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Literature Review of Solar Energy Engineering

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ABSTRACT

Scientific concept of energy is capacity to do work. Energy is the basic ingredient to sustain life and development. It is the key to industrial development for the promotion of economic and living standard of the society. The growth of world population coupled with rising standard of living has escalated the growth of energy consumption. The modern industrialization has been dependent upon the conventional energy resources i.e. crude oil, natural gas and coal.

KEYWORDS: *Global warming, greenhouse affect, climate change, ozone layer depletion, acid rain, greenhouse gases, carbon dioxide (CO2), methane (CH4), conduction, convection, radiation*

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INTRODUCTION

Energy resources are categorized into conventional and non-conventional energy resources. Crude oil, natural gas and coal come under conventional energy resources. The non-conventional energy resources can be further sub-divided as:

Non-renewable energy is the energy obtained from the static sources of energy that remained bound unless released by human interaction. Examples are nuclear fuels and fossil fuels of coal, oil and natural gas. It may be noted that the energy is initially an isolated energy potential and external action is required to initiate the supply of energy for practical purposes. To avoid using the ungainly word 'non-renewable', such energy supplies should be called 'finite supplies'. Also, it can be said that non-renewable energy is the energy not renewed after use such sources as nuclear, geothermal, peat, oil shale and tar sands fall in this category.

Renewable energy is the energy obtained from the continuous or repetitive currents of energy occurring in the natural environment. An obvious example is solar (sun-shine) energy, where 'repetitive' refers to the 24-hour major period. In other words, renewable energy is the energy which is renewed over a short period of time like solar energy, hydro energy, wind energy, biomass energy, tidal energy, ocean, animal and human energy that fall in this category. Table 1.1 shows availability of various renewable energy resources.

Table - Availability of various renewable energy resources

Energy resources	Power 10^6 x MW	Energy 10^9 x MWhr /Yr
Solar energy	57,000	500,000
Ocean thermal energy	30	260
Wind energy	20	175
Hydro energy	2.857	25
Tidal energy	0.064	0.56

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near ultraviolet. Areas lying between 30^o N to 30^o S latitudes receive maximum solar radiation. Thus, India (8^o N to 32^o N) is blessed with abundant solar radiation. On an average, India's annual solar energy potential is about 7000 MJ/m^2.

The major drawback with this resource is its low intensity and intermittent nature. Even in the hottest region on earth, the solar radiation flux available rarely exceeds 1 KW/m^2. Solar energy, despite its limitations of low intensity and intermittent nature, appears to be the most promising amongst the renewable energy resources and can fill the energy gap, if proper storage and utilization systems are developed.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined.

Solar radiation is an integral part of different renewable energy resources. It is the main the continuous input variable from the practically inexhaustible sun. Solar energy is expected to play a very significant role in the future. On an average, India’s annual solar energy potential is about 7000 MJ/m^2.

APPLICATIONS OF SOLAR ENERGY

Solar powered electrical generation relies on heat engines and photovoltaic. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, day-lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. To harvest the solar energy, the most common way is to use solar panel.

Architecture and Urban Planning

Sunlight has influenced building design since the beginning of architectural history Greeks and Chinese, had oriented their buildings toward the south to provide light and warmth. The common features of passive solar architecture are orientation relative to the Sun, compact proportion (a low surface area to volume ratio), selective shading (overhangs) and thermal mass. When these features are tailored to the local climate and environment, they can produce well-lit spaces that stay in a comfortable temperature range. The most recent approaches to solar design use computer modeling tying together solar lighting, heating and ventilation systems in an integrated solar design package. Active solar equipment such as pumps, fans and switch-able windows can complement passive design and improve system performance.

- Agriculture
- Solar Home Lighting
- Solar Thermal

During the winter in the Indian subcontinent. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain.

Water Treatment

Solar distillation can be used to make saline or brackish water potable. A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas. The plant, which had solar collection area of 4,700 m^2, could produce up to 22,700 liters per day and operated for 40 years. Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect. These stills can operate in passive, active, or hybrid modes. Double-slope stills are the most economical for decentralized domestic purposes, while active multiple effect units are more suitable for large-scale applications.

Solar Cooking

Solar cookers use sunlight for cooking, drying and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers.

Solar Electrical Generation

Sunlight can be converted into electricity using photovoltaic (PV), concentrating solar power (CSP), and various experimental technologies.

Solar Chemical

Solar chemical processes use solar energy to drive chemical reactions. These processes offset energy that would otherwise come from an alternate source and can convert solar energy into storable and transportable fuels. Solar induced chemical reactions can be divided into thermo chemical or photochemical.

