Investigating the different process parameters and design of solar air heater -A review

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***Abstract*: Solar energy is the most promising field for the coming generation for power generation. Researcher are finding different means of conventional fuels, in that solar energy is the cheapest and easily available source of energy. Solar air heaters are basically used to convert solar energy in useful application like air and water heater. The performance of solar air heater depends on different process parameters like solar air heater duct design, fluid flow behaviour, flow speed and many other. In order to further increase the heat transfer from solar air heater, it is necessary to understand the working of solar air heater. This paper includes the working and different process parameters of solar air heater. It mainly focuses on the research work carried out so far for the enhancement of heat transfer.**

***Keywords*: Heat transfer, Solar air heater, types, process parameters**

1. Introduction

Energy demand is dependent on five different factors which include wealth status of a nation, the statistics of weather and climate conditions throughout the year, human populations, the efficient consumption of energy resources, and the energy conversion technologies. The growing energy demand of the globe has mainly been mitigated by the habit of non-renewable energy resources such as fossil fuels (oil, gas and coal) and nuclear energy. The use of these non-renewable energy resources contributes to environmental degradations such as acid rain, greenhouse gas emission, global warming and the depletion of natural resources. The global energy demand has been greatly influenced by the global human population growth which was rated at 1.23 % per year for the years between 2000 and 2015 (World-Bank 2017). This growing energy demand can be accredited to the increased economic growth and advanced lifestyles of luxury among individuals as well as technological advancements. Fossil fuels (oil, natural gas and coal) are usually combusted for energy and power generation in plants. The combustion of the fuels produces carbon dioxide which is considered the dominant/primary greenhouse gas emitted to the atmosphere. This increasing demand of energy if depends only on fossil will be a great burden on the environment, thus requires a shift to more environmentally friendly energy resources. With the pollution of the environment and the continuing decline in oil reserves, renewable energies appear as a solution to providing clean and cost competitive energy in the future. Nowadays, solar power plants are one of the main applicants for a significant amount of clean electrical energy, Kaygusuz, K et.al (2012)

Renewable energy has long been the interest quest in the field of electricity power generation. Considering the various renewable sources of energy, solar energy is considered the Earth's predominant source of energy but time and location dependent. The radiant heat as well as light approaching from the Sun can be rehabilitated directly or indirectly into different forms of energy. However, it is known that the solar power is being disadvantaged by the low efficiencies of the energy conversion systems. One of the shortcomings of solar power systems is the initial investment cost which restrains the masses from investing into the energy system. The economic disadvantage is accompanying with the increased costs of the installation of solar energy technologies while producing only a relatively small amount of energy related to other conventional energy system, thus characterized of low efficiency. As a result, the solar power still remains considerably a high-cost energy option when compared to conventional energy sources such as the fossil fuels, nuclear and hydropower.

In latest years, there had been an increasing interest in utilizing the solar energy for electricity generation and various reviews have stated that the advantages of the solar technologies outweigh their disadvantages. For examples, some of the benefits of solar energy embrace free and abundant supply, and its environmentally friendly nature. Solar energy also is inexhaustible in supply which has recorded 1.8 × 1014 kW/hr interception on the earth surface out of the total 3.8 × 1023 kW/hr emitted by the Sun. The unlimited source of solar energy makes it a promising option to provide continuous supply of electricity to meet the global energy demand. Asian countries receive a reasonably high volume of solar radiation during the year. Even though the Asian countries receive higher solar radiation from the Sun with longer sunshine duration as compared to other temperate countries, solar energy is yet to be effectively harnessed in this region. Solar energy can be converted directly and indirectly to electrical power using different energy conversion systems. Example of well-known technology for the direct conversion of solar energy into electrical energy is the use of the photovoltaic cells.

2. Solar Air Heater

A solar air heater is a very simple solar gadget, which is used to heat air by using the solar radiation flux. Conventional solar air heaters mainly consist of absorber plate with parallel plate or plates, forming a passage for air flow. A transparent cover, which is generally made up of glass, is fixed above absorber plate and the system is thermally insulated from the edges and rear. The use of a fan is based on design [Patil *et.al* (2012)].

The major parts of flat plate type solar air heater are:

(a) **Absorber Plate** this is the most vital component of unit. It collects the heat of the sun that is transferred to air traveling across it. It is painted with black to maximize absorption of solar radiation.

