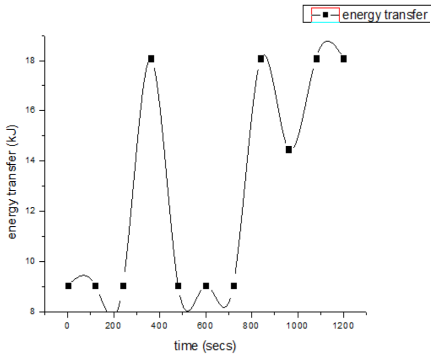


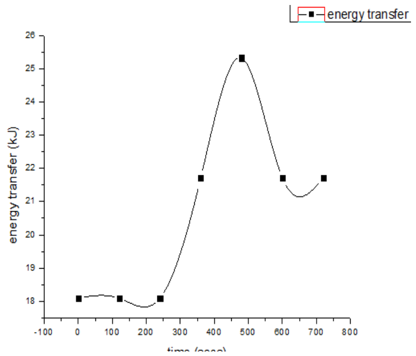
Graph (a) low speed dry conditionGraph (b) high speed dry condition



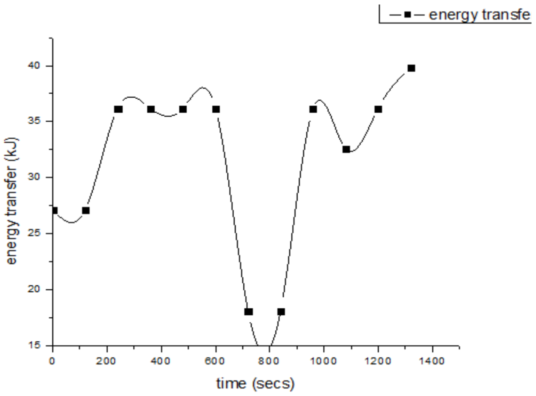


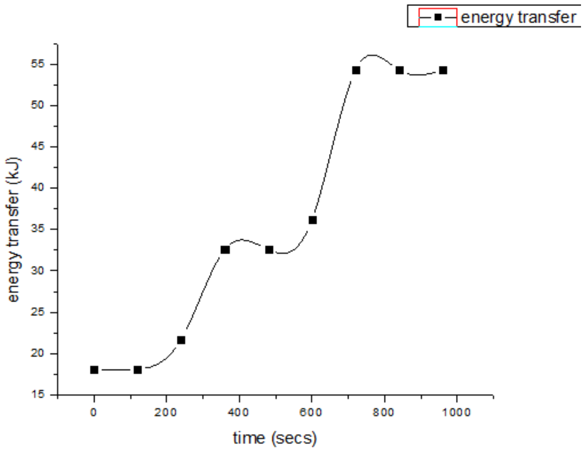
Graph (c) low speed wet conditionGraph (d) high speed wet condition





Graph (e) low speed dry conditionGraph (f) high speed dry condition





Graph (g) low speed wet conditionGraph (h) high speed wet condition

Graphs (a) to (d) represents variation of Temperature with respect to Time at low and high speeds of fan in dry and wet conditions. At low speed of fan rotates with low velocity so mass flow rate of air decreases which increases duration of cooling produced using PCM.In low velocity dry condition outlet temperature of air is decreased by using latent heat stored in PCM.In high velocity dry condition as the speed of fan increases the amount of air drawn through converging portion of air cooler increases which increases load on PCM section. So the cooling time duration decreases. In dry condition at low speed the total time of cooling is 20 minutes, in dry condition at high speed total time of cooling reduced to 12 minutes.In low velocity wet condition outlet temperature of air is decreased by using both PCM and evaporative cooling section. In low velocity wet condition mass flow rate of air is less compared to high velocity wet condition which increases duration of cooling to 22 minutes.

Graphs (e) to (h) represents energy transfer of air with respect to time is plotted. In low speed dry condition as the speed of fan is less mass flow rate of air is also less so exchange of energy between PCM and air is less compared to high speed dry condition. In high speed dry condition as velocity of air increases which helps to increase convective heat transfer coefficient of air also improves energy transfer.In high speed wet condition the graph slope increases which indicates that energy transfer is progressively increases. Because in high speed wet condition the mass flow rate of air increases and cooling of air is happened by using PCM as well as evaporative cooling section. So energy transfer capability of air increases.

5. CONCLUSION

In the present work investigation have been carried out experimentally on Production of cost effective cooling using eco-cooler. The experimental investigation had been carried out in four phases that are

1) Low speed dry condition
2) High speed dry condition
3) Low speed wet condition
4) High speed wet condition

The experiment is carried out inAnantapuramu which is hot and dry climate region. All the four phases of experiments yielded satisfactory results. In low and high speed dry condition using PCM outlet air temperature is

reduced by 0.5℃ to 1℃as compared to ambient temperature. In low and high speed wet condition using PCM outlet air temperature is reduced by 1.5 ℃ to 2℃.
So through experimental results for hot and dry climatic region like Anantapuramu high speed wet condition is most recommended technique to control indoor hot environment conditions.

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