Effects of Artificial Roughness on Solar Duct: A Review

Vijay Kumar[1] Prof. Anil Kumar Rao[2] Prof. Vinay Yadav[3]
[1]M.Tech. Student [2]Professor [3]Head of Dept.
[1,2,3]Department of Mechanical Engineering
[1,2,3]Aisect University, Bhopal, India

Abstract— As the Solar effects regulate to constant work at a rapid pace, it starts to generate heat. If this heat is not kept in evaluation, the space could excess heat and eventually turbulate itself. Fortunately, a cooling space include a solar duct, which dissipates the heat from the space, preventing it from excess heating with the increase in heat dissipation from space and the reduction in overall form factors, thermal management becomes a more and more important element of solar duct product design. 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 conjugate and convective heat transfer techniques, in order to optimized a performance of thermo hydraulic performance of a solar air heater, is done. The aim of this paper is to survey of literature various studies, in which variable artificial roughness elements are used to enhance the heat transfer rate with little effect of friction. A relation developed by various researchers and research scholars with the help of experimental results and simulation results for heat transfer and friction factor for solar air heater ducts by taking various roughened surfaces profiles are given in table form. These relations are used to analyze the thermo hydraulic performance of solar air heaters having roughened ducts. The objective is to view a detailed review on heat transfer enhancement by using an artificial roughness technique. This paper will be very helpful for the research scholars who are predicting effect of new artificial roughness for solar air heater ducts to enhance the heat transfer rate and comparing with artificial roughness already studied by various researchers.

Key words: Solar Duct, Roughness, Literature, Friction Factor, Nusselt Number

I. Introduction

The rapid depletion of fossil fuel resources is necessary in an urgent search for alternative sources of energy. Of the many of various sources, solar energy stands out as the rising long range promise towards enhancing the continually increment for a demand for energy. Solar energy is available freely, omnipresent and an indigenous source of energy gives a clean and pollution free environment. The easy and the most effective way to use solar energy are conversion it into thermal energy for heating applications by using solar collectors. Solar air heaters, because of their continuous availability and they are cheap and widely used collector devices. Solar air heaters are being utilized for various applications at lesser temperatures. Few of these are crop drying, timber seasoning, space heating, chicken brooding and curing / drying of concrete / clay making components. Sunlight access freely as a right away and perennial supply of energy gives a less polluting reservoir of fuel. The good and also the most effective way to utilize solar energy are to conversion it into thermal energy for heating applications by designing solar collectors. Solar air heaters, because of their inherent easy are cheap and usually used assortment devices. More viable, their thermal efficiency effects needs to be improved. This could be done by enhancing the heat transfer co-efficient between the absorber plate and air flow through a duct. In general, heat transfer co-efficient enhancement techniques can be differentiated into two groups; namely active and passive. The active techniques require outer forces, e.g. electric field, acoustic and surface vibration. Over the past 70 years, the heat transfer enhancement by using a powered electric field has been continuously studied. The electro hydrodynamic (EHT) enhancement of heat transfer refers to the coupling of an electric field with the fluid field in a dielectric fluid medium – EHD induced secondary flow or ionic wind. This type of flow can be used not only for the pressure drop control in a flow channel but also for the enhancement of heat transfer. The passive techniques require special surface geometries, such as rough and external surface,

Fluid additives and swirl flow devices i.e. twisted tap inserts to create a swirling flow.

II. Concept of Artificial Roughness

Artificial roughness is basically a passive heat transfer enhancement technique by which thermo hydraulic performance of a solar air heater can be improved. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent. However, energy for creating such turbulence has to come from the fan or blower and the excessive power is required to flow air through the duct. Ducts commonly conjointly deliver ventilation air as a part of the supply air. As such, air ducts are one methodology of ensuring acceptable indoor air quality as well as thermal comfort. A duct system is also referred to as ductwork. Planning (laying out), sizing, optimizing, specifying, and verdict the pressure damages through a duct system is termed duct design. This idea is widely applied in enhancing the thermo-hydrodynamic efficiency of various industrial applications like thermal power plants, heat exchangers, air conditioning elements, refrigerators, chemical processing plants, automobile radiators and solar air heaters. Solar air heater is a device used to augment the temperature of air with the help of heat extracted from solar energy. These are cheap, have simple design, require less maintenance and are eco-friendly. As a result, they have major applications in seasoning of timber, drying of agricultural products, space heating, curing of clay/concrete building components and curing of industrial products. The shape of a solar air heater of conventional application is that of rectangular duct encapsulating an absorber plate at the top, a rear plate, insulated wall under the rear plate, a glass cover over the sun-radiation exposed surface, and a passage between the bottom plate and absorber for air to flow in. The detailed constructional details of a solar air heater are shown in figure.