(b) **Transparent Cover** it is situated at upper side of the unit, which receives the sunrays and then fall over the absorber plate then build up the interior temperature. It also minimizes radiation and convection losses.

(c) **Insulation** it provided on lower and lateral walls of unit that reduce the conduction losses.

(d) **Fluid Tube** in this fluid is flowing, and absorber plate gives the heat to that fluid. In solar air heater except fluid tube there is a duct in which air is flowing.

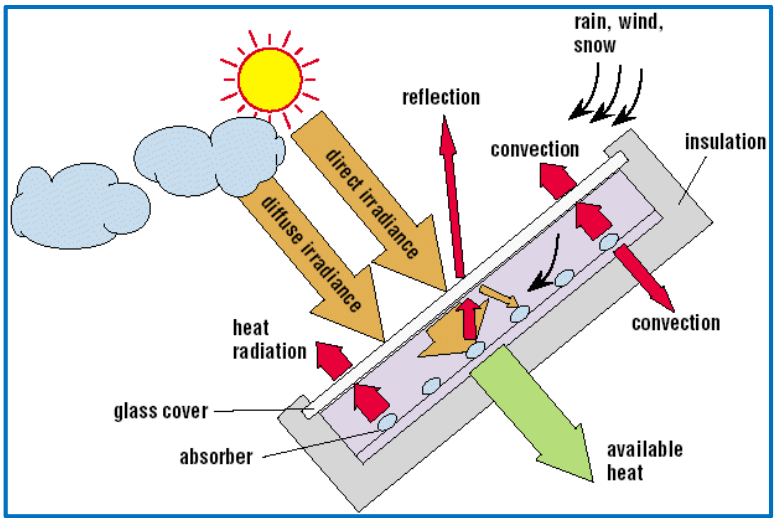

Figure: Cross section of a basic flat plate collector [Patil et.al (2012)]

3. Types of Solar Air Heaters

These are categorized in two ways. The first one is considered channel flow design for increment in system efficiency. The different configurations are; (a) single flow single pass (b) double flow single pass (c) single flow double pass and (d) single flow recycled double pass. The second one is associated with the air channel design. It also enhances the system efficiency. These are expressed in three sub categories such as; (a) flat plate (b) extended surface (c) porous media. SAH is a device through which solar energy transfer to air. It is very typical task to divide SAH in proper manner. There are many numbers of patterns and different ways of experimental constructions [Patil *et.al* (2012)]. They can be explained based on the pattern as active, passive & hybrid. Here SAH depends on the medium of energy storage as PCM, numbers of glass cover, extended surface area shown below in Figures. Energy storage medium as PCM is mostly introduced in active SAH to generate worm air in the off-day hours. Passive type SAH is applicable to daytime only.

4. Heat Transfer Enhancement and its Need

Due to poor thermal characteristics of air, rate of heat transfer between the absorber plate and working fluid is very less which results in lower thermal efficiency of the solar air heater. Hence, different modifications are applied to improve thermal efficiency of the solar air heater while maintaining the smaller size and operational cost. These techniques are simply termed as a heat transfer enhancement technique [Inderjeet Singh *et.al* (2018)]. These modifications increase the thermal efficiency largely but there is also increase in the pressure drop which becomes important at larger volume flow rates. The energy efficiency effect of these techniques varies depending upon the use of the method and heat exchanger type to which it is applied. Heat transfer enhancement techniques are generally classified into three categories:

Table Classification of heat transfer enhancement techniques

Category	Method
i. Surface methods (which are applicable to the surfaces)	Extended surfaces Roughened surfaces Surface vibrations Surface rotations
ii. Fluid methods (which are applicable to the fluids)	Fluid vibration Fluid additives Electrostatic fields
iii. Combined methods	Suction Injection

5. Existing Research work-

Some of the recent work for the enhancement of solar air heater is included in this section.