Solar Vehicles

Development of a solar powered vehicle has been an engineering goal. The World Solar Challenge is a biannual solar-powered car race, where teams from universities and enterprises compete over 3,021 kilometers (1,877 mi).

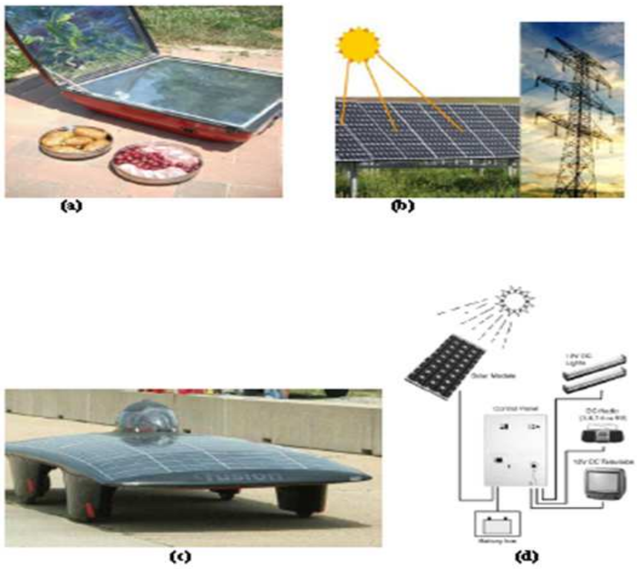

Fig. - Shows application of Solar Energy (a) Solar Cooking (b) Solar Electrical (c) Solar Vehicle (d) Solar Home Lighting

ADVANTAGES OF SOLAR ENERGY

- Solar energy is a renewable resource.
- Fossil fuels are not renewable. Once it is gone, it is gone. Yes we may find another non-renewable source but that may exhaust one day or the other.
- Mechanism involved in utilizing solar energy is simple rather than fossil fuels as it involves heavy machineries for extracting it and for utilization as well.
- Solar energy is pollution free. It is the main advantage over other resources as fossil fuels produces noise and air pollution during their utilization and extraction processes.
- Solar panels require very less maintenance (They have no moving parts that will need to be fixed and they last a long time.
- Solar powered products are easy to install and do not involve any worries about wires and complex circuit mechanism.

DISADVANTAGES OF SOLAR ENERGY

- Solar cell/panels etc. can be very expensive.
- Solar power cannot be created at night.

SOLAR COLLECTORS

The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors. A solar collector is basically a heat exchanger which intercepts the incident solar radiations and converts them into heat and finally transfers this heat to the working fluid for the end use system.

Various solar energy collection and conversion systems like water heaters, air heaters for crop drying and industrial application, solar air conditioning and water distillation systems, green houses, solar cookers, solar cells for electrical power generation, solar pumps, and solar furnaces have been developed. Solar thermal systems have been found to be the most attractive in actual applications. In all such systems, a solar collector is the most important element.

Several designs of solar collectors have been developed. These collectors may be classified broadly in the following types:

A. Concentrating or Focussing collectors
B. Flat plate collectors

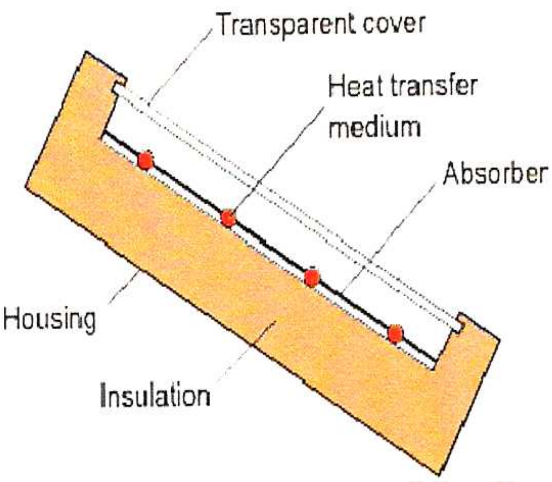

Fig- Flat-plate collector

Various Designs of Solar Air Heater For Thermal Performance Enhancement

The low value convective heat transfer coefficient of the air being heated and the absorber plate is a major limiting factor in solar air heater performance. Several different designs have been proposed to increase the heat transfer coefficient of the absorber plate and the air, the poor heat transfer rate from the absorber plate to air in the duct results in relatively higher absorber plate temperature leading to higher thermal losses to the environment. These losses can be reduced by lowering the absorber plate temperature by increasing the heat transfer coefficient between absorber and air. This objective can be achieved by using:

1. extended surface on the absorber plate
2. artificial roughness
3. porous materials in the air flow duct

Porous matrices

For improving the performance of solar air heater use of porous matrices have been proposed by several investigators.