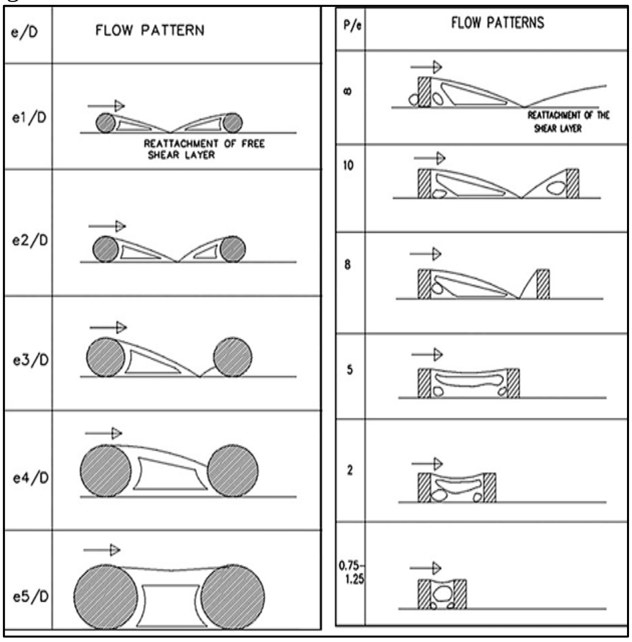

Fig. 1: Flow Patterns

The solar air heater occupies a vital place among solar heating plant attributable to lowest use of materials and value. The thermal potency of solar air heaters as compared of solar water heaters has been found to be typically poor attributable to their inherently low heat transfer capability between the absorbent plate and air flowing within the duct. Therefore on kind the solar air heaters economically viable, their thermal potency must be improved by enhancing the heat transfer constant. There are a pair of basic methods for rising the heat transfer constant between the absorbent plate and air. The first methodology involves increasing the area of heat transfer by victimization furrowed surfaces or extended surfaces spoken as fins while not touching the convective heat transfer constant. The second methodology involves increasing the convective heat transfer by making turbulence at the heat-transferring surface.

III. Shape of Roughness Element

Besides a relative roughness pitch, relative roughness height and angle of attack, shapes of various roughness elements also influence the heat transfer coefficient and friction factor. Different shapes of roughness elements are discussed. of a staggered discrete V- apex up and down on the thermal performance as depicted in Figure 4. The Stanton number for V-down discrete ribs was higher than the corresponding V-up and transverse discrete roughened surfaces. So as to achieve higher heat transfer coefficient, it's desirable that the flow at the heat-transferring surface is created turbulent. However, energy for creating such turbulence has to come from the fan or blower and the excessive power needed creating the air flow through the duct. it's thus desirable that the turbulence should be created solely within the region terribly near the heat transferring surface, i.e., within the laminar sub layer solely wherever the heat exchange takes place and the flow should not be unduly disturbed so on avoid excessive friction losses.

The Stanton number ratio enhancement was found to be 1.32 to 2.47 in the range of parameters covered in the investigation. Further for the Stanton number, it was seen that the ribbed surface friction factor for V-down discrete ribs was highest among the three configurations investigated. More secondary flow cells and produce more local turbulence in the opposite wall region in comparison to the continuous V-shaped or continuous parallel Ribs. The average heat transfer coefficient for the ribbed surfaces turned out to be higher than those for the unribbed surface by a factor of up to 2 when the transverse ribs were continuous, and by a factor of up to 3 when they were broken. Karwa (2003) found that the best heat transfer occurs for the equal pumping power for V-down discrete ribs. Sahu and Bhagoria (2005) investigated experimentally the effect of pitch varying from 10 to 30 by taking the height of the rib to be1.5 mm and duct aspect ratio 8 on the heat transfer coefficient and friction factor for 90° broken transverse ribs. This can be done by keeping the height of the roughness element small in assessment with the duct measurement. Although there are many parameters that characterize the arrangement and form of the roughness, the roughness component height (e) and pitch (p) are the most vital parameters. It was found that the separation occurred not only at the top edge of the rib but also at the edges at the end of the ribs. This secondary flow interrupted the growth of the boundary layer downstream of the nearby attachment zone in case of 90° broken ribs. It was found out that the maximum Nusselt number attained for a pitch of 20 mm and decreased with an increase in roughness pitch.

