A COMPREHENSIVE REVIEW ON SOLAR ABSORBER PLATE OF EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

Surendra Agrawal [1], Dr. Anil Kurchania[2], Dr. Dinesh Kumar Soni[3]
Research Scholar[1],Professor[2,3],
Department of Mechanical Engineering[1,2]
UIT, RNTU Bhopal (M.P.) India

Abstract — The term solar air heating is a technology in which the radiant energy emitted by the sun is captured in an absorber and is used for space heating. Needless to say it is a renewable and pollution free method to produce space heating and when is used in commercial buildings or industries could be very cost effective. Improvement in the thermo hydraulic performance of a solar air heater can be done by enhancing the heat transfer. In general, heat transfer enhancement techniques are divided into two groups: active and passive techniques. Providing an artificial roughness on a heat transferring surface is an effective passive heat transfer technique to enhance the rate of heat transfer to fluid flow. In this paper, reviews of various artificial roughness elements used as passive heat transfer techniques, in order to improve thermo hydraulic performance of a solar air heater, is done. The objective of this paper is to review various studies, in which different artificial roughness elements are used to enhance the heat transfer rate with little penalty of friction. In this review paper, solar air heaters are discussed along with the problems associated, when use on large scale. Improvement in present technologies which are used for the manufacture of solar air heaters is the main area of focus in this paper and recent progress in enhancing the design of solar air duct are reported. Enhancement of effectiveness of the solar air heater which is in use today by applying small changes in the same so that the use of solar energy for space heating could be encouraged in lieu of using electricity was the main area of study in this paper. When being used for industrial purposes, however a lot of research work is still needed to be done.

Keywords — *Computational Fluid, Artificial roughness, Thermo-hydraulic performance parameter, Friction factor*

I INTRODUCTION

Increase in global demand and consumption of energy, on account of economic development, technological and population growth, has forced the scientific community to think of ways and means to conserve energy in every industrial, commercial and domestic application. The conversion, utilization and recovery of energy invariably involve a heat exchange process, which makes it imperative to improve the thermal performance of heat exchangers [1]. Several viable engineering solutions, particularly with the use of heat transfer enhancement techniques, are available to achieve this objective. Constantinos [2] classified the enhancement techniques as fluid, surface and compound enhancement techniques. Heat transfer enhancement techniques have been employed to improve the performance of a solar air heater which is the simplest and most commonly used device in solar energy applications, requiring low grade thermal energy, such as drying of agricultural produce, seasoning of wood, space heating, curing of industrial products. Performance of a solar air heater is adversely affected on account of low thermal capacity of air and absorber to air convective heat transfer coefficient, which needs design considerations, and to the extent possible, compensation. For this purpose surface techniques, which directly involve the heat exchanger surface, are employed on the underside of absorber plate that comes in contact with air. These techniques improve the thermal performance either by increasing the heat-transfer area with the use of corrugated/finned absorber surfaces or by enhancing the absorber to air convective heat transfer coefficient with the use of roughened absorber surfaces. The roughness, on the absorber plate can be provided by several methods such as sand blasting, machining, casting, forming, welding ribs and or fixing thin circular wires. The use of artificial roughness in different forms and shapes is the most effective and economic way of improving the performance of a solar air heater. Numbers of experimental investigations involving roughness elements of different shapes, sizes and orientations with respect to flow direction have been carried out in order to obtain an optimum arrangement of roughness element geometry. Varun et al. [35] carried out a review of roughness geometry in solar air heaters. They discussed different roughness geometries used in solar air heaters and explained the concept of artificial roughness, effects of various roughness parameters on the flow pattern and also briefly discussed the roughness geometries used in heat exchangers other than solar air heaters. Mittal et al. [36] compared the effective efficiency of solar air heaters having six different types of roughness elements on the absorber plate and reported that solar air heaters roughened with inclined ribs and wire mesh perform better in the upper and lower range of parameters considered respectively. However, since then a number of new roughness element geometries have been reported in literature and there is a need to categorize and compare the performance of these geometries.

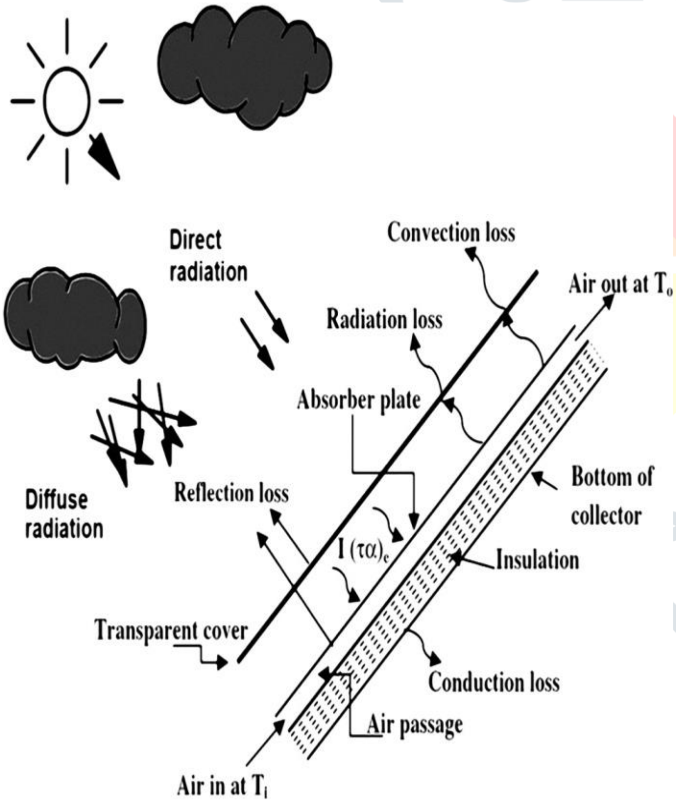


Fig. 1. Conventional solarairheater.

