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A Review on Packed Bed Storage Type of Solar Air Heaters

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Abstract

Under this study a rigorous literature review has been carried out to investigate the research progress in storage type of solar air heaters and to know the scope for future research work. The research work carried out by various investigators in storage type of solar air heaters along with their findings have been delivered and also presented in tabulated form. Finally the paper is concluded with the scope for future work.

Keywords: *Solar air heater, Heat transfer coefficient, Storage material, Latent heat, Sensible heat.*

1. Introduction

Solar energy which is an abundant, clean and safe source is an attractive substitute for conventional fuels for passive and active heating in many applications. Solar air heaters have many attractive advantages over liquid heaters regarding the problems of corrosion, boiling, freezing, salt deposits and leaks.

Solar air heaters are important in many industrial and agricultural applications, including the drying of crops and medicinal/aromatic plants, timber, natural rubber, tea and coffee products, and fodder for animals. Other possible applications include poultry egg incubation, chicken brooding, and heating livestock housing [7]. Also it has wide applications in textile and marine products, and the heating of buildings to maintain a comfortable environment, especially in the winter season.

Air heaters show, in general, two main drawbacks:

a) Relatively lower collection efficiency and
b) Limited storage capabilities

Collection efficiency can be improved by improving the heat transfer coefficient by increasing fluid turbulence near the heating surface or by increasing the heat transfer area. The heat transfer coefficient and the heat transfer area were conventionally increased by using corrugated absorbers but it has the drawback of more frictional losses due to the resistance offered to the air flow.

2. Literature Review

The consolidate report of the investigations carried out in relevance to packed bed solar air heaters is tabulated as shown in Table 1.

Jain D. presented a periodical analysis of multi-tray crop drying using an inclined multi-pass solar air heater with in-built thermal storage. The performance of multi-tray drying integrated with a solar air heater was evaluated for drying of the paddy crop. The effect of change in the tilt angle, length and breadth of a collector and mass flow rate on the temperature of crop was studied. It has been observed that the crop moisture content decreases with the drying time of the day and the thermal efficiency of the drying increases with increase in mass of the crop.

Ozturk H.H. et al. investigated experimentally energy and exergy efficiency of a packed-bed heat storage unit for greenhouse heating. In this research, solar energy was stored daily using the volcanic material with the sensible heat technique for heating the tunnel greenhouse of 120 m^2. The packed bed heat storage unit was built under the soil at the centre of the tunnel greenhouse. It was found that the net energy and exergy efficiencies in the charging periods were 39.7 and 2.03% respectively. The results showed that 18.9% of the total heating requirement of tunnel greenhouse was obtained from the heat storage unit.

Fath Hassan E.S. presented the thermal performance of a simple design solar air heater with built-in thermal energy storage system. The conventional flat plate absorber is replaced by a set of tubes filled with a thermal energy storage material. The proposed integrated system heat transfer area and heat transfer coefficient are increased and the heat loss is decreased. Based on a simple transient analysis, explicit expression for the heater absorber and glass cover temperatures, effective heat gained, outlet temperature, and the heater efficiency have been developed as a function of time. The integrated system performance curves were presented and a marked improvement in the system performance was noticed over the conventional flat plate heater system.

