International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015) pp 43818-43821

Thermal Energy Storage Capacity of Composite Solid Desiccant Combined with Paraffin Wax for Solar Drying Applications

R.Mani

Assistant Professor, Department of Mechanical Engineering, Vidyaa Vikas College of Engineering and Technology, Namakkal– 637 214, Tamilnadu, India, maniskpcpri@gmail.com

V.Shanmugam

Professor and Dean, Centre for Research in Energy Systems, Mahendra Engineering College (Autonomous) Namakkal– 637 503, Tamilnadu, India,
**Corresponding author E-mail: maniskpcpri@gmail.com ph: +91 9751952524*

Abstract
Thermal energy storage systems have become most essential in case of solar thermal applications in order to supply the energy during cloudy and off sunshine hours. In this study, the thermal energy storage and recovery capacity of solid desiccant consisting of 60% bentonite, 10% calcium chloride, 20% vermiculite and 10% cement on dry weight basis combined with paraffin wax latent heat storage medium are studied. The ratios for volume percentage of solid desiccant and paraffin are 90: 10, 80: 20 and 70: 30. The paraffin wax with melting point of about 61.6 ^{O} C and latent heat of fusion 253 kJ/kg is filled inside the hollow cylindrical solid desiccant mould. An experiment is conducted at air mass flow rate of 0.01, 0.02, and 0.03 kg/m^{2}s with temperatures of 40, 50 and 60^{O}C. The heat storage and retrieval capacity of 80% solid desiccant with 20% paraffin wax at 50^{o}C and 0.02kg/m^{2}s show the better results which are suitable for solar drying.

Keywords: Solid desiccant, Paraffin, Thermal storage, Phase change material, solar drying.

Introduction and literature
Thermal energy storage becomes imperative particularly for solar energy applications due to the intermittent and unpredictable nature of solar energy. Energy storage is therefore essential to any system that depends largely on solar energy. It adjusts temporal mismatches between the load and the intermittent or variable energy source, thereby improving the system operability and utility. Solar energy is the primary source of energy among renewable energy resources which can be harnessed for diversified applications such as water and space heating, water desalination, agricultural food crops drying and electricity generation. Sporadic and inconsistent nature of solar energy makes it incongruous for many solar thermal applications that require constant energy delivery. This necessitates the incorporation of an efficient thermal energy storage system with a solar thermal device that stores the collected thermal energy during sunshine hours and delivers energy during non-solar hours. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists. Energy storage not only reduces the mismatch between supply and demand, but also improves the performance and reliability of energy systems and plays an important role in conserving the energy [1].
It also leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. In spite of various thermal energy storage methods, latent heat storage is the most attractive one due to its high storage density and small temperature variation from storage to retrieval. In a latent heat storage system, energy is stored by phase change, solid–solid, liquid–solid or gas–liquid of the storage medium. Storage systems based on phase change materials with solid-liquid transition are considered to be an efficient alternative to sensible thermal storage systems. From an energy efficiency point of view, phase change material (PCM) storage systems have the advantage that they operate with small temperature differences between charging and discharging. Furthermore, these storages have high energy densities when compared to sensible heat storages [2]. Paraffin is an advantageous phase change material since it is readily available in the market and comparatively less expensive than some salt hydrates. Recently, several works are being carried out in order to study the thermal characteristics of paraffin during solidification and melting processes. These studies show that commercial-grade paraffin wax and other pure paraffin have stable properties after 1000–2000 cycles [3]. A wide range of PCMs have been explored by different researchers for energy storage, including salt hydrates and their mixtures, paraffin compounds, non-paraffin and fatty acids. The choice of PCM is dictated by the temperature range of its application. Among various PCMs applied in low thermal energy systems like solar heating system, technical grade paraffin wax has been recently used in a wide range [4]. Paraffin wax is considered to be the most prospective PCM between several materials, because of some of its desirable characteristics. Paraffin wax has high latent heat of fusion, limited super cooling and low vapour pressure in the melt. Also, it is chemically stable and can be 100% recyclable. Devahastin and Pitaksuriyarat [5] investigated the feasibility of using latent heat storage with paraffin wax as a phase change material to store excess solar energy during drying and release, when the energy availability is inadequate or not available. The effect on drying kinetics of a food product (sweet potato) was explored. In the latent heat storage

technology, many researches are underway in latent thermal energy storage materials, including phase change materials (PCMs) based on solid–liquid or solid–solid transition and adsorbents based on hygroscopic action.