The twenty-first century is forming into the perfect energy storm. Rising energy prices, diminishing energy availability and security, and growing environmental concerns are quickly changing the global energy panorama. Energy and water are the keys to modern life and provide the basis necessary for sustained economic development. Industrialized societies have become increasingly dependent on fossil fuels for my riaduses. Modern conveniences, mechanized agriculture ,and global population growth have only been made possible through the exploitation of in expensive fossil fuels. Securing sustain able and future energy supplies will be the greatest challenge faced by all societies in this century. Due to a growing world population and increasing modernization, global energy dem and is projected to more than double during the first half of the twenty-first century and to more than triple by theen do fthe century. Presently, the world’s population is nearly 7billion, and projections are for a global population approaching 10 billion by midcentury. Future energy demands can only bemet by introducing an increasing percentage of alternative fuels. Incremental improvements in existing energy networks will be inadequate to meet this growing energy demand Due to dwindling reserves and ever-growing concerns over the impact of burning carbon fuels on global climate change, fossil fuel sources cannot be exploited as in the past. Finding sufficient supplies of clean and sustain able energy for the future is the global society’ most daunting challenge for the twenty-first century. The future will be a mix of energy technologies with renewable sources such as solar, wind, and bio mass playing an increasingly important role in the new global energy economy. The key question is :how long it will take forth is sustainable energy change over to occur? And how much environmental, political, and economic damage is acceptable in the meantime? If the twenty-first century sustainable energy challenge is not met quickly, many less-developed countries will suffer major famines and social instability from rising energy prices. Ultimately, the world’s economic order is at stake. Approximately one-third of the world’s population lives in rural regions without access to the electric grid, and about half of the sesame people live with- out access to safe and clean water. Solar energy is unique in that it can easily provide electricity and purified water for these people today with minimal infrastructure requirements by using local energy resources that promote local economic development. Solar air heaters, because of their simple in design, are cheap and most widely used collection devices of solar energy. It is one of the basic equipment through which solar energy is converted into thermal energy. The main applications of solar air heaters are space heating, seasoning of timber ,curing of industrial products and the secan also be effectively used for curing/

drying of concrete/clay building components. A conventional solar air heater generally consists of an absorber plate, insulation below the rear plate, transparent cover on the exposed side ,and the air flows between the absorbing plate and rear plate. A solar air heater is simple in design and requires little maintenance. However, the value of the heat transfer coefficient between the absorber plate and air is low and this results in a lower efficiency [6,7].

II SOLAR AIR HEATER

A conventional solar air heater generally consists of an absorber plate with a parallel plate below forming a passage of high aspect ratio through which the air to be heated flows. As in the case of the liquid flat-plate collector, a transparent cover system is provided above the absorber plate, while a sheet metal container filled with insulation is 'provided on the bottom and sides. Solar air heaters, because of their inherent simplicity are cheap and most widely used collector devices. Solar air heaters are being used for many applications at low and moderate temperatures. Some of these are crop drying, timber seasoning, space heating, chicken brooding and curing drying of building components. Solar air heaters, because of their inherent simplicity, are cheap and most widely used as collection device. The thermal efficiency of solar air heaters has been found to be generally poor because of their inherently low heat transfer capability between the absorber plate and air flowing in the duct. In order to make the solar air heaters economically viable, their thermal efficiency needs to be improved by enhancing the heat transfer coefficient and hence the heat transfer. The heat transfer between the absorber surface (heat transfer surface) of solar air heater and flowing air can be improved by either increasing the heat transfer surface area (by using fins), without enhancing heat transfer coefficient or by increasing heat transfer coefficient using the turbulence promoters in the form of artificial roughness on absorber surface. In this report the main focus will be on the second method i.e. by creating turbulence inside the duct with the help of the artificial ribs created on the contact surface.

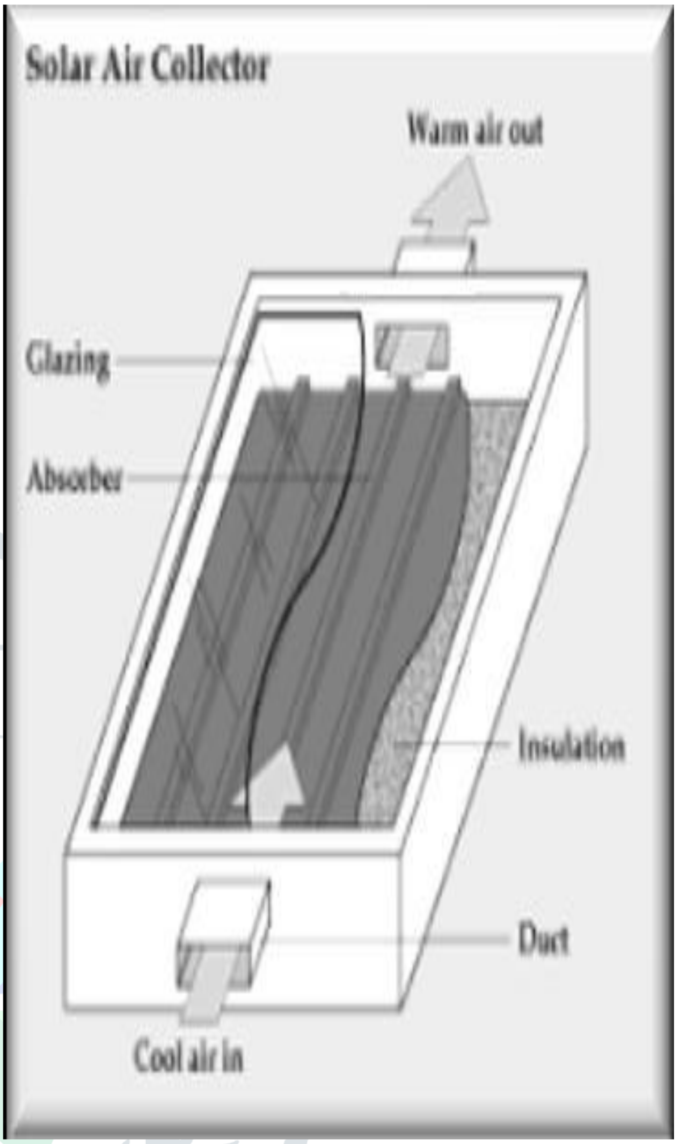


Fig 2. Solar Air Heater

II CLASSIFICATION OF AIR HEATERS

Solar air heater is a device in which energy transfer is from a distant source of radiant energy to air. Solar air heaters can be used for many purposes such as crop drying, space heating, marine products, heating a building to maintain a comfortable environment especially in the winter season. A comprehensive review on numerous designs, construction and working of solar air heater for drying is presented by Ekechukwu and Norton [3]. Here an attempt is made to classify the solar heater on the basis of with and without energy storage, numbers of covers, extended surface and their tracking axis is presented in Fig

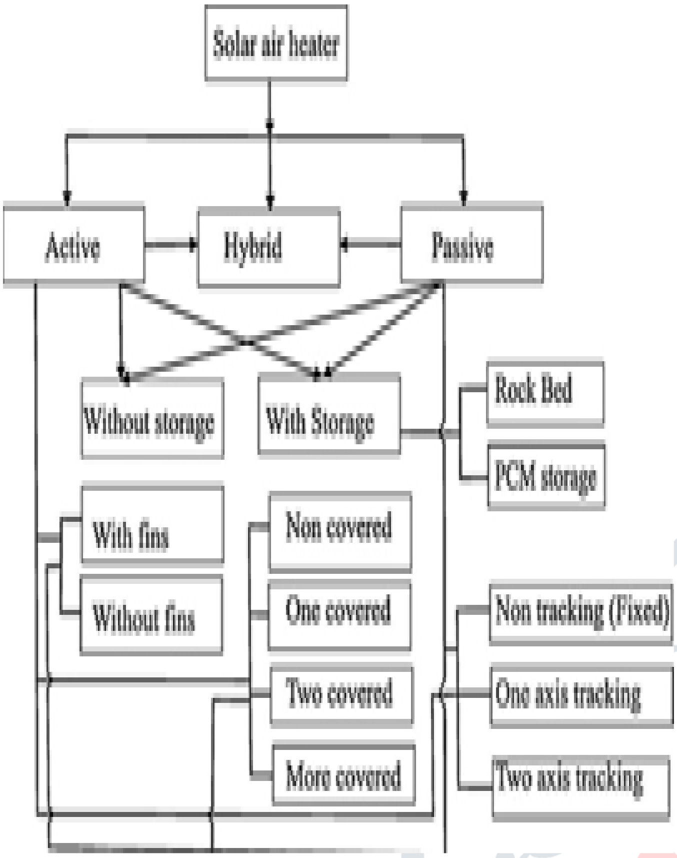


Figure 1 Classification of the SAHs

II EFFECT OF RIB HEIGHT AND PITCH

The flow patterns downstream of a rib with variation in rib height and pitch [41]. The flow separation occurs downstream of a rib and reattachment does not occur if relative roughness pitch (p/e) is less than 8. Maximum heat transfer occurs in the vicinity of reattachment point. Similarly, by decreasing the relative roughness pitch (p/e) for fixed relative roughness height (e/D) or by increasing relative roughness height (p/e) for fixed relative roughness pitch (e/D), heat transfer is enhanced. An upper limit of 10 has been imposed on relative roughness pitch (p/e) beyond which there is a decrease in heat transfer enhancement.

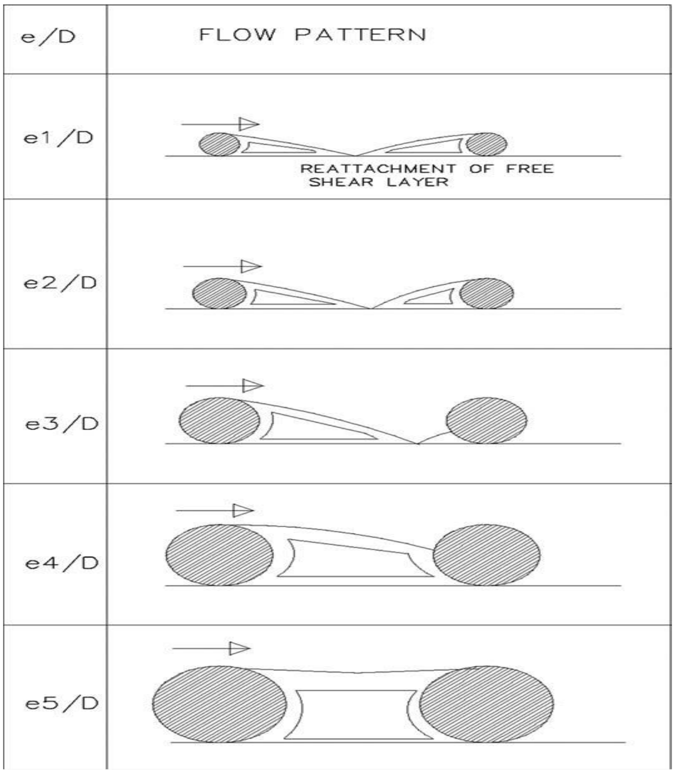


Fig. 2. Effect of rib roughness height on flow

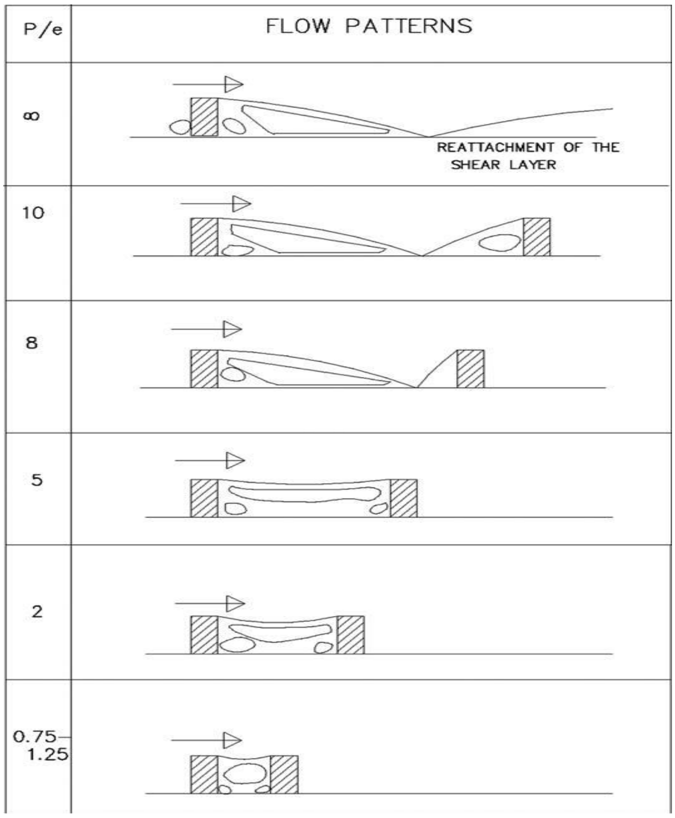


Fig. 3. Flow pattern of rib as a function of relative roughness pitch

Effect of inclination of rib

The angling of the rib with respect to flow creates counter rotating secondary flow along the span that causes span wise variation of heat transfer coefficient. The vortices move along the rib to subsequently join the main stream i.e. the fluid enters at the leading end of the rib and comes out near the trailing end. The moving vortices bring the cooler channel fluid in contact with leading end, raising heat transfer rate while the trailing end heat transfer is relatively low. This results in strong span wise variation of heat transfer [42].

Effect of width and position of gap in continuous inclined rib

With the introduction of a gap in a rib, secondary flow along the rib joins the main flow to accelerate it, which in turn, energizes the retarded boundary layer flow along the surface resulting in enhancement of heat transfer. Position of gap with respect to leading and trailing edge has a considerable effect on heat transfer enhancement. Position of the gap near the trailing edge, results in more contribution of secondary flow in energizing the main flow through the gap and recirculation loop in the remaining part of the rib, thereby, increasing the heat transfer rate

Effect of v-shaping of rib

Shaping of a long, angled rib into v-shape helps in the formation of two leading ends (where heat transfer rate is high) and a single trailing end (where heat transfer is low) resulting in much large area of heat transfer. V-shaped ribs form two secondary flow cells as compared to one in case of a straight angled rib resulting in higher overall heat transfer coefficient in case of v-shaped rib. V-shaped rib with apex facing downstream has a higher heat transfer as compared to that of with apex facing upstream [42].

Effect of discretizing of v-shaped ribs

The v-shaped ribs along with staggered rib pieces in between further increase the number and area of heat transfer regions. Additional rib parameters related to the size and positioning of rib pieces (length ratio, B/S, segment ratio, S0/S and staggering ratio, P0/ P) with respect to main rib produce complex interaction of secondary flow [44].

Effect of rib cross-section

Rib cross-section affects the size of separated region and level of disturbance in the flow. The friction factor is less for circular cross section ribs in comparison to that of rectangular or square cross section ribs on account of reduction in the size of separated region. This results in decrease in inertial losses and increase in skin friction, thereby, decreasing the friction factor. As the size of separated region diminishes, level of disturbance in flow also decreases which affects the heat transfer adversely. Another possible factor contributing to the Nusselt number decrease is the reduction in heat transfer surface area associated with circular cross-section ribs [45].

III ENHANCEMENT IN PERFORMANCE OF MATRIX SOLAR AIR HEATER

The efficiency of a solar air heater can be increased by packing its duct with wire screen matrices [40,42], iron chips [43], iron foils [44], etc. Thermal performance of wire screen meshes as heat exchanger material was done numerically by Xuetal .had found that using wire mesh improves heat transfer rate [45]. A schematic diagram of matrix solar air heater with single and double pass. In general a matrix material in the air flow duct induces turbulence in the flow and enhances heat transfer rate from the absorber plate to the fluid. Many experimental studies are reported in the literature on matrix solar air heater and percentage enhancement in thermal and thermohydraulic efficiency of packed bed solar air heaters as compared to conventional type

Enhancement in thermal efficiency

Theoretical study on double pass solar air heater were done by P.Naphon [46] and Languri etal. [47]. The theoretical models were compared with experimental results in both the above studies. Naphon [46] reported 25.9% higher thermal efficiency of porous media than that without porous media. 40% higher thermal efficiency in porous bed solar air heater. Initial conditions for the theoretical calculation were reported to be same for both the studies. But there as on for the increase in thermal efficiency high lighted by the authors in both the works were different.

Enhancement in thermohydraulic efficiency

Thermo hydraulic efficiency is important to design an energy efficient solar air heater. A solar air heater with high thermal efficiency and low fan running cost attributes to high thermo hydraulic performance. Ahmad etal. [57] evaluated thermo hydraulic performance of packed bed solar air heater experimenttally. It was reported that the thermohydraulic efficiency decreased with increase in the values of bed epth to element size ratio and bed porosity, but it increased with increase in mass flow rate of air ,attained a maximum and subsequently decreased with further increase in mass flow rate. Enhancement in thermo hydraulic efficiency increased from 8.8%at the highest mass flow rate of 0.0252kg/m2s to24.5% at lowest mass flow rate of 0.0138kg/m2s.

IV PROPERTIES AFFECTING THE PERFORMANC EOF MATRIX SOLAR AIR HEATER

Effect of thermo-physical property of packing material

The different matrix materials reported in literature and their efficiencies. Thermophysical property implies thermal conductivity, thermal stability, etc. Thermal conductivity plays an important role in the bed heat transfer when all other parameters are constant. Choudhury and Garg [25] figured out that the conduction heat transfer in the bed is negligible because of the point contact between the packing materials, but the effect of thermal conductivity of the bed element is relevant in a modified heat transfer coefficient between the packing material and the fluid. Parm pal Singh [64] evaluated the performance of packed bed solar air heater with irons having s and iron wires .It was observed that air heater with iron havings showed a higher outlet temperature in the morning time and after3:00p.m.the case was reverse while air heater with iron wires showed superior performance than air heater with irons havings. This is due to the fact that the thermal capacity of the iron wire was more than the thermal capacity of irons havings. Ahmad etal. [41] studied with iron, copper and brass matrices and observed that copper screen matrices exhibited better performance than brass and iron due to its high thermal conductivity.

Effect of geometrical parameters of matrix collector

Different studies are reported in the literature for matrix solar air heaters by varying the geometrical parameters. To find the effect of geometrical parameters on the efficiency of the system, experimental and mathematical models for varying parameters of packing wire mesh like diameter, pitch, porosity, extinction coefficient, bed to element size ratio, etc. a represented by many researchers Porosity depends on the geometrical parameters of the wire mesh like wire diameter, pitch, number of layers of a fixed bed depth. The geometrical parameters may vary for same porosities Besides porosity, number of layers and pitch to diameter ratio play an important role in the flow behavior reported by Varshney and Saini [70]. Increasing the porosity increases the heat removal factor and hence decreases the efficiency. Bansal and Singh [53]

Effect of operating parameter

Air mass flow rate is an important operating parameter of solar air heaters. The efficiency of air heater increases with increasing mass flow rate, because the heat removal capacity depends directly on the air mass flow rate [46]. When the mass flow rate increased from 0.002kg/s to 0.042kg/s the temperature rise parameter decreased whereas the efficiency increased for a matrix plate solar air heater [53]. Mass flow rate plays an important role altering the performance parameters of air heaters like collector heat removal and collector efficiency factor. Lower the mass flow rate, lower is the heat removal and collector efficiency factor. For the flow rate ranging from 41.9kg/m2 h to 76.8kg/m2 h, the collector heat removal factor and plate efficiency factor varied from 0.24to0.71 and from 0.26 to 0.89, respectively for a matrix solar air heater designed and tested by Sharma etal. [44]. Thermal efficiency of a steel wire mesh packed solar air heater increased with increasing mass flow rate from 0.012kg/s to 0.038kg/s and yielded a maximum efficiency at 0.038kg/s [55]. Dhiman et al [34]

V CORRELATION FOR HEAT TRANSFER AND FRICTION FACTOR

An analogy exists between heat transfer and friction factor for the packed bed wire mesh solar air heaters. Heat transfer and friction factor area strong function of wire diameter, pitch and number of layers of wire mesh. Various correlations have been developed by different researchers according to the data obtained for flow through the packed bed solar air heater. Correlations developed by different researchers are given in developed correlations for col burn j h factor and friction factor for fluid flow in solar air heater packed with wire screen matrices. Investigation was carried on varying Reynolds number from 2800 to 10,000, mass flow rate from 0.01 to 0.03kg/s, pitch to diameter ratio from 3.77 to 7.55.The heat transfer are a was more for the collector with lower porosity and pitch to diameter ratio .It has been reported that the porosity of the bed affects the heat transfer coefficient developed correlations for low porosity range and Reynolds number ranging from 182 to 1168 which correlated the experimental data satisfactorily with the maximum deviation of 10.5 for col burn j h factor and 7% for friction factor .Prasad et al. [62] developed correlations for col burn j h factor and friction factor and compared with experimental results. From their correlations it was concluded that the heat transfer coefficient increased with a decrease in porosity and with an increase of mass flow rate. Col burn j h factor decreased with an increase of porosity where as the friction factor decreases with an increase of Reynolds number and porosity..

VI CFD METHODOLOGY

Computaional Fluid Dynamics or CFD has become a powerful tool for pure or applied research or industrial applications and it focuses on the investigations of system involving fluid flow, heat and mass transfer and other associated phenomemon such as study of che mical reactions through simulations. Some of the areas where CFD is used prominently area erospace engineering, automotive engineering, breathing and blood flow, fluids flowing through pumps and pipes, rivers and pollutants, turbines and furnaces and sports like golf and and swimming etc. CFD analysis of any phenomenon in devices can be divided into three main elements discussed briefely below:

6.1 Pre-processor

This deals with definition and creation of geometry of the flow region with the help of various modeling software. Mesh is generated for the given domain in which analysis is to be done and it is one of the most important steps of preprocessing. The computational domain is divided into a number of small domains (discritization) to solve the flow problems with in the domain geometry. The seare also called as grids or cells where the fluid flows are solved numerically to get the discrete values of flow properties like velocity, pressure, temperature and other transport phenomenon as per requirement. Grid independence is also checked to avaoid axcess time reqirement by solver

.6.1.1 Solver

Selection of fluid properties and the under lying physics is adopted to solve the computational problem. Boundary conditions are specified at inlet, outlet and on the surfaces of geometry as per the requirement of the problem. Selection of proper boundary conditions is vital in obtaing the final results. Initialization of the iterative procedure involving all the discrete values of the flow properties, like velocity, pressure, temperature, and other transport parameters of interest. Convergence is monitored for successful computational solution and it is an important criterion to acess the progressive imbalances of the over all conseavation of flow properties. Aconverged solution is achieved when the residual sreach below the given convergence criteria.

6.1.2 Post-processing

It shows the computational results through graphical displays and values of the flow properties. Graphical User Interface (GUIs) allow us to view the results of CFD simulation. The various flow phenomenon which takes place during simulation, velocity contours, pressure contours can be obtained as well The values of parameters related with flow processes like heat transfer coefficient can also be obtained

VII TESTING OF SOLAR AIR HEATERS

Thermal performance testing of solar collectors is essential for generating basic design data required for system design of such collectors. There are two methods for standard testing of solar collectors, namely

- National Bureau of Standards(NBS
- ASHRAE Standard

NB and ASHRAE standards provide the necessary features for solar air heaters including the detailed specifications of conditions relating to air flow measurement, air temperature measurements, air mixing and pressure drop measurements. The some essential features of the testing procedures can be summarized as follows [54]:

- Means are provided to feed the collector with fluid at a controlled inlet temperature and mass flow rate
- Solar radiation is measured by a Pyranometer on the plane of the collector.
- Means of measuring flow rate, inlet and outlet fluid temperatures, and ambient conditions are provided.
- Means are provided for measurements of pressure and pressure drop across the collector.
- Means are provided for measurements of temperature of the collector's elements at various locations within the collector and the outgoing air at the outlet.

VIII EFFECT OF PARAMETERS ON COLLECTOR PERFORMANCE

The performance of a solar collector is a complex function of various parameters investigated by several researchers. It was reported that performance of a solar collector greatly affected due to any alteration in one of them and yields a considerable change in the performance of solar collector. Various parameters which affect the performance of the solar air collector can be classified as follows

Meteorological parameters.

Incident solar radiation

Higher incident radiation results higher outlet air temperature but increases the radiative heat losses through glass cover as well Moreover, some studies reported a very small decline in the thermal efficiency for the given inlet fluid temperature. The influence of incident solar radiation on the collector efficiency is given in Ho et al. [41].

Ambient temperature

Ambient temperature affects the performance of collector indirectly through the heat losses. For a given outlet temperature, low ambient temperature results in low efficiency and vice-versa.

Wind speed

Convective heat transfer from the cover plate to the ambient air is significantly dependent on the wind speed. Higher the wind speed greater is the thermal loss which causes the collector efficiency to decrease. The relative influence of wind speed on a one- cover system is larger as compared to that for two and three cover systems .Moreover, the effect of double glass cover is clearly illustrated

Shading and dust on the top cover

Hottel and Woertz [51], based on experiments with two-cover collectors, recommend that the radiation absorbed by the plate be reduced by 3% to account for shading effects if the net (unob- structed) glass area is used in all calculations. The net area accounts for the blockage by the supports for the glass. Dust effects can also be significant. In order to account for reduction in transmitted solar energy flux due to dust, the incident flux has to be multiplied by the correction factor depending on many factors like location, time of the year and material of the collector. From long term experiments on collectors in the Boston area, Hottel and Woertz [51] found that collector performance decreased approximately 1% due to dirty glass. In a rainless 30-days experiment in India, Gurg [66] found that dust reduced the transmit an ceby an average of 8% for glass tilted at 45°. To account for dust in temperate climates, it was suggested that radiation absorbed by the plate be reduced by 1%; in dry and dusty climates, absorbed radiation can be reduced by 2%.

VIII ARTIFICIAL ROUGHNESS

Artificial roughness is basically a passive heat transfer enhancement technique by which thermo hydraulic performance of a solar air heater can be improved. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent [11]. However, energy for creating such turbulence has to come from the fan or blower and the excessive power is required to flow air through the duct. Therefore, it is desirable that the turbulence must be created only in the region very close to the heat transferring surface, so that the power requirement may be lessened

This can be done by keeping the height of the roughness elements to be small in comparison with the duct dimensions. The key dimensionless geometrical parameters that are used to characterize roughness are:

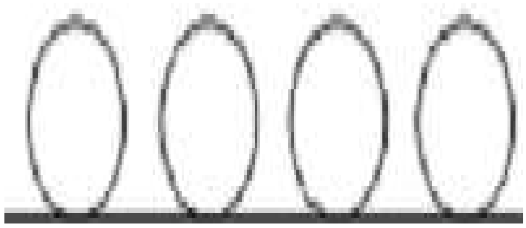
1. Relative roughness pitch (p/e): Relative roughness pitch (p/e) is defined as the ratio of distance between two consecutive ribs and height of the rib.
2. Relative roughness height (e/D): Relative roughness height (e/D) is the ratio of rib height to equivalent diameter of the air passage.
3. Aspect ratio: It is ratio of duct width to duct height. his factor also plays a very crucial role in investigating thermo-hydraulic performance
4. The shape of the roughness element: The roughness elements or the ribs can be 2D or 3D, transverse or inclined, continuous or broken with or without gaps between them.

The artificial roughness on absorber surface may be created, either by roughening the surface randomly with a sand grain/sand blasting or by use of regular geometric roughness known as ribs. It is well known that in a turbulent flow a laminar/viscous sub-layer exists in addition to the turbulent core. The artificial roughness on heat transfer surface breaks up the laminar boundary layer of turbulent flow and makes the flow turbulent adjacent to the wall. The artificial roughness that results in the desirable increase in the heat transfer also results in an undesirable increase in the pressure drop due to the increased friction; thus the design of the flow duct and absorber surface of solar air heaters should, therefore, be executed with the objectives of high heat transfer rates and low friction losses.

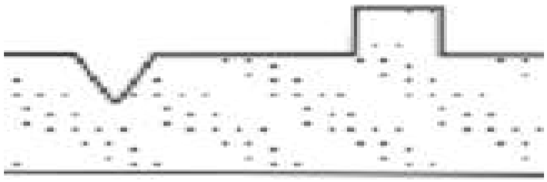
Artificial roughness up to laminar sub-layer to enhance heat transfer coefficient is used in various applications like solar air heaters, heat exchangers, nuclear reactors and gas turbine blade cooling channels. A number of experimental studies in this area have been carried out but very few attempts of numerical investigation have been made so far due to complexity of flow pattern and computational limitations. Hence, these investigations reveal that not only the rib geometry but also its geometrical arrangement play a vital role in enhancing the heat transfer coefficient. Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows **[1]**.Computers are used to perform the millions of calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. Even with high-speed super computer only approximate solutions can be achieved in many cases. CFD - a computational technology that enables one to study the dynamics of things that flow. Using CFD, one can build a computational model that represents a system or device that is required for study.

Artificial roughness technique

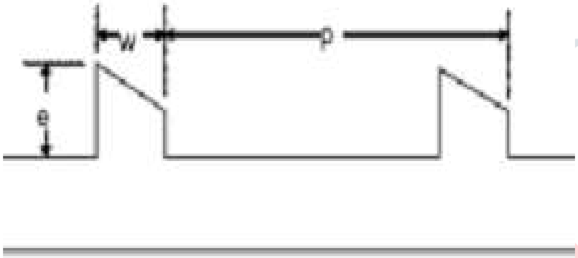
Artificial Roughness technique has been used by the researchers since long for the enhancement of heat transfer from the absorber plate of the solar air heater. In this technique the air flowing over the absorber plate is provided turbulence so as to improve heat transfer. The turbulence is provided by the artificial elements. The artificial roughness elements are kept over the plate surface where transfer of heat is taking place. The turbulence in air is created by these elements and depends upon the shape and size of the elements of roughness. Since the artificial roughness provides resistance to flow, power requirement for the flow also increases. It is therefore required to keep the power requirement as low as possible by maintaining surface resistance to a minimal value. For the analysis of the performance of the solar air heater with artificial roughness, some parameters are used e. g Relative roughness pitch, Relative roughness height, Angle of attack and aspect ratio. Various roughness geometries have been used by the researchers for heat transfer analysis some of the geometries are V shaped, Square shaped, wire rib, transverse rib grooved, metal grit rib and chamfered rib as shown in figure3.



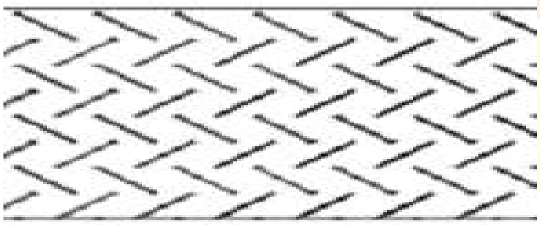
(a) Wire rib



(b) Transverse rib grooved



(c)Chamfered rib



(d)Metal grit rib

Figure 3: Different Roughness geometries

VIII CONCLUSION

Solar air heater is a simple device which captures the solar energy. Producing hot air by using solar air heater is a renewable energy heating technology used to process heat generation for space heating. Such systems produce heat at zero cost. Minimum maintenance like cleaning of collectors only is required. Energy storage not only plays an important role in conservation of the energy but also improves the performance and reliability in wide range of energy systems and becomes more important where the energy source is intermittent in nature such as solar. Energy storage process reduces the rate of mismatch between energy supply and its demand. The thermal energy storage can be used in such places where the variation between the day and night temperature is much more. In this comprehensive review, a detailed research work is accumulated for air heating system with and without thermal energy storage. Obstacle, Fin, baffles based air heating system, latent heat storage based air heating system and PV/T hybrid air heating systems are covered. It can also be concluded that from these comprehensive reviews lot of works have been carried out globally to evaluate the performance of different types of solar air heaters. Mostly flat plate air heater produces hot air at low temperature and found suitable for drying agricultural products. Hybrid PV/T type solar air heater shows their viability in force convection type air heating with electricity production. Various investigators have developed thermal energy storage type air heater for effective and efficient utilization of hot air for space heating. Many investigations reported that PCM based thermal energy storage solar heater is suitable for crop drying applications.

References

1. M.M. Sahu, J.L. Bhagoria, "Augmentation of heat transfer coefficient by using 90^0 broken transverse ribs on absorber plate of solar air heater" Renewable Energy 30 (2005) 2057–2073.
2. Anil Kumar et. al. "Artificial roughness in the form of repeated ribs is one of the effective way of improving the performance of a solar air heater ducts". Renewable Energy. 2012, 29, 402- 426.
3. Kumar &Saini et.al. "A Comprehensive Review on Roughness Geometries and Investigation Techniques Used in Artificially Roughened Solar Air Heaters", International Journal of Renewable Energy Research, 2012, 2, 1-15.
4. Karmare SV, Tikekar AN. "Heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs". Int J Heat Mass Transfer.2007, 50, 4342-4351.
5. Sharma AK and Thakur NS. "CFD based Fluid Flow and Heat Transfer Analysis of a V-Shaped Roughened Surface Solar Air Heater". International

Journal of Engineering Science and Technology, 2012, 5, 2115-2121.

6. Sachin Choudhary Kumar Manish, “Heat transfer and friction factor characteristics using continuous M shape ribs turbulators” International Journal of Energy and Environment (IJEE), Volume 3, Issue 1, 2012, pp.33- 48.
7. Sourabh Khurana “Computational Fluid Dynamics Based Analysis of Angled Rib Roughened Solar Air Heater Duct” International Journal of Thermal Technologies ISSN 2277 – 4114.
8. Singh et.al. “Heat transfer and fluid flow analysis of solar air heater: A review of CFD approach”, Renewable and Sustainable Energy Reviews 23 (2013) 60–79.
9. Sandeep M Joshi “Mathematical Modeling of Solar Air Heater” Vol. 3, Issue 3, May-Jun 2013, pp.1000-1010
10. Anil Singh Yadav, J.L.Bhagoria, “Heat transfer and fluid flow analysis of solar air heater: A review of CFD approach”, Renewable and Sustainable Energy Reviews 23 (2013) 60–79.
11. Jaurker AR, Saini JS, Gandhi BK. “Heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness”. Solar Energy.2006, 80, 895-907.
12. Prasad BN, Saini JS. “Effect of Artificial Roughness on Heat Transfer and Friction Factor in a Solar Air Heater”, Solar Energy, 1988, vol. 41, 555-568.
13. Karwa K, Solanki SC, Saini JS. “Study of heat transfer and friction in solar air heaters roughened with staggered discrete ribs”. Proceedings of the fourth ISHMT-ASME heat and mass transfer conference, Pune, India. 2000, 33, 391-408.
14. Karmare, A.N. Tikekar “Heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs” International Journal of Heat and Mass Transfer 50 (2007) 4342–4351.
15. AtulLanjewar, J.L. Bhagoria, R.M. Sarviya, “Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate”Energy 36 (2011) 4531-4541.
16. AtulLanjewar, J.L. Bhagoria, R.M. Sarviya, “Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness Experimental Thermal and Fluid Science 35 (2011) 986–995.
17. Bhagoria JL, Saini JS, Solanki SC. “Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate”. Renew Energy. 2002, 25, 341–369.
18. J.L. Bhagoria, J.S. Saini, S.C. Solanki “Heat transfer coefficient and friction fact correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate” Renewable Energy 25 (2002) 341–369.
19. Anil Singh Yadav, J.L. Bhagoria, “A CFD (computational fluid dynamics) based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate” Energy 55 (2013) 1127-1142.
20. Anil SinghYadav, J.L.Bhagoria, “Heat transfer and fluid flow analysis of solar air heater: A review of CFD approach”, Renewable and Sustainable Energy Reviews 23 (2013) 60–79.
21. S.C. Lau, R.T. Kukreja, R.D. Mcmillin, “Effects of V-shaped rib arrays on turbulent heat transfer and friction of fully developed flow in a V-Shape rib with different relative gap width channel” Int. J.Heat Mass Transfer. Vol. 34, No. 7 .pp 1605-1616, 1991.
22. J.C. Han, P.R. Chandra, C.R Alexandra, “Heat transfer and friction behaviors in rectangular channels with varying number of ribbed walls” International Journal of Heat and Mass Transfer 46 (2003) 481–495.
23. Jaurker AR, Saini JS, Gandhi BK. “Heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness”. Solar Energy.2006, 80, 895-907.
24. TabishAlam, R.P.Saini, J.S.Saini “Effect of circularity of perforation holes in V-shaped blockages on heat transfer and friction characteristics

of rectangular solar air heater duct" Energy Conversion and Management 86 (2014) 952–963.

25. R. Karwa, S.C Solanki ,J.S Saini "Heat transfer coefficient and friction factor correlations for the transitional flow regime in rib roughened rectangular ducts" International Journal of Heat and Mass Transfer 42 (1999) 1597-1615.
26. Dhanjay Gupta, S.C. Solanki, J.S. Saini "Thermo hydraulic Performance On Solar air Heater With Roughened Absorber Plates" Solar Energy Vol. 61, No. 1, pp. 33-42, 1997.
27. RajendraKarwa "Experimentally investigated that heat transfer and friction factor in rectangular duct with rectangular cross-section rib on one broad wall in transverse inclined V-continues and V-discrete pattern" Int. Comm. Heat Mass Transfer Vo.30,No.2,pp.241-250,2003.
28. P. R. Chandra, C. R. Alexander and J. C. Han, "Heat transfer and friction Behaviors in Rectangular Channels with Varying Number of Ribbed Walls," Int. J. Heat Mass Transfer, Vol. 46, pp. 481-495. 2003.
29. Bhagoria JL, Saini JS, Solanki SC. "Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate". Renew Energy. 2002, 25, 341–369.
30. Abdul-Malik EbrahimMomin, J.S. Saini S.C. Solanki "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 (2002) 3383–3396.
31. Sahu MM, Bhagoria JL. "Augmentation of heat transfer coefficient by using 90 degree broken transverse ribs on absorber plate of solar air heater". Renew Energy. 2005, 30, 2057-2063.
32. AlokChaube, P.K. Sahoo, S.C. Solanki "Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber Plate of a solar air heater" Renewable Energy 31 (2006) 317–331.
33. RajendraKarwa, B.K. Maheswari, NitinKarwa "Experimental study of heat transfer enhancement in an asymmetrically heated rectangular duct with perforated baffles" International Communications in Heat and Mass Transfer 32 (2005) 275–284.
34. A.R. Jaurker, J.S. Saini , B.K. Gandhi "Heat transfer and friction characteristics of rectangular Solar air heater duct using rib-grooved artificial roughness" Solar Energy 80 (2006) 895–907.
35. Aharwal KR, Gandhi BK, Saini JS. "Experimental investigation on heat transfer enhancement to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater". Renew Energy. 2008; 33, 585-596.
36. Rajesh Maithani , J.S. Saini "Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with V-ribs with symmetrical gap" Experimental Thermal and Fluid Science 70 (2016) 220–227.
37. Thakur SK, Thakur NS, Thakur Anoop, Vijay Mittal Use of artificial roughness to enhance heat transfer in solar air heaters- A review Journal of Energy in Southern Africa 2010
38. M.K. Gupta, S.C. Kaushik .Performance evaluation of solar air heater for various artificial roughness geometries based on energy, effective and exergy efficiencies. Renewable Energy 34 (2009) 465–476
39. Apurba Layek, J.S. Saini, S.C. Solanki. Effect of chamfering on heat transfer and friction characteristics of solar air heater having absorber plate roughened with compound turbulators. Renewable Energy 34 (2009) 1292– 1298.
40. Aharwal, K.R. Gandhi, B.K. and Saini, J.S., (2008). 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.
41. R.P. Saini , Jitendra Verma. Heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters. Energy 33 (2008) 1277– 1287
42. R. Kamali , A.R. Binesh . The importance of rib shape effects on the local heat transfer and flow friction characteristics of square ducts with ribbed

internal Surfaces. International Communications in Heat and Mass Transfer 35 (2008) 1032–1040