A. *Compound Roughness*

Eiansaard and Promvonge (2009) investigated experimentally the combined effect of rib-grooved turbulators on the turbulent forced convection heat transfer and friction characteristics in a rectangular duct. These parameters are typically specified in terms of dimensionless parameters, namely, relative roughness height (e/D) and therefore the relative roughness pitch (p/e). The roughness components are two-dimensional ribs or three-dimensional separate components, thwart wise or angled ribs or v-shaped continuous or broken ribs. There are three types of rib-groove arrangements: rectangular-rib with triangular-groove, triangular- rib and rectangular-groove and triangular-rib with triangular-groove, which were examined. All rib-groove arrangements significantly enhance the heat transfer rate in comparison with the smooth duct. The thermal enhancement index for the triangular- rib and triangular-groove was achieved and better than that for the rectangular-rib and triangular- groove and triangular-rib and rectangular groove were around 7% and 4% respectively Jaurker et al. (2006) investigated the effect of relative roughness pitch, relative roughness height and relative groove position on a heat transfer coefficient and friction factor of rib-grooved artificial heat transfer was obtained for a relative roughness pitch of about 6, and it was decreased either side of the relative roughness pitch. The optimum condition for heat transfer was found at a groove position to pitch ratio of 0.4 as compared to the smooth duct. As compared to smooth surface, the presence of rib grooved artificial roughness increased the Nusselt number up to 2.7 times, while the friction factor raised up to 3.6 times in the range of parameters investigated.

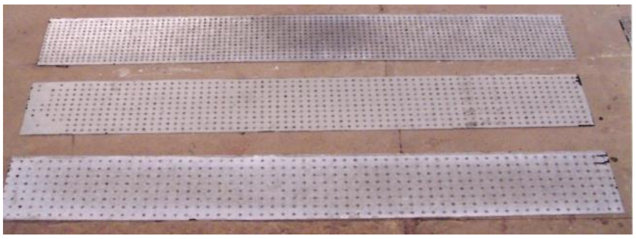

Fig. 2: Rough plate of different Pitches

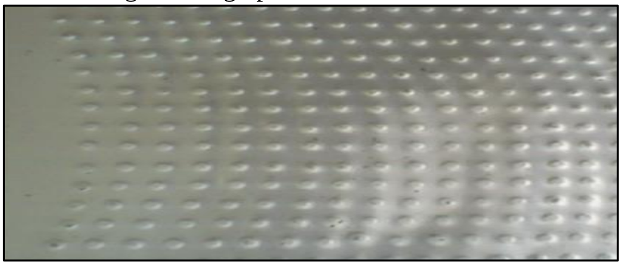

Fig. 3: Protruded roughness geometry

IV. ANALYSIS OF SIMULATION EFFECTS

As compared to experimental activities being carried on solar air heaters, very less numerical work has been done in this field. Numerical study of solar air heaters using CFD software is an excellent method to understand in detail how flow behaves under the presence of obstacles in solar air heaters. CFD results are more accurate as compared to experimental results. Other benefits of using CFD software are saving of time and less costs required completing the work. Some commercially available CFD software packages are FLUENT, FLOVENT, CFX, STARCD and PHOENICS.

A. Duct

Ducts are employed in heating, ventilation, and air conditioning (HVAC) to deliver and remove air. The required air movements include, for instance, supply air, reoccurrence air, and exhaust air. Ducts commonly conjointly deliver ventilation air as a part of the supply air. As such, air ducts are one methodology of ensuring acceptable indoor air quality as well as thermal comfort. A duct system is also referred to as ductwork. Planning (laying out), sizing, optimizing, specifying, and verdict the pressure damages through a duct system is termed duct design.