Whillier [1963] suggested that heat transfer coefficient between the air and the radiation absorbing surface can be increased by the use of screen (mesh) of blackened metallic wire or plastic in duct.

Chiou et al. [1965] proposed the use of porous matrices as the heat absorbers in solar air heaters. Porous matrices absorb solar radiation in depth and have high heat transfer area per unit volume. They found these collectors to be more efficient as compared to the flat plate type. They studied three basic types, viz. the unidirectional flow, counter flow and cross flow type. The unidirectional flow type has been found to be superior to the counter flow type because in the unidirectional type, the cover glass and the upper surface of the matrix is in contact with cool incoming air resulting into relatively low matrix surface temperature. The upper heat losses are, therefore, low. The cross-flow type has also been found to have poorer performance as compared to the unidirectional type because of greater heat and friction losses. The use of porous bed increases the pressure drop across the collector. While pressure drop is strong function of air velocity, the convenient heat transfer coefficient is relatively a weaker function of velocity. For these reasons flow arrangement with low velocity are preferred for this type of collector. Such a collector is also not suitable for the application where the temperature of the incoming air is likely to be well above the ambient temperature (say 20°C or more). If the incoming air is laden with dust, the build-up of dust on the absorbing surfaces of the matrix and on the inside surface of the cover will cause reduction in absorption of solar radiation. Further, the possible condensation of water vapour from circulating air which is trapped in the collector overnight can lead to corrosion of the matrix.

Gupta and Garg [1998] conducted experimental study on mesh type solar air heaters. One of the heaters consisted of a single galvanized-iron wire mesh screen held inclined between the glass cover and a corrugated galvanized-iron sheet below. As the wire-mesh consisted of 44% open space, nearly half the radiation was absorbed at the bottom plate. The other wire-mesh absorber was similar to the first type except that double layer of aluminium expanded screen (with 69 percent open space for single layer) was employed in place of galvanized-iron wire-mesh. They reported efficiency of 50% and air supply up to 20°C above the ambient. **Porous absorber,** Because of intermittent nature of solar energy, storage is required for uninterrupted supply of heated air in order to match the needs. Packed beds are generally used for storage of thermal energy from solar air heaters. A packed bed is a volume of porous media obtained by packing particles of selected material into a duct. A number of studies carried out on packed beds for their performance analysis are reported in the literature. These studies included the design of packed beds, materials used for storage, heat transfer enhancement, flow phenomenon and pressure drop through packed beds. Solar collectors with porous absorbers/packed beds have been found to be more efficient as compared to conventional collector because they have high heat transfer rates. In such an absorber, the solar radiation penetrates to greater depths and is absorbed gradually depending on the density of the packing. Heat losses associated with a higher absorber temperature are reduced resulting into improvement in the thermal efficiency of the collectors. Use of porous beds for the enhancement of collector performance has been shown to have certain specific advantages over the other methods.

Packed bed solar air heater having its bed packed with semi-transparent materials like glass beads, porcelain beads and glass tubes was investigated, theoretically as well as and experimentally by Hasatani et al. [1985]. The energy balance equations were solved numerically to obtain the collector performance. Based on the analysis and experimentation, it was reported that solar air heater having semi-transparent materials for the heat collector-cum-storage has 15 to 20% higher efficiency of the energy collection as compared to that of a smooth collector.

The effect of a system and operating parameters on the performance characteristics of a single duct packed bed solar air heater has been investigated analytically as well as experimentally by Sharma et al. [1991]. The experimental investigations showed that the enhancement in thermal efficiency is a strong function of geometry of the wire mesh screen and operating parameters like insolation, inlet temperature and mass flow rate.

Prasad and Saini [1993] carried out studies on single pass air heaters packed with wire mesh screen matrix in unidirectional as well as cross flow arrangement. It was reported that packed bed with unidirectional arrangement has higher efficiency as compared to cross flow type. Thermal performance of the packed bed collector is a strong function of porosity, extinction coefficient, heat transfer area, density and the orientation of packing.

Experimental investigations were carried out by Ahmad et al. [1995, 1996] on solar air heater with iron screen matrices of different geometrical parameters as packing material in cross flow fashion. Thermohydraulic performance was evaluated and compared with that of the conventional collector. It was observed that thermohydraulic efficiency of the packed bed air heater decreases with an increase in the value of ratio of bed depth to element size and porosity but it increases with an increase in mass flow rate of air.

