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A Review on Packed Bed Solar air Heating System

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Abstract: Packed beds are generally used for storage of thermal energy from solar air heaters. Packed bed is a volume of porous media obtained by packing particles of selected materials into a container. A number of studies carried out on packed bed solar air heater for their performance analysis were reported in the literature. This paper present an extensive review on the research carried out on packed beds. A considerable scope for research and development in forced convection solar air heater with packed bed sensible heat storage with double flow or double pass has been determined.

Keywords: Solar air heater, Heat transfer coefficient, Packed bed, Heat storage, Porous medium.

1. INTRODUCTION

In solar energy applications, solar air heater is the most simple and commonly used heat exchanger to convert the incoming radiations into thermal energy, which is extracted by air flowing below or above the absorbing surface. Solar air heater are the cheapest and extensively used solar energy collection device employed to deliver heated air at low to moderate temperature for space heating drying agriculture product such as fruits, seeds and vegetable and some industrial application . These air heaters have low thermal efficiency because of low convective heat transfer coefficient between the absorber plate and air leading to higher temperature of the absorber plate which results in higher heat losses to the surrounding. Several methods including the use of packing of porous material like wire screen, cross rod matrices slit and aluminums foil matrices in the duct of solar air heater have been proposed for the enhancement of the thermal performance of the solar air heater. Different factor affect the air heater efficiency such as collector dimension, type and shape of an absorber plate, glass cover inlet temperature, wind speed etc. Several designs of solar air heaters have been developed over the year in order to improve their performance. In this study, various design of solar air heaters have been considered and technical information is obtained which has been used to determine best performing design scope under economics and thermohydraulic consideration.

2. LITERATURE SURVEY

Malik Ebrahim Momin-Abdul et al [1] experimentally investigated on the effect of geometrical parameter of v- shaped rib on heat transfer and fluid flow characteristics of rectangular duct of solar air heater with absorber plate having V-shaped rib. The investigation covered a Reynold number range of 2500-18000, relative roughness height of 0.02-0.034 and angle of attack of flow of 30-90 for a fixed relative pitch of 10. Naphon Paisarn found [2] the performance and entropy generation of the double-pass flat plate solar air heater with longitudinal fins are studied numerically. The mathematical models described the heat transfer characteristics of the double-pass flat plate solar air heater derived from the conservation equations of energy. The predictions are done at air mass flow rate ranging between 0.02 and 0.1 kg/s. The effects of the inlet condition of working fluid and dimension of the solar air heater on the heat transfer characteristics, performance, and entropy generation are considered. Jaurker et al [3] experimental investigated and encompassed the Reynold number range from 3000 to 2100, relative roughness height 0.0181-0.0363, relative roughness pitch 4.5-10.0 and groove position to pitch ratio 0.3-0.7.The condition for the best performance have been determined. Correlations for Nusselt number and friction factor have been developed that predict the value within reasonable limits. Ramadan M.R.I et al found [4] the thermal performance of a double glass double pass solar air heater with packed bed above the heater absorber plate was investigated experimentally and theoretically. The effect of the mass flow rate of air and the mass and porosity of the packed bed material were also studied. The thermo hydraulic efficiency was found to increase with increasing until a typical value of 0.05kg/s beyond which the increase in η_{TH} become insignificant. They recommended to operate the system with packed bed with values of mass flow rate equal 0.05 kg /s or lowering to have a lower pressure drop across the system.

Saini R.P et al [5] investigated on the heat transfer and friction characteristics of solar air heater ducts. They reviewed on element geometries used as artificial roughness in solar air heater in order to improve the heat transfer capability of solar air heater duct. Saini R.P & Verma [6]investigated on the heat transfer coefficient between the absorber plate and air can be considerably increased by using artificial roughness on the underside of the absorber plate of as solar air heater ducts. The investigation has covered the range of Reynold number (Re) from 2000 to12000, relative roughness height (e/D) from 0.018 to 0.037 and relative pitch (P/e) from 8 to 12. Correlations for Nusselt number and friction factor has been developed for solar air heater duct provided artificial roughness geometry of investigated type. Aharwal K.R.et al[7] experimentally investigated on the duct having width to height ratio of 5.84 relative roughness pitch of 10, relative roughness height of 0.377 and angel of attack of 60.The gap width and gap position were varied in the range of 0.5-2 and 0.16667-0.667.The effect of gap position and gap width has been investigated for the range of flow Reynold number from 3000 to 18000.The maximum enhancement in Nusselt number and friction factor is observed to be 2.59 and 2.87 times of that of the smooth duct. It is found thermo- hydraulic performance parameter is found to be maximum for the relative gap width of 10 and relative gap position of 0.25.

