Experimental Study of Forced Circulation Solar Air Heating System with Phase Change Materials (Paraffin Wax) Energy Storage

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ABSTRACT
The continuous increase in the level of greenhouse gas emissions and rise in fuel prices are the main driving forces behind efforts for more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. In Bihar mean yearly global solar radiant exposed is 18.31MJm^{-2}day^{-1}, this is sufficient amount of energy for use. This energy can be used as electrical energy or thermal energy. The storage of thermal energy for continuous operation in solar air heater is major challenge. 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. So, this study is concentrated on the thermal performance of storage type solar air heater by phase changed material (PARAFFIN WAX). A series of experimental tests undertaken on plain aluminium absorber plate which was placed over the paraffin wax bed (2 m×0.30 m×0.10 m). 490 aluminum fins (Ø 4 mm×100 mm) are welded on other side. These fins are dipped into the PCM's bed for better conduction of heat from absorber plate to PCM and vice-versa. The experiment was conducted day and night (24 hr.) continuously after 1 hr. interval under no-load conditions over the ambient temperature range of 22-47ºC, and a daily global irradiation range of 984.53- 325.051W/m^2. The experimental investigation shows that the maximum temperature rises up 60.5ºC in mid days. The temperature difference between output and input ranges of 1.5 ºC – 7.50ºC in morning time (06:00 hr) for different mass flow rate of air (0.015Kg/s, 0.020 Kg/s, 0.025 Kg/s). The average temperature rise of atmospheric air is 8º C, in 24 hours consistently. The time average instantaneous collector efficiency is 37.16 %. So, this setup can be used for various applications such as space heating, in painting shop, crop drying and poultry egg incubation for 24 hours application. Latent heat thermal energy storage is basically attractive technique because it provides high energy storage density. When comparing to conventional sensible heat energy storage systems, latent heat energy storage system requires a smaller weight and volume of material for a given amount of energy. In addition, latent heat storage has the capacity to store heat of fusion at a constant or near constant temperature which respond to the phase transition temperature of the phase change material (PCM).

***Keywords**:* Phase Change Materials (PCM), Latent Heat, Sensible Heat, Energy Storage

I INTRODUCTION

The quest for new technologies to avert the growing concern for environmental problems, the imminent energy shortage and the high cost of energy and new power plants has been a scientific concern over the last three decades. Central to the problem is need to store excess energy that would otherwise be wasted and also to bridge the gap between energy generation and consumption. Latent heat thermal energy storage is basically attractive technique because it provides high energy storage density. When comparing to conventional sensible heat energy storage systems, latent heat energy storage system requires a smaller weight and volume of material for a given amount of energy. In addition latent heat storage has the capacity to store heat of fusion at a constant or near constant temperature which respond to the p has e transition temperature of the phase change material(PCM). The study of phase change materials was pioneered by T elkes and Raymond in 1940, but did not receive much attention until the energy crisis of late1970 and early1980, where it was extensively researched for use in different applications especially for solar heating systems. After 1970 a large number of studies have been conducted to assess the overall thermal behaviour of latent heat thermal storage system. Studies of phase change system have investigated design fundamentals of system and process optimization, transient behaviour, and field performance. The research and development has been broad based and productive, concentrating on both their solution of specific phase change material and the study of the characteristics of new materials. As reported by many researchers the major disadvantage has been the low thermal conductivity possessed by PCM that leads to low charging and discharging rates especially for organic based materials. The growth of a latent heat thermal energy storage system thus involves the understanding of heat transfers/exchanges in the PCMs when they undergo solid-to-liquid phase transition in the required operating temperature range, the design of the container for holding the PCM and problem raised due to formulation of the phase change. The experiment was conducted on phase change materials (PARAFFIN WAX-IOCL) and smooth aluminium absorber plate having 490aluminium fins for better thermal conductivity. Air heating collectors have been occasionally used since World War II, mostly for low temperature space heating applications. The collectors are typically flat with large air flow channels. In the 1959 Colorado solar house used a glass and metal collector with many glazing staggered on top of each other, and achieved 30% efficiency. Figure1 shows the layout of Colorado house collectors. In the 1960s, solar energy developed as a means of chief energy for crop drawing. Gupta and Garg tested several designs that used both corrugated absorber surfaces as well as wire mesh packing the absorber. The also provided an overall efficiency that look in to account the power to force air through the heater. They shows corrugated performed better than those enhanced wire mesh. Achieving of maximum of 65% overall energy converge efficiency. A design by close was able to achieve temperature around 65°C with a collector efficiency of 50%.this study also investigated the use of corrugated absorber surface to maximize heat transfers by increasing surface area, and used a trapped layer of air between a single glazing surface and absorber. Insscsial experiment using polymer material done by WI hillier who tested glazing made of tedlar, a polyvinyl fluoride (PVF) film. it was found that despite higher heat losses from the tedlar its, improved transmittance commenced it work especially well when there was more than one glazing and only out glazing of glass. Interest in solar air heating and alternative energy in general picked up with the oil crisis. Many air heaters were patented in this period, and they included novel designs using multiple glazing forcing air through jets to create more turbulent to enhance heat transfer near the absorber plate and circulating air between the glazing's. Satcunanathan and Deonarien also explored passing air between multiple glazing's before heating it, and they found collector efficiency gains of 10-15%. The previous designs mainly painted absorber surfaces and glass glazing. These surfaces are prone of corrosion and falling especially in the presence of humid air. With the advent of new type of polymers it became possible to experiment with new design that used materials with much lower thermal conductivity. Interest in polymer materials also occurred with Banal who tested PVF glazing in the environment of an extend period of time, and found increased collector performance with PVF glazing use of packing to enhance heat transfer were investigated by Choudhury and Garge who achieved collector efficiency of 70% by using packing materials placed above the absorber plate and alloying air pass through it. Sharma et al used wire matrix packing above the absorber plate to in hence to heat transfer