Varshney and Saini [1998] have experimentally investigated the heat transfer and fluid flow characteristics of a single duct solar air heater packed with wire mesh screen matrices. A wide range of geometrical parameters of wire screen matrix with wire diameter from 0.360 ml11 to 0.795111111, pitch from 2.08 mm to 3.19 mm and number of layers from 5 to 14 has been used. They have developed the heat transfer and friction factor correlations for air flowing through the bed in the cross flow arrangement. The range of packing Reynolds number Rep and porosity covered was from 300 to 1500 and 0.89 to 0.96 respectively.

The following correlations were developed,:

$$j_h = 0.647\left[\left(\frac{1}{nP}\right)\left(\frac{P_t}{d_w}\right)\right]^{2.104} Re_p^{-0.55}$$

$$f_p = 2.484\left[\left(\frac{1}{np}\right)\left(\frac{P_t}{d_w}\right)\right]^{-0.699} Re_p^{-0.44}$$

where,
P_t pitch of the wire mash screen

n number of wire mesh screen layers

j_h is the Coluburn j factor ($= StPr^{2/3} = h_c Pr^{2/3}/G_o C_p$)

G_o is the superficial mass velocity, (kg s^{-1} m^{-2})

where,
pitch of the wire mesh screen

number of wire mesh screen layers

is the Colburn} factor (= StPr2/3 hcPr2/3 jGoCp)

is the superficial mass velocity, (kg S-1 m-2)

It has been observed from the effect of porosity on the volumetric heat transfer coefficient that there is a general increase in volumetric heat transfer coefficient as the porosity decreases.

Wu and Hwang [1998] investigated experimentally and theoretically the flow and heat transfer characteristics inside packed and fluidized beds. Spherical particles were randomly packed in the test section for simulating the packed bed with porosity range of 0.38 to 0.97 and Reynolds number (defined as Re=pUdp/μ) range of 200 - 7000. The results showed that the heat transfer increases with decrease in porosity and increase in the particle Reynolds number.

Thakur et al. [1998] experimentally investigated the heat transfer and fluid flow characteristics of a solar air heater having its single duct packed with wire mesh screen matrices. A wide range of geometrical parameters of wire screen matrix with wire diameter from 0.795 mm to 1.4 mm, pitch from 2.50 mm to 3.19 mm and number of layers from 5 to 12 has been used, The range of packing Reynolds number R*ep* and porosity covered in these experiments was from 182 to 1168 and 0.667 to 0.880 respectively. The following correlations have been developed to find the convective heat transfer coefficient between the packed material and fluid flowing through it.

$$j_h = 0.4\left[\left(\frac{1}{nP}\right)^{0.50}\left(\frac{P_t}{d_w}\right)^{0.25}\right]^{1.4} Re_p^{-0.61}$$

$$f_p = 3.0\left[\left(\frac{1}{nP}\right)^{0.50}\left(\frac{P_t}{d_w}\right)^{0.25}\right]^{0.90} Re_p^{-0.41}$$

Kolb et al. [1999] described the development and testing of an efficient and single glazed solar matrix air collector. The absorber consisted of two parallel black galvanized industrially woven fine meshed copper wire screens. The collector was very durable and flexible with respect to mass flow rate and collector duct height and yielded high thermal performance at very low-pressure losses. Matrix collectors offered large heat transfer area to volume ratio and large heat transfer coefficients due to small hydraulic diameters. In this way, the operating temperatures of the system, and thus the heat losses from the collector were reduced. This resulted into higher collector efficiencies.

Parsad et al. [2009] have experimentally investigated the heat transfer and fluid flow characteristics of packed bed solar air heater using wire mesh as packing material. A wide range of geometrical parameters of wire screen matrix with wire diameter from 1.06 mm to 1.48 mm, pitch from 2.16 mm to 4.23 mm and number of layers from 5 to 11 has been used. The range porosity covered in these experiments was from 0.599 to 0.816 respectively. The following correlations have been developed to find the convective heat transfer coefficient between the packed material and fluid flowing through it.

$$j_h = 0.2563\left(\frac{1}{nP}\right)^{0.609}\left(\frac{P_t}{d_w}\right)^{0.7954} Re_p^{-0.63}$$

$$f_p = 3.5722 \left(\frac{1}{nP}\right)^{1.0431} \left(\frac{P_t}{d_w}\right)^{1.1507} Re_p^{-0.43}$$

PACKED BED SOLAR AIR HEATER

It has been observed that the performance of plate collector improves appreciably by packing its duct with blackened wire screen matrices and this improvement is a strong function of bed and operating parameters of Packed bed. If can be successfully used for the enhancement of heat transfer coefficient in solar air heaters. The air flows through the porous medium on which the solar radiation is directly incident. The radiation penetrates absorbing medium in depth and in turn gets absorbed. The high heat transfer area to volume ratio promotes heat transfer capability and the turbulence producing air flow path through the bed provide for a rapid increase of heat exchange.