For the enhancement of heat transfer from solar

1. **Inderjeet Singh *et.al* (2018)** computationally investigated the heat transfer and fluid flow analysis for non-uniform cross-section transverse rib of square wave profile (using ANSYS fluent). To study the effect of roughness and flow parameters on Nusselt number and friction factor in non-uniform cross-section square wave profile transverse rib roughened solar air heater duct. To determine optimum roughness and flow parameters based on thermo-hydraulic performance. The investigation covered the parameters range as relative roughness pitch from 4 to 30, relative roughness height from 0.015 to 0.043 and relative roughness width from 10-310 and Reynolds number from 3000-15000. It was found that with the increase in Reynolds number, the Nusselt number value augments while the friction factor declines for all values of investigated roughness parameters. Nusselt number and friction factor both increases with the increase in relative rib height for the considered range of Reynolds number.

2. **Yuen Zheng et.al [2018]** This research work had focused on enlightening the efficiency of the collector of inclined SCPP through the usage of underneath air-vents. The study engaged numerical method employing a Computational Fluid Dynamics software, Star-CCM+. In the system modelling and simulation, radiation modelling principles were adopted under condition of steady state. The study discovered that with the usage of underneath air-vents, there was 4.25% and 4.64% reduction in convection and radiation heat transfer respectively from the collector cover to the ambient at 1000 W/m^2. It was also pragmatic that the air mass flow rate was augmented by 210% and consequently the power output of the plant enhanced by 60%. The study exposed that for a 100 m^2 inclined collector used in the study, 15 number of air-vents were obligatory for optimum performance enhancement. The study also revealed that the system without chimney could operate but with reduced efficiency as compared with the system incorporated with chimney.

3. **Xu Haoxin et al. (2017)** have suggested the purpose of material assessment methodology in latent heat in thermal energy storage for the waste heat recovery purpose. He has made a details and systematic methodology of a PCM's assessment for the Latent Heat Thermal Energy Storage fabrication, which comprises the prescreening, ranking and performance objective examination based on Multi-Criteria Decision-Making tools. Firstly, a large candidate pool is pre-screened with the crucial boundary constraints. The material of solar air heater is then ranked by employing the Analytical of Hierarchy Process & Techniques for Order Preference by the Similarity to Ideal Solutions. Three distinctive objective functions are to suggested by explicitly evaluate the performance of Phase Change in Materials.
4. **Ayadi et.al [2017]** The objective of this work was to study and optimize the characteristics of a chimney power plant (SCPP) using numerical and experimental methods. The numerical simulations were simulated using the Ansys Fluent commercial CFD code. The effect of the collector ceiling height on the performance of the solar chimney is realized. The local characteristics of the airflow within the SCPP system have been presented and analysed, such as; the characteristics of temperature, speed, pressure and turbulence. The results confirmed that the height of the collector roof is very influential in the optimization of the SCPP. In fact, an increase in the power generated is recorded while the height of the roof of the collector is reduced. Since the optimization of the chimney device is characterized by high costs, this document could be a solution to improve the power generated by an existing chimney solar system.
5. **Hans *et.al* (2017)** experimentally evaluated the heat transfer and fluid flow characteristics of broken arc rib roughened solar air heater duct. The investigation considered rib parameters as relative roughness pitch from 4 to 12, relative gap width from 0.5-2.5, relative gap position from 0.2-0.8, relative roughness height from 0.022-0.043 and arc angle from 15˚-75˚ for Reynolds number range of 2000–16000. The enhancement obtained in Nusselt number and friction factor values were 2.63 and 2.44

times respectively corresponding to geometrical parameters as relative roughness pitch of 10, relative gap width of 1.0, arc angle of 30˚, relative gap position of 0.65 and relative roughness height of 0.043.

