

# A Review on “Comparison of Artificially Rough Surface with the Smooth Surface Solar Air Heater”

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**Abstract-** Applications of artificial roughness on the underside of absorber plate in solar air heater duct have been widely used to improve heat transfer with moderate increase of friction factor. The design of the roughness shape and arrangement is most important to optimize the roughened surfaces.

A Finite Element Analysis of artificial roughness geometry of V rib type in the absorber plate of solar air heater duct has been carried out and compared with smooth duct. A comparative Finite element analysis has been carried out for air at different velocity (inlet) and temperature of fluid for both absorber plate surfaces. The outcomes of the present Finite Element analysis represents the artificial roughened surface is more suitable than the flat plate surface solar air heater.

The objective of the present study is to review on the comparative study of flat surface solar air heater with an artificially roughened surface solar air heater on the basis of various conditions like as, Varying fluid inlet temperature, Varying fluid inlet velocity

**Index Terms-** artificial roughness, solar air heater, heat transfer co-efficient, etc.

## 1. INTRODUCTION

### 1.1 General

In the present world, the prosperity of a nation is measured by the energy consumption of that nation and the GDP of a country is directly linked with energy consumption. Therefore, the demand for energy resources is increasing day by day. There are various forms of energy resources, but they are divided into two main forms, renewable energy resources (solar, air, wind) and non-renewable energy resources (coal and petroleum). The industrial growth is accelerated by non-renewable energy resources, but the stock is limited in nature. The rapid depletion of fossil fuel resources has necessitated an urgent need for alternative energy sources in order to meet

the energy demands of the immediate future and the generations to come. Among the many alternatives, solar energy stands out as the brightest and long range promise towards meeting the continually increasing demand for energy.

A solar thermal collector is a heat exchanger that converts radiant solar energy into heat. In essence this consists of a receiver that absorbs the solar radiation and then transfers the thermal energy to a working fluid. Because of the nature of the radiant energy (its spectral characteristics, its diurnal and seasonal variability, changes in diffuse to global fraction, etc.), as well as the different types of applications for which solar thermal energy can be used, the analysis and design of solar collectors present unique and unconventional problems in heat transfer, optics, and material science. The classification of solar collectors can be made according to the type of working fluid (water, air, or oils) or the type of solar receiver used (non-tracking or tracking).

Passive systems are defined, quite generally, as systems in which the thermal energy flow is by natural means: by conduction, radiation, and natural convection. A passive heating system is one in which the sun's radiant energy is converted to heat upon absorption by the building. The absorbed heat can be transferred to thermal storage by natural means or used to directly heat the building. Passive cooling systems use natural energy flows to transfer heat to the environmental sinks: the ground, air, and sky.

The Solar Air Heater (SAH) occupies an important place among solar heating systems because of the minimal use of materials, low heat transfer coefficients and also for the utilization of the unfavorable thermo-physical properties of air. These are widely used in different thermal systems.

A normal flat plate collector contains of an absorber surface (typically a dark, thermally conducting surface); a trap for irradiation losses from the absorber surface (like as glass which transfers shorter wavelength solar radiation but blocks the longer wave length radiation from the absorber); a heat transfer medium such as air and some thermal insulation behind the absorber surface.

The energy is transferred from the absorber plate to a carrier fluid circulating across the collector. Thermal insulation is usually placed on the rear side to prevent heat loss. The front side has transparent covers generally glass that allows transmission of incoming solar radiations, but it is opaque to the infrared radiations from the absorber plate. Flat plate collectors are for all time settled in position and require no following of the sun. The collector ought to be situated straightforwardly towards the equator, confronting south in the northern half of the globe and confronting north in the southern side of the equator. For the year round applications, the ideal tilt edge of the collector is equivalent to the scope.

For winter, the tilt angle of solar air heater should be approximately 10° to 25° more than the latitude and for summer the tilt angle should be approximately 10° to 25° less than latitude. The maximum temperature of about 65°C above ambient can be achieved through flat plate collectors. Flat plate solar collectors are divided into two main classifications based on the type of heat transfer fluid used.

