Performance Evaluation of Latent Heat Thermal Storage Unit by integrating it with Flat Plate type Solar Air Heater

Jatinkumar Patel, Dhyey Shukla, Anurag Mudgal, Vivek Patel and Harshil Raval
Pandit Deendayal Petroleum University, Gujarat, INDIA
jrpmech@gmail.com

Abstract. Renewable energies are sustainable and expected to play the significant role for pollution-free energy supply soon. Most traditional renewable energies are solar energy, wind energy, bioenergy, geothermal energy, tidal energy, and hydro-energy. Moreover, solar energy is characterized by their intermittent nature, as it is not available all the time. Another characteristic of these types of energy source is strong fluctuations (on the day), i.e., strong variations of available energy. This intermittent and fluctuation problem can be resolved by energy storage. This paper presents the performance studies on a forced convection solar air heater integrated with the latent-heat type thermal energy storage. The thermal energy storage is designed to maintain 50°C to 55°C temperature during sunshine hours and off sunshine hours especially for food processing. The experimental studies were carried out in the month of summer 2018. The average percentage of the energy recovered is found to be 44% during the trials. There is a 6°C to 9°C temperature difference between thermal energy storage outlet and ambient air was invariably observed for 6 hours after adequate sunshine hours which is noticeable. Further, the maximum temperature of flat plate type air heater was not increased beyond 70 °C while the maximum outlet temperature from thermal energy storage system was observed 56°C during the entire day during the experiments. It shows no overheating of the system and assures outlet air in the required temperature range for food processing. This system is most useful with the solar dryer which can be used to dry fruits, vegetables, and fishes. This system can also be customized for any particular food item too.

Keywords: Solar air heater, flat plate collector, thermal storage, phase change material

1. Introduction
The conversion of solar energy into thermal heat using flat plate collector is the easiest and most effective way. The solar air heater is the simplest technology amongst the other solar collector options. However, the fluctuations and intermittency of sun radiation energy raised the necessity of thermal storage in solar air heaters. Thermal energy can be stored in sensible heat form or latent heat form of mix of these all (D. K. Rabha and P. Muthukumar, 2017). Salwa Bouadila et al. 2014 proposed an innovative solar air heater with a latent heat storage system using PCM spherical capsules. The experimental outcome was used to examine the performance of the system. The daily energy efficiency variation was in the range of 32% to 45%. Yan-hua Diao et al. 2017; have developed a new type of solar air heater with PCM heat storage. Flat micro-heat pipe arrays were used as a core heat transfer element in thermal storage unit. They have concluded that high volume flow rate of air improved the thermal
efficiency and reduced the charging discharging time. It was found steady outlet temperature during discharging period at the volume flow rate of air as 60 m³/h. The cumulative heat transfer during discharging was found between 4210 and 4300 kJ. B. Kanimozhi et al., 2017; have evaluated the characteristics of charging- discharging processes of fabricated thermal energy storage system using latent heat storage materials. The storage and release of heat were found more for paraffin wax as a latent heat storage material. Rupali. M. Patil et al., 2017 have checked the feasibility of storing solar energy in Phase Change Materials (PCMs) using heat pipes and copper pipes utilizing the energy to heat water for domestic purposes during low sunshine hours. They observed that the heat pipes could be selected as a better thermal conductor. The present work deals with latent heat storage in solar air heating. The experimental analysis of solar air heater integrated with latent heat thermal storage is presented in this paper for the location of the western part of India.

2. System description

The main elements of the present solar air heating system are blower, flat plate solar collector and latent heat storage unit. Figs. 1(a) and (b) show the schematic diagram and pictorial view of the proposed system respectively. The solar air heater was of 2 m² area made up of a corrugated type absorber plate. The solar air heater was tilted at 15° due south at the local latitude of 23.2° N, Gandhinagar, India. The shell and tube type heat exchanger was used as latent heat storage in which shell contained PCM while tubes carried air. Paraffin wax was used as the latent heat storage material with phase change temperature in the range of 50-55 °C. During the peak sunshine hours, the thermal heat was stored and it released during the period when no enough solar radiation available for further heating. An air blower of 0.5 HP capacity was installed at the inlet of the solar air heater. PT-100 type temperature sensors with accuracy ± 0.2°C and a pyranometer [Make: Hukseflux; Model: SR20-D1; Non - linearity: <1% (up to 1500 W/m²)] were connected to a data logger (Thermo Fisher – DT80) to record the temperature of air at various locations of the heating system and the solar radiation intensity, respectively. An orifice meter was installed at the inlet of the air heater for air flow rate measurement.

The solar air heating system with storage has experimented in April 2018 in the Western region of India. The heating test was started from 10:30 am and stopped at 9:30 pm. The temperatures at the various locations of the solar air heating system as shown in Fig. 1 (a), were logged at every 10 minutes time interval. The solar radiation sensor was kept on the plane of the solar air heater to measure the global radiation on the tilted surface. It was also logged at every 10 minutes time interval. The air flow rate was kept constant during the entire experiment.

3. Energy analysis

The energy analysis of the different parts of the heating system was carried out using the general mass and energy conservation equations. Experimental results were considered to accomplish the energy analyses. The temperature of the air at different locations, air flow rate and energy inputs and outputs of the heating system; are the primary data requirements for the energy analyses. The solar and the electrical energy are the energy inputs of the heating system. The energy outputs of the heating system are the heat losses from the solar air heaters, heat losses at different sections of the connecting ducts and heat losses from the energy storage. The steady flow is the assumption in the energy analysis.

The steady flow general mass and energy conservation equations are revealed as follows (Cengel and Boles, 2008).

\[ \sum m_{in,a} = \sum m_{out,a} \]  \hspace{1cm} (1)

\[ \dot{Q} - W = \sum m_{out,a} \left( h_{out,a} + \frac{v_{out,a}^2}{2} + g z_{out,a} \right) - \sum m_{in,a} \left( h_{in,a} + \frac{v_{in,a}^2}{2} + g z_{in,a} \right) \]  \hspace{1cm} (2)
Figure 1: (a) schematic layout of the solar air heater, (b) pictorial view of the solar air heating system

In this heating system, there is a negligible effects of the kinetic and the potential energy and hence are neglected.

3.1. Energy analysis of the solar air heater

The mass and energy conservation equations for the solar air heater can be conveyed by Eqs. (3) and (4), respectively.

\[
\dot{m}_{in,a} = \dot{m}_{out,a} = \dot{m}_a \\
\dot{Q}_{in,SAH} - \dot{Q}_{loss,SAH} = \dot{m}_a c_p (T_{out,a} - T_{in,a})
\]

Where \( \dot{Q}_{in} \) in is the incoming solar energy received by the absorber plate of air heater, and it is given by Eq. (5)
The instantaneous efficiency of the solar air heater is defined as the useful heat gain to the solar radiation incident on tilted absorber surface. Therefore, it is expressed by Eq. (6) for solar air heater.

\[ \eta_{SAH} = \frac{\dot{m}_a c_{p,a} (T_{out,a} - T_{in,a})}{\alpha T_{A_{ab}}} \] (6)

The absorptivity \( (\alpha) \) of the absorber plate and the transmissivity \( (\tau) \) of glass cover system are taken as 0.95 and 0.85 respectively as reported in the literature (Duffie and Beckman, 2013). The temperature at the inlet of solar air heater is assumed to be the ambient air temperature,

\[ T_{in,a} = T_{amp} \] (7)

3.2. Energy analysis of the thermal energy storage

The rate of heat input to the storage during the charging process is expressed by Eq. (8).

\[ \dot{Q}_{ch} = \dot{m}_a c_{p,a} (T_{in,st} - T_{out,st}) \] (8)

Then net heat input to the storage during the charging period is given by Eq. (9)

\[ Q_{ch} = \int_0^{t_{ch}} \dot{Q}_{ch} dt \] (9)

Similarly, the rate of heat and net heat retrieved from the storage during the discharging period can be calculated from Eqs. (10) and (11).

\[ \dot{Q}_{dich} = \dot{m}_a c_{p,a} (T_{out,dich} - T_{in,dich}) \] (10)

\[ Q_{dich} = \int_0^{t_{dich}} \dot{Q}_{dich} dt \] (11)

The energy efficiency of the storage in one charging-discharging cycle is defined as the ratio of the net heat retrieved to the net heat input. It is expressed by the following equation.

\[ \eta_{st} = \frac{Q_{dich}}{Q_{ch}} \] (12)

