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Exergetic Analysis of Solar Air Heater: A Review

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Abstract-Solar energy is a clean, most exuberant and freely available renewable source of energy. Due to lower value of convective heat transfer coefficient (h), thermal performance of solar air heater does not take into account. Now exergetic efficiency considered as most effective performance evaluation criteria for solar air heater. The exergy is given for any system at particular state is maximum extraction of work up to its thermodynamic equilibrium state with the surrounding. Exergetic concept is very important for all energy producing, energy consuming and energy conveying system. In this paper an attempt has been made to present holistic view on exergetic efficiency and its importance to evaluated best operating parameters.

1. Introduction

Energy is defined as the universal measure of work for human, nature and machine. It is basically an input to everything to perform work however it also refers to a condition or state of matter. Energy is a basic ingredient to the recipe of day to day life. Solar energy, one of the sources of renewable energy, is the only energy whose small amount supplies a lot of energy. It is clean and most plentiful energy resource among renewable energy resources. Solar energy is universally available source of inexhaustible energy but the major drawbacks of this energy are that it is a dilute form of energy, which is available sporadically and uncertainly. Solar air heating is a solar thermal technology in which the energy from the sun, insolation, is captured by an absorbing medium and used to heat air. Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating.

The exergy is given for any system at particular state is maximum extraction of work up to its thermodynamic equilibrium state with the surrounding. Exergetic concept is very important for all energy producing, energy consuming and energy conveying system. First law of thermodynamics clarifies energy analysis of thermodynamic system without any comment on its quality. Second law of thermodynamics clarify that different form of energy has different quality and energy always degrade by its quality. it is analyzed from first and second law of thermodynamics that energy and exergy based analyses has to be carried out for every energy producing, energy consuming and energy conveying system to make them more exergy efficient, which leads us to energy saving for given system. So it is the second law of thermodynamics which provides information about quality of energy. It provides the concept of available energy or exergy. With the concept it is possible to analyze means of minimizing the consumption of exergy to perform given process, thereby ensuring the most efficient possible conversion of energy for the required task.

$$\eta_{II}=\left(\frac{Minimum\ exergy\ intake\ to\ perform\ given\ task}{Actual\ exergy\ intake\ to\ perform\ given\ task}\right)$$

2. Problem Definition

Solar air heater has lower thermal heat transfer coefficient, which gives lower thermal efficiency of the solar air heater. Comparative study has been required for better comparison of the model. Thermo hydraulic investigation based performance analysis has been carried out for solar air heater having artificial roughness on absorber plate. The analysis was fully based on Nusselt number and friction factor. So to compare better artificial roughness and operating parameters exergetic efficiency will be more useful.

3. Objective and Goals of Study

This dissertation work is focused on the way emphasize the effect of exergetic efficiency over thermo hydraulic performance analysis and make way to obtain better artificial roughness and operating parameter either using rib roughness, protrusion, baffles, blocks etc. as artificial roughness. So, the motive of this study is to increase the efficiency of the solar air heater with using low cost, easily available and highly effective product.

To implement the concept in this research study several literature surveys has been carried out as following:

Solar air heaters are mostly acceptable because of their simplicity in structure, functioning and most widely used solar energy collector device [1]. These are the device which converts solar energy into thermal energy which is used for various purposes. They are less efficient because of low convective heat transfer coefficient value between absorber plate and flowing air. Their efficiency can be increased with the provision of roughness that can break laminar sub layer. Due to this artificial roughness, local turbulence is created which helps in increasing the amount of heat transfer. Numerous study of artificial roughness attributed largely in the field of solar air heater to enhance their performance. Important phenomena responsible for heat transfer enhancement in solar air heater are enhanced turbulence, generation of secondary flows, flow separations and reattachments and mixing. Initial investigated roughnessesare transverse wires [2, 3], transverse, inclined, V-up and V-down [4], arc shaped [5], and multiple V-rib[6]. They contributed well in thermal performance but do not affect value of convective heat transfer coefficient. It was obtained that inclination of rib results generation of vortices and secondary flow which affect value of heat transfer as compared to the transverse ribs. With the continuous research over solar air heater roughness further enhancement in effectiveness of solar air heaters, studies were performed by applying discrete rib roughness in various configurations such as staggered V-shaped discrete [7], V-up and V-down discrete rib arrangements [8] and discrete W-shaped ribs[9]. In all these arrangements V-down discrete arrangement gives the best heat transfer performance [10, 11, 12] but at the expanse of large friction losses. To reduce frictional losses investigator introduce gaps with in the roughness geometries; viz. inclined rib with gap[13], V-rib with gap [14] and multi V-rib with gap[15]. With the help of gap added advantage of secondary flow through the gaps while moving along inclined ribs and through gaps fluid accelerated which erupting the growth of boundary layer and on the other hand friction factor encountered less then continuous ribs.