II LITERATURE REVIEW

B.Kumar used a tank of paraffin wax which absorb solar radiation, and heat was removed by water flowing through three finned heat exchangers. In some cases, water flowed through pipes between an absorber surfaces with integrated phase change material. The oil served as an interface between the PCM and water, spreading the heat over the surface. A black absorber plate was above the oil to collect the solar energy. **DR. F. Bruno** unlike conventional sensible thermal storage method PCM provide much higher energy storage density and the heat is stored and released at an almost constant temperature, PCM can be used for both the active and passive space heating and cooling systems. In passive systems Phase change material can be encapsulated in building material such as concrete , gypsum wallboard, in the ceiling or floor to increase their thermal storage capacity, they can either capture solar energy or thermal energy through natural convection. Increasing the thermal storage capacity of an area can increase human comfort by decreasing the magnitude of internal air temperature swings so that the indoor air temperature is closer to the desired over a longer period of time. **Edward K.Summer** investigated on a high efficient solar air heater with novel built in heat storage for use in a humidification and dehumidification desalination cycle. He used paraffin wax with melting temperature of 51°C, as a phase change material below the aluminium absorber plate. The volume of PCM's bad was $1\times0.30\times0.10m^3$.The result showed, it was sufficient to produce a consistent (day or night) output temperature close to the PCM's melting temperature. **W.Saman** used PCM for aroof integrated solar heating system .His unit consists of several layer of phase change material slabs with a melting temperature of 29°C. Warm air delivered by a roof integrated collector passed through the spaces between the PCM layers to charge the storage unit. The stored heat is utilized to heat ambient air before admitting ta a living space. Form this study he conclude that

- A higher inlet air temperature increases the heat transfer rate and shortens the melting time. Conversely, during freezing, a lower inlet air temperature increase the heat transfer rate and shortens the freezing time.
- A higher air flow rate increases the heat transfer rate and shortens the melting time but increases the outlet air temperature and reverse in the case of freezing.

III METHODOLOGY

As we know that there is lots of analytical as well as experimental work done on the calculation of heat transfer and fluid flow characteristics in smooth absorber plate of solar air heater without storage or sensible heat storage type, but there is very few experiments performed on latent heat storage (paraffin wax) type solar air heater. The main problem with paraffin wax is that their low thermal conductivity, but paraffin wax contains high latent heat. So, with the aid of high conductive materials,this difficulty can be resolved.

In view of this extensive experimentation work is planned to produce heat transfer, fluid flow and thermal performance data on storage type solar air heater with paraffin wax as a latent heat storage material.