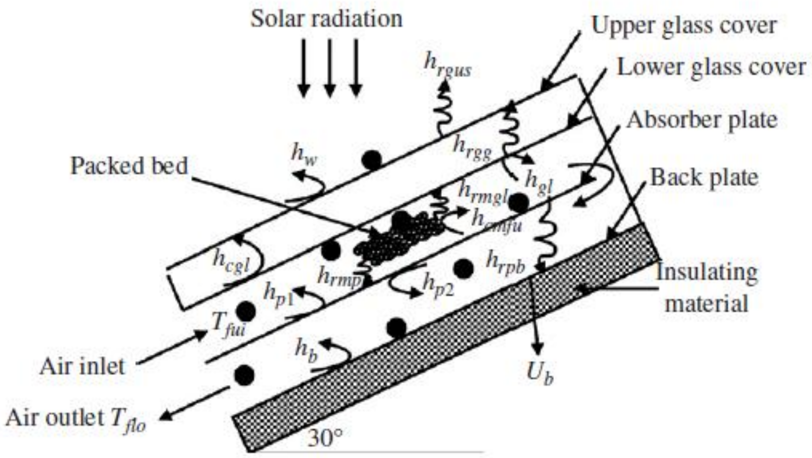

Figure 1 A schematic diagram of solar air heater used by Ramadan et al[4]

Prasad S.B et al [8]investigated on Data pertaining to heat transfer and friction characteristics were collected for air flow rate ranging from 0.0159 to 0.0347kg/s-m^{2}for eight sets of matrices with varying geometrical parameters. The thermal efficiency of a packed bed solar air heater was compared with that of a conventional solar air heater to determine the enhancement which was found to be strong function of system and operating parameter of the bed .It is utilized to develop correlation for colburn J_h factor and friction factor as function of geometrical parameters of the bed and the flow Reynolds number. Karmare S.V & Tikekar A.N. [9] experimentally investigated on thermohydraulic performance of roughened solar air heater with metal rib grits. The range of variation of system and operating parameters is investigated within the limit of (e/d)0.035-0.044,p/e15-17.5 and 1/s as 1.72 against variation of Reynolds number Re:3600-17000.The thermal efficiency (10-35%), over solar air heater with smooth collector plate. The thermal efficiency enhancement is also accompanied.

Omajaro A.P et al [10] experimentally investigated on the thermal performance of a single and double pass solar air heater with fins attached using a steel wire mesh as an absorber .The effect of air mass flow rate range between 0.012 and 0.038kg/s on the outlet temperature and thermal efficiency was studied. The bed heights were 7cm & 3cm for the lower and upper channel. The efficiency increase with increasing air mass flow rate. It is found efficiency of the double pass is found to be higher than the single pass by 7-19.4%. They found the maximum efficiency were 59.62 & 63.74% for the mass flow rate 0.038kg/s. Aldabbagh L.B.Y et al [11] the thermal performance of single and double pass solar air heaters with steel wire mesh layer are used instead of a flat absorber plate are investigated experimentally. It indicate that efficiency increase with increasing the mass flow rate for the range of the flow rate used in this work between 0.012and 0.038kg/s. for the same flow rate, the efficiency of the double pass is found to be higher than the single pass by 34-45%.The maximum efficiency obtained for the single and the double pass collector 45.93 and 83.65% respectively for the mass flow rate of 0.038kg/s.