B. Materials

Ducts can be made out of the following materials:

1) Galvanized Steel

Galvanized mild steel is the standard and most typical material employed in fabricating ductwork. For insulation purposes, metal ducts are generally lined with faced fiberglass blankets (duct liner) or wrapped outwardly with covering material blankets (duct wrap). Once called for, a double walled duct is employed. This may typically have an inner perforated liner, then a 1–2" layer of fiberglass insulation contained within an outer solid pipe. Rectangular ductwork usually is fabricated to suit by specialized metal shops. For ease of handling, it most frequently comes in 4' sections (or joints). Round duct is created employing a continuous spiral forming machine which may create round duct in nearly any diameter when using the proper forming die and to any length to suite, however the most common stock sizes range evenly from 4" to 24" with 6"-12" being most commonly used. Stock pipe is generally sold in 10' joints. There are also 5' joints of non-spiral type pipe available that is commonly employed in residential presentations.

2) Aluminum

Aluminum duct work is light-weight and fast to put in. Also, custom or special shapes of ducts could also be merely fictitious within the look or on required site. The duct work construction starts with the tracing of the duct explain onto the aluminum metal element pre-insulated panel. The elements are then usually cut at 45°, bent if required to induce the assorted fittings (i.e. elbows, tapers) and at last assembled with glue. Aluminum type metal tape is applied to all or any seams wherever the external surface of the aluminum foil has been cut. A range of flanges are gettable to suit various installation necessities. All internal joints are sealed with sealing material. Metallic element is to boot accustomed creating spherical spiral duct, but it's abundant less common than galvanized steel.

3) Polyurethane and Phenolic Insulation Panels

Traditionally, air ductwork is formed of sheet metal that was installed initial and then lagged with insulation. Today, a sheet metal fabrication shop would ordinarily fabricate the galvanized steel duct and insulate with duct wrap before installation. However, ductwork manufactured from rigid insulation panels doesn't require any other insulation and may be installed in a single step. Both polyurethane and phenolic foam boards are factory-made with workshop realistic aluminum metal facings on dual sides. The width of the aluminum foil can differ from 25 µm. for indoor use to 200 µm for external use or for higher mechanical characteristics. There are numerous varieties of rigid polyurethane foam panels obtainable, as well as a water formulated panel that the foaming method is obtained through the utilization of water and CO_2 rather than CFC, HCFC, HFC and HC gasses.

4) Waterproofing

The end for external ductwork exposed to the weather may be sheet steel coated with aluminum otherwise an aluminum and zinc alloy, a multi-coating shield, a fiber steel-clad polymer and water-resistant coating.

V. DUCT SYSTEM COMPONENTS

A. Vibration Isolators

A duct system usually begins at an air handler. The blowers in the air handler will produce substantial vibration, and the large space of the duct system would transmit this noise and vibration to the occupants of the structure. To evade this, vibration isolators are ordinarily inserted into the duct instantly previously and afterwards the air handler. The rubberized canvas-like material of these sections allows the air handler to vibrate without transmission much vibration to the attached ducts. A similar flexible section will reduce the noise that may occur when the blower engages and positive air pressure is introduced to the ductwork

B. Take-offs

Take off again an important part of duct. Downcast-tributary of the air handler, the amount of air stem duct can ordinarily fork, providing air to several individual air outlets like diffusers, grilles, and registers. when the system is intended with a main duct branching into several subsidiary branch ducts, fittings referred to as take-offs permit a small portion of the flow in the main duct to be amused into each branch duct. Take-offs may be fitted into round or rectangular openings cut into the wall of the main duct. The take-off ordinarily has many small metal tabs that are then bent to connect the take-off to the main duct. Round versions are known as spin-in fittings. Alternative take-off designs use a snap-in attachment methodology, generally joined with an adhesive for better-quality sealing. The outlet of the take-off then connects to the rectangular, oval, or round branch duct.

C. Stack Boots and Heads

Ducts, particularly in households, should often permit air to travel vertically within comparatively tinny barriers. These perpendicular ducts are known as stacks and are formed with either very wide and comparatively squeaky rectangular sections or oval sections. At the bottom of the stack, a stack boot provides a transition from a normal large round or rectangular duct to the thin wall-mounted duct. At the top, a stack head will provide a transition back to standard ducting while a register head permits the transition to a wall-mounted air register.

D. Volume Control Dampers (VCD)

An opposed-blade, motor-operated zone damper, shown within the "open" position. Ducting systems ought to sometimes supply a way of adjusting the quantity of air flow to various elements of the system. Volume control provides this function. Besides the regulation provided at the registers or diffusers that unfold air into individual rooms, dampers could also be fitted among the ducts themselves. These dampers could also be manual or automatic. Zone dampers give automatic management in straightforward systems whereas variable air volume permits management in refined systems.