6. **Singh and Singh *et.al* (2017)** numerically evaluated the solar air heater duct roughened with non-uniform cross-section saw tooth rib. The 3-D CFD investigation encompassed the parameter range as Reynolds number from 3000-15000 and relative roughness pitch from 4- 30. The relative roughness height and saw-tooth angle were taken as 0.043 and 45° respectively. Both the Nusselt number and friction factor were maximum at relative roughness pitch of 16 for the investigated Reynolds number range. The maximum Nusselt number and friction factor enhancement over smooth duct was 2.18 and 3.34 respectively at Reynolds number of 15000 and relative roughness pitch of 16.
7. **Mekhail et.al [2017]** In this study a very small model of the chimney height of 6 m was installed, the collector diameter of 6 m and the chimney diameter of 0.15 m. The mathematical model, based on the thermodynamic analysis of the flow within the SCPP, was used to predict its performance. The city of Aswan is one of the hottest and sunniest cities in the world. These climatic conditions make the city an ideal place to generate electricity for the Solar Chimney power plant (S.C.P.P). The experimental performances and the theorems calculated by the mathematical model were in good agreement. This model was used to predict the production of a larger model of chimney height 20 m, collector 30 m 2 and chimney diameter of 1 m, which is still under construction. The results revealed that the largest model can produce a theoretical power of about 600 times the smallest. This study helps to select the power of the generator for the largest model.
8. **Vieira et.al [2017]** This research project aimed to examine the influence of geometrical parameters on the available power of stacked solar power plants (SCPPs) by design. The influence of different soil temperatures (mimicking the effect of different solar influences on the collector device) on the optimal shapes is also appraised. The geometry is subject to three limitations: sensor zones, turbines and chimneys. In addition, three degrees of freedom are taken into account: R / H (ratio between the bend radius and its entry height), R1 / H2 (ratio between the radius and the height of the chimney) and H1 / H (ratio between collector base height and sensor entry height) constant (H1 / H 10.0). The time averaged conservation of mass, momentum and energy equations (RANS) was solved numerically with the finite volume method (FVM). For turbulence modelling, the standard model k e-ε was used. The results showed a strong influence of the geometry of the chimney and the collector on the available power. In addition, the geometric parameters of the collector and stack must be evaluated in combination. It has also been noticed that the temperature of the soil is very sensitive to the force and geometric effects that are available.
9. **Okoye et.al [2017]** The purpose of this paper was to raise awareness that Stacked Solar Power Plants (SCPPs) are a viable and sustainable alternative in rural communities with limited or no access to the grid. The study considered site-specific hourly meteorological data to assess the feasibility of SCPP in seven selected areas of Nigeria. A theoretical model has been developed for the power output, the electricity cost paid (LCOE) and the avoided CO2 emissions forecasts. In addition, the effects of seasonality on solar radiation, ambient temperature and energy were investigated. The outcomes revealed that the SCPP with a collector diameter of 600 m and a stack height of 150 m on a typical day under Nigerian conditions would yield an average power of 154 to 181 kW. Over a lifetime of 40 years, the cost of electricity is between € 0.216 and € 0.254 / kWh, compared to € 0.563 / kWh for widely used diesel generators, and the annualized decline in CO2 emissions is between 162 and 191 tonnes. The analysis also revealed that the proposed SCPP would advance the social, economic and environmental development of the regions.
10. **Ghalamchi et.al [2016]** In this work, a pilot plant was built to study the temperature fields and obtain new experimental data. The sensor roof was made of 4 mm soda-lime glass and black aluminum foils were applied to the sensor absorber. In this work the temperature and velocity distribution in different pilot sizes and collector materials was described and compared. Lastly, the best condition was achieved and the maximum velocity of the fluid at the inlet of the chimney was 1.7 m / s and the best data with respect to the temperature of the absorber and the fluid were each 353.78 and 329.01 K. It has been noticed that reducing the size of the inlet has a positive effect on the performance of the solar fireplace, but this reduction has an optimum range and this optimum number is 6 cm for this configuration. The diameter of the chimney is the most influential geometric parameter in the performance of the solar chimney.
11. **Pandey *et.al* (2016)** Thermo-hydraulic characteristics of gapped multiple-arcs shaped roughness elements on absorber plate were analyzed. Conclusions on the base of results indicated good augmentation in *Nu* using this type of roughness configuration. Maximum augmentation achieved in *Nu* and f is 5.85 and 4.96 respectively. The maximum increment for Nu was found at Reynolds number value of 21,000, for geometric configuration (g/e = 1, d/x = 0.65, *W/w* = 5, *e/D* = 0.044, *P/e* = 8 and α = 60 °. Statistical equations were developed for Nusselt number and friction factor as function of various geometric and flow parameters.
12. **Kabeel A.E. *et.al* (2016)** Made an attempt to investigate the thermal performance of flat and vcorrugated plate SAH with and without PCM as medium of thermal energy storage. In this research he has carry out a practical investigation of flat & v-corrugated plate SAH with built in PCM as thermal energy of storage material. The integrated SAH with PCM was 12% more than the parallel ones without using the PCM, it is also 15% & 21.3% higher than the consequent values when the flat plate was used with & without PCM when mass flow rate is 0.062 kg/s, respectively.
13. **Kumar and Kim *et.al* (2016)** carried out 3-D CFD analysis of various V-pattern ribs namely, V- rib, protrusion rib in V-pattern, dimpled rib in V-pattern, and V- rib combined with groove in the Reynolds number range 5000-20000. The fixed parameters were relative roughness height of 0.040, relative roughness pitch of 10 and angle of attack of 60°. They concluded that V-pattern rib with a combination of groove results in maximum thermohydraulic performance as compared to other investigated shapes of V-pattern rib in this study.
14. **Hanna et.al [2016]** In this research study, they had constructed a experimental setup for ten run days in Aswan, Egypt to appraise the operation of the turbine inside the lantern factory. It has been perceived that ambient temperatures, however, play a vital part in the effect on the production of electricity for solar energy. Most importantly, the efficiency of the solar cooker is