Flat plate air heating collectors, because of their inherent simplicity, are cheap and therefore used widely. These have found several applications including space heating and crop drying. A typical configuration of flat plate air heating solar collector is shown in Figure 1.1.

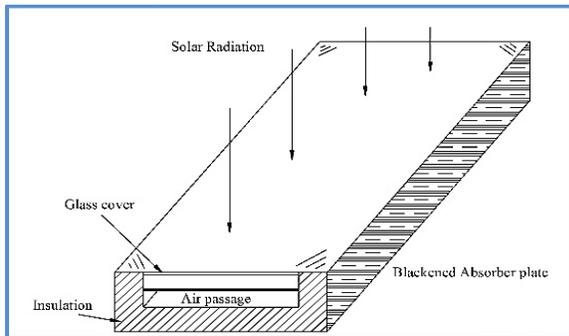


Figure 1.1 Flat plate collector

A conventional sun powered air warming framework for the most part comprises of an absorber plate with

another parallel plate underneath it shaping an entry for air with a high width to profundity proportion. The sun powered radiations go through the straightforward cover or covers and encroach on the darkened absorber plate and after that exchange to the air streaming underneath the absorber plate.

Solar air heaters are categorized into two types. The first category is related to the air channel flow configuration. In this it is sub-categorized into four types namely; single flow single pass, double flow single pass, single flow double pass and single flow recycled double pass. The second category is related to the air channel design. This category can also be expressed in three sub-types such as; flat plate, extended surface assisted, porous media assisted. The above categories are discussed in detail below.

### 1.2 Solar Thermal Heat Utilization

Part of the solar radiation energy can be converted into heat by using absorbers (e.g. solar collectors). The absorbers together with the other essential segments are the close planetary system. Heavenly bodies are establishments changing over sun powered radiation into warm with a specific end goal to warm swimming pools, deliver residential high temp water, cover the interest for space warming or supply other warmth shoppers.

The fundamental rule of sunlight based warm usage is the change of short-wave sun oriented radiation into warm. This vitality transformation process can likewise be portrayed as photograph warm change. In the event that radiation rates on material a specific piece of the radiation is retained. A body's ability to assimilate radiation is called retaining limit or ingestion  $\alpha$ , where  $\alpha$  mirrors the offer of consumed radiation as a component of the whole radiation on issue. A perfect dark body ingests radiation at each wavelength and accordingly has a retention coefficient equivalent to one.

### 1.3 Role of artificial roughness

Generally, thermal performance of smooth absorber plate is considered to be low because of low convective heat transfer coefficient. Sub laminar layer is developed over absorber plate which acts as thermal resistant to flowing air. For enhancing the heat transfer rate, sub laminar layer is broken/disturbed by creating local turbulence which is achieved using artificial roughness. Artificial

roughness are created underside of absorber plate by means of small height wires attached to absorber plate in repeated nature.

As the air flows over roughened surface, separation and reattachment are occurred in between the consecutive ribs leading to local wall turbulence and thereby improving the convective heat transfer coefficient of absorber plate. Auxiliary distribution streams additionally help to enhance to improve the warmth exchange rate as it advance the blending from warmed surface to center stream. Upgraded warm exchange is additionally connected with expanded weight drop in term of rubbing factor which is ominous. In this way, it ends up plainly important to limit the weight drop punishment since additional vitality for making turbulence is required which originates from the blower, coming about high pumping power prerequisite.

This issue can be explained by keeping the rib stature little in contrast with conduit tallness. Little stature unpleasantness makes the turbulence at first glance and it doesn't irritate the center stream. Unpleasantness parameters, for example, ribs course of action, state of wires, rib pitch and rib tallness impact the warmth exchange and grating component. Different rib courses of action have been explored and a few game plans are transverse ribs, calculated ribs, V-ribs, W-ribs, multi V-ribs, rib with groove, stunned ribs, chamfered ribs and discrete ribs

## 2 LITERATURE REVIEW

Studies have been carried out in different absorber plate solar air heaters, some of them are as:

1. *"Nusselt number and friction factor correlations for forced convective type counterflow solar air heater having discrete multi V shaped and staggered rib roughness on both sides of the absorber plate"*, 2017, Ravi Kant Ravi, R.P. Saini, Applied Thermal Engineering (2017)

In this work, the consequences of an exploratory examination on warm exchange and rubbing factor in a counter stream twofold pass sunlight based air warmer (DPSAH) channel with discrete multi V-formed and amazed rib unpleasantness on two wide surfaces of the warmed plate have been researched. The examination covers an extensive variety of Reynolds number (Re) from 2000 - 20000, relative

amazed rib pitch ( $p/p$ ) from 0.2– 0.8, relative stunned rib measure ( $r/e$ ) from 1– 4 and relative unpleasantness width ( $W/w$ ) from 5-8. The ideal estimations of stream and geometrical parameters of harshness have been achieved and clarified in detail. For the Nusselt number (Nu), the most extreme increment of 4.52 times to the relating estimation of smooth twofold pass channel has been accomplished, in any case it has likewise been seen that the grinding factor ( $f$ ) upgraded by 3.13 overlays when contrasted with smooth one. The rib parameters relating to greatest increment in Nu and  $f$  are  $r/e=3.5$ ,  $p/p=0.6$  and  $W/w =7$ . Further, relationships for Nu and  $f$  have likewise been produced based on test information.

2. *"A critical review on artificial roughness provided in rectangular solar air heater duct"*, 2017 Tabish Alam, Man-Hoe Kim, Renewable and Sustainable Energy Reviews 69 (2017) 387–400

Utilizations of fake harshness on the underside of safeguard plate in sun based air warmer pipe have been broadly used to enhance warm exchange with direct increment of grating variable. The outline of the harshness shape and game plan is most vital to upgrade the roughened surfaces. The unpleasantness parameters and ribs plan are capable to modify the stream structure and warmth exchange instruments are essentially represented by stream structure. The basic audits on different simulated unpleasantness components accessible in writing have been led and the impacts of the harshness designs are examined. The Nusselt number and grating element connections for different harshness components have been abridged. A correlation investigation of thermo-pressure driven execution of various harshness components has likewise been accounted for to comprehend the consequences of utilizations of simulated unpleasantness.

3. *"Performance prediction for solar air heater having rectangular sectioned tapered rib roughness using CFD"*, 2017, L. Varshney, A.D. Gupta

In the present work CFD analysis of a solar air heater (SAH) duct provided with artificial roughness in the form of rectangular sectioned tapered rib has been performed using Ansys FLUENT. Twelve different configurations of tapered rib with taper angle, of  $1.6^\circ$ ,

2.3° and 3.2° for pitch of 10,15,20 and 25 mm and constant rib width,  $w_r=0.7$  mm have been considered as roughness element. A three-dimensional non-uniform hybrid grid is generated according to the configuration using cutcell method. The differential equations involved in the model are solved with a finite-volume-based numerical method. The RNG k turbulence model with enhanced wall function is used to solve the transport equations for turbulent flow and energy dissipation rate. Effect of roughness parameters namely tapered angle and relative roughness pitch on Nusselt number and friction factor for a constant value of heat flux ( $1000 \text{ W/m}^2$ ) is discussed. The optimal values of geometrical parameters are obtained on the basis of the performance index in the range of Reynolds number 3800 to 18000. Optimum performance index is found to be 1.91 corresponding to the  $1.6^\circ$  and relative roughness pitch,  $P/e$  of 10.7 at Reynolds number,  $Re$  of 12,000.

4. *“Experimental analysis of double flow solar air heater with multiple C shape roughness”*, 2017 Mohitkumar G. Gabhane, Amarsingh B. Kanase-Patil

The Thermal and hydraulic performance of Double Flow Solar Air Heater (SAH) roughened with multiple C-shape rib was investigated experimentally. Three rib angles were used for different rib geometries with varying pitch distance, an angle of attack and Reynolds number. Multiple C-shaped ribs in double flow arrangement provides better heat transfer than other arrangements. Correlations were developed for Nusselt number, friction factor, Stanton number and Thermo-hydraulic performance parameter to increase the usefulness of result.