In recent years, solid sorption technologies have been developed on account of being friendly to environment. Latent heat storage based on sorption/desorption of water on porous materials appears to be suitable for the application of low grade thermal energy storage systems. Recently, composite sorbents have been prepared by impregnating hygroscopic salt inside a porous adsorbent matrix to improve the specific water sorption capacity. The new composite sorbents have been developed for various applications including gas drying, fresh water production from the atmosphere, ice making on fishing boats, sorption refrigeration as well as thermal energy storage from low grade heat sources [6]. The drying potential in a regenerated solid desiccant represents one of the most promising mechanisms of thermal storage for the purpose of drying. Many researches have been carried out using different desiccant materials for various applications. The desiccant materials reported are silica gel, molecular sieve, synthetic zeolite, activated alumina, composite materials, Liquid and polymer desiccants, Bio desiccants and activated carbons, Montmorillonite and bentonites clay. Several advantages of using desiccant dryer have been discussed by Misha et al. [7], which include continuous drying even during off-sunshine hours, which would reduce drying time due to hot and dry air, drying that is more uniform, and increased product quality especially for heat sensitive products. The dryer system will be more cost effective when solar energy is used to regenerate the desiccant materials. Thoruwa et al [8] developed a low-cost solar regenerative solid clay–$CaCl_2$ based desiccant to continue the drying at nighttime. The moisture sorption characteristics of solid desiccant obtained from the comparative tests showed that bentonite-$CaCl_2$ (type1-60% bentonite, 10% $CaCl_2$, 20% vermiculite, and 10% cement) desiccant achieved the maximum moisture sorption of 45% (dwb). The experiments showed that the fabricated desiccants have the potential to become a competitive alternative to be used in crop drying and agricultural air dehumidification applications in tropical countries. Shanmugam and Natarajan [9, 10] designed and fabricated an indirect forced convection and desiccant integrated solar dryer to investigate its performance under the hot and humid climatic conditions of Chennai, India. The system consists of a flat plate solar air collector, drying chamber and a desiccant unit. The desiccant unit was designed to hold 75 kg of $CaCl_2$-based solid desiccant consisting of 60% bentonite, 10% calcium chloride, 20% vermiculite and 10% cement. The desiccant supported the drying process even in the off sunshine hours with uniform drying and good quality when compared to solar drying. The desiccant material used was stable even after continuous operation for more than a year. The above review shows that integrating thermal storage system in the solar system offers more continued drying process during the cloudy and off sunshine hours. Combining phase change material with $CaCl_2$ based solid desiccant for solar drying application has not been reported. This paper deals with the study of charging and discharging of thermal character of the solid desiccant combined with different volume percentage of paraffin wax for solar drying applications.

