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A Review on Exergy Analysis of Solar Air Heater

K.Kishor[1], A.Ghildiyal[2] & A.S.Bisht[3]

[1,2]Research Scholar, [1,2,3]Department of Thermal Engineering Research, Faculty of Technology, Uttarakhand Technical University, Dehradun, Uttarakhand.

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ABSTRACT

Solar Energy is non-polluting, freely available and sustainable form of energy. This review work focused on exergy analysis of solar air heater. A lot of previous research work has been discussed and main emphasize is given on the different vital parameters involved in exergy analysis of solar air heater. Useful heat gain, thermal efficiency, Carnot efficiency are the important parameters involved n exergy analysis. Exergy losses occurred in solar air heater system majorly due to pressure and frictional losses Exergy analysis the real output of solar air heater system.

Keywords: Useful heat gain, Thermal efficiency, Carnot efficiency, Exergy losses, Exergy Efficiency.

INTRODUCTION

Fossil fuel like petroleum, coal, natural gas, wood etc., is non-renewable energy which is widely used at present. But these energy sources are limited on earth and these sources are going to finish in few years and the requirement of energy is increasing day to day. Lot of investigators doing research of alternative source of energy [1] and eco-friendly materials [2]. When the absorber plate is perpendicular to the sun radiation the average value of solar Radiation evaluated as 1000W/m^2. Among the other existing method of converting solar radiation into thermal energy, flat plate solar air collectors are most common in other type of solar air collector. Solar water heater [3-4] and solar air heater have lot of applications [5-7]. Efficiency of flat plate solar air heater is very low because it's one of the region is its low convective heat transfer coefficient between absorber plate and flowing air which in turn increase the temperature of absorber plate which leads higher heat loss to the environment and second is presence of viscous sub-layer which can be broken by providing artificial roughness. Because of artificial roughness local turbulence is created and turbulence increases the heat transfer rate.

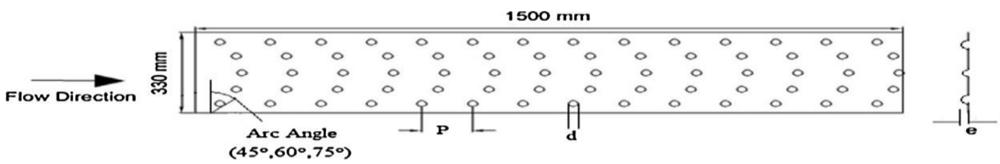

Fig.1. Protruded roughened geometry in arc shape [8]

Nomenclature

A_P Surface area of absorber plate(m^2)

C_p Specific heat of air(J kg^{-1} K^{-1})

D Hydraulic diameter of duct(m)

E_{1A} Exergy losses by absorption of insolation by the absorber (W)

E_{1a} Exergy losses by heat transfer to environment (W)

$E_{1\Delta T}$ Exergy losses by heat transfer to the fluid (W)

$E_{1\Delta P}$ Exergy losses by friction (W)

f Friction factor

F_o Heat removal factor

F_p Collector efficiency factor

G Mass velocity of air (kg s−1 m−2)

H Height of the duct (m)

h Heat transfer coefficient (W m−2 K−1)

I Solar insolation (W m−2)

K Thermal conductivity of air (W m−1 K−1)

$\dot{m}$ Mass flow rate of air (kg s−1)

Nu Nusselt number

Re Reynolds number

Ti Temperature of fluid at inlet (K)

T_o Temperature of fluid at outlet (K)

Tp Mean temperature of absorber plate (K)

T_f Bulk mean temperature of flowing fluid (K)

T_{sun} Sun temperature (K)

U_L Overall heat loss coefficient (W m−2 K−1)

W Width of the duct (m)

ρ_{air} Density of air at bulk mean air temperature (kg m−3)

μ Dynamic viscosity of air at bulk mean temperature (Pa-s)

ΔT Air temperature rise across the duct (K)

α Angle of attack of flow (degree)

η_{th} Thermal efficiency

η_{exer} Exergetic efficiency

$(\tau\alpha)$ Transmittance absorbance product of glass cover

ΔP Pressure drop across test section (Pa)

Q_u Useful heat gain (W)

η_C Carnot efficiency

LITERATURE REVIEW

S. Chamoli et al. [9] study the Exergetic performance evaluation of solar air heater having V-down perforated baffles on the absorber plate. Design plots are prepared to predict the optimum roughness parameter as a function of temperature rise parameter. And final outcome is:

1.The increase in exergetic efficiency is up to 76 % of smooth duct solar air heater with V down perforated baffled roughened absorber plate.

2. the exergetic efficiency is increases with increases in Reynolds number and obtain maximum efficiency and then start decreasing, effective efficiency is the highest for the Reynolds number ranges from 4,000 to 12,000.

