USING A PARAFFIN WAX-ALUMINUM COMPOUND AS A THERMAL STORAGE MATERIAL IN A SOLAR AIR HEATER

Alkilani Mahmud, Sopian K., Alghoul M. A. and Mat Sohif
Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia
E-Mail: mahmoud_alkilani@yahoo.com

ABSTRACT

This paper presents a theoretical investigation of thermal and physical properties of a phase change material (PCM) consists of paraffin wax with 5% aluminum powder, this composite used as a thermal storage compound in a solar air heater, the compound supposed be encapsulated in cylinders as a solar absorber in cross flow of pumped air. An indoor simulation supposed that the PCM initially heated by solar simulator until liquid phase temperature (50˚C) while the pumped air over the cylinders at room temperature (28˚C), results show that the air temperature gained due to thermal energy discharge process decreases with increasing of air mass flow rate, and the freezing time for this compound takes long time interval for the lower mass flow rates.

Keywords: Phase change material, solar heating system, air temperature, freezing time, discharge process, mass flow rate.

1. INTRODUCTION

Energy storage is not only plays an important role in the conservation of energy but also improves the performance and reliability of wide range of energy systems, and become more important where the energy source intermittent such as solar.

The applications of solar energy to heat the fluids, including air, can be used to heat buildings, drying vegetables, fruits, meats, eggs incubation, and other industrial purposes. However, the needs for a continuous heat supply became an important issue.

In field of solar heating systems, water is still used as a heat storage material in liquid based systems, while a rock bed is used for air based system, but when you compare the volume requirements for the storage of heat energy between water and phase change material like Glauber’s salt, you will see that the water heat storage requires almost five times amount of space as the Glauber’s salt heat storage, this space savings would result in reduced costs for insulation and construction.

The latent heat method of storage and their materials that have been studied during the last forty years have been reviewed recently by Farid *et al.*, (2004) these are usually hydrated salts, paraffin’s, non-paraffin’s ,fatty acids and eutectics of organic and non-organic compounds.

The low thermal conductivity represents the common problem to PCMs, to enhance the heat exchange between PCM and heat transfer fluid the researchers used high thermal conductivity additives like aluminum powder and graphite-PCM composite material (Marín *et al.*, 2005) or by using fins of various configurations (Lacroix, 1993; Veraj *et al.*, 1997; Shatikian *et al.*, 2008).

Eman-Bellah *et al*. (2006) investigated a method of enhancing the thermal conductivity of paraffin wax by embedding aluminum powder in paraffin wax in a water base collector. The time wise temperatures of the PCM were recorded during the processes of charging and discharging. In the discharging process, experiments were conducted for different water flow rates of 9-20.4 kg/h. It was found that the useful heat gained increased when adding aluminum powder in the wax as compared to the case of pure paraffin wax.

In this study a prediction of output air temperature and freezing time due to the discharge process from a PCM unit in a solar air collector, the absorber consists of PCM containers as a set of cylinders detached from each other to handle the PCM unit easily. A Mat Lap computer program has been developed to compute the air temperature; cylinder by cylinder along the duct, freezing time for each cylinder, and the time required to discharge all the thermal energy.

2. ASSUMPTIONS

For predicting the output air temperature due to discharge process in a PCM unit we assumed the following assumptions:

a) Air behaves as an incompressible fluid.
b) The Stefan number is very low.
c) The heat loss assumed very low, and neglected.
d) The heat transfer process in every cylinder is radially symmetric; the heat transfer in PCM is by conduction.

3. RESEARCH METHODOLOGY

This system consists of three essential parts which are: a single transparent glass, isolated duct and the storage unit which is consist of a single row of cylinders contain a PCM, the cylinders placed in the cross flow of forced air stream, this unit works to satisfy two goals; absorb and storage the solar energy. The dimensions of the collector are 0.1808m x 1.06m x 2m has aluminum cylindrical containers as an absorber painted black. The total mass of the phase change material is about 72 kg.

The design take into consideration many concerns such as, the integration with PCM storage unit, the simplicity of construction, dismantlement, and handling the PCM unit, the collector length which proposed in accordance with Choudhury studies on the design of solar air collectors (1995), and the number of cylinders which controlled by the collector length. A reflector sheet adjusted under the cylinders to reflect the escaped rays through the spaces between them.

A solar simulator charge the collector by thermal energy until the cylinders became at liquid phase, there is no conflict between charging and discharging, and are assumed to take place at different times so, to investigate the output air temperature due to discharge process consider that no radiation. Under these conditions, the air mass flow rate increased by 0.02 kg/s each time until to reach the maximum magnitude 0.19 kg/s.

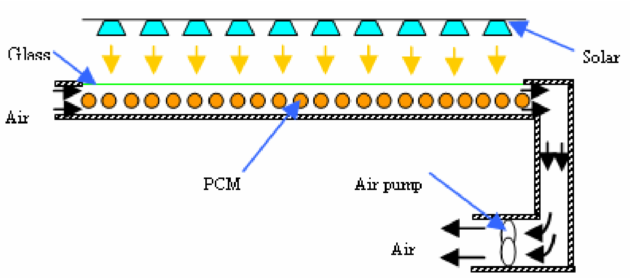

Figure-1. Cross section of the solar air collector with PCM cylinders.

To overcome the low thermal conductivity of paraffin wax we can add a powder of material has a good conductivity property such as aluminum powder the size of the aluminum powder particles has been considered as 80 µm, the physical properties of the new composite then calculated as follows:

The thermal conductivity of the compound is defined as

$$K_c = K_{p.w} v_{p.w} + K_{Al} v_{Al}$$

The specific heat of the compound is defined as

$$C_c = C_{p.w} m_{p.w} + C_{Al} m_{Al}$$

The density of the compound is defined as

$$\rho_c = \rho_{p.w} v_{p.w} + \rho_{Al} v_{Al}$$

Table-1. Physical properties.

	Paraffin wax (Sunoco P116)	Aluminum	New compound
(Tcr)	50˚C	-	50˚C
(H)	190KJ/kg	-	190KJ/kg
(ρ_s)	930kg/m^3	2707kg/m^3	933kg/m^3
(ρ_l)	830kg/m^3	-	832kg/m^3
(K_s)	0.21x10^{-3} KJ/ms˚K	0.204 KJ/ms˚K	0.56 KJ/ms˚K
(Cs)	2.1KJ/kg	0.896KJ/kg	2.09KJ/kg

where $v_{p.w} = V_{p.w}/V_c$ is the volume fraction of paraffin wax; $v_{Al} = V_{Al}/V_c$ is the volume fraction of aluminum powder; $m_{p.w} = M_{p.w}/M_c$ is the mass fraction of paraffin wax; $m_{Al} = M_{Al}/M_c$ is the mass fraction of aluminum powder.

4. THERMAL MODELING FOR DISCHARGE PROCESS

The heat balance for each typical cylinder [3]:

$$(T_{in} - T_{out})C_a \dot{m}_a = 2\pi R_\circ lh(T_{in} - T_{sfc}) \quad (1)$$

$$T_{j+1} = \gamma T_{cr} + T_j(1-\gamma)\text{, j=1, 2…N} \quad (2)$$

The freezing time for each cylinder,

$$t_j = \omega[1 + (j+1)\gamma] \quad (3)$$

Where,

$$\omega = \frac{R_\circ^2 H\rho}{2K_s\Delta T}[\frac{1}{2} + \frac{K_s}{hR_\circ}] ,$$

$$\gamma = \frac{2\pi R_\circ lh}{\dot{m}_a C_a} \quad (4)$$

The fluid temperature $T_j(t)$ after cylinder j is approximately

$$T_j(t) = T_j,\ 0 \le t \le t_1$$
$$T_{j-1},\ t_1 \langle t \le t_2$$
$$T_{j-2},\ t_2 \langle t \le t_3 \quad (5)$$
$$T_s,\ t_j \langle t$$

The heat transfer coefficient approximated McAdams (1954),

$$h = \frac{K_a}{D_\circ} b_2 \text{Re}^n \quad (6)$$

Where b_2 and n are constants equal to 0.3 and 0.6, respectively.

5. RESULTS AND DISCUSSIONS

A Mat lab computer program was developed to compute the air temperature; cylinder by cylinder along the duct, freezing time for each cylinder, and the time required to discharge all the thermal energy. In this study supposed that the room temperature was 28˚C, and the total mass of the PCM was about 72kg. Figure-2 shows the effect of mass flow rate ($\dot{m}$) on air temperature along the 2 meter duct contains 36 cylinders of PCM. In this simulation, all parameters were kept constant except the system flow rate, which set between 0.05 to 0.19 kg/s. it is show that the increasing in mass flow rate will decrease the output air temperature.

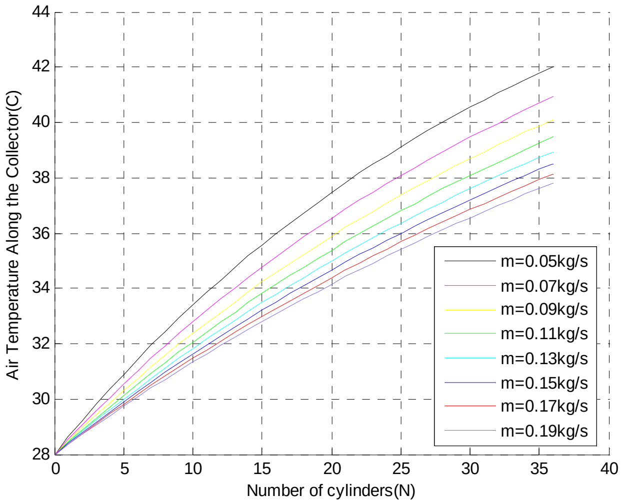

Figure-2. Simulated air temperature curves along the collector with different mass flow rates.