5. *“Heat Transfer and Friction Factor Correlations Development for Solar Air Heater Duct Artificially Roughened with ‘S’ Shape Ribs”*, 2016, Khushmeet Kumar, D.R. Prajapati, Sushant Samir

This paper presents the experimental investigation for heat transfer and friction factor for an artificially roughened solar air heater duct with an aspect ratio of 12. Arc shape wire ribs arranged in ‘S’ shape having roughness parameters as relative roughness pitch ( $p/e$ ) in the range of 4-16, relative roughness height

( $e/D_h$ ) in the range of 0.022-0.054, arc angle ( $\alpha$ ) of  $30^\circ$ - $75^\circ$ , relative roughness width ( $W/w$ ) of 1-4 and Reynolds number ( $Re$ ) ranges from 2400 to 20000. It was found that performance of roughened solar air heater duct is better than the performance of smooth duct for the range of roughness parameters investigated. Experimental results shows that maximum enhancement in Nusselt number ( $Nu$ ) and friction factor ( $f$ ) found to be at relative roughness width ( $W/w$ ) value of 3, relative roughness ( $p/e$ ) value of 8, arc angle ( $\alpha$ ) value of  $60^\circ$  and relative roughness height ( $e/D_h$ ) value of 0.043. Based on the data collected from the test runs for roughened duct for various combinations of the roughness parameters correlations were also developed for heat transfer and friction factor in terms of roughness parameters and operating parameter (Reynolds number).

6. *“Experimental investigation on performance of a double pass artificial roughened solar air heater duct having roughness elements of the combination of discrete multi V shaped and staggered ribs”*, 2016, Ravi Kant Ravi, R.P. Saini

Double pass solar air heater (DPSAH) provided with roughness on each side of the absorbing surface is considered as a significant and interesting design advancement that has been used to enhance the performance of the collector. In this paper an experimental analysis has been conducted to study the effect of roughness parameters on thermohydraulic performance of double pass duct having discrete multi V shaped and staggered rib. The study has involved the values of Reynolds number ( $Re$ ) from 2000 to 20000 and relative staggered rib size ( $r/e$ ) from 1 to 2.5. Other parameters like relative staggered rib position ( $P_0/P$ ) of 0.2, angle of attack ( $\alpha$ ) of  $60^\circ$ , relative gap distance ( $G_d/L_v$ ) of 0.70, relative pitch ratio ( $p/e$ ) of 10, relative roughness height ( $e/D$ ) of 0.043 and relative gap width ( $g/e$ ) of 1.0 are kept constant. Based on the study, heat transfer and pressure drop in single and double pass mode have been estimated at range of ribs and performance parameters and results are compared with smooth ducts under same operating conditions. It has been found that the roughness geometry used on each side of the plate in double pass mode enhances both frictional losses as well as heat dissipation rate.

7. *“Heat transfer and friction factor correlations for solar air collectors with hemispherical protrusion artificial roughness on the absorber plate”*, 2015, Li Shui-lian , Meng Xiang-rui, Wei Xin-li

In order to improve the efficiency of solar air collectors, this paper presents a novel solar air collector with hemispherical protrusion/ dimple on the absorber plate, and analyses the performance from the two aspects of optics and thermodynamics. For the purpose of enhancing the absorption rate, the optical path shining on the dimple and protrusion artificial roughness was simulated by using TRACEPRO software. The optical path of hemispherical and the spherical cap dimple was simulated too. The conclusions show that the hemispherical dimple is the best in term of the optics. Then the heat transfer performance of the hemispherical protrusion (back of the dimple) was investigated by experiments. The investigation has covered Reynolds number (Re) ranging from 3000 to 11,000, relative roughness height ( $e/D_h$ ) from 0.033 to 0.1 and relative pitch (P/E) from 3.5 to 5.5. In order to determine the enhancement in heat transfer and increment in friction factor, values of Nusselt number and friction factor have been compared with those of smooth duct under similar flow conditions. Correlations for Nusselt number and friction factor have been developed for solar air collector with such hemispherical protrusion artificial roughness, which can provide reference for the design of this kind of collector.

8. *“Effect of artificial roughness on heat transfer and friction characteristics having multiple arc shaped roughness element on the absorber plate”*, 2014, Anil P. Singh, Varun, Siddhartha

In this present experimental investigation the effect of geometrical parameters of multiple arc shaped roughness element on heat transfer and friction characteristics of rectangular duct solar air heater having roughness on the underside of the absorber plate have been studied. The parameters were selected on the basis of practical considerations and operating conditions of solar air heaters. The experiments carried out encompasses Reynolds number (Re) in the range of 2200–22,000, relative roughness height ( $e/D$ ) range of 0.018–0.045, relative roughness width (W/w) ranges from 1 to 7, relative

roughness pitch (p/e) range of 4–16 and arc angle ( $\alpha$ ) ranges from 30 to 75. The thermo-hydraulic performance parameter was found to be best for relative roughness width (W/w) of 5.

9. *“A CFD based thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate”*, 2014, Anil Singh Yadav, J.L. Bhagoria

In this article, a numerical investigation is conducted to analyze the two-dimensional incompressible Navier–Stokes flows through the artificially roughened solar air heater for relevant Reynolds number ranges from 3800 to 18,000. Twelve different configurations of equilateral triangular sectioned rib ( $P/e = 7.14–35.71$  and  $e/d = 0.021–0.042$ ) have been used as roughness element. The governing equations are solved with a finite-volume-based numerical method. The commercial finite-volume based CFD code ANSYS FLUENT is used to simulate turbulent airflow through artificially roughened solar air heater. The RNG k– $\epsilon$  turbulence model is used to solve the transport equations for turbulent flow energy and dissipation rate. A total numbers of 432,187 quad grid intervals with a near wall elements spacing of  $y^+$ 2 are used. Detailed results about average heat transfer and fluid friction in an artificially roughened solar air heater are presented and discussed. The effects of grid distributions on the numerical predictions are also discussed. It has been observed that for a given constant value of heat flux (1000 W/m<sup>2</sup>), the performance of the artificially roughened solar air heater is strong function of the Reynolds number, relative roughness pitch and relative roughness height. Optimum configuration of the roughness element for artificially roughened solar air heater is evaluated

10. *“Use of artificial roughness to enhance heat transfer in solar air heaters – a review”*, 2010, Thakur Sanjay Kumar et al., Journal of Energy in Southern Africa , Vol 21 No 1 , February 2010

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. Correlations developed by various researchers with the help of experimental results for heat transfer and friction factor for solar air heater ducts by taking different roughened surfaces geometries are given in tabular form. These correlations are used to predict the thermo hydraulic performance of solar air heaters having roughened ducts. The objective is to provide a detailed review on heat transfer enhancement by using an artificial roughness technique. This paper is helpful for the researchers who are researching new artificial roughness for solar air heater ducts to enhance the heat transfer rate and comparing with artificial roughness already studied by various researchers.

11. *"A review on methodology of artificial roughness used in duct of solar air heaters"*, 2010, Brij Bhushan, Ranjit Singh, Energy 35 (2010) 202–212

In order to enhance rate of heat transfer to flowing air in the duct of a solar air heater, artificially roughened surface of absorber plate is considered to be an effective technique. Investigators reported various roughness geometries in literature for studying heat transfer and friction characteristics of an artificially roughened duct of solar air heaters. In the present paper an attempt has been made to categorize and review the reported roughness geometries used for creating artificial roughness. Heat transfer coefficient and friction factor correlations developed by various investigators for roughened ducts of solar air heaters have also been reported in the present paper.

12. *"Performance evaluation of solar air heater having expanded metal mesh as artificial roughness on absorber plate"*, 2009, M.K. Gupta, S.C. Kaushik

A parametric study of artificial roughness geometry of expanded metal mesh type in the absorber plate of solar air heater duct has been carried out and

compared with smooth duct. The performance evaluation in terms of energy augmentation ratio (EAR), effective energy augmentation ratio (EEAR) and exergy augmentation ratio (EXAR) has been carried out for various values of Reynolds number (Re) and roughness parameters of expanded metal mesh roughness geometry in the absorber plate of solar air heater duct. It is found that the augmentation ratios decrease at faster rate with Re in the order of EAR, EEAR and EXAR. It is also found that augmentation ratios increase with increase in duct depth and intensity of solar radiation. The artificially roughened solar air heater duct performs better as per EAR or heat energy gain criteria for any values of Re and roughness parameters of expanded metal mesh. The EAR is high for the parameters of expanded metal mesh type roughness geometry which create more turbulence, however the pump work required for flow of air will also increase. The EXAR is a more suitable criterion to incorporate the quality of heat collected and pump work required. The EXAR is more for higher duct depth and low Re range. Based on EXAR the suitable design parameters of expanded metal mesh roughness geometry are determined.

13. *"CFD based performance analysis of a solar air heater duct provided with artificial roughness"*, 2009, Sharad Kumar, R.P. Saini

In the present work the performance of a solar air heater duct provided with artificial roughness in the form of thin circular wire in arc shaped geometry has been analysed using Computational Fluid Dynamics (CFD). The effect of arc shaped geometry on heat transfer coefficient, friction factor and performance enhancement was investigated covering the range of roughness parameter (relative roughness height ( $e/D$ ) from 0.0299 to 0.0426 and relative roughness angle ( $a/90$ ) from 0.333 to 0.666) and working parameter (Reynolds number, Re from 6000 to 18,000 and solar radiation of  $1000 \text{ W/m}^2$ ). Different turbulent models have been used for the analysis and their results are compared. Renormalization- group (RNG) k-3 model based results have been found in good agreement and accordingly this model is used to predict heat transfer and friction factor in the duct. The overall enhancement ratio has been calculated in order to discuss the overall effect of the roughness and working parameters. A maximum value of overall

enhancement ratio has been found to be as 1.7 for the range of parameters investigated.

### 3 THERMAL PERFORMANCE OF SOLAR AIR HEATER

Performance of any system signifies the degree of utilization of input to the system. It is essential to investigate thermal and hydraulic performance of a solar air heater for making an efficient design of such type of a system. Thermal performance concerns with heat transfer process with in the collector and hydraulic performance concerns with pressure drop in the duct. A Conventional solar heater is considered for the study.

Thermal concert of a solar air heater can be calculated with the use of *Hottel-Whillier-Bliss equation presented by Duffie and Beckman*

$$Q_u = A_c F_R [ I (\tau\alpha)_e - U_L (T_i - T_a) ] \quad \dots\dots\dots (3.1)$$

The proportion of useful energy gain through the moving air by duct of a solar air heater may also be considered by using the following relations:

$$Q_u = mC_p (T_o - T_i)$$

Where

- Ac surface area of absorber plate, m<sup>2</sup>
- F<sub>R</sub> heat removal factor
- I intensity of solar radiation, W/m<sup>2</sup>
- (τ $\alpha$ )<sub>e</sub> effective transmittance-absorptance product
- U<sub>L</sub> overall heat loss coefficient, W/m<sup>2</sup> K
- T<sub>i</sub> fluid inlet temperature, K
- T<sub>a</sub> ambient temperature, K

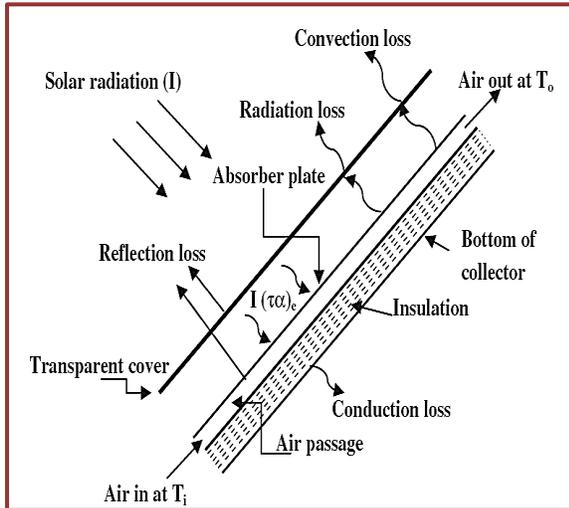


Figure 2.1 Solar Air Heater Principle

The heat transfer coefficient (h) can be improved via applying artificial roughness on the surface of absorber plate. It can be signified in non-dimensional form via expending the following relationship of Nusselt number (Nu) described by Duffie and Beckman