Table 1. Research review of packed bed storage type solar air heaters

S. N.	Authors	Research Topic	Exp / Theo	Packed / Porous Bed	Storage material	Major Applications	Type of Heat Energy storage
1	Dilip Jain	Modeling the system performance of multi-tray crop drying using an inclined multi-pass solar air heater with in-built thermal storage	Theo	Packed Bed	-----	Drying of Agricultural Products	-----
2	H. H. Ozturk et al.	Energy and Exergy Efficiency of a Packed-bed Heat Storage Unit for Greenhouse Heating	Exp	Packed Bed	Volcanic material	Heating Tunnel Green Houses	Sensible Heat
3	Hassan E. S. Fath	Thermal performance of a simple design solar air heater with built-in thermal energy storage system	Theo	Packed Bed	Sand / Wax	Agriculture, Marine, Textile	Sensible Heat / Latent Heat
4	Hassan E. S. Fath	Transient analysis of thermo-syphon solar air heater with built-in latent heat thermal energy storage system	Exp	Packed Bed	PCM-1 / PCM-2 / PCM-3 / PCM-4 (PCM Not Defined)	Drying Agricultural Product	Latent Heat
5	A. Mawire et al.	Experimental and simulated temperature distribution of an oil-pebble bed thermal energy storage system with a variable heat source	Exp & Theo	Packed Bed	Oil-Pebble Bed	Solar cookers	Sensible Heat
6	M. Hadjieva et.al	Thermo-physical properties of some paraffins applicable to thermal energy storage	Exp	Packed Bed	Paraffin-A ($C_{22}H_{41}$) Paraffin-B ($C_{23}H_{404}$) Paraffin-C ($C_{47}H_{13}$)	Drying of Agricultural Products	Latent Heat
7	S. O. Enibe	Thermal analysis of a natural circulation solar air heater with phase change material energy storage	Exp	Packed Bed	Paraffin	Drying Agricultural Product	Latent Heat
8	T. Kiatsiriroat et.al	Performance analysis of a direct-contact thermal energy storage-solidification	Exp & Theo	Packed Bed	Sodium Thiosulphate Pentahydrate	-----	Latent Heat
9	M. S. Sodha et al.	On the boundary conditions applicable in the analysis of a matrix air heater	Theo	Porous Bed (Matrix Absorber)	Copper / iron / aluminium / material coal / glass / bricks / stone (Matrix Absorber)	-----	Sensible Heat

Fath Hassan E.S. also presented thermosyphon solar air heater with built-in latent heat thermal energy storage system using various phase change materials (PCM) having different melting temperatures 'Tm' of 61^{o}C, 51 ^{o}C, 43 ^{o}C and 32 ^{o}C, and also compared the results with the system with no storage material. It was found that solar air heaters with PCM of melting temperature 51 ^{o}C and 43 ^{o}C show the best performance. His proposed air heater was simple in design and added no operational or maintenance complexities over conventional heaters.

Mawire A. et al. investigated the experimental and simulated temperature distribution of oil-pebble bed thermal energy storage (TES) system with a variable heat source. The Schumann model and the modified Schumann model for the dynamic temperature distributions in the TES system are implemented in Simulink. The Simulink results were compared with experimental results during the charging and discharging of the TES system. The Schumann simulation model was in close agreement with the experiment at lower TES temperatures during the early stages of the charging process. However, larger deviations between equipment and simulation are seen at later stages of the charging process and this is due to the heat losses that are unaccounted for. The modified Schumann model is in closer agreement with experiment at later stages of the charging process.

Hadjieva M. et. al conducted an experimental study with the aim to investigate and evaluate thermo-physical properties of technical grade paraffins appropriate for solar energy storage applications. A method for the automatic computer controlled thermal cycling has been developed. The dynamic mode of precise uniform rising and lowering of the temperature at various rates has been accomplished. Nine hundred thermal cycles have been carried out on two different mixtures of technical grade paraffin, varied by their composition.

The calculated enthalpies of three paraffin mixtures (indicated as A, B, and C with hydrocarbon formula $C_{22.2}H_{44.1}$, $C_{23.2}H_{40.4}$ and $C_{24.7}H_{51.3}$ respectively) were found to depend on their oil content and the distribution of atoms defined by chemical and gas chromatographic analysis.

Enibe S.O. presented thermal analysis of a natural circulation solar air heater with phase change material (paraffin) energy storage. The PCM is prepared in modules, with the modules equispaced across the absorber plate. Energy balance equations were developed for each major component of the heater and linked with heat and mass balance equations for the heated air flowing through the system. The predicted performance of the system was compared with the experimental data. It was observed that predicted temperatures at specific locations on the absorber plate, heat exchanger plate, glazing, and heated air agree closely with experimental data to within 10, 6, 8 and 10 ^{o}C respectively. Maximum predicted cumulative useful and overall efficiencies of the system are within the ranges 2.5-13 and 7.5-18%, respectively. The correlations of the predicted efficiencies were also presented by him.

Kiatsiriroat T. et. al investigated the performance of a direct-contact latent heat energy storage during discharging process. The storage medium used was sodium thiosulphate pentahydrate of which the melting temperature is 48 ^{o}C and the heat exchanging fluid was heat transfer oil. A lumped model analysis has been done to predict the thermal behaviour of the storage during the solidification process. It was observed that the analytical results agree well with those of the experiments.

Sodha M.S. et al. performed an analysis of a matrix air heater to study the effect of different boundary conditions on its performance. In such air heaters, the absorbing plate was made of porous material, usually painted black. The solar radiation in such constructions got gradually absorbed depending on the matrix density. The theoretical results were compared with measurements of an experiment conducted for one type of matrix solar heater.

3. Future Research Scope

It has been observed clearly that conventional flat plate solar air heater has limited storage capability due to sinusoidal varying nature of heat source. The thermal load is zero at sunrise, increasing to its maximum at noon and then dropping back to zero again at sunset. This system has therefore, the disadvantage of non-uniform thermal load during the sunny hours and zero thermal loads during the dark hours.

This drawback associated with conventional solar air heater can be considerably overcome by using thermal energy storage, so that excess thermal energy during the day can be stored and will be delivered after sunset extending its hours of operation.

From the thermal energy storage point of view, the latent heat storage has the advantage of large heat capacity at a constant temperature. But the major drawback of the latent heat storage, in general is its low charging and discharging rates, owing to the low thermal conductivity of the storage phase change material (PCM). Further in PCMs during the discharging process, a material solidifies onto the heat transfer surface thus a high thermal resistance is obtained. This fact re-opens the possibilities and scope for development of packed bed solar air heaters using sensible heat storage materials. Generally the materials that have a large change in internal energy per unit volume, minimizes the space needed to store energy. The major important properties to be considered for sensible heat storage applications are as follows.

a) Internal Energy and Heat Capacity
b) Density
c) Heat Storage Temperature
d) Storage material Cost
e) Containment and heat exchange cost
f) Thermal Conductivity
g) Vapor pressure
h) Toxicity & Corrosiveness

Table 2 gives list of some possible sensible heat storage materials with their specific heats and density values.

Table 2. Sensible heat storage materials

S. N.	Storage Material	Specific Heat (J/kg-K)	Density (m^3/kg)
1.	Granite	820	2640
2.	Lime Stone	900	2500
3.	Brick	840	1698
4.	Concrete	1130	2240
5.	Water	4190	1000
6.	Therminol (Organic Heat transfer Fluid)	2630	806

4. Discussion

In literature rock is suggested as packed bed storage medium but not much better results have been obtained. Further previously it was concluded by experts during a meeting hosted by Food and Agricultural Organization of the United Nations in Bangkok that rock heat storage was not considered viable. It has been reported by the investigators that the heat storage density and thermal conductivity of the solids is usually less than liquids. This fact strengthens the suitability of liquids as sensible heat storage medium in packed bed solar air heaters in comparison to solids.

In the process of improving the performance of packed bed solar air heaters some of the investigators either used iron filings as the filler material or used the finned tubes to improve the heat transfer. With these solutions, however the air heater loses its main characteristics, being simple in design and cheap in cost [4].

In view of future study and research to takes in solar air heaters still there is a considerable scope in the analysis of natural convection solar air heaters, with or without thermal energy storage.

5. Conclusion:

The conventional solar air heaters can only provide hot air during sunny hours due to the limited heat capacity of the system absorber. Introducing inbuilt thermal energy storage with the conventional air heaters adds no complexity to the simple conventional heater design. By using suitable thermal energy storage material, the system storage capability will be increased and the system heat loss will be reduced, due to the reduced absorber temperature, thereby increasing the overall system efficiency. In view of low charging and discharging rate of latent heat storage (PCM) type packed bed solar air heaters, the sensible heat storage type packed bed solar air heaters seems efficient. To develop a cost effective packed bed sensible heat storage type solar air heater particularly for agricultural utility in Indian scenario it is highly desired to be of natural convection mode.

Literature study further show that a considerable discrepancy between the results of theoretical considerations and experimental investigations occurs in case of convection heat transfer. In the light of all the discussed fact it is concluded that there is a considerable scope for research and development in natural convection solar air heater with packed bed sensible heat storage.

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