proportional to the temperature of the air from solar collectors, especially in the range of 1:00 to 3:00. Based on the result, it can be judged that the rotational speed of the fan can be chosen at 1650 rpm, with the average fan efficiency of 57%. The conclusion is that this digital model is a valid basis for the system to generate solar thermal output and the simulation model can easily be employed to predict the efficiency of any solar exhaust system. The results and results of the test results are good. Finally, the maximum effectiveness of the solar chimney power plant in this study is specified as the high value than it is in previous work according to the site that the study was performing in Aswan, Egypt.

15. **Driss et.al [2015]** In this work, numerical studies were carried out to investigate the turbulent flow around Savonius' unconventional wind rotors. This study compares various rotor designs characterized by blade elbow angles equal to 60 °, 75 °, 90 °, and 130 °, while the other geometric parameters are kept constant. Under these conditions, the third case concerns a conventional Savonius wind rotor. The results revealed that the design of the blade had a direct impact on the local properties. In particular, it has been perceived that the depression areas increase with increasing nose angle of the bucket. The large depression zone appears with $\psi = 130^{o}$. It is positioned in the concave surface of the blade and downstream of the rotor. The acceleration zone, in which the maximum speed values are recorded, is formed in the convex surface of the rotor blade and increases as the arc angle of the blade increases. The trailing properties of the maximum turbulent characteristic values are more informative with the increase of the vane angle ψ.
16. **Azawie et.al [2014]** In this work, the conversion capacity of six different base materials that may be available in Malaysia has been investigated experimentally and numerically. An experimental device was built to record the measured data. In the FLUENT software environment, a numerical model was created to model and simulate the energy conversion process. The materials chosen were ceramics, black chalk, sawdust, dark green lacquered wood (DGPW), sand and pebbles. The results of the simulation showed good agreement with the experimental results in terms of air flow rate and energy conversion efficiency. Ceramic and black stone showed better performance on other materials. However, due to its availability, black stone is recommended as absorbent material in the solar chimney in Malaysia and the countries of the region.
17. **Yadav et.al (2013)** benevolences a study of heat transfer in the rectangular network of a triangular-shaped solar wind heater on the edge of an absorber plate using CFD. The effects of Reynolds number and Nusselt number were investigated. Calculations based on a finite volume method using the Sims algorithm were performed for the air flow with respect to the Reynold numbers ranging from 3000-18000. A limited ANSYS 12U commercial package is used to analyze and visualize the nature of the flow through the solar tube. The results of the CFD simulations were found to be in good agreement with experimental results and with standard theoretical methods. Nusselt numbers were found to increase with the increase of the Randall.

6. Conclusion

The performance of solar air heater depends on different process parameters like heat flux available on the absorber plate, thermal conductivity of the materials that are used for the manufacturing of heat sink, velocity of working fluid, flow behavior of working fluid and many others. In most of the cases forced convection is used to transfer heat from solar air heater to working fluid. Many researchers have optimized the different process parameters of solar air heater. People basically worked on forced convection type solar air heater, very few people have worked on natural convection solar air heater. Here in this work, heat transfer and efficiency of natural convection solar air heater was enhances using ribs inside the convex shaped solar air heater.

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