E. Smoke and Fire Dampers

Smoke and fire dampers are found in ductwork where the duct passes through a firewall or fire curtain. Smoke dampers are driven by a motor, referred to as an actuator. An inquiry connected to the motor is put in within the run of the duct and detects smoke, either within the air that has been extracted from or is being equipped to an area, or elsewhere among the run of the duct. Once smoke is detected, the actuator can automatically close the smoke damper till it's manually re-opened. Fire dampers may be found in the same places as smoke dampers, depending on the application of the area when the firewall.

F. Turning Vanes

Turning vanes are installed inside ductwork at changes of direction (e.g. at 90° turns) so as to minimize turbulence and resistance to the air flow. The vanes guide the air thus it will follow the modification of direction more simply.

G. Plenums

Plenums are the central distribution and collection units for an HVAC system. The return plenum carries the air from many large return grilles (vents) or bell mouths to a central air handler. The supply plenum directs air from the central unit to the rooms that the system is intended to heat or cool. They have to be rigorously planned in ventilation style.

H. Terminal Unit

Whereas single-zone constant air volume systems usually don't have these, s multi-zone systems often have terminal units in the branch ducts. Typically there's one terminal unit per thermal zone. Some sorts of terminal units are VAV boxes, and induction terminal units. Terminal units can also include a heating or cooling coil.

I. Air Terminals

Air terminals are the supply air outlets and return or exhaust air inlets. For supply, diffusers are most common, but grilles, and for very small HVAC systems registers are also used wide. Exhaust grilles are used primarily for look reasons, but some collectively incorporate an air cleaner and are mentioned as filter returns.

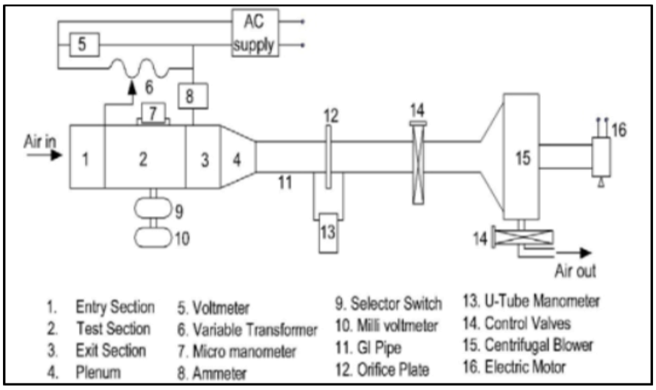

Fig. 4: Circuit Diagram

J. Roughness

So as to achieve higher heat transfer coefficient, it's desirable that the flow at the heat-transferring surface is created turbulent. However, energy for creating such turbulence has to come from the fan or blower and the excessive power needed creating the air flow through the duct. it's thus desirable that the turbulence should be created solely within the region terribly near the heat transferring surface, i.e., within the laminar sub layer solely wherever the heat exchange takes place and the flow should not be unduly disturbed so on avoid excessive friction losses. This can be done by keeping the height of the roughness element small in assessment with the duct measurement. Although there are many parameters that characterize the arrangement and form of the roughness, the roughness component height (e) and pitch (p) are the most vital parameters. These parameters are typically specified in terms of dimensionless parameters, namely, relative roughness height (e/D) and therefore the relative roughness pitch (p/e). The roughness components are two-dimensional ribs or three-dimensional separate components, thwart wise or angled ribs or v-shaped continuous or broken ribs.

VI. ANALYSIS PERFORMED IN VARIOUS PROFILE OF SOLAR DUCT

A. Numerical and Experimental Investigation

Rajesh Maithani, J.S. Saini, et al [2015] – The study of this paper is to analyze plate which is artificially roughened with v experimentally a correlation between heat transfer and friction factor analysis in solar absorber - ribs of different relative width a different angle of attack are also considered on v-ribs to analyze an effect of friction factor and nusselt number. [1]

Ehsan Ebrahimnia Bajestan, Mohammad Charjouei Moghadam et al [2015] – Study of those papers the numerical investigation indicated that the analyzed heat transfer coefficients utilizing single-phase and common two-phase systems, depend on experimental thermo physical properties of nano-fluids, analyzes it. Therefore, some optimizations are enforced to the common two-phase model so as to achieve a lot of correct results of a heat transfer properties of nano-fluids. This optimized model is analyzed the consequences of particle concentration, particle diameter/radius, and intermolecular particle and base material on the heat transfer rate at totally different Reynolds numbers. The results expected that the convective heat transfer coefficient will increase with a rise in nanoparticle concentration with increase in Reynolds number, whereas particle size has an opposite impact. The obtained results may be utilized the investigation of the potential application of nanofluid-based solar collectors. [2]