Use of packed bed for the improvement of performance of solar air heater has been proposed by several investigators. The materials used for packed bed includes wire mesh screen, matrices, pebble bed, chips of different materials etc. Fig. 1.13 shows the principle of packed bed solar air heater.

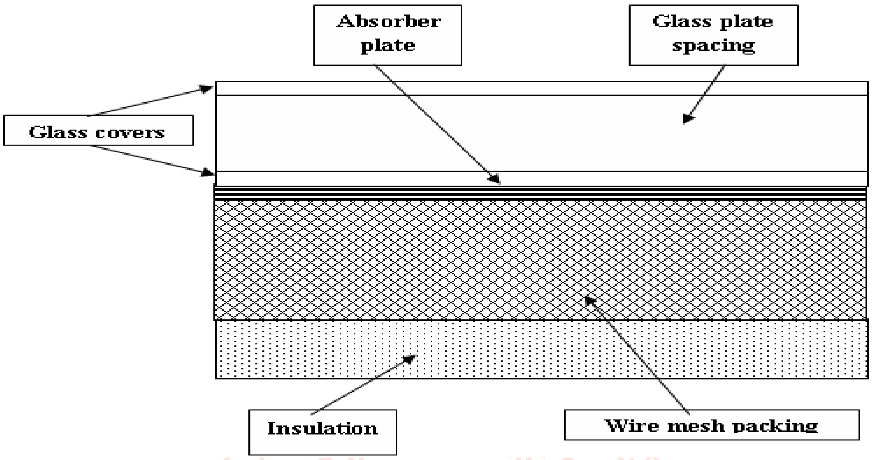

Fig.- Packed Bed Solar Air Heater principle

Importance of Packed Bed Solar Air Heater

Flat plate solar air heaters are extensively used in low temperature solar energy utilization. The efficiency of such heaters has been found to be low because of the low convective heat transfer coefficient between the absorber and the flowing air, which increases the absorber plate temperature, leading to higher heat losses to the ambient. Several designs of solar air heaters have been proposed over the years to enhance the thermal performance of such heaters.

N.S. Thakur et al [2003] carried experimental investigation on a low porosity packed bed solar air heater. Investigation covered a wide range of geometrical parameters of wire screen matrix, i.e. wire diameter 0.795 to 1.40 mm, pitch 2.50 to 3.19 mm and number of layers from 5 to 12. Correlations were developed for the Colburn *j* factor and friction factor for a low range of porosities from 0.667 to 0.880 and packing Reynolds number range from 182 to 1168. It is observed that both the heat transfer coefficients and the friction factor are strong functions of geometrical parameters of the porous packed bed. A decrease in porosity increases the volumetric heat transfer coefficient.

LITERATURE SURVEY ANALYSIS

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
1.	N. S. Thakur, J. S. Saini, S. C. Solanki (2003)	Wire screen matrix	182 - 1168	2. 50 - 3. 19	0. 795 - 1. 40	05 to 12	0. 667 - 0. 880	The friction factor, correlated with the experimental data satisfactorily.
2.	B. Paul, J. S. Saini (2004)	Wire mesh screen matrix and pebble bed	-	3. 77 - 7. 55 (P_t/d_w)	4 - 12 (D_p)	5 to 14	0. 89 - 96	Optimum values of various parameters were determined by programming in "C' for optimum design of packed bed solar air heater
3.	N. S. Thakur, J. S. Saini, S. C. Solanki (2003)	Low Porosity System	182 to 1168	2. 50 -3. 19 mm	0. 795 to 1. 40	5 to 12	0. 667 to 0. 880	A decrease in porosity increased the volumetric heat transfer coefficient.
4.	A. R. Jaurker, J. S. Saini, B. K. Gandhi (2006)	Ribbed Groove artificial roughness	3000 to 21,000	4. 5 to10. 0	-	-	-	The present investigation clearly demonstrated that the heat transfer coefficient for rib-grooved