Sebaii A.A.El et al [12] experimentally investigated the double pass flat and V- corrugated plate solar air heaters. Thermo-hydraulic efficiency of the flat and V-corrugated plate solar air heater are obtained when the mass flow rate of the flowing air is 0.02 kg/s. Khawajah El, M.F et al [13] experimentally investigated on the thermal performance of a double pass solar air heater with fins using wire mesh as an absorber. They found the maximum efficiency were 75%, 82.1%85.9% with 2, 4and 6 fins for the mass flow rate 0.042kg/s. They also found substantial enhancement in thermal efficiency of a counter flow packed bed collector. El-Sebaii A.A. et al [14] experimentally investigated on the results showed that the double pass v-corrugated plate solar air heater is 9.3–11.9% more efficient compared to the double pass-finned plate solar air heater. It was also indicated that the peak values of the thermohydraulic efficiencies of the double pass-finned and v-corrugated plate solar air heaters were obtained when the mass flow rates of the flowing air equal 0.0125 and 0.0225 kg/s, respectively. Dhiman Prashant et al [15] experimentally investigated the counter and parallel flow packed bed solar air heaters. The thermal efficiency of the counter flow packed bed solar air heater is 11-17% more compared to the parallel flow packed bed solar air heater whereas, parallel flow system achieved a 10% higher thermohydraulic efficiency when air steadily flowed at differential mass rate in its upper and lower duct compared to the counter flow system. Chamoli et al [16] investigated the thermal performance of a solar air heater can be enhanced by enhancing the rate of heat transfer. The thermal efficiency of double pass solar air heater is higher in comparison to single pass with concept involved of doubling the heat transfer area without increase in the system cost.

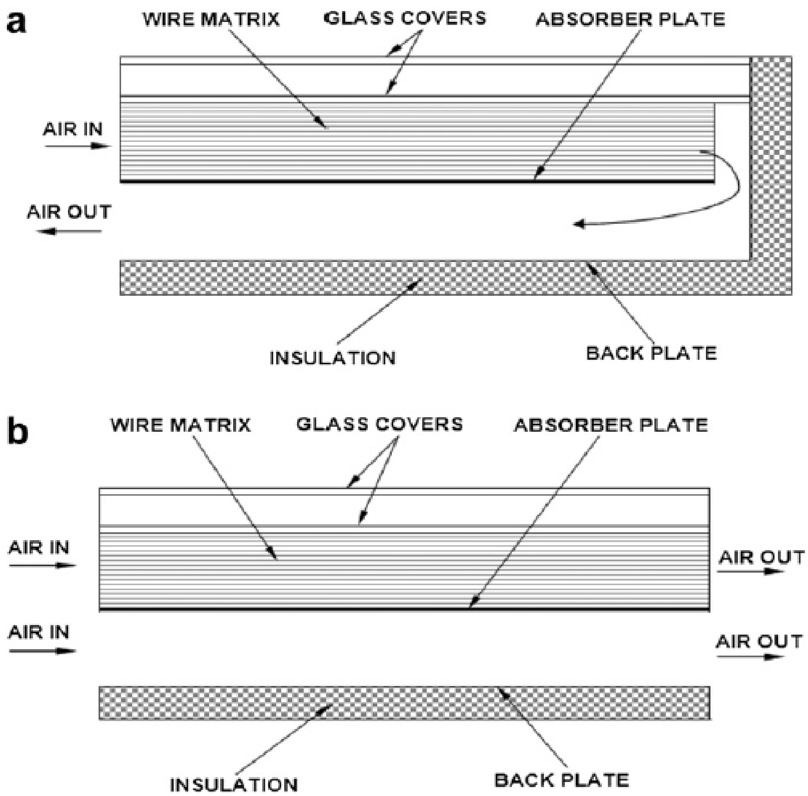

Figure 2. Schematic diagram of solar air heater used by Dhiman et al[15]