Hamdi E. Ahmed, M.I. Ahmed, et al [2015] – In this proposed article presents the varied impact of nano fluid and vortex on heat transfer and friction factor in equilateral triangular duct. 2 kinds of nanofluids Al_2O_3 and SiO_2 nanoparticles immersed in H_2O with two particle concentrations were ready and tested. At totally different Reynolds number was taken from 500 to 8000. The results of smooth triangular duct utilizing water as a significant fluid is valid with experimental information and a decent result was obtained. this results shows a decent result in heat transfer by handling vortex generator with fluid as water whereas a major improvement was registered by handling the compound of vortex generator and nano fluids are decrease within the friction factor. [3]

Alireza Zamani Aghaie, Asghar B. Rahimi et al [2015] – This article presents the Thermal management concept includes maximization of heat transfer coefficient and minimum factor of friction factor. Increment of thermal management factor for optimization. At a constant flow of Reynolds number at high value of 10,000, rib relative pitch (P/H), rib relative height (e/H), rib relative tip breadth (a/H) are utilized because the shape optimization factors. Results show that rib pitch, rib height, rib tip breadth and rib front shape have the best advantage on the thermo-hydraulic performance. A triangular rib geometry with rib height of 0.2H and P ¼ 2H during which the rib front is perpendicular to the flow direction is recognized as optimum configuration. [4]

Adem Acır [2015] – This research article presents a the heat transfer, friction factor and thermal performance factor of a solar air heaters with circular type turbulators having different angle of attack angles and distances were performed. Effect of the pitch ratio and angle ratio were analyzed to boost performance in heat transfer during a range of between 3000 and 7500 Reynolds number under radiation heat flux. The experimental results obtained using various turbulators were analyzed and compared with conventional plain tube. [5]

Anil Kumar, et al. [2015] – In this thermal-fluid flow parameters in solar air duct having different V-rib with staggered rib roughness. Four kind's turbulent models (RNG k–e model, realizable k–e model, standard k–e model and SST k–x model) were simulated for smooth solar air duct. The RNG k–e models were finally selected as the most suitable one. The impact of relative breadth ratios of various multi V-rib with staggered rib form on the common Nusselt number, average friction factor and overall thermal performance are expected. [6]

Dongxu Jin, Manman Zhang et al [2015] – In this study, a numerical analysis of heat transfer and fluid flow is analyzed in a solar air heater duct having variable V-shaped ribs on the absorber plate is done in this study. 3-D simulations are performed using the ANSYS FLUENT code and the Renormalization-group k-ε turbulence model. The computational equation analysis are performed for various rib geometries with a variable span wise V-rib number, relative rib pitch, relative rib height, and angle of attack, and for various Reynolds numbers. [7]

R S Gill [2015] – In this paper, results of experiment was analyzed on heat transfer and friction on rectangular ducts roughened with broken arc-rib roughness combined with staggered rib piece has been presented. The rib roughness has relative gap width of 0.65, relative staggered rib position of 0.6, relative staggered rib size of 2.0, and relative roughness pitch of 10, arc angle of 30° and relative roughness height of 0.043. The relative gap size was varied from 0.5 to 2.5. The effects of gap size on Nusselt number, friction factor and thermo-hydraulic performance parameter have been analyzed and results compared with smooth duct and continuous arc rib roughened duct under similar conditions. [10]

Surendra Agrawal, J.L. Bhagoria, Rupesh Kumar Malviya [2014] – It is accepted indisputable fact that the heat transfer coefficient between the absorbent material surface of solar air collector & flowing fluid i.e. air may be improved by providing artificial roughness geometry on heat transfer surface (absorber surface). During this approach the Thermal efficiency is enhanced. However at instant time because of roughness geometry pumping power of solar air collector in enhanced because of fictional losses in duct. Therefore it necessary to look at the form, size & flow pattern different roughness components to get most efficiency with minimum resistance losses. so the choice of roughness geometry should be supported the parameter that takes into consideration each Thermal & Hydraulic (friction) performance i.e. Thermo-hydraulic Performance of solar air collector. Number of roughness components has been investigated on heat transfer & friction characteristics of solar air collectors. during this paper, reviews of different artificial roughness components used as passive heat transfer techniques, so as to enhance Thermo-hydraulic performance of solar air collectors is reviewed & given. Correlations developed by numerous researchers with the assistance of experimental results for heat transfer & friction factor for solar air collector by taking various roughness geometries are given & these correlations are helpful to predict the Thermo-hydraulic performance of solar air collector having rough ducts.