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
								arrangement was higher than that for transverse ribs.
5.	S. K. Saini, R. P. Saini (2006)	Arcshaped wire as artificial roughness	2000 to 17000	10	-	-	-	Considerable enhancement in heat transfer coefficient had been achieved with roughness element.
6.	M. K. Mittal, L. Varshney (2006)	Wire Mesh Packed solar air heater	0. 005 to 0. 05 kg/s	-	-	-	-	Efficiency of such collectors was relatively higher as compared to smooth collectors
7.	L. Varshney, J. S. Saini (1998)	Wire mesh screen matrices	2800 to 10000	p/d= 3. 77 -7. 55	-	5 to 14	0. 89 to 0. 96	generalized correlations had been developed for J-factor and friction factor
8.	Ranjit Singh, J. S. Saini, R. P. Saini (2006)	large sized elements of different shapes	1257-2157 (T-joint masonry tile bricks) 1047-1797 (standard masonry tile bricks) 1257-2157 (standard masonry bricks) 1558-2674 (concrete cubes) 1139-1955 (concrete spheres	-	-	-	-	The present correlations could be used to predict the performance of the actual packed bed solar energy storage system having elements of different shapes and bed porosities
9.	A. M. E Momin, J. S. Saini, S. C. Solanki (2002)	V-shaped rib roughness	Re=2500–18000 e/D=0. 02-0. 034	p/e = 10	-	-	α=30º -90º	In general, Nusselt number increased whereas the friction factor decreased with an increase of Reynolds number.
10.	M. M. Sahu, J. L. Bhagoria (2006)	90° broken transverse ribs	3000–12,000	10–30 mm	-	-	-	It could be seen that for lower of Reynolds number, improvement in the Nusselt number over the smooth duct was small.
11.	Paisarn Naphon (2005)	double-pass solar air heater with longitudinal fins	0. 02 and 0. 1 kg/s	-	-	-	-	Thermal efficiency increases with increasing the height and number of fins
12.	F Ozgen, M Esen,H Esen (2009)	double-flow solar air heater having aluminium cans	0. 03 kg/s and 0. 05 kg/s.	-	-	-	-	The double-flow type of the SAHs with aluminium cans had been introduced for increasing the heat-transfer area, leading

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
								to improved thermal efficiency
13.	Nasri J. Rabadi, Saed A. Mismar (2003)	curved flow technology coupled with flow in porous media	50 and 400 l/h	-	-	-	0. 1453	The existence of the porous media inside the flow channel will increase the average convection heat transfer coefficient by 28. 01% for 200 l/h flow rate and by 17. 98% for 300 l/h flow rate
14.	B. Paul, J. S. Saini(2004)	packed bed solar energy collection system	-	Pt/dw =4. 0126	-	9	0. 888	Collector with this optimum bed will yield a thermal efficiency of approximately 0. 7636
15.	A. Ahmed, J. S. Saini, H. K Verma (2005)	Iron wovel screen of different geometry	m=0. 01380-. 0252	P_t=12x12to 30x30per inch	D_w=0. 17-0. 63	-	P=0. 823-0. 968	The thermal performance enhanced by Geometrical and Operating parameters & by the thermal conductivity of matrix.
16.	B. Paul, Saini (2004)	Wire mesh screen matrix and pebble bed	P_t= /d_w = 3. 77-7. 55	D_p=4 -12			P=0. 89-96	Optimum values of various parameters had been determined by programming in "C' for optimum design of packed bed solar air heater
17.	R. Singh R. P. Saini, J. S Saini (2006)	Five different shape element of storage material					Spherecity = 0. 55-1. 00	Friction factor and Nusselt number correlated the experimental data satisfactorily
18.	L. Varshney and J. S Saini (1998)	Wire mesh screen matrix	m= 0. 01-0. 03 Re= 300 to 1500	P_t/d_w =3. 77-7. 55			P=0. 89-0. 96	The lower porosity will give rise to higher heat transfer coefficient
19.	M. R. I Ramadan, A. A. EI-Sebaii, S. A Enein, E . EI. Bialy(2007)	Lime stone and Gravel were used as Packed bed materials	m= 0. 01-0. 05					It was best to use Gravel rather than limestone with low porosity &high mass flow rate and a material of high thermal conductivity.
20.	M. K. Mittal, L. Varshney (2006)	Blackened wire screen matrices	m= 0. 0005-0. 05 Re= 300 to 1500	P_t=2. 08-3. 19	d_w=0. 36-0. 795		P=0. 89-0. 96	Wire mesh packed solar air heaters had been found to have a better effective efficiency as compared to conventional smooth air heaters.
21.	A. A. Mohamad & Ahmed M.	A highly permeable wire mesh is	m= 0. 010-0. 020					Efficiency of85% was obtained using such configuration.