Sarviya R.M, Bhagoria J.L[17] studied the performance of packed bed solar air heater for high porosity range and for different shapes of matrices. They developed the correlations for heat transfer coefficient and friction factor for packed bed solar air heater and its comparison with conventional design. Saxena Abhishek et al [18] investigated on thermal performance of solar heater having four different configurations by operating it on natural and forced convection. The thermal behavior of the system has also been evaluated by operating it on auxiliary power by placing a halogen tube (300W) inside the inlet and outlet ducts. Because of using halogen lights their system was feasible to perform in night or bad climatic conditions. The thermal performance of all new configurations was found better in comparison of conventional solar air heater on both natural and forced convection. Dong –chii ho et al [19] experimentally investigated the performance of the new design of wire mesh packed double flow solar air heater with attaching wire mesh under external recycle . The wire mesh packed double flow device introduced in their study was proposed for aiming to strengthen the convective heat transfer coefficient for air flowing through the wire mesh packed bed and to determine the optimal design on an economic consideration in term of both heat transfer efficiency improvement and power consumption increment. Yadav Anil Singh & Bhagoria J.L [20] investigated to analyze the two –dimensional in compressible Navier -Stokes flow through the artificially roughened solar air heater for relevant Reynold number range from 3800 to 18000. Twelve different configuration of equilateral triangular sectioned rib (P/e=7.14-35.71 and e/d= 0.021-0.042) have been used as roughness element. The commercial finite volume based CFD code ANSYS FLUENT is used to simulate turbulent air flow through artificially roughened solar air heater.

