A Review of Solar Air Dryer Based on the Phase Change Material as Thermal Storage

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Abstract - Energy is a most important requirement of our living life and it plays a crucial part in human development, but today's demand for energy increases tremendously and it makes difficulties to provide the necessary amount of energy in the different field of applications. Energy storage medium helps to conserve energy and improve the performance of a large number of energy systems. The performance of any solar application is bounded by interruption at night as well as low isolation condition. Research has been conducted on the different phase change materials (PCM) as thermal storage in the application of solar air dryer to enhance its performance. Integration of PCM can play a major role to maintain a constant temperature of the heating air and maximize working hours of the system. PCM work as latent heat storage system, the heat gets absorbed or released when PCM changes its phase from solid to liquid and vice versa. The paper summarized various commonly used PCM thermal storage mediums and how that can be improving the thermal efficiency of solar heating systems.

Keywords —Air Dryer, Phase Change Material, Solar Energy, Thermal Storage

I. INTRODUCTION

Solar energy is the ultimate source of power that converted into thermal or electrical energy for a variety of purposes like generating electricity and various heating applications. It always plays a major role in rural areas from long times for preserving food and crops by direct sun drying. Solar energy technologies consist of solar photovoltaic cells, concentrating collectors and solar flat plate, etc. out of which flat plate collector is capable to produce hot water and hot air for further uses in the domestic and agricultural field. The product going to dry in the solar dryer while the temperature of passing air varying between 45 °C and 60 °C, which is a much suitable temperature range of drying air for many agricultural products [1].

The enhancement of solar power for air heating using the solar air collectors, it faces problem in the absence of solar radiation and that allow for the system to work only in the daytime. The storage system combined with the collector can play a crucial part to clear the supply and demand variation [2]. The thermal storage systems dominating this problem by the store energy during sun hours and that can be utilized in off sunshine hours [3]. Phase change materials able to store a large amount of heat energy in form of latent heat. Latent heat has a much higher capacity than sensible heat storage as well as requires less material to store the same amount of heat. Solar dryer integration with latent thermal storage increases the efficiency due to controlled temperature and continues operation [4].

The literature describes the studies on solar air heater/dryer with phase change material. D. K. Rabha et al. (2017) tested a forced convection solar dryer by drying 20 kg of red chilli in the drying air temperature range of 36–60 °C. The dryer was integrated with a paraffin wax-based shell and tube latent heat storage unit. The integration of heat storage was accelerating the drying process during the low-intensity solar radiation period [1]. An experimental investigation conducted by Kabeel et al. (2016) on flat and v-corrugated plate solar air heaters with built-in PCM as thermal energy storage material. It concluded that the daily efficiency of the v-corrugated solar heater using PCM was 12% higher than the corresponding ones without using the PCM [2]. Aymen El Khadraoui et al. (2017) finalize that after using the solar energy accumulator, the temperature of the drying chamber is higher than the ambient temperature by 4-16 °C, all the night. The relative humidity in the drying chamber was observed 17-34.5% lower than the ambient relative humidity, in the case of the solar dryer with PCM [5].

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Amol Wadhawan et al. (2017) carried out an experimental and CFD analysis to predict the values of pressure drop and friction factor for various mass flow rates. It revealed that an increase in the mass flow rate of air decreases the output temperature of the air. Here the lauric acid had used as a phase changing material (PCM) in a solar air heater [6]. The paraffin wax having a high melting point 70 °C is used as thermal energy storage by Ehsan Baniasadi et al. (2017). He observed that due to high-temperature selection, the rate of drying is almost constant along the drying chamber [7]. Ndukwu et al. (2017) performed an experiment with a combination of thermal energy storage. The sodium sulfate decahydrate ($Na_2SO_4.10H_2O$) and sodium chloride (NaCl) has been used as thermal energy storage for drying red chilli. The result revealed that NaCl has no positive impact on the drying process but $Na_2SO_4.10H_2O$ to be the best option for thermal storage [8]. Kabeel et al. (2017) observed that the flat plate solar air heater with PCM improve the daily efficiency by 10.8-13.6% [9]. M. Nicholas et al. (2016) designed the updraft solar dryer that induces thermo-siphoning effect which leads to a natural convectional flow of air that leads to improving efficiency [10]. S. M. Shalaby et al. (2015) presented the indirect type solar dryer for drying the nerium oleander. It concluded that 12 kg of paraffin wax as heat storage has been successfully maintaining the temperature of drying air around 50 °C for seven consecutive hours [11]. Some elements like Carbon fibers, expanded graphite, graphite foam and high thermal conductive particles doped with PCM may improve the thermal efficiency of solar energy devices [12].