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
	Qenaway (1997)	used						The lower the Temp., higher the heat loss & lower the efficiency
22.	M. K. Paswan &S. P Sharma (2009)	Wire screen mesh (metal)	m=0. 033-0. 067	P_t=5. 5x5. 5 - 14x14 per inch or 1. 814-4. 614mm	d_w= 0. 508			Roughness of absorber plate and decreasing the wire pitch will increase the thermal performance & also geometrical parameters will affect it.
23.	C. Choudhury and H. P Garg (1993)	Cylinder, ring sphere &crushed material	Re=50-300		d=1mm to 5mm			Increase in duct length with increase in mass flow rate & decrease in duct depth increased efficiency.
24.	Masanobu Hasatani Yoshinori itaya & kouji adachi (1995)	Glass beads Porcelain vbeads Glass tubes			d= 3. 4,5. 2,10mm			The solar air heater with such packed bed material has higher efficiency than simple flat plate heater.
25.	M. J. Shoemaker (1961)	Slit & hollow spheres &other irregular shapes	Foil thickness=0. 002	thickness of layer =0. 0065per inch		Foil layers no. =7&17		They were highly efficient in transferring temp. of air stream thereby reducing the cost of the collector.
26.	Robert K. swartman, O. Ogunlade (1966)	Solid & hollow spheres & other irregular shapes						The result revealed slightly higher water exit temp. with overall efficiency ranging from 20-60%.
27.	P. Chiou, M. M. El-Wakil J. A. Duffe (1966)	Slit & expanded Aluminum foil matrices of sixdifferent types	Foil thickness = 0. 002-0. 006inch				Voidage= 96. 2-98. 3%	Such collectors indicate higher efficiency than flat plate &much lower friction losses & comparatively low cost.
28.	S. P. Sharma, J. S. Saini and H. K. Verma (1991)	Blackened wire screen matrices	m=0. 0159-0. 0318	P_t=5. 5x5. 5 to 14x14 per inch	d_w=0. 46-0. 69mm		P=0. 875-0. 953	Appreciable improvement in performance of plane collectors Also bed &operating parameters has strong functioning for such improvement
29.	C. B. Mishra and S. P. Sharma (1981)	Iron chips, G. I sheet turnings &black painted pebbles	Constant mass flow rate =17. 523kg/hr-sq. m					Packed bed solar collectors acted as energy collector as well as energy devices with iron chips showing the best performance as packed bed material

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
30.	J. L. Bhagoria, J. S Saini S. C Solanki (2002)	Transverse Wedge shaped ribs	e/D=0. 015-0. 033 W/H=5. 0 Re=3000-18000	60. 17-1. 0264 p/e =12. 12 Wedges angle= 8°-15°				Nusselt Number increases attained maximum for relative roughness pitch of about at p/e =7. 52 maximum heat transfer occurs
31.	Karwa Rajendra. (2003)	Transverse, Incliced, V-Discrete	e/D=0. 0647-0. 050 W/H=7. 19-7. 75	p/e=10				V-down discrete gave the best heat transfer
32.	Rajendra Karawa, S. C. Solanki, J. S. Saini (2001)	Integral chamfered rib roughness	e/D=0. 0197-0. 0441 Chamfer Angle =15°	p/e=4. 58,7. 09				Thermal efficiency is increased by 10 to 40% of solar air heater
33.	R. L. Webb et al (1972)	Helical rib	e/D=0. 01 p/e=10-12				α=30°,40°,70°	Helical rib yielded greater heat transfer compared to transverse rib
34.	K. Prasad, S. C. Mullick (1983)	Small diameter wire	Re=10,000-40,000 e/D=0. 019	p/e=12. 7			α=90°	Heat transfer coefficient increased by 38. 5%
35.	L. T. Miin & J. T. Hwang	Different ridgeshapes triangular, square, semicircular	Re=78,000-50,000 e/D=0. 08	p/e=8-20				Square ridge had maximum heat transfer coefficient & semi-circular ridge had lowest
36.	D. Gupta & S. C. Solanki (1997)	Circular wire	Re=3000-18,000 e/D=0. 023	p/e=10			α = 40 - 90°	Maximum heat transfer at a=60° and max . friction factor at a=70°
37.	B. N. Prashad &J. S. Saini (1988)	Transverse wires	Re= Turbulent regime e/D=0. 02-0. 033	p/e=10			α = 90°	For given p/e,f &Nu increased with increases in e/D, and f,Nu decreases with increase in p/e
38.	Jia R & A. Saidi (2003)	>>II<<	Re=15,000-32,000 e/D=0. 062				α = 45°	<<ribs performed superior to >> and II ribs
39.	Jain A& J. L Bhagoria et al B (2005)	Shot peened absorber plate	Re=3000-12,000		Short dia. 3. 1mm to 4. 8mm		Coverage 50. 80. 100%	Shot peening yields increased in heat transfer 4. 8mm shot with 80% converge gave the highest n
40.	A. R. Jaurker et al (2005)	Rib grooved	Re=3000-21,000 e/D =0. 0181-0. 0363	p/e=4. 5-10			α=90°	The maximum heat transfer occured for p/e =6. 0 compared to smooth duct, the presence of rib grove roughness yields Nu=2. 7 times & f= 3. 6 times
41.	R. P. Saini et al (2008)	Curved shape wire	Re=2000-17,000 e/D=0. 0213-0. 0422 p/e=10	p/e=10			α=90°	Maximum enhancement in Nu obtained as 3. 8 times and f=1. 75times at a/90°=0. 333 to 0. 666