Experimental setup and Procedure

Based on the research work of Thoruwa et al (2000), a low cost, solar regenerative and $CaCl_2$ based solid desiccant consisting of 60% bentonite, 10% $CaCl_2$, 20% Vermiculite and 10% cement on dry mass basis was prepared and used in this work. Care was taken to prevent the damage in the size of the vermiculite during mixing and moulding. The prepared mixture was added with adequate water and was moulded in the shape of hollow cylinders. Uniform pressure was applied during the mould preparation in order to maintain uniform porosity and density. These desiccant moulds were processed in a vacuum furnace at a temperature of 50°C for 24 h and dried at 200°C for the next 24 h. The dimension of the desiccant mould is 100mm in external diameter and 125 mm in length. The bulk density of the mould is 595 kg/m^3 and Desiccant porosity (volumetric) is 0.65. Hollow moulds with an internal diameter of 32mm, 45mm and 55mm were prepared to accommodate the paraffin wax with volume percentage of 10, 20 and 30 respectively. The type-II paraffin wax with melting point of about 61.6°C and latent heat of fusion 253 kJ/kg was used as phase change material. In order to avoid the wax blocking the pores of the desiccant mould and to act as a thermal conductor, a copper mesh with a size of 300 micron was used. The paraffin wax was poured inside the hollow portion of the composite desiccant mould. A small volume gap is provided for the thermal expansion of the paraffin wax when it is subjected to heating. Both the sides of the hollow portion were sealed to avoid leakage of paraffin wax.

Fig.1. Photographic view of experimental setup

The schematic of the setup used in this study is shown in Fig.1. The experimental setup consists of heating chamber, blower, heater and temperature controllers. The heating chamber was fabricated using mild steel sheet of 1mm thickness. The dimensions of the heating chamber were $0.5\times0.3\times0.3$ m^3 and all the sides were insulated with 30 mm polystyrene board. The base of the heating chamber which acts as a tray to hold desiccants was made up of steel wire mesh. The experiment was conducted by varying the mass flow rates of air from 0.01 to 0.03kg/m^{2}s at different temperature levels of 40, 50 and 60 ^{o} C. The hot air was delivered constantly at a particular mass flow rate to the desiccant chamber. 0.850kW electrical heater was used to heat the ambient air and the desired temperature of the hot air was maintained by the temperature controller. An electrical blower of 0.65kW capacity was used to force the air through the desiccant chamber. Thermostat was used to control the heater input to maintain the uniform air temperature inside the desiccant chamber during the process. Copper constantan thermocouples were used to measure the temperature at different locations and were connected to a multi-channel temperature scanner with a sensitivity of ± 0.1^{o}C for continuous monitoring of data.

Fig.2. Picture of solid desiccant mould

The temperature was recorded at 60 minutes interval. Air was passed through the bottom of the desiccant chamber with the diverged inlet, to assist uniformly distributed air flow inside the desiccant chamber. All the experiments were carried out in a conditioned room, where the ambient temperature was about 30^{o}C. The experiments were repeated at least two to three times with similar results. To prevent any heat loss to the surrounding, the entire system was covered using 50 mm thick fiberglass insulation.

Experimental results and discussion

Experiments were conducted to determine the thermal storage and discharge behaviors of the solid desiccant mould alone and with three different volume percentage of paraffin wax. Fig.3 shows the variation of the solid desiccant temperature as a function of time for the mass velocities of 0.01 to 0.03 kg/m^2 s and temperature levels of 40^{o}C, 50^{o}C and 60^{o}C. The maximum temperature level at 0.01 kg/m^2 s and 40^{o}C reaches to 39.5^{o}C in a period of 6 hours.

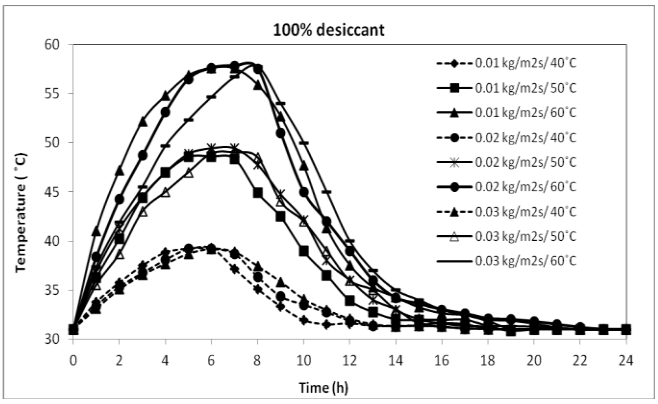

Fig.3. Variation of temperature profile of 100% solid desiccant with time for different mass flow rates and temperatures