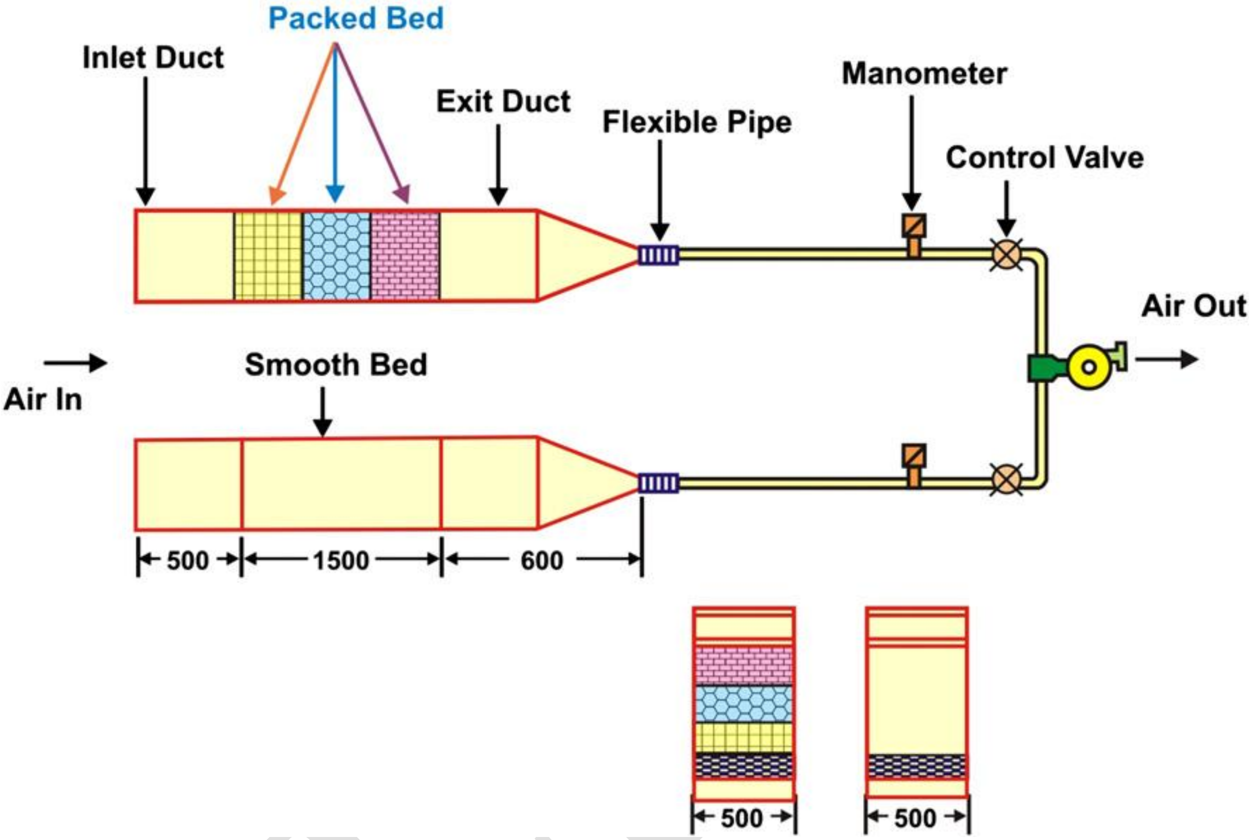

Figure 3. Experimental set up for the analysis of packed bed solar air heater by Lalji etal.[17]

Dhiman Prashant &Singh Satyender [21] analytically predicted the thermal and thermohydraulic efficiencies of two different designs of double pass packed bed solar air heater under external recycle. They predicted that Model A with the single air pass through the first channel as well as the recycle of the air exiting from the second channel through the third channel can enhance the heat transfer rate more as compared to Model B. The wire mesh screen as an absorbing media above the absorber plate is used in both of the solar air heater models. The recycle ratio and the mass flow rate are varied from 0.1 to 1 and 0.01-0.025 kg/s, respectively. The results of the study depict that the recycle ratio and the mass flow rate substantially increases the heaters efficiencies by increasing the fluid velocity. The maximum value of the thermal efficiency of Model A is found to be about 6.6% higher than that of Model B. The optimum values of the recycle ratio and the mass flow rate, at which the heaters yield maximum values of thermohydraulic efficiencies, are identified and presented. In addition, the effect of the channel depth ratio on the thermal performance improvement is also delineated. The effect of Reynolds number on thermal energy gain is given by Mittal and Varshney [22] It was given that as the air flow rate increases, the effective efficiency increases up to a threshold value of the Reynolds number , attains a maximum value and then decelerate sharply. A tabular report of the various authors and their contribution on different type of solar air heater is listed in table 1.

Table 1. Contribution of various authors on the investigation of solar air heater

Sl. No.	Name of Author	Year	Type of Solar air heater	Analysis
1	Malik Ebrahim Momin-Abdul et al	2002	Roughnend solar air heater	Experimentally investigated on the effect of geometrical parameter of v- shaped rib on heat transfer and fluid flow characteristics of rectangular duct solar air heater.
2	Naphon Paisarn	2005	Double pass flat plate solar air heater	Numerically studied the performance and entropy generation of the double-pass flat plate solar air heater with longitudinal fins.
3	Jaurker et al	2006	Artificially roughened solar air heater	Investigated experimentally on the heat transfer & friction characteristics of rib- grooved artificial roughness. Their investigation encompassed the Reynold number range from 3000 to 21000, relative roughness height 0.0181-0.0363, relative roughness pitch 4.5-10.0 and groove position to pitch ratio 0.3-0.7.They compared the effect of important parameters on smooth & ribbed duct on the heat transfer coefficients and friction factor. They also developed Correlations for Nusselt number and friction factor within reasonable limits.
4	Ramadan M.R.I et al	2007	Double glass double pass solar air heater	Investigated experimentally and theoretically on the thermal performance of a double glass double pass solar air heater with packed bed having packing above the absorber plate.
5	Varun et al	2007	Roughened Solar air heater	Reviewed on roughness geometry for the improvement of the heat transfer capability of solar air heater duct. They also presents the various correlation developed by several investigation heat transfer and friction factor in roughened solar air heater duct.
6	Saini R.P & Verma Jitendra	2008	Roughened solar air heater	Experimentally studied the heat transfer and friction factor characteristics of solar air heater having dimple shaped roughness.
7	Aharwal K.R. et al	2008	Roughened solar air heater	Experimentally investigated on the duct has having width to height ratio of 5.84 relative roughness pitch of 10, relative roughness height of 0.377 and angel of attack of 60.They varied the gap width and gap position in the range of 0.5-2 and 0.16667-0.667.
8	Prasad S.B et al	2009	Packed bed solar air heater	Experimentally investigated heat transfer and friction characteristics