(a) Major components of the set-up:

- Insulated PCM box
- Air flow channel
- Smooth absorber plate
- Glazing
- Air Blower
- Piping system
- Thermocouple
- Hot wire anemometer
- Temperature indicator
- Pyranometer
- Mill volt meter
- Stand

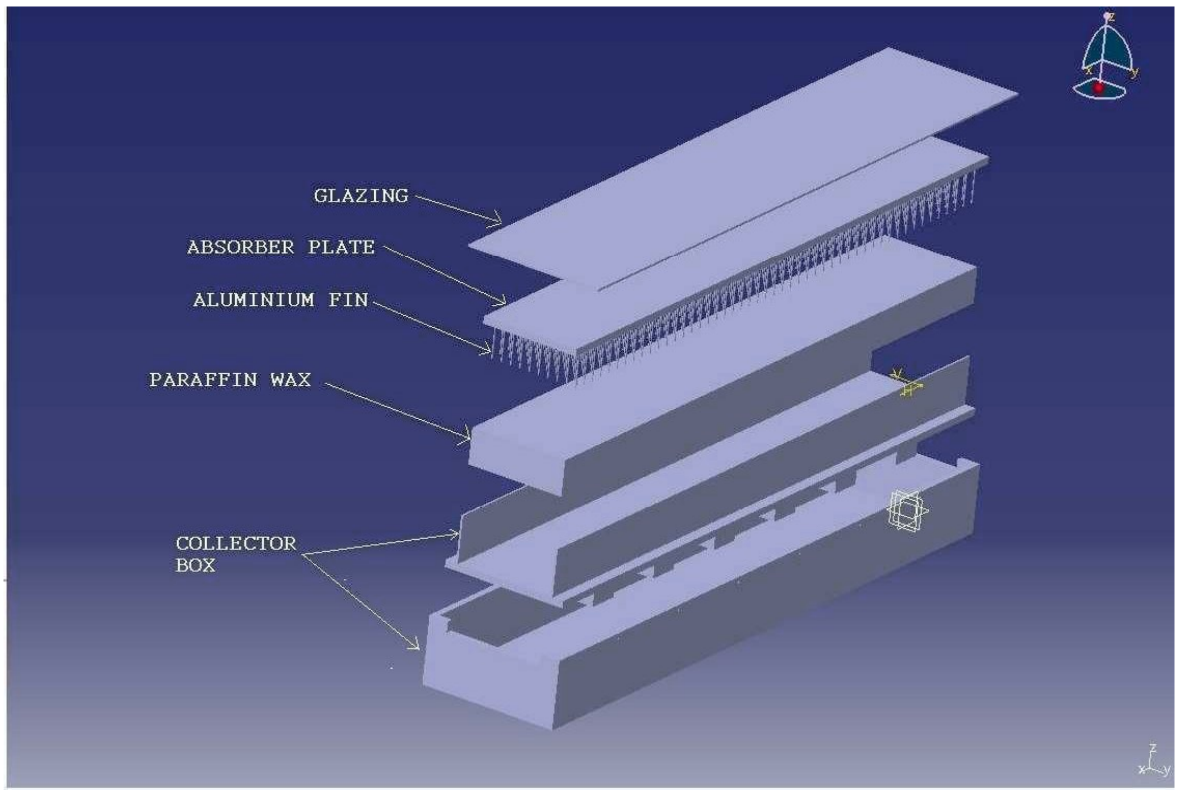

Fig. 1 3-D View of various parts of air heater

Fig. 2 Assembled Set up view

IV EXPERIMENTAL PROCEDURE

The solar collector along with its inlet and outlet ducts was installed at an angle of 20.58° south to the horizontal. A centrifugal air blower was attached to the inlet and equipped with a voltage regulator so that the inlet air flow rate can be varied precisely across a wide scale. However, in this test measurement range was up to 1.5-4m/s. A flow straightener (Triangular) was used at the inlet and outlet, to give uniform flow into the solar collector. A pyranometer measuring short wave radiation was connected at the same slope to as the collector to read solar radiation flux (W/m^2) on the inclined surface (as shown in fig.4.13). A hot wire anemometer (AVM08) was installed, and its reading was taken at several locations across the perpendicular plane to the flow direction so that an average velocity is measured. This measurement is used to gives the air flow rate across the unit. Reading were obtained for two inlet air and two outlet air temperature values, in addition to six reading of the temperature of the absorber plate at different location along the length and across the width. These six reading were taken by the use of J-Type thermocouple. The thermocouples were connected to 6-channel thermocouple amplifier. The pyranometer output reading was converted into a heat flux using the calibration relation (1mV=129.31W/ m^2 as per specification). Once the unit was connected, it was left to run for 2 days before the measurements were taken, in order to overcome the initial transient effects and to confirm reliable operation of the unit. Then, the experiment was run at steady state for a period of 9 days (from 20th April-28th April).