Other than inclined and transverse ribs roughness arc shape roughness are also investigated to enhance the heat transfer and efficiency of solar air heater. Saini and Saini[5] investigated arc shaped ribs in whichenhancement obtained in order of 3.6 and 1.75 for Nusselt number (Nu) and Friction factor (f). Singh et al [16] investigate multi arc shaped rib roughness on the underside of absorber plate to produce an effective and economical method to improve thermal performance of solar air heater where maximum enhancement in Nusselt number (Nu) and friction factor (f) is 5.07 and 3.71 respectively for multiple arc-shaped roughness geometry as compared to smooth one. Pandey et al [17] experimental studied the effect of multiple arc with gap on absorber plate. The air passing through gap creates turbulence at the downstream side. Larger the value of gap width, smaller is air velocity through gap and higher the downstream disturbance area. Further increase in relative roughness pitch (p/e) number of reattachment point diminish hence less amount of heat transfer takes place. Various CFD investigation have reported enhancement in the thermal performance of solar air heaters by testing roughness geometries similar to those being employed for the experimental investigations by many researchers in the past. Bhagoria et al. [17]studied a CFD based thermo hydraulic investigation of Equilateral triangular sectioned rib roughness on the absorber plate. The maximum enhancement in the Nusselt number (Nu) and friction factor (f) has been found to be 3.073 & 3.356 times over the smooth duct. Bhagoria et al. [18] studied a CFD based heat transfer and fluid flow characteristic investigation of repeated transverse square sectioned rib roughness on the absorber plate. The maximum enhancement in the Nusselt number (Nu) and friction factor (f) has been found to be 2.86 & 3.14 times over the smooth duct.

4. Exergetic evaluation based literature review

Investigators carried out exergy analysis on different systems such as on simple solar parabolic cooker (SPC) by Petela [19]. Joshi et al. [20]has investigated exergy and energy analysis of photovoltaic (PV) and photovoltaic–thermal (PV/T) system.

Exergetic performance evaluation of solar air heater having arc shape oriented protrusions as roughness element carried out by **yadav et al.[21].** The exergetic efficiency of a solar air heater was calculated analytically using developed correlations and the results were compared with that of a smooth flat-plate solar air heater. Design plots were also prepared in order to facilitate the designer for designing such type of roughened solar air heater within the investigated range of system and operating parameters. The exergy based criterion suggests use of the arc shaped protruded roughened solar air heater for the Reynolds number range used in solar air heaters, i.e. for Reynolds number less than 20,000. For the Reynolds number greater than 20,000, the smooth conventional flat-plate solar air heater is suitable. At the higher Reynolds number, the exergetic efficiency may be negative or the exergy of pumping power required exceeds the exergy of heat energy collected by solar air heater. A set of ribroughness parameters namely relative roughness pitch (P/e) of 12, relative roughness height of 0.03 and arc angle of 60º, yields maximum exergetic efficiency for DT/G= 0.02 K m^2/W.

The exergy based criterion suggests use of the discrete v-shaped rib roughness roughened solar air heater for the Reynolds number range used in solar air heaters for the Reynolds number normally used in solar air heater. The study presented by**singh [22]** presents a mathematical model for predicting the exergetic efficiency of soalar air heater having discrete v-shaped rib roughness. The exergy based criterion suggests use of the arc shaped protruded roughened solar air heater for the Reynolds number range used in solar air heaters, i.e. for Reynolds number less than 18000. For the Reynolds number greater than 18000, the smooth conventional flat-plate solar air heater is suitable.A set of ribroughness parameters namely relative roughness pitch (P/e) of 8, relative gap position of 0.65 and arc angle of 60º, yields maximum exergetic efficiency for DT/G= 0.0175 K m^2/W.

The exergy based criterion suggests use of the arc shaped wire roughened solar air heater sahu[23] for the Reynolds number range used in solar air heaters, i.e. for Reynolds number less than 15,000. For the Reynolds number greater than 15,000, the smooth conventional flat-plate solar air heater is suitable. At the higher Reynolds number, the exergetic efficiency may be negative or the exergy of pumping power required exceeds the exergy of heat energy collected by solar air heater. A set of ribroughness parameters namely relative roughness pitch (P/e) of 10, relative roughness height of 0.0422 and relative angle of attack 0.3333, yields maximum exergetic efficiency for G= 1000 W/m^2.

5. Conclusion

From above review we concluded that thermo hydraulic performance analysis of different artificial roughness gives information about percentage increment in Nusselt number and friction factor over flat plate solar air heater but they does not signify which has higher performance. It is clear from the study the artificial roughness which has higher Nusselt number and friction factor enhance convective heat transfer coefficient (h) between absorber surface and incoming fluid but due to higher friction factor a large amount of friction loss and pressure drop penalty has to pay. On the other hand exergetic efficiency evaluation of solar air heater having artificial roughness gives us vast range of information such as up to which value of Reynolds number the roughness will give maximum thermal performance, which loss factor has to be encountered during further use of roughness and at the end comparative study has to be done between two different kind of artificial roughness. One of the most important advantages is determine optimum roughness parameters for different isolation values.

6. References

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