Figure-3 shows the effect of mass flow rate on discharge time, which takes long range approximately (8 hours) for lower mass flow rate 0.05kg/s, and takes short time range to discharge, approximately (3.50 hr) for the higher mass flow rate 0.19kg/s.

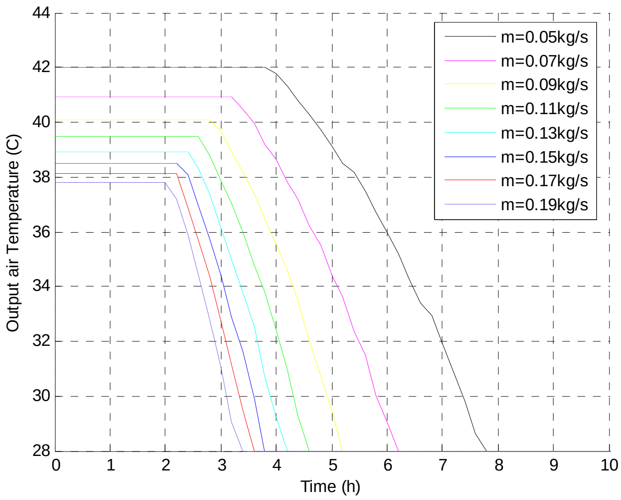

Figure-3. Air temperatures against discharge time with different mass flow rates.

Have been simulated for eight different values of mass flow rate, and reached the maximum temperature (42˚C), with mass flow rate (0.05kg/s). The PCM consists of paraffin wax with mass fraction 0.5% aluminum powder to enhance the heat transfer, the size of the aluminum powder particles has been considered as 80 µm. The freezing time for the PCM unit has been predicted for each mass flow rate, the freezing time of the PCM cylinders related inversely to the mass flow rate, and take longer time approximately (8 hours) with flow rate of 0.05 kg/s.

6. CONCLUSIONS

Output air temperatures due to a discharge process in a solar air heater integrated with a phase change material.

Notation

T Temperature $^{\circ}C$

l Cylinder length m

$D_{\circ}$ Cylinder diameter m

$R_{\circ}$ Cylinder radius m

C Specific heat $kJ/kg^{\circ}C$

$\dot{m}$ Mass flow rate kg/s

h Heat transfer coefficient $kJ/m^2 s^{\circ}C$

H Latent heat kJ/kg

K Thermal conductivity $kJ/m.s^{\circ}C$

G_{max} Superficial mass velocity $kg/s.m^2$

A_{min} Minimum free flow area m^2

Subscripts

a Air

cr Critical

s Solid PCM

l Liquid PCM

sfc Surface

REFERENCES

Farid M. M., Khudhair A. M., Razack S. A. and Al-Hallaj S. 2004. A review on phase change energy storage: materials. Energy Conversion and Management. 45: 1597.

Fatah H. E. S. 1994 Thermal performance of a simple design solar air heater with built-in thermal energy storage system. Energy Conversion and Management. 36: 989.

Mettawee Eman-Bellah S. and Assassa Ghazy M.R. 2007. Thermal conductivity enhancement in a latent heat storage system. Solar Energy. 81: 839.

Hed G. and Bellander R. 2006. Mathematical modeling of PCM air heat exchanger. Energy and Buildings. 38: 82-89.

Choudhury C., Chauhan P. M. and Garg H. P. 1995. Design curves for conventional solar air heaters. Renewable Energy. 6: 739-749.

Enibe S.O. 2002. Thermal analysis of a natural circulation solar air heater with phase change material energy storage. Renewable Energy. 27(28): 2269-2299.

Jurinak J. J. and Abdel-Khalik S. I. 1978. Properties optimization for phase-change energy storage in air-based solar heating systems. Solar Energy. 21: 377-383.

Jurinak J. J. and Abdel-Khalik S. I. 1979. Sizing phase-change energy storage units for air-based solar heating systems. Solar Energy. 22: 355-359.

Lacroix M. 1993. Study of the heat transfer behaviour of a latent heat thermal energy unit with a platened tube. Int. J. Heat Mass Transfer. 36: 2083-2092.

Marín *et al*. 2005. Improvement of a thermal energy storage using plates with paraffin-graphite composite. International Journal of Heat and Mass Transfer. 48: 2561-2570.

Morrison D. J. and Abdel-Khalik S. I. 1978. Effects of phase-change energy storage on the performance of air-based and liquid-based solar heating systems. Solar Energy. 20: 57-67.

Shatikian V., Ziskind G. and Letan R. 2008. Numerical investigation of a PCM-based heat sink with internal fins: constant heat flux. International Journal of Heat and Mass Transfer. 51: 1488-1493.

Solomon A. 1981. Some of approximations of use in predicting the behavior of a PCM cylinder array. Letters in Heat and Mass Transfer. 8: 237-246.

Veraj R., Seeniraj R.V., Hafner B., Faber C. and Schwarzer K. 1997. Experimental analysis and numerical modeling of inward solidification on a platened vertical tube for a latent heat storage unit. Solar Energy. 60: 281-290.