3. The exergetic efficiency is strong function of flow Reynolds number and roughness parameter, for $\Delta T/I>0.01753$ K m^2 W^{-1} that the optimum combination of roughness parameters is same for all insolation values, and the optimum combination is e/H = 0.514, P/e = 2, and β = 12 %. For $\Delta T/I<0.01753$ K m^2 W^{-1}, the optimum combination of roughness parameters varies as a function of temperature rise parameter and insolation.

4. The exergetic efficiency-based criteria are found suitable for design of roughened solar air heater, and design plots can be used to design the V down perforated baffled roughened solar air heater.

K. Altfeld et al.[10] study the concept of net exergy flow and the modeling of solar air heaters. And the conclusion comes the net exergy flow is a suitable quantity for the second law optimization of flat-plate solar air heaters. The result of such optimizations are relevant not only from the thermodynamics but also from the technical point of view, because high thermal efficiencies in connection with low pressure drops (friction power) can be obtained.

Hossein Ajam, Saeid Farahat and Faramarz Sarhaddi et al.[11] study the Exergetic Optimization of Solar Air Heaters and Comparison with Energy Analysis and final conclusion In this paper, an integrated mathematical model of thermal and optical performance of a heater was derived. This simulation was followed with the achievement of the heater exergy efficiency. Finally, through the MATLAB toolbox the exergy efficiency equation was maximized. Figures show that the behavior of exergy and thermal efficiency are always not the same. Results show that exergy analysis is a better method for optimizing and designing solar air heaters because exergy efficiency is a proportion to common quantities in solar engineering such as thermal efficiency, temperature, pressure drop, mass flow rate of fluid and others. On the other hand, the exergy analysis developed for the selected model allows the establishment of the optimal values for the characteristic quantities of the solar air heater. Unlike other optimization methods, this method decreases internal irreversibility.

Irfan Kurtbas and Aydın Durmus et al.[12] study the Efficiency and exergy analysis of a new solar air heater. In our study, 5 solar collectors with dimensions of 0:9×0:4 m were used and the flow line increased wherever it had narrowed and enlarged geometrically in shape.

These collectors were set to four different cases with dimensions of 1×2m.M.K. Gupta and S.C.

Kaushik et al.[13] study aims to establish the optimal performance parameters for the maximum exergy delivery during the collection of solar energy in a flat-plate solar air heater.

The energy and exergy output rates of the solar air heater were evaluated for numerous values of collector aspect ratio (AR) of the collector, mass flow rate per unit area of the collector plate (G) and solar air heater duct depth (H). Results are given to discuss the consequences of G, AR and H on the energy and exergy output rates of the solar air heater. The energy output rate increases with G and AR, and decreases with H and the inlet temperature of air. The exergy-based evaluation criterion shows that performance is not a monotonically increasing function of G and AR, and a decreasing function of H and inlet temperature of air. Based on the exergy output rate, it is found that there must be an optimum inlet temperature of air and a corresponding optimum G for any value of AR and H. For values of G lesser than optimum equivalent to inlet temperature of air equals to ambient, higher exergy output rate is achieved for the low value of duct depth and high AR within the range of parameters investigated. If G is high, for an application requiring less temperature increase, then either low AR or high H would provide higher exergy output rate. Hüseyin Benli et al.[14] study is to provide a remedy for the low thermo-physical properties of air which is used as different absorber surface of air heater. This paper presents an experimental investigation on the absorber surface of the collector whose shape and arrangement were made up to provide better heat transfer surfaces. In the study an experimental performance and exergy analysis of five types of air heating solar collectors: corrugated trapeze, reverse corrugated, reverse trapeze, and a base flat-plate collector are presented. conclusions can be drawn from the experimental study of the new collectors designed, and show that the efficiency of the collector improves with increasing mass flow rates due to an enhanced heat transfer to the air flow. The efficiency of air collectors increases depending on the surface geometry of the collector and extension of the air flow line. When the surface roughness is increased, both the heat transfer and pressure loss increases. The corrugated absorber surface has narrowed-extended shape. In this way, the heat transfer was increased by being extended along the flow line of fluid (air) and changing velocity and pressure in narrowed-extended area in which swirl and secondary flows form. As known, swirl and secondary flows cause the convection coefficient of the heat transfer to increase.

A. Ucar and M. Inallı et al.[15] study the Thermal and exergy analysis of solar air collectors with passive augmentation techniques. In this experimental investigation, the shape and arrangement of absorber surfaces of the collectors were reorganized to provide better heat transfer surfaces suitable for the passive heat transfer augmentation techniques. the present passive techniques like dividing 3 or six sheets to absorbent surface, attaching fins on absorber surface and giving an oblique angle (2°) to the three sheets absorber surface, the efficiency of solar collector has been increased or so 100 percent to half-hour compared with the conventional solar collector. The largest irreversibility occurs at the conventional solar air heater, since, in conventional collector (type A) only a little part of solar energy absorbed by the collector can be used.