Almost similar trend is found in other mass flow rates with other two temperature levels. The discharging happens rapidly within 6 hours at 40^{o}C for all the mass flow rates. This may be due to longer duration of air interaction with the desiccant. The maximum temperature level at 0.01kg/m^{2}s reaches to a maximum value for all the inlet temperature. The higher temperature value of 39^{o}C, 49.5^{o}C and 59^{o}C reaches in 4, 5.5 and 6 hours respectively at the given inlet temperature. Typically for the other flow rates at various temperatures, the maximum temperature reaches in about 6 hours and discharging time is less than 8 hours. This shows that the desiccant can supply heat energy for only a partial time which is not sufficient for solar applications. Increasing the volume of storage materials for small quantity of drying may support during off load period and it will occupy more volume of desiccant and space.

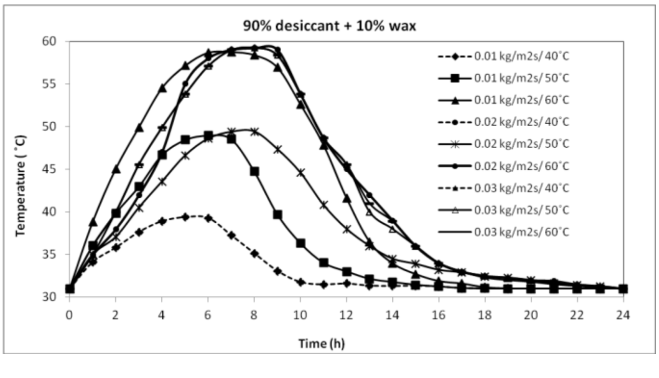

Fig.4. Variation of temperature profile of 90% solid desiccant + 10% paraffin wax on volume basis with time for different mass flow rates and temperatures

ig.4 shows the charging and discharging profile of the 90%desiccant and 10% paraffin wax with respect to time at 0.01 to 0.03kg/m^{2}s for different temperature level. It is seen from the graph that the time taken for reaching the maximum temperature level at 40^{o}C is about 5 hours which is an hour higher than that of the previous case, but the discharging duration is almost same. Similarly for other two temperature levels the charging period is about 6 and 6.5 hours respectively and discharging time is less than 10 hours.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015) pp 43818-43821

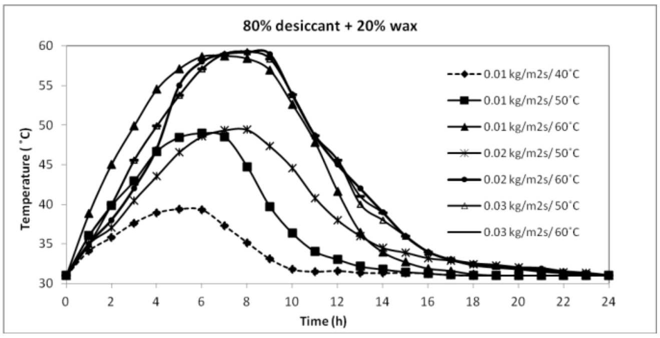

Fig.5. Variation of temperature profile of 80% solid desiccant + 20% paraffin wax on volume basis with time for different mass flow rates and temperatures

From Fig.5 it can be observed that the charging and discharging time increase for all temperature level when compared to the mass flow rate of 0.01 kg/m^{2}s and more discharging time is evident at 50^{o}C with 12 hours. The longer discharging time is due to the thermal energy release of the paraffin wax. The temperature level at 40^{o}C in all the mass flow rates does not seem to make much difference and it is not taken in to consideration.