Uttara Shakya, R. P. Saini, M. K. Singhal [2013] – Artificial roughness as kind of ribs on the absorbent material plate is a good technique to boost the rate of heat transfer to flowing fluid within the rough duct of solar air heater. Numerous artificial roughness geometries are reported within the literature by investigators, for deciding the result of varied roughness geometries on heat transfer improvement and friction characteristics in rough duct of solar air heater. Reviews of varied studies are given during this paper. Development of correlation for heat transfer coefficient and friction factor by investigators and comparison of thermo hydraulic performance of duct has been given. [18]

Shailesh Gupta, Alok Chaube and Prakash Verma [2013] – The impact of the rib angle orientation and influence of a gap provided in integral ribs on heat transfer and pressure drop by a sq. duct with 2 opposite in-line ribbed walls is investigated. The experimental investigation has been performed for continuous ribs (with no gap) and ribs with a gap having relative roughness pitch (p/e) of ten, relative roughness height (e/Dh) of 0.060 and rib attack angle of 90° and 60° for Reynolds number from 5000 to 40,000. Distinct ribs with relative gap position (d/W) of 1/5 and relative gap width (g/e) of 1.0 are investigated to compare their heat transfer performance with corresponding continuous ribs (without gape). The improvement in heat transfer and friction factor of this roughened duct is additionally compared with smooth duct with similar flow condition. The results show that inclined ribs performs better than transverse ribs for each the cases i.e. for continuous ribs and ribs with a gap. The 60° ribs with a gap yields concerning 3.8-fold enhancements in Nusselt number and concerning 7.4-fold increase within the friction factor compared with smooth duct and concerning 1.1 times and 1.2 times that of 60° continuous ribs (without gaps) for the whole vary of parameters investigated. But for 90° ribs the improvement in heat transfer and factor is incredibly low as compared to it of corresponding 60° ribs. [21]

VII. CFD GOVERNING EQUATIONS SOLVE BY FLUENT

This section is a summary of the governing equations used in CFD to mathematically solve for fluid flow and heat transfer, based on the principles of conservation of mass, momentum, and energy. These equations solve by the fluent software. The conservation laws of physics form the basis for fluid flow governing equation

A. Law of Conservation of Mass

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \qquad (3.1)$$

B. Momentum Equation

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu\frac{\partial u_i}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} \qquad (3.2)$$

C. Energy

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_i}{\partial x_i}\right) \qquad (3.3)$$

The fluid behavior can be characterized in terms of the fluid properties velocity vector u (with components u, v, and w in the x, y, and z directions), pressure p, density ρ, viscosity μ, heat conductivity k, and temperature T. The changes in these fluid properties can occur over space and time But for simplification we use changes occurs only in space. Using Fluent, these changes are calculated for the fluid, following the conservation laws of physics listed above. The changes are due to fluid flowing across the boundaries of the fluid element and can also be due to sources within the element producing changes in fluid properties.

D. Solution Techniques

After create geometry and meshing, incorporate boundary conditions as per model and then export this file as an .msh file. Now the problem is ready to solve by using fluent software. The solution algorithm SIMPLE (semi-implicit method for pressure-linked equations) is used to solve for the velocity field in all three directions and the pressure.

1) The realizable k-ε model

This is a non-linear version of the k-ε model. It retains the two-equation k-ε equations, but expands the model by as well as further effects to account for Reynolds stress anisotropy without actually using the seven further equations utilized in the RSM to exactly model the Reynolds stresses. The turbulent viscosity expression and the rate of dissipation of K.E. equation of the k-ε model are each modified within the realizable k-ε model to require into account that turbulence doesn't always adjust itself instantaneously whereas moving through the flow domain, which means that the Reynolds stress is partially based on the mean strain rate itself. This implies that the non-linear realizable k-ε model allows for the phenomena of the state of turbulence lagