Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P) Vol.9 No.1, 2020, pp.1-4

DOI: https://doi.org/10.51983/arme-2020.9.1.2477

Theoretical Study on Methods to Increase the Efficiency and Performance of Solar Air Heater

Vishwas Nagrath[1], Seyed Hunzela Haq[1], Harshit Mishra[1], and Adil Wazeer[2]
[1] Department of Mechanical Engineering, Allenhouse Institute of Technology, Kanpur, Uttar Pradesh, India
[2]School of Mechanical Engineering, Galgotias University, Greater Noida, Uttar Pradesh, India
E-mail: vishwasnagrath585@gmail.com

***Abstract* - Due to the low thermal performance of solar air heater, different methodologies are adopted to increase its performance namely fins, artificial roughness etc. Thermal performance is obtained for different values of Reynolds number, emissivity of a plate, tilt angle and by employing different kinds of artificial roughness. There are numerous techniques which can be used on the absorber plate to increase the efficiency and Thermo-hydraulic performance of the solar air heater. We can use single roughness geometry or can combine two different roughness geometries also to get best output. By defining different correlations of heat transfer and friction factor in roughened ducts of solar air heater, we can get the best artificial roughness that can be utilized in the solar air heater. By selecting the coating material, we can improve the performance of solar air heater. As we must use our energy for future purpose, we have to store it and for that thermal energy storage materials are used. This is also one of the techniques to increase the effectiveness of solar air heater. In this article, focus has been given on study of methods of increasing the performance of solar air heater such as providing artificial roughness, increasing the collector aspect ratio etc.**

***Keywords*: Thermal Performance, Solar Air Heater, Artificial Roughness, Efficiency, Solar Energy.**

I. INTRODUCTION

Solar energy is a purely free form of energy which can be easily accessed. Due to the mammoth depletion of fossil fuels and other non-renewable resources there is an urgent need of renewable resources which can reduce the consumption of fossil fuels. Because of the eco-friendly nature, there will be a large scope of these resources in the upcoming days. One of the renewable resources is the Sun from which solar energy is obtained. Solar energy is used in various devices like solar air heater, solar cooker, solar cell etc. For heating applications, the simple and efficient means which can be converted into thermal energy by using solar collectors. Many solar collectors are available but solar air heater is one of the cheapest technologies. The main applications of solar air heater are space heating, seasoning of timber, curing of industrial products, drying of agricultural product such as crops, grains, seeds, fruits, vegetables, and medicinal plants. Its thermal efficiency is quite low because of its low convective heat transfer coefficient between the absorber plate and flowing air leads to higher plate temperature and greater thermal losses. For the analysis and design of the air solar heater, ANSYS CFD software is used. CFD is a simulation tool which uses powerful computer and applied mathematics for the model fluid flow situations, for the prediction of heat, mass and momentum transfer and optimal design in various heat transfer and fluid flow process. ANSYS CFD Technology is highly scalable, allowing for efficient parallel calculations on thousands of processing cores. To increase the thermal efficiency of the SAH, an extended surface in the form of turbulators and fins are used to increase the convective heat transfer coefficient between the absorbing surface and the flowing air. [1,2].

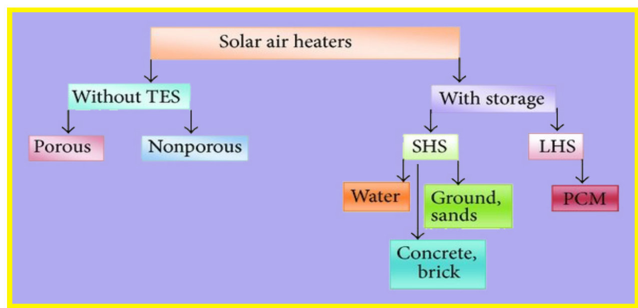

Fig.1 Classification of Solar Air Heaters [3].

The main applications of solar air heaters are space heating and drying. The solar air heater occupies an important place among solar heating systems because of minimal use of materials. Furthermore, direct use of air as a working substance reduces the number of components required in the system. The primary disadvantage of solar air heaters is it's need for handling relatively large volumes of air with low thermal capacity as working fluid.

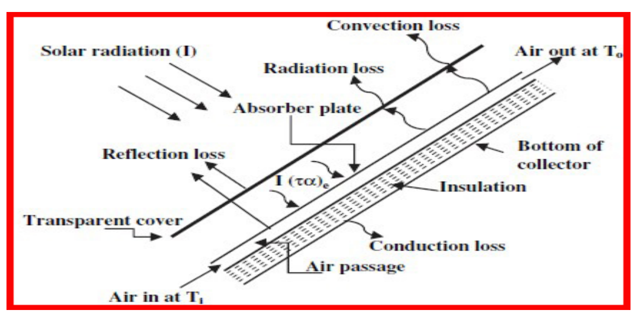

Fig. 2 Conventional Solar Air Heater [4].

The main applications of SAH are seasoning of timber, space heating [4], curing of industrial products, and drying processes in several applications [5, 6]. In addition, in order to generate heat for crop drying, marine products, building's heating, textile dyeing and water desalination, solar air heaters are used [7]. Solar energy has a lot of methods or techniques for utilizing. Commonly, it is used to provide heat, light or to produce electricity [8].

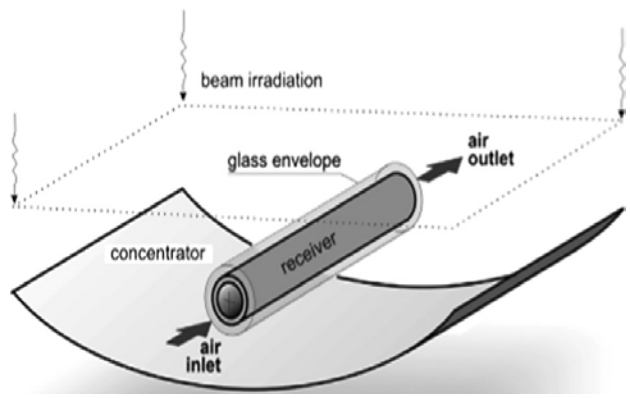

Fig. 3 Concentrating Type SAH [9]

Fig. 4 A Prototype PV/T Air Collector [10].

Hughesetal. [11] had studied two basic types of off-peak solar energy systems. The systems were designed so that sufficient energy remains available inside the system, either from stored solar energy or through hauxiliary energy to meet the space heating load during peak demand periods. Auxiliary energy can be stored on- site, (oil or LPG), or provided by utility (electricity or natural gas).

II. ARTIFICIAL ROUGHNESS

In order to increase the heat transfer coefficient artificial roughness of different geometries on the heat transfer surface is provided. The use of artificial roughness on the underside of the absorber plate disturbs the viscous sub-layer of the flowing medium [12]. We can provide roughness in the form of ribs or fine wires and it can be of any shape and size like wedge shaped, arc shaped, U-shaped, dimple shaped and many more. Use of artificial roughness is to increase heat transfer coefficient has been studied using CFD by various investigators [13-20]. One can use more than one artificial roughness in the SAH so that it's efficiency and thermal performance can be increased. By providing roughness one can create the turbulence in the laminar sub-layer only when heat exchange takes place without disturbing the flow as it would avoid excessive friction losses. This method is quite useful in increasing the turbulence if compared with the use of fan or blower as it will produce excessive turbulence and because of that excessive power is required. The application of artificial roughness in the form of fine wires and staggered inclined ribs of different shapes has been recommended to enhance the heat transfer coefficient by several investigators. Roughness elements have been used to improve the heat transfer coefficient by creating turbulence in the flow. However, it would also result in an increase in friction losses and hence greater power requirements for pumping the air through the duct. In order to keep the friction losses at a low level, the turbulence must be created only in the region very close to the duct surface, i.e. in the laminar sub layer. A number of investigations have been carried out on the heat transfer characteristics of channels or pipes with roughness elements on the surface.

III. COLLECTOR ASPECT RATIO

In its simplest form, a flat-plate solar-energy heater consists of a sheet of glass or a transparent material situated above a flat plate and is so constructed that it acts as a blackbody to absorb heat. The sun's rays pass through the glass and are trapped in the space between the cover and plate or absorbed by the black body. The heat may then be utilized by passing a fluid through a conduit system located between the bottoms and absorbing plates, the heated fluid subsequently being used to heat a home, water supply, or swimming pool. On increasing the collector aspect ratio, the collector efficiency increases keeping the collector area constant. Considerable improvement in the collector efficiency of a flat-plate solar air heater is obtainable if the collectors are constructed with fins, and the improvement will be extended if the fins in the collectors have been attached by baffles to create air turbulence and an extended heat-transfer area [21, 22].

So, if the area of collector is increased then its collector efficiency is increased and because of which the performance of SAH is also increased. The way the collector is designed makes a great influence in the fluid velocity and on the strength of forced convection. A simple procedure for changing the fluid velocity and the strength of forced convection involves adjusting the aspect ratio of a rectangular flat-plate collector with constant flow rate [23].

However, if we increase the collector aspect ratio or we construct the collector with fins or baffles increases the fan power which leads to higher operating cost. Consequently, proper increase of the collector aspect ratio and proper installation of fins and baffles should be economically feasible in the design of a solar air heater [24].

IV. PACKED BED MATERIALS

On using the packed bed materials with higher masses and low porosity the outlet temperature of the flowing air after sunset will increase. To have a lower pressure drop across the system one must operate the system with packed bed with values of mass flow rate equal to 0.05 kg/s or lower than that. The packed bed material provides an increase of turbulence of air which increases the heat transfer rate from the bed to the flowing air [25].

Solar air heater can be used as a single channel or double channel packed bed solar air heater. The single channel packed bed solar air heaters were discussed by several investigators [26–29]. Limestone and gravel can be used as packed bed materials and if we use gravel as a packed bed material in the SAH then the performance of the heater will be improved as compared with limestone.

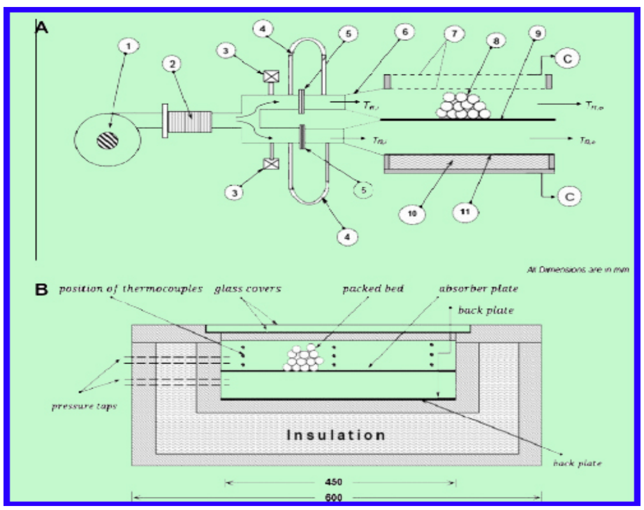

Fig.5 A schematic diagram of the experimental set-up for packed bed SAH (A). (1) air blower, (2) flexible pipe, (3) by pass valve, (4) inclined manometer, (5) orifice meter, (6) diverging section, (7) glass covers, (8) packed bed, (9) absorber plate, (10) insulation, (11) back plate. (B): Cross-sectional view (C-C) of (A) [29].

V. SELECTIVE COATING

Another method that may be used in improving the thermal performance of flat plate solar air heaters is by using selected coatings, which have a very high absorptive of solar radiation but a very small emissivity of thermal radiation, on the absorber and glass cove [30, 31].

Various types of coating play an important role in the performance of SAH. Coatings like black paint, Cu-O, Cr–Cr_2O_3, Ni–Sn and Co-O are used at a mass flow rate of 0.005 kg/s. These selective materials are compared with the black painted absorber and among those materials' Co-O is found to be better. As the heat loss decreases and the rate of useful energy increases with the use of Co-O.

TABLE 1 VALUES OF THE ABSORPTIVITY AND EMISSIVI SOME SELECTIVE MATERIALS [32]

Name of the absorber plate	Chemical formula for the coating material	Absorptivity	Emissivity
Galvanizediron	Black paint	0.88	0.88
Copper oxide above nickel	CuO	0.81	0.17
Chromium black above galvanized iron	Cr–Cr_2O_3	0.95	0.15
Nickel–Tin above galvanized iron	Ni–Sn	0.98	0.14
Cobalt oxide above iron coated with nickel	Co-O	0.92	0.08

VI. THERMAL ENERGY STORAGES MATERIALS

For the utilization of solar energy in future, storage of energy is very much important. There are many factors on which the capacity of solar device for a given solar process depends like time dependence of solar availability, nature of the load, cost of auxiliary components etc. These factors must all be weighed carefully for a particular application to arrive at the system design (including storage size), which minimizes the final cost of delivering energy [33, 34]. The major problem is the selection of materials having suitable thermo-physical characteristics in which solar energy in the form of heat can be stored [35]. In SAH thermal energy storage systems are used because of fluctuations in solar energy input. The selection of the type of TES depends on various factors such as the storage period, economic viability, operating conditions [36].

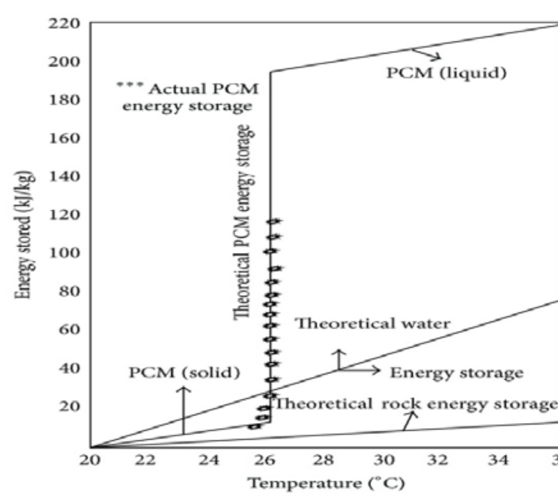

Fig.6 Performance Comparison of PCM, Water, and Rock Storage Systems [37].

On using those TES materials which can be worked on both SHS and LHS are the best suited materials because of their higher sensibility in sunshine hours and can release heat absorbed during off sunshine hours. Among all the tested TES materials, granular carbon is found to be best because it is economical, efficient, easily available, light in weight and without any leakage problem. One can use PCM with high latent heat and large surface area to improve the performance of SAH. It can give better performance if compared with the combination of LHS and SHS materials like granular carbon.

VII. CONCLUSION

Solar air heaters (SAHs) form the foremost component of solar energy utilization system. These air heaters absorb the irradiance and convert it into thermal energy at the absorbing surface and then transfer this energy to a fluid flowing through the collector. SAHs are inexpensive and most used as collection devices because of their inherent simplicity. SAHs are found in several solar energy applications, especially for space heating, timber seasoning and agriculture drying. In this article various methodologies such as artificial roughness, effect of collector aspect ratio, influence of packed bed materials, performance of selective coatings and usage of thermal energy storage devices were discussed in order to increase the efficiency and the mechanical performance of the solar air heaters which find their applications in major fields and also will be a part of day to day life in the near future.

REFERENCES

[1] Donggen Peng, Xiaosong Zhang, Hua Dong, Kun Lv. "Performance study of a novel solar air collector". *Applied Thermal Engineering*, Vol. 30, pp.2594-2601, 2010.

[2] M.A. Karim, E. Perez, Z.M. Amin. "Mathematical modelling of counter flow v-groove solar air collector". *Renew Energy*, Vol. 67, pp.192–201, 2014.

[3] Abhishek Saxena and Varun Goel. "Solar Air Heaters with Thermal Heat Storages". *Chinese Journal of Engineering*, pp.1-11, 2013.

[4] Ciril Arkar, Tomaž Šuklje, Boris Vidrih, Sašo Medved. "Performance analysis of a solar air heating system with latent heat storage in a lightweight building". *Applied Thermal Engineering*, Vol. 95, pp.281–287, 2016.

[5] Md Azharul Karim, M.N.A. Hawlader. "Performance evaluation of a v-groove solar air collector for drying applications". *Applied Thermal Engineering*, Vol.26, pp.121–130, 2006.

[6] A. Sreekumar. "Techno-economic analysis of a roof-integrated solar air heating system for drying fruit and vegetables". *Energy Convers Manag* Vol.51, pp.2230–2238, 2010.

[7] A.S. Abdullaha, b, Y.A.F. El-Samadonyb, Z.M. Omarac. "Performance evaluation of plastic solar air heater with different cross-sectional configuration". *Applied Thermal Engineering*, Vol. 121, pp.218–223.doi:10.1016/j.applthermaleng.04.0, 2017.

[8] The Energy Report, "Texas Comptroller of Public Accounts", May, 2008.

[9] "Guide for preparing active solar heating systems operation and maintenance manuals", *ASHRAE*, 1990.

[10] Sopian K, Yigit K S, Liu HT, Kakaç S, Veziroglu TN. "Performance analysis of Photovoltaic thermal air heaters". *Energy Convers Manage*; Vol.37, pp.1657–70, 1996.

[11] Hughes PJ, Duffie JA, Beckman WA. "Simulation study of several solar heating systems with off-peak auxiliary". *Sol Energy*; Vol.19, pp. 317–9, 1997.

[12] Anil Kumar, R.P. Saini, J.S. Saini. "A review of thermo hydraulic performance of artificially roughened solar air heaters". *Renewable and Sustainable Energy Reviews*, Vol.37, pp.100–122, 2014.

[13] Grenard Ph, Quintilla-Larroya V, Laroche E. "Numerical study of heat transfer on a dimpled surface with CEDRE' code, *In: second European conference for aerospace sciences*; May 2007.

[14] Saha Arun K, Acharya Sumantha. "Turbulent heat transfer in ribbed coolant passages of different aspect ratios: parametric effects". *J Heat Transfer April*; Vol.129, pp.449–63, 2007.

[15] Ozceyhan Veysel, Gunes Sibel, Buyukalaca Orhan, Altuntop Necdet. "Heat transfer enhancement in tube using circular cross-sectional rings separated from wall". *Applied Energy*; Vol.85, pp.988–1001, 2008.

[16] Ooi A, Iaccarino G, Durbin PA, Behnia M. "Reynolds averaged simulation of flow and heat transfer in ribbed ducts". *International Journal of Heat and Fluid Flow*; Vol.23, pp.750–7, 2002.

[17] Craft TJ, Iacovides H, Mostafa NA. "Modelling of three-dimensional jet array impingement and heat transfer on a concave surface". *International Journal of Heat and Fluid Flow*; Vol.29, pp.687–702, 2008.

[18] Iaccarino G, Ooi A, Durbin PA, Behnia M. "Conjugate heat transfer predictions in two dimensional ribbed passages". *International Journal of Heat and Fluid Flow*; Vol. 23, pp.340–5 2002.

[19] Iacovides H, Kelemenis G, Raisee M. "Flow and heat transfer in straight cooling passages with inclined rinds on opposite walls: an experimental and computational study". *Experimental Thermal and Fluid Science*; Vol.27, pp. 283–94, 2003.

[20] Chaube Alok, Sahoo PK, Solanki SC. "Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater". *Renewable Energy*; Vol.31, pp.317–31, 2006.

[21] Yeh, H. M. and Chou, W. H., *Energy—the International Journa*l, Vol.16, pp.983, 1991.

[22] Yeh, H. M., *Energy—The International Journal*, Vol.17, pp.697, 1992.

[23] Yeh, H. M. and Lin, T. T., *Energy — The International Journal*, Vol.20, pp.1041, 1995.

[24] Ho-Ming Yeh, Chii-Dong Ho and Chi-Yen Lin. "The Influence of Collector Aspect Ratio on the Collector Efficiency of Baffled Solar Air Heaters". *Energy*, Vol.23, No. 1, pp.11-16.

[25] M.R.I. Ramadan, A.A. El-Sebaii, S. Aboul-Enein, E. El-Bialy. "Thermal performance of a packed bed double-pass solar air heater". *Energy*, Vol.32, pp. 1524–1535, 2007.

[26] Sharma VK, Sharma S, Mahajan RB, Garg HP. "Evaluation of a matrix solar air heater". *Energy Convers, Manage*, Vol. 30, pp.1–8, 1990.

[27] Sharma VK, Rizzi G, Garg HP. "Design and development of a matrix type solar air heater". *Energy Convers. Manag*e , Vol. 31, pp.379–88, 1991.

[28] Choudhury C, Garg HP. "Performance of air-heating collectors with packed air flow passage". *Sol Energy*; Vol.50,pp.205–21, 1993.

[29] Hamdan MA. "Investigation of an inexpensive solar collector storage systems". *Energy Convers. Manage*; Vol. 39, pp.415–20, 1998.

[30] Liu T, Lin W, Gao W, Luo C, Li M, Zheng Q, *et al*." Parametric study on thermal performance of a solar air collector with a V-groove absorber". *International Journal of Green Energy*; Vol. 4, pp. 601–22, 2007.

[31] Liu T, Lin W, Gao W, Xia C. "Comparative study of the thermal performance of cross-corrugated and v-groove solar air collectors". *International Journal of Green Energy*; Vol. 4, pp. 427–51, 2007.

[32] Elsayed MA, Fathi KA, Megahid IE. "Mathematical models for solar-thermal systems". *Jeddah: Center of Scientific Publishing, King Abdul Aziz University, Saudi Arabi*a; [In Arabic], 1994.

[33] G. O. G. Lof and R. A. Tybout, "Cost of house heating with solar ¨ energy," *Solar Energy*, Vol. 14, No. 3, pp. 253–278, 1973.

[34] S. K. Roy and H. Liu, "Solar heating in Wiley Encyclopedia of Electrical and Electronics Engineering", *John Wiley & Sons, New York, NY, USA*, 1999.

[35] T. Tanaka, T. Tani, S. Sawata, K. Sakuta, and T. Horigome, "Fundamental studies on heat storage of solar energy," *Solar Energy*, Vol. 19, No. 4, pp. 415–419, 1977.

[36] I. Dincer and S. Dost, "A perspective on thermal energy storage systems for solar energy applications," *International Journal of Energy Research*, Vol. 20, No. 6, pp. 547–557, 1996.

[37] B. K. Huang, M. Toksoy, and Y. A. Cengel, "Transient response of latent heat storage in greenhouse solar system," *Solar Energy*, Vol. 37, No. 4, pp. 279–292, 1986.