Where A<sub>c</sub> is the surface area of absorber plate (m<sup>2</sup>) F<sub>R</sub> is the Heat removal factor, I is the turbulence intensity/intensity of solar radiation (W/m<sup>2</sup>), (τ $\alpha$ )<sub>e</sub> is the effective transmittance absorptance product, U<sub>L</sub> is the overall heat loss coefficient (W/m<sup>2</sup>/K), T<sub>i</sub> fluid inlet temperature (K) and T<sub>a</sub> ambient temperature (K).

The three design factors, F<sub>R</sub>, (τ $\alpha$ )<sub>e</sub>, and U<sub>L</sub>, are events of thermal performance and syndicate to yield complete collector efficiency in terms of the operating variables of temperature and insolation. The three factors can be used to identify features which would enhance performance with the highest cost-benefit. Conversely, factors that are not economically justifiable in improving performance may be eliminated to reduce costs.

Heat removal factor is known as,

$$\text{Heat Removal factor } F_R = \frac{\text{Usefull Energy}}{\text{Using Energy}} = \frac{T_i - T_a}{T_{pm} - T_a}$$

The rate of valuable energy gain by flowing air in the duct of a solar air heater can also be calculated from the following equation

$$Q_u = mC_p (T_o - T_i) = hA_c (T_{pm} - T_{am}) \quad \dots\dots\dots (3.2)$$

The overall heat loss Q<sub>L</sub> from the air heater is a summation of the losses from the surfaces of top, back, and edge of the collector. The overall loss coefficient is well-defined as (*Rajendra Karwa et al*)

$$U_L = \frac{Q_L}{A(T_{pm} - T_a)} \quad \dots\dots\dots (3.3)$$

The heat transfer over the glass shield of thickness  $\delta$  by conduction is

$$Q_{tg} = \frac{K_g A (T_{gi} - T_{go})}{\delta} \quad \dots\dots\dots (3.4)$$

Where K<sub>g</sub> is the thermal conductivity of the glass and T<sub>go</sub> is temperature of the outer surface of the glass cover. The back loss from the collector can be calculated from the following equation:

$$Q_b = \frac{A (T_b - T_a)}{(\delta / K_i + 1 / h_w)} \quad \dots\dots\dots (3.5)$$

Where  $\delta$  is the insulation thickness,  $k_i$  is the thermal conductivity of the insulating material and  $T_b$  is the temperature of the bottom surface of the collector duct.  $h_w$  is the wind heat transfer coefficient. *McAdams (1954)* reported a correlation, based on experimental data of Jurges, between wind induced convective heat transfer coefficient and wind speed as

#### 4. CONCLUSION

On the basis of previous research it can be concluded as the *artificial roughened surface is more suitable than the flat plate surface solar air heater.*

- While having the same volume the outlet air temperature achieved is more in solar air heater having artificial roughness compare then without artificial roughness solar air heater.
- The turbulence intensity, also often referred to as turbulence level and used for showing the effects of turbulence. The turbulence is much lower in case of artificial roughened surface as compare with flat plate surface solar air heater due to the geometrical changes. While increasing the fluid inlet temperature the turbulence decreases in both the cases.
- Higher value of Stanton number can be achieved using artificial roughened surface when the inlet temperature of the air is lowest, which shows high value of heat transfer achieved.
- There is increment in air outlet temperature as wind velocity increases this is due to the fact that wind velocity increases the heat transfer through the radiation and convection, thus results in increment in air outlet temperature.
- Turbulence kinetic energy is the mean kinetic energy per unit mass associated with eddies in turbulent flow. There is increment in Turbulent Kinetic Energy as wind velocity increases. Turbulence is maximum in inlet and outlet zone of the SAH as shown in contours.

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