S. No.	Author's Name	Packed bed Material	Re/Nu/ Mass flow rate	Pitch	Diameter	No. of layers	Porosity	Conclusion
42.	Irfan Kurtbas Aydin Durmus (2006)	Black- painted galvanic zed sheet with 0. 8mm thick	Five solar collectors with dimensions of 0. 9-0. 4 m					The efficiency of air collectors increased depending on the surface geometry of the collector and extension of the air flow line the more important parameters in order ro decrease the exergy loss were the collector efficiency, temperature difference (To-Ti) of the air and pressure loss.
43.	Hikmet Esen (2009)	The absorbers were made of stainless steel with blackchrome selective coating.	Dimension and plate thickness for all four collectors were 1. 25 m, 0. 8m and1 mm					The results showed that the largest irreversibility was occurring at the flat plate (without obstacles) collector efficiency is smallest.
44.	M. K. Gupta ,S. C. Kaushik B (2006)	Expended metal mesh as artificial roughness on absorber plate	Performance evaluation in terms of energy augmentation ratio (EAR), & EEAR exergy augmentation ratio (EXAR)					The EAR and EEAR based criteria suggested the use of the roughened geometries up to very large value of Re. The EXAR based criteria showed that the EXAR fortresses with Re.
45.	Momin Abdul M. E, J. S. Saini, S. C. Solanki (2002)	V-shaped ribs	e/D=0. 2-0. 034	p/e=10			α=60°	Performance maximum enhancement of rough surface at taken values
46.	Rajendra Karawa, S. C. Solanki, J. S. Saini(2001)	Integral chamfered rib roughness	e/D=0. 0197-0. 0441	p/e=4. 58,7. 09			Chamfer angle= 15°	Thermal efficiency increased 10 to 40% of solar air heater
47.	R. K. Mittal, Varun, R. P. Saini, S. K. Singal (2007)	Different types of rib geometry	e/D=0. 02-0. 24, W/H =10 Re=2000-15000	p/e=10			α =30°-90°	Inclined ribs were is found to have better efficiency in the Re and expended Mesh was in the Lower range of Re.
48.	L. B. Y. Aldabbagh, F. Egelioglu, and M. Ilkan (2010)							The results indicated that the efficiency increased with increase in the mass flow rate for the range of the flow rate used in this work between 0. 012 and 0. 038 kg/s. For the same flow rate, the efficiency of the double pass was found to be higher than the single pass

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								by 34–45%. Comparison of the results of a packed bed collector with those of a convent-ional collector showed a substantial enhancement in the thermal efficiency
49.	A. A. El-Sebaii, S. Aboul-Enein, M. R. I. Ramadan, S. M. Shalaby, B. M. Moharram (2011)	Theoretical analysis						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 thermo-hydraulic 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.
50.	Prashant Dhiman, N. S. Thakur, Anoop Kumar, Satyender Singh(2011)	Analytical study						The comparison between the simulation results and experimental data with an average error of 9. 2%.
51.	P. Velmurugan and P. Ramesh (2011)	Performance analysis of solar air heater corresponding to mass flow rate of 0. 012-0. 038 kg/s.						Overall efficiency was observed when compared with conventional system. Mass flow rate influenced the thermal efficiency of the air heater. Solar intensity had no effect on thermal efficiency

CONCLUSIVE REMARKS OF LITERATURE REVIEW

The review of heat transfer studies in packed bed solar air heaters indicated that sufficient research work had been carried out on packed beds used in different designs of solar air heaters. In the studies of heat transfer and fluid flow behaviour, it was observed that there is substantial rise in the heat transfer coefficient with packed bed solar air heaters and hence, improved thermal efficiency. Also, theoretical and experimental studies indicate that the packed bed solar air heater perform better than the solar air heaters owing to the reduced thermal losses from the front cover and back surfaces of duct system.

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