43. SharadKumar, R.P.Saini CFD based performance analysis of a solar air heater duct provided with artificial roughness (2008).
44. Aharwal, K.R. Gandhi, B.K. and Saini, J.S., (2006). Effect of gap in inclined ribs on the performance of artificially roughened solar air heater duct. Advances in Energy Research, pp.144-150.
45. Alok Chaube, P.K. Sahoo, S.C. Solanki. Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater, Renewable Energy 31 (2006) 317–331
46. M.M. Sahu, J.L. Bhagoria, Augmentation of heat transfer coefficient by using 90° broken transverse ribs on absorber plate of solar air heater, Renewable Energy (30) (2005) 2057–2073.
47. Tanda G. Heat transfer in rectangular channels with transverse and V- shaped broken ribs. Int J Heat Mass Transfer 2004;47: 229–43.
48. J.L. Bhagoria , J.S. Saini , S.C. Solanki. Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. Renewable Energy 25 (2002) 341–369
49. Prasad BN, Saini JS. Effect of artificial roughness on heat transfer and friction factor in a solar air heater. Solar Energy 1988; 41:555–60.
50. Hussain Akhtar , Arif Sayed Md, Aslam Md. Emerging renewable and sustainable energy technologies: State of the art. Renewable and sustainable energy reviews 2017; 71: 12-28.
51. Rajaseenivasan T, Srinivasan S, Srithar K. Comprehensive study on solar air heater with circular and V-type turbulators attached on absorber plate Energy 2015; 88: 863-73.
52. Ekechukwu OV, Norton B. Review of solar-energy drying systems II: an overview of solar drying technology. Energy Convers Manag 1999; 40(6):615–55.
53. V.V Tyagi, N.L Panwar, N.A.Rahim, Richa Kothari, Review on solar air heating system with and without thermal energy storage system. Renewable and Sustainable Energy reviews, 2012; 16; 2289-2303.
54. Alkilani Mahmud M, Sopian K, Alghoul MA, Sohif M, Ruslan MH. Review of solar air collectors with thermal storage units. Renew Sustain Energy Rev 2011; 15: 1476–90.
55. Chamolia Sunil, RanchanChauhana, Thakura NS, Sainib JS. A review of the performance of double pass solar air heater. Renew Sustain Energy Rev 2012; 16: 481–92.
56. Ho CD, Yeh HM, Cheng TW, Chen TC, Wang RC. The influences of recycle on performance of based double-pass flat-plate solar air heaters with internal fins attached. Appl Energy 2009; 86:1470–8.
57. Chabane Foued, Moummi Noureddine, Benramache Said. Experimental study of heat transfer and thermal performance with longitudinal fins of solar air heater. J Adv Res 2014; 5:183–92.
58. Ebru Kavak Akpinar , Fatih Koçyiğit . Experimental investigation of thermal performance of solar air heater having different obstacles on absorber plates. Int Commun Heat Mass Transf 2010; 37:416–21.
59. Bayraka Fatih, Oztopb Hakan F, Hepbaslic Arif. Energy and exergy analyses of porous baffles inserted solar air heaters for building applications. Energy Build 2013; 57:338–45.
60. El-Sebaii AA, Aboul-Enein S, Ramadan MRI, Shalaby SM, Moharram BM. Thermal performance investigation of double pass-finned plate solar air heater. Appl Energy 2011; 88:1727–39.
61. Gao Wenfeng, Lin Wenxian, Liu Tao, Xia Chaofeng. Analytical and experimental studies on the thermal performance of cross-corrugated and flat-plate solar air heaters. Appl Energy 2007;84:425–41.
62. Bouadila Salwa, Kooli Sami, Lazaar Mariem, Skouri Safa, Farhat Abdelhamid. Performance of a new solar air heater with packed-bed latent storage energy for nocturnal use. Appl Energy 2013;1 10:267–75.
63. Krishnananth SS, Kalidasa Murugavel K. Experimental study on double pass solar air heater with thermal energy storage. J King Saud Univ – Eng Sci 2013; 25:135–40.

64. Yamali C, Solmusf I. A solar desalination system using humidification-dehumidi-fication process: experimental study and comparison with the theoretical results. Desalination 2008; 220:538–51.
65. Rabin Y, Bar-Niv I, Korin E, Mikie B. Integrated solar collector stor-age system based on a salthydrate phase change material. Solar Energy 1995; 55(6):435–44.
66. Hasan A. Phase change material energy storage system employing palmitic acid. Solar Energy 1994; 52:143–54.
67. Enibe SO. Thermal analysis of a natural circulation solar air heating system with phase change material energy storage. Renewable Energy 2003; 28:2269–99.
68. Tyagi VV, Buddhi D. PCM thermal storage in buildings: a state of art. Renewable and Sustainable Energy Reviews 2007; 11(6):1146–66.
69. Morrison DJ, Abdel-khalil SI. Effects of phase-change energy storage on the performance of air-based and liquid-based solar heating systems. Solar Energy 1978; 20:57–67. A Review On Solar Air Heater Technology http://www.iaeme.com/IJMET/index.asp 1131 editor@iaeme.com
70. Hammou ZA, Lacroix M. A new PCM storage system for managing simultane-ously solar and electric energy. Energy and Buildings 2006; 38:258–65.
71. Qi Q, Deng S, Jiang Y. A simulation study on a solar heat pump heating system with seasonal latent heat storage. Solar Energy 2008; 82:669–75.
72. Kaygusuz K. Experimental and theoretical investigation of a solar heating sys-tem with heat pump. Renewable Energy 2000; 21:79–102.
73. Nallusamy N,Velraj R. Experimental investigation on a com-bined sensible and latent heat storage system integrated with constant/varying (solar) heat sources. Renewable Energy 2007; 32: 1206–27.
74. Alkilani MM, Sopian K, Mat S, Alghoul MA. Output air temperature prediction in a solar air heater integrated with phase change material. European Journal of Scientific Research 2009; 27(3):334–434.
75. Ravish Kumar Srivastava and Ajeet Kumar Rai, Studies on the Thermal Performance of a Solar Air Heater. International Journal of Mechanical Engineering and Technology, 7(6), 2016, pp. 518–527.
76. Ravish Kumar Srivastava and Ajeet Kumar Rai, Thermal Performance Investigation of A Finned Absorber Plate Solar Air Heater, International Journal of Mechanical Engineering and Technology, 8(6), 2017, pp. 622–630.
77. Saman W, Bruno F, Halawa E. Thermal performance of PCM thermal storage unit for a roof integrated solar heating system. Solar Energy 2005; 78:341–9.
78. Saket Kumar, R.K. Prasad and K.D.P. Singh. Thermal Performance and Economics Analysis of Double Flow Packed Bed Solar Air Heater. International Journal of Mechanical Engineering and Technology, 8(2), 2017, pp. 176–182.