4. Results and discussion

The air heating experiment was conducted in the month of April 2018. The test was performed for 11 h from 10:30 h to 21:30 h. The changes in the absorber plate temperature, phase change material temperature, ambient temperature and temperature across the latent heat storage during the test are shown in Fig. 2. The air temperature was found as 42 °C at the exit of storage unit even at 10:30 pm. Thermal energy storage system is the main heart of this experimental setup. The results of the temperatures of the inlet and outlet thermal energy storage system during whole day is compared in the Fig. 3. The maximum inlet temperature is reached at 70°C in thermal energy storage system while the maximum outlet temperature was observed 56°C which shows that this thermal energy storage system stores heat energy and it also giving the required temperature range at the outlet. It prevents overheating too. The normally drying temperature range of the solar air dryer is about 40°C to 60°C. Thus, this thermal energy system is also useful to maintain the require temperature range. Here 44°C temperature at thermal energy storage outlet was observed at 22:00h time which is in favorable range of drying temperature while ambient temperature was observed 35°C at the same time.
Figure 2. Variations in the inlet and outlet air temperatures of the solar air heater with time

Figure 3. Comparison of heat given by the solar radiation and heat gained by the solar air heater

The variations in the solar energy falling on and received by the solar air heater is shown in Fig. 3. Thermal energy storage system absorbs heat during sunshine hours it includes sensible heat and latent heat gain which is known as charging process. Thermal energy storage releases heat after the sunshine hours which is known as discharging process of phase change material. During discharging process maximum 9°C temperature difference was observed from inlet and outlet of thermal energy storage system which is notable, while during charging process 16°C difference was observed from inlet and outlet of thermal energy storage system. Average heat input and heat recovered during charging and
discharging process was observed as shown in the Fig. 4. The overall energy efficiency of the storage is defined as the ratio of the net heat recovered to the net heat supplied which is found to be 44.33%.

![Energy released during the discharging process](image)

**Figure 4.** Energy released during the discharging process

5. Conclusion

The performance evaluation of latent heat thermal storage unit by integrating it with flat plate type solar air heater is reported in this paper. The percentage of the energy retrieved from storage is found to be 44.33% during the experiment. There is a 6°C to 9°C temperature difference constantly observed at thermal energy storage outlet up to 22:00 h night time. It is notable temperature difference. The maximum inlet temperature is reached at 70°C in thermal energy storage system while the maximum outlet temperature was observed 56°C during whole day which shows that, this system prevents overheating and assures outlet in the required temperature range. This system is most useful with the solar air dryer which is used to dry fruits, vegetables and fishes. This system can be also customized for the any particular food item too. The running cost of this system is very less. It requires just 2 to 3 units of electricity to run this system for 12 hours.

6. References

[1]. B. Kanimozhi, K. Harish, B. S. Tarun, P. S. Sainath Reddy, and P. S. Sujeeth, “Charging and Discharging Processes of Thermal Energy Storage System Using Phase change materials,’’ In *IOP Conference Series: Materials Science and Engineering* (Vol. 197, No. 1, p. 012040). IOP Publishing.

[2]. Yunus A. Çengel. Thermodynamics: An engineering approach. McGraw-Hill Higher Education; 2007.

[3]. Duffie JA, Beckman WA. Solar engineering of thermal processes. John Wiley & Sons; 2013 Apr 15.

[4]. D. K. Rabha and P. Muthukumar, “Performance studies on a forced convection solar dryer integrated with a paraffin wax–based latent heat storage system,’’ *Solar Energy*, vol. 149, pp. 214–226, 2017.
[5]. R. M. Patil and C. Ladekar, “Experimental Investigation for Enhancement of Latent Heat Storage using Heat pipes in Comparison with Copper Pipes,” *International Refereed Journal of Engineering and Science*, vol. 3, no. 9, pp. 44–52, 2014.

[6]. S. Bouadila, M. Lazaar, S. Skouri, S. Kooli, and A. Farhat, “Energy and exergy analysis of a new solar air heater with latent storage energy,” *International Journal of Hydrogen Energy*, vol. 39, no. 27, pp. 15266–15274, 2014.

[7]. T. Yue Wang, Y. Hua Diao, T. Ting Zhu, Y. Hua Zhao, J. Liu, and X. Qian Wei, “Thermal performance of solar air collection-storage system with phase change material based on flat micro-heat pipe arrays,” *Energy Conversion and Management*, vol. 142, pp. 230–243, 2017.