Formula Used

1. **Reynolds number (R_e)** $= \frac{4R_h V}{P}$
2. **Friction Factor (f)** $= \frac{1}{(1.82 \log R_e - 1.64)^2}$
3. **Nusselt Number (Nu)** $= \frac{(f/8)(R_e - 1000)Pr}{1 + 12.7\sqrt{f/8}\,(\sqrt[3]{Pr^2} - 1)}$
4. **Convective Heat Transfer Coefficient (h)** = ——
5. **Efficiency (η)** $= \frac{\dot{m}C_P(T_{avgo} - T_{avgi})}{}$

I AC

Nu×k De

V SAMPLE CALCULATION

The reading was taken for first three days in one mass flow rate (0.015 Kg/s) and for next three daysin second mass flow rate (0.020 Kg/s) and same for next three days in third mass flow rate(0.025 Kg/s).Observation was taken from 6:00 am to 5:00 am next day with one hour interval, for 24 hour(Day and night). we considered third set of reading only second day. The reading absorbed from experiment

T_{amb}= 25°C I = 5.95 mv = (3.95× 129.31) = 511.25 W/m^2

T_{avgi}= 25 °C V= 1.5 m/s

T_{avgo}= 30°C $\rho_{27.5}$=1.175 Kg/m^3

T_{mf}= 27.5°C

Data obtained from hand-book (**Data Hand book by Domkundwar & Domkundwar)**

ρ_{20} = 1.205 Kg/m^3

ρ_{30}= 1.165 Kg/m^3

ρ29.5= 1.167 Kg/ m^3

ρ_{42} = 1.120 Kg/m^3

P29.5= 1.5953×10^{-5}m^2/s

$K_{29.5}$ = 0.02634 W/m KPr = 0.699

Cp= 1005 J/Kg K

Geometrical Data:

Cross-section Area of duct (A_C) = (w × d) = (0.31×0.04) = 0.0124 m^2

Perimeter of duct (p) = 2(0.31+0.04) = 0.70 m

Panel Area (AP) = (1 × w) = (2× 0.31) = 0.62 m^2

Equivalent Diameter (e) = $\frac{4AC}{P}$ = 0.7086 m

Hydraulic Radius (R_h) = $\frac{AC}{P}$ = 0.017714 m

Calculation:

1. Mass flow rate(ṁ1) = 0.015 Kg/s **2.Mass flow rate(ṁ2)** = 0.020 Kg/s **3.Mass flow rate(ṁ3)** = 0.025 Kg/s

4.**Reynolds number (R_e)** = $\frac{4R_h V}{P}$ = 6662.3205

5.**Friction Factor (f)** = $\frac{1}{(1.82 \log R_e - 1.64)^2}$ = 0.024124

6. **Nusselt Number (Nu)** = $\frac{(f/8)(R_e - 100)Pr}{1+12.7\sqrt{f/8}\,(\sqrt[3]{Pr^2} - 1)}$ = 13.16

7. **Convective Heat Transfer Coefficient (*h*)** = $\frac{Nu \times k}{De}$ = 7.2356 W/m^{2}k

8. **Efficiency (η)** = $\frac{\dot{m}C_P(T_{avgo} - T_{avgi})}{I\,AC}$ = 23.68%

VI RESULT

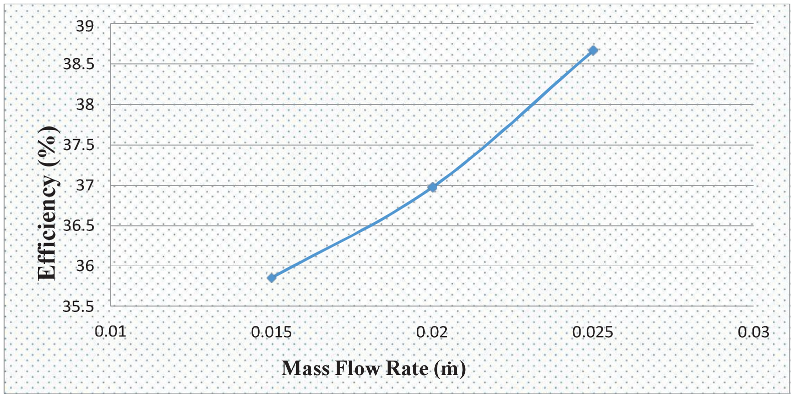

Fig. 3 variation of efficiency with Mass flow rate

It is shown from fig. that the air heater efficiency is strongly depends on mass flow rate; it increases with increasing mass flow rate (ṁ). Increasing the mass flow rate causes increase of the time average instantaneous collector efficiency. Average efficiency of the collector are 35.85 %, 36.97 %, and 38.66%, On three different mass flow rate (i.e. $\dot{m}1$= 0.015 Kg/s,$\dot{m}2$=0.020 Kg/s, and $\dot{m}3$= 0.025 Kg/s) of air respectively.