The Acetamide (CH_3CONH_2) used as PCM by Prashant Kumar et al. (2015). The containers for PCM were fabricated of stainless steel which has adequate heat transfer facility. [13] Preeti Sain et al. (2013) developed the natural convection type solar dryer with latent heat storage for drying of ginger. The dryer consisted of 2 sq. m solar collector area, 0.8 m² of drying chamber and 0.0060 m³ paraffin wax thermal storage volume. The natural convection flow helps to reduce the expense of fans and motor [14]. Aiswarya.M.S et al. (2015) an evaluate the payback period of solar dryer system calculated on information of production scales, operating costs of the dryer and price of the dried products [15]. Srivastava et al. (2013) used the lauric acid as PCM to store excess solar energy for drying process and release it when the energy availability is inadequate or not available for the solar drying process [16]. Karunesh Kant et al. (2016) reviewed both sensible and latent heat storage in the field of solar drying systems and suggests some software for modeling and analysis such as Statistica, V, TRNSYS, etc. [17]. Sari Farah Dina et al. (2015) studied an effectiveness of continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans and concluded that system was more effective in term of drying time (reduces drying time nearby 45%) and specific energy consumption [18].

II. Discussion

The literature review highlighted the different points that associated with a study on solar air dryer and its reformation with various thermal storage mediums mainly for improving performance. Direct and indirect solar drying are the main methods of drying, where indirect drying have more benefits over the direct sun drying. The flat plate collectors for air heating are generally used as the purpose of drying. The thermal storage additionally designed in collector helps to increase the working hour and performance of the system. Mostly the latent heat storage is getting used in the solar application over the sensible heat storage. PCMs are the most studying and reviewed heat storage materials because of their ability to store a large amount of heat and continuity to absorb/release heat at constant temperature. It maintains the temperature of outlet air above the atmospheric temperature at low radiation and night condition.

Table1. Comparison of phase change materials [7], [19]

Properties	Organic		Inorganic	
	Paraffin wax	Non-paraffin	Hydrated salt	Metalics
1. Heat of fusion	High	High	High	Medium
2. Thermal conducti-vity	Very low	Low	High	Very high
3. Melting point (° C)	-20 to 100+	5 to 120+	0 to 100+	150 to 800+
4. Latent heat (KJ/Kg)	200 to 280	90 to 250	60 to 300	25 to 100
5. Thermal cycling	Stable	Elevated Tempera-ture cause decompo-sition	Unstable over repeated cycles	Stable
6. Weight	Medium	Medium	Light	Heavy
7. corrosive	Non-corrosive	Mildly	Corrosive	Varies

The different aspects considered for selection of PCM, mainly economically feasible and viable, the melting point of the material and should have the high latent heat of fusion. The solid phase materials are more convenient than liquid or gaseous because the large volume or pressure is

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required for storing material in their gas phase. PCM likes paraffin wax, acetamide, lauric acid, sodium sulfate decahydrate are the most utilized materials for heat storage. Also capric acid, polyethylene glycol and phenol may also be alternative storage materials. Literature shows that paraffin wax is most focused and executed thermal storage material for drying purpose. Paraffin has a large melting point selection options.

Researchers also conducted an experimental study on air dryer with rebuilding their structure for increasing heat transfer rate, increase the turbulence of air flow streams by the providing single or double pass, increase the heat transfer area by adding fins to absorber plate. PCM implement directly below or above the absorber plate as per collector type and air pass. Also, the absorber plate is directly replaced by black-coated, PCM filled container. The highly thermal conductive nanoparticles and the use of encapsulation can improve the thermal conductivity of PCMs. The mass flow rate of air also play a major role in dryer output, it decides the heat transfer rate and temperature of the output air. It outrights that combination of PCM increases the efficiency of the air dryer in term of drying time and specific energy consumption.

III. Conclusion

The study briefly describes the solar air dryer combination with latent thermal heat storage, mainly phase change materials are the best change in solar air heating system. There is no use of any conventional fuels for drying that shows the PCM based dryers be the environment-friendly. Above study highlight that paraffin was most examined material medium for energy storage, therefore here have a chance to find and utilize different phase change materials for energy storage. Solar air dryer with PCM will be ease to available and feasible to design as well as it provides more choice to select different materials based on their the favorable properties. The study shows the thermal efficiency of solar air dryer will be increased by adding a thermal storage medium, mainly by using the phase change materials.

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