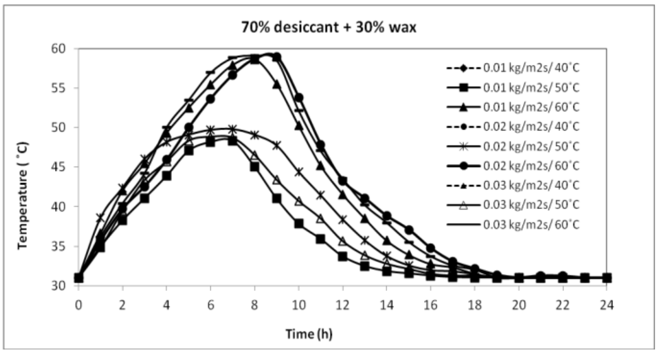

Fig.6. Variation of temperature profile of 70% solid desiccant + 30% paraffin wax on volume basis with time for different mass flow rates and temperatures

The heat storage and release at 50^{o}C and 60^{o}C for three mass flow rates with 70% desiccant and 30% paraffin wax is shown in Fig.6. It is observed that the storage time increases with increase in time for all the mass flow rates and the charging takes about 6hours for 50^{o}C and 8 hours for 60^{o}C respectively. This may be due to the little higher volume of the paraffin wax and the release profile shows almost the same trend as that of 20% paraffin wax.

Conclusion

The thermal storage and release characteristic of solid desiccant combined with paraffin wax was investigated experimentally. The solid desiccant with 10%, 20% and 30% paraffin wax on percentage volume basis is tested with varied temperature and mass flow rates. Based on the experiment the following conclusions were drawn:

- The solid desiccant alone cannot support the thermal energy for longer duration when it is integrated with solar drying.
- 100% solid desiccant also has the potential to store release thermal energy. However the presence of phase change material with desiccant is shown to be better in terms of storage and release of heat energy than that of 100% solid desiccant.

The charging and discharging temperature at 0.02 kg/m^{2}s with 5^{o}C for 80% desiccant and 20% paraffin wax reveal more energy release for almost 12 hours that suits well for solar drying applications during off sunshine hours.

References

[1] Kousksou, T., Jamil, A., El Rhafiki, T., and Zeraouli, Y., 2012, "Paraffin wax mixtures as phase change materials", Solar Energy Materials and Solar Cells., 94(12), pp. 2158-2165.

[2] Mulan Mu., Basheer, P.A.M., Wei Sha., Yun Bai., and Tony McNally., 2016, "Shape stabilised phase change materials based on a high melt viscosity HDPE and paraffin waxes", Applied Energy., 162(15), pp. 68-82.

[3] Mete Avci., and Yusuf Yazici, M., 2013, "Experimental study of thermal energy storage characteristics of a paraffin in a horizontal tube-in-shell storage unit", Energy Conversion and Management., 73, pp. 271-277.

[4] Sharma, A., Tyagi, VV., Chen, CR., and Buddhi, D., 2009, "Review on thermal energy storage with phase change materials and applications", Renewable and Sustainable Energy Review., 13(2), pp. 318–45.

[5] Sakamon Devahastin., and Saovakhon Pitaksuriyarat., 2006, "Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product", Applied Thermal Engineering, 26(15), pp. 1705–1713.

[6] Dongsheng Zhu., Huijun Wu., and Shengwei Wang., 2006, "Experimental study on composite silica gel supported $CaCl_2$ sorbent for low grade heat storage", International Journal of Thermal Sciences, 45(8), pp. 804-813.

[7] Misha, S., Mat, S., Ruslan, M.H., and Sopian, K., 2012, "Review of solid/liquid desiccant in the drying applications and its regeneration methods", Renewable and Sustainable Energy Reviews, 16(7), pp. 4686-4707.

[8] Thoruwa, T.F.N., Johnstone, C.M., Grant, A.D., and J.E Smith, JE., "Novel, low cost CaCl2 based desiccants for solar crop drying applications", Renewable Energy, 19(4), pp. 513-520.

[9] Shanmugam, V., and Natarajan, E., 2007, "Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror", Applied Thermal Engineering, 27(9), pp. 1543-1551.

[10] Shanmugam, V., and Natarajan, E., 2006, "Experimental investigation of forced convection and desiccant integrated solar dryer", Renewable Energy, 31(8), pp. 1239-1251.