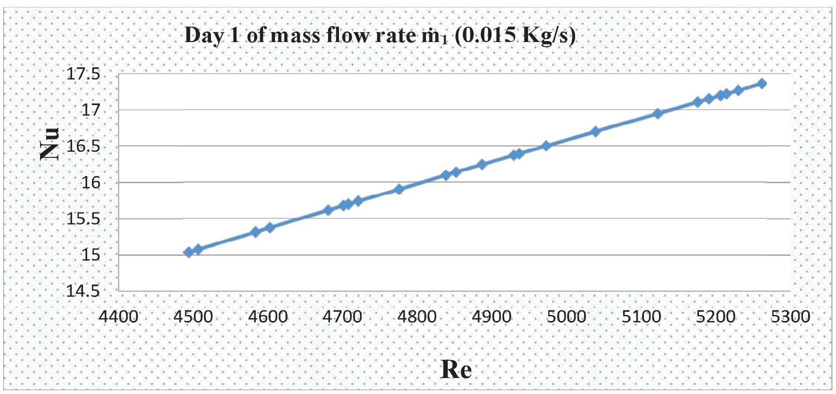

Fig. 4 Variation of Nusselt number with Reynolds number

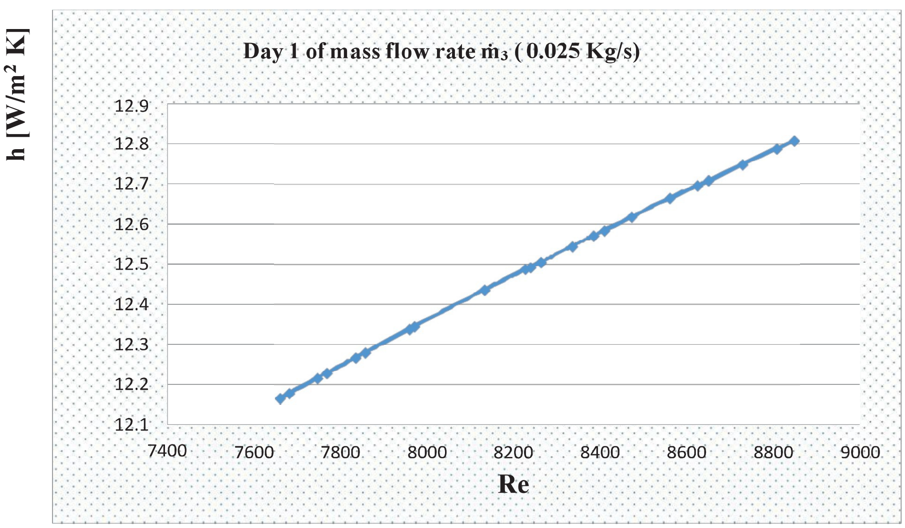

Fig. 5 Variation of Convective heat transfer coefficient with respect to Reynolds number for massflow rate of 0.025Kg/s.

Fig. show the variation of convective heat transfer coefficient with Reynolds number. It is seen that convective heat transfer coefficient is maximum (12.80W/m^2 k), when the mass flow rate(0.025 Kg/s) and Reynolds number (8847.36415) is maximum .It may concluded that the heat transfer decreases as increasing the mass flow rate. As the mass flow rate increases, the temperature difference between absorber plate and air stream increases, so higher the absorber plate temperature. Higher the platetemperature leads to increase the air viscosity. The increase in air viscosity greatly affects the wall shear stress and decrease the local Reynolds number as well which cause an increase in thermal boundary layer thickness, and results in decreasing the convective heat transfer coefficient.

VI CONCLUSION

On the basis of the experimental results obtained for nine days on three different mass flow rate of air, for force convection solar air heating system with phase change material (Paraffin wax) energy storage, manufactured and tested the following conclusion can be drawn.

- As the mass flow rate and Reynolds number increases the friction factor decreases, this is duemore turbulence of flowing fluid less the skin friction.
- As mass flow rate increase heat transfer decreases.
- Heat transfer is inversely proportional to the Reynolds number.
- As the mass flow rate of air increases the mean temperature difference of absorber plate andair stream decreases.
- The outlet temperature increases with the decrease in mass flow rate of air or vice versa.

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