				for air flow rate ranging from 0.0159 to 0.0347kg/s-m^{2}for the eight sets of matrices with varying geometrical parameters.
9	Karmare S.V & Tikekar A.N.	2009	Roughened solar air heater	Experimentally investigated on thermohydraulic performance of roughened solar air heater with metal rib grits.
10	Omajaro A.P et al	2010	Double pass solar air heater	Experimentally investigated on the thermal performance of a single and double pass solar air heater with fins attached using a steel wire mesh as an absorber.
11	Aldabbagh L.B.Y et al	2010	Packed Bed solar air heater	The thermal performance of single and double pass solar air heaters with steel wire mesh layer are used instead of a flat absorber plate are investigated experimentally.
12	Sebaii A.A.El et al	2011	Double pass Solar air heater	Experimentally investigated the double pass flat and V- corrugated plate solar air heaters.
13	Khawajah El, M.F et al	2011	Double pass solar air heater	Experimentally investigated on the thermal performance of a double pass solar air heater with fins using wire mesh as an absorber.
14	El-Sebaii A.A. et al	2011	Double pass solar air heater	Experimentally investigated on the double pass v-corrugated plate solar air heater.
15	Chamoli et al	2012	Double pass solar air heater	Investigated the thermal performance of a solar air heater by enhancing the rate of heat transfer.
16	Dong –chii ho et al	2013	Double pass solar air heater with packed bed	Experimentally investigated the performance of the new design of wire mesh packed double pass solar air heater with attaching wire mesh under external recycle.
17	Yadav Anil Singh & Bhagoria J.L	2014	Roughened solar air heater	Investigated to analyze the two –dimensional in compressible Navier -Stokes flow through the artificially roughened solar air heater for relevant Reynold number range from 3800 to 18000.
18	Dhiman Prashant, Singh Satyender	2015	Double pass packed bed solar air heater	Developed analytical models to predict the thermal and thermohydraulic efficiencies of two different designs of double pass packed bed solar air heater under external recycle have been proposed.

Future Research Scope

It has been seen clearly that plane solar air heater has very limited storage capability due to sinusoidal varying nature of heat source. The thermal load is null at sunrise, accelerating up to its maximum at noon and then retarding 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. 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 Internal Energy and Heat Capacity, Density, Heat Storage Temperature, Storage material Cost, Containment and heat exchange cost, Thermal Conductivity, Vapor pressure, Toxicity & Corrosiveness.

Discussion

In the process of improving the performance of packed bed solar air heaters some of the investigators either used iron chips, wire mesh, rock beds as the filler material or used the finned tubes to improve the heat transfer rate. With these enhancements, however the air heater loses its basic features of being simple in design and cheap in cost but the improved efficiency and temperature rise has been achieved which is also the main objective of a solar air heater. In the view of future study and research on solar air heaters still there is a considerable scope in the analysis of forced convection solar air heaters, with or without thermal energy storage and by changing the design of air heater either in single or double flow or pass.

Conclusion:

The conventional solar air heaters can only provide hot air during sunny hours due to the limited heat capacity of the system absorber. Introduction of packed bed energy storage with the conventional air heaters adds no complexity to the simple conventional heater design. By using suitable packed bed energy storage material, the system storage capability will be increased and the air heater heat loss will be reduced, because of the reduced absorber plate temperature, thus increasing the overall collector efficiency. In view of sensible heat storage such as wire mesh and metal chips 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 convection mode. Literature survey reveals that a considerable discrepancy between the results of theoretical considerations and experimental investigations occurs in case of convection heat transfer. In the view of above discussed fact it is concluded that there is a considerable scope for research and development in forced convection solar air heater with packed bed sensible heat storage with double flow or double pass.

REFERENCES:

[1]. Ebrahim Momin Abdul-Malik, Saini J.S, Solanki S.C. "Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate" International Journal of Heat and Mass Transfer 45 ,pp.3383–3396, 2002.

[2]. Naphon Paisarn "On the performance and entropy generation of the double-pass solar air heater with longitudinal fins" Renewable Energy 30, pp. 1345–1357, 2005.

[3]. Jaurker A.R , Saini J.S., Gandhi B.K. "Heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness" Solar Energy 80,pp. 895–907, 2006.

[4]. Ramadan M.R.I, El-Sebaii A.A., Aboul-Enein S., El-Bialy E "Thermal performance of a packed bed double-pass solar air heater" Energy 32 ,pp.1524–1535. 2006.

[5]. Varun , Saini R.P. , Singal S.K. " A review on roughness geometry used in solar air heaters" Solar Energy 81 ,pp.1340–1350, 2007.

[6]. Saini R.P, Verma Jitendra "Heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters" Energy 33, pp.1277– 1287. 2008.

[7]. Aharwal K.R, Gandhi B.K, Saini J.S. "Experimental investigation on heat-transfer enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater" Renewable Energy 33 ,pp.585–596. 2008.

[8]. Prasad S.B , Saini J.S., Singh Krishna M. "Investigation of heat transfer and friction characteristics of packed bed solar air heater using wire mesh as packing material "Solar Energy 83 ,pp.773–783, 2009.

[9]. Karmare S.V, Tikekar A.N. "Experimental investigation of optimum thermohydraulic performance of solar air heaters with metal rib grits roughness" Solar Energy 83 ,pp.6–13, 2009.

[10]. Omojaro A.P, Aldabbagh L.B.Y. "Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber" Applied Energy 87.pp. 3759–3765, 2010.

[11]. Aldabbagh L.B.Y, Egelioglu F, Ilkan M. "Single and double pass solar air heaters with wire mesh as packing bed " Energy 35,pp. 3783–3787. 2010.

[12]. El-Sebaii A.A, Aboul-Enein S, Ramadan M.R.I, ShalabyS.M, Moharram B.M. "Investigation of thermal performance of-double pass-flat and v-corrugated plate solar air heaters" Energy 36 ,pp.1076–1086, 2011.

[13]. El-khawajah M.F, Aldabbagh L.B.Y., Egelioglu F " The effect of using transverse fins on a double pass flow solar air heater using wire mesh as an absorber" Solar Energy 85 ,pp.1479–1487, 2011.

[14]. El-Sebaii A.A, Aboul-Enein S, Ramadan M.R.I., Shalaby S.M, Moharram B.M. "Thermal performance investigation of double pass-finned plate solar air heater" Applied Energy 88 ,pp.1727–1739, 2011.
[15]. Dhiman Prashant , Thakur , N.S. Chauhan S.R. "Thermal and thermohydraulic performance of counter and parallel flow packed bed solar air heaters" Renewable Energy 46 ,pp.259–268,2012.
[16]. Chamol Sunil , Chauhan Ranchan, Thakur N.S, Saini J.S. "A review of the performance of double pass solar air heater" Renewable and Sustainable Energy Reviews 16 ,pp.481– 492,2012.
[17]. KumarLalji Mukesh, Sarviya R.M, .Bhagoria J.L "Exergy evaluation of packed bed solar air heater" Renewable and Sustainable Energy Reviews 16 ,pp.6262–6267,2012.
[18]. Saxena Abhishek , Agarwal Nitin , Srivastava Ghansyham "Design and performance of a solar air heater with long term heat storage" International Journal of Heat and Mass Transfer 60, pp.8–16,2013.
[19]. Chii-Dong Ho, Chun-Sheng Lin, Yu-Chuan Chuang, Chun-Chieh Chao "Performance improvement of wire mesh packed double-pass solar air heaters with external recycle" Renewable Energy 57,pp. 479–489, 2013.
[20]. Yadav Anil Singh, Bhagoria J.L. "A CFD based thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate" International Journal of Heat and Mass Transfer 70 ,pp. 1016–1039. 2014.
[21]. Dhiman Prashant, Singh Satyender "Recyclic double pass packed bed solar air heaters" International Journal of Thermal Sciences 87 ,pp. 215-227 , 2015.
[22]. Mittal MK, Varshney L. "Optimal thermohydraulic performance of wire mesh packed bed solar air heaters. "Solar Energy 80, 1112-1120, 2006.