Sanjay Yadav, Maneesh Kaushal, Varun and Siddhartha et al.[16] study the Exergetic performance evaluation of solar air heater having arc shape oriented protrusions as roughness element. Thermal performance of solar air heater doesn't take into consideration the energy loss because of friction for propellant air through the duct. In this work a trial has been created to evaluate exergetic efficiency of rough solar air heater duct given protrusions arranged in arc fashion over the absorber plate. This study presents an analytical study for predicting the exergetic efficiency of a solar air heater having protrusions as rough absorber plate. Effects of the Reynolds number and roughness parameters on exergetic efficiency were determined. 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 larger than 20,000, the smooth conventional flat-plate solar air heater is suitable. A set of rib roughness parameters namely relative roughness pitch (P/e) of 12, relative roughness height of 0.03 and arc angle of 60^0, yields maximum exergetic efficiency for DT/G = 0.02 K m^2/W. For DT/G < 0.02 K m^2/W, optimum protruded-roughness parameters are function of DT/G and G.

Ebru Kavak Akpinar and Fatih Kocyigit et al.[17] study the Energy and exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates. This study through an experiment investigates performance analysis of a new flat-plate solar air heater (SAH) with several obstacles (Type 1, Type 2, Type 3) and without obstacles (Type 4). Experiments were performed for two air mass flow rates of 0.0074 and 0.0052 kg/s. The first and second laws of efficiencies were determined for SAHs and comparisons were created among them. The values of first law efficiency varied between 20% and 82%. The values of second law efficiency changed from 8.32% to 44.00%. The highest efficiency were determined for the SAH with Type 2 absorbent plate in flow channel duct for all operating conditions, whereas the lowest values were obtained for the SAH without obstacles (Type 4). The results showed that the efficiency of the solar air collectors depends considerably on the solar radiation, surface geometry of the collectors and extension of the air flow line. The largest irreversibility was occurring at the SAH without obstacles (Type 4) collector in which collector efficiency is smallest. At the end of this study, the energy and exergy relationships are delivered for different SAHs.

Salwa Bouadila, Mariem Lazaar, Safa Skouri, Sami Kooli and Abdelhamid Farhat et al.[18] study the Energy and exergy analysis of a new solar air heater with latent storage energy.

Propose a new solar air heater with a packed-bed latent storage energy system using PCM spherical capsules. At daytime, the solar heating system stored the thermal solar energy as sensible and heat. The experimentally obtained results are used to analyze the performance of the system, based on temperature distribution in several parts of the collectors, absorbed, instantaneous stored and used thermal energy. The daily energy efficiency varied between 32nd and 45th. While the daily exergy efficiency varied between 13% and 25%. The impact of the mass flow rate of air on the outlet temperature of the solar air heater is examined. the following conclusions were drawn.

1.The solar air heater remains a consistent useful heat during the discharging process.

The value of the heat was 200 W/m^2 during 11 h at night.

2.The outlet temperature remains approximately constant around 20^0c all the night.

3.The daily average energy efficiency of the SAHLSC is about 40%.

4.The daily average exergy efficiency of the SAHLSC is about 22%.

5.The mass flow rate of air influences the amount of the outlet temperature SAHLSC.

N.L. Panwara, S.C. Kaushika and Surendra Kotharib et al.[19] study a review on energy and exergy analysis of solar dying systems. Exergy analysis is a tool to access the efficient usage of solar energy.

In this review, energy and exergy analysis of different solar dryer were made and following conclusions can be drawn:

1. The exergy efficiency is actual efficiency of the process because of the irreversibility. It is found from case studies that, the total energy efficiency is high in spite of low total exergy efficiency.

2. The energy used in drying of agricultural and industrial produce is significant and, therefore, represents an often reducible element of process cost.

Sukhmeet Singh, Subhash Chander and J.S. Saini et al.[20] study the Exergy based analysis of solar air heater having discrete V-down rib roughness on absorber plate.

This study presents a mathematical model for predicting the exergetic efficiency of a solar air heater having the discrete V-down rib roughened absorber plate. Effects of the Reynolds number and rib-roughness parameters on exergetic efficiency are determined. The exergy based criterion suggests use of the discrete V-down rib roughened solar air heater for the Reynolds number range normally used in solar air heaters i.e. for Reynolds number less than 18,000. For the Reynolds number greater than 18,000, 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 pump work required exceeds the exergy of heat energy collected by solar air heater. A set of rib-roughness parameters namely relative roughness pitch of 8, relative gap position of 0.65, angle of attack of 60^o, relative gap width of 1.0 and relative roughness height of 0.043 yields maximum exergetic efficiency for DT/I> 0.0175 Km^2/W. For DT/I<0.0175 Km^2/W, optimum rib-roughness parameters are function of DT/I and I.

EXERGETIC ANALYSIS OF SOLAR AIR HEATER

Mathematical modelling [9,10,20]

1. First of all select the system and operating parameters like(System parameters--Collector length, Collector width ,Collector height , Transmittance-absorbance, Emittance of glass , Emittance of plate , Thickness of glass cover , Number of glass covers , Thickness of insulation , Thermal conductivity of insulation , Relative roughness pitch , Relative roughness height, Open area ratio , Angle of attack) and(Operating parameters--Ambient temperature , Wind velocity ,Temperature rise parameter, Insulation).
2. To start the calculation process of useful heat gain, first the mean plate temperature (Tp) is assumed.
3. Calculate the overall heat transfer coefficient (U_L).

4.The useful heat gain is calculated as-

$$Q_{u1} = A_P[I(\tau\alpha) - U_L(T_P - T_a)]$$

5. The mass flow rate (m), mass velocity (G) and Reynolds number (Re) are calculated as:

$$m = \frac{Q_{u1}}{C_P \times \Delta T}$$

$$G = \frac{m}{W \times H}$$

$$Re = \frac{G \times D}{\mu}$$

6.The Nusselt number is calculated using the correlation developed from experimental results.

7.. The collector efficiency factor (F_P) and heat removal factor (F_O) are determined as-

$$F_P = \frac{h}{h + U_L}$$

$$F_O = \frac{mC_P}{U_L A_P}\left[1 - exp\left(-\frac{U_L A_P F_P}{mC_P}\right)\right]$$

Where, convective heat transfer coefficient is-

$$h = \frac{Nu \times K}{D}$$

8.The useful heat gain, Q_{u2}, is computed as

$$Q_{u2} = F_O A_P[I(\tau\alpha) - U_L(T_i - T_a)]$$

9.The values of Q_{u1} and Q_{u2} are compared. Ideally the two values should be same. If the difference is more than the 0.1 % of Q_{u1}, then plate temperature is modified as

$$T_P = T_a + \left[\left\{I(\tau\alpha) - \frac{Q_{u2}}{A_P}\right\}\Big/ U_L\right]$$

10. . Using the new plate temperature, the calculations are performed again till the difference between the two values of useful heat gain i.e., Q_{u1} and Q_{u2} are reduced to a value below 0.1 % of Q_{u1}.

11. Then the friction factor is calculated using the correlation developed from experimental results.

12.The pressure drop in the duct is computed as-

$$(\Delta P)_d = \frac{4fL\rho V^2}{2D}$$

13.The mechanical power is calculated as

$$P_m = \frac{m \times (\Delta P)_d}{\rho}$$

14. The thermal efficiency is calculated from useful heat

gain Q_u, the average of Q_{u1} and Q_{u2} and defined as-

$$\eta_{th} = \frac{Q_u}{IA_P}$$

15.The net exergy flow is expressed as,

$$E_n = IA_P\eta_{th}\eta_c - P_m(1-\eta_c)$$

whereη_c is the Carnot efficiency, $IA_P\eta_{th}\eta_c$ is the exergy of absorbed solar energy transferred to air and $P_m(1-\eta_c)$ is the exergy loss.

16.The exergy inflow associated with solar irradiation on the solar collector surface is-

$$E_s = IA_p\left(1-\frac{T_a}{T_{sun}}\right)$$

17.The exergetic efficiency is defined as-

$$\eta_{exer} = \frac{E_n}{E_s}$$

The exergy efficiency can be maximized by minimizing exergy losses. The components of exergy losses are Altfeld et al[14].

1.Optical exergy losses:

$$E_{lo} = IA_P\eta_{exer}(1-(\tau\alpha))$$

Where $\eta_{exer} = \left(1-\frac{T_a}{T_{sun}}\right)$

2.Exergy losses by absorption of insolation by the absorber:

$$E_{la} = A_PI(\tau\alpha)\left(\eta_{exer} - \left(1-\frac{T_a}{T_p}\right)\right)$$

3.Exergy losses by heat transfer to environment:

$$E_{le} = U_LA_P(T_P - T_a)\left(1-\frac{T_a}{T_p}\right)$$

4.Exergy losses by heat transfer to the fluid:

$$E_{I\Delta T} = IA_P\eta_{th}\left(\frac{T_a}{T_f}-\frac{T_a}{T_p}\right)$$

5.Exergy losses by friction:

$$E_{I\Delta P} = \dot{m}\Delta P\left(\frac{T_a}{\rho_f T_f}\right)$$

The calculations are repeated for the next set of roughness parameters, temperature rise parameter, and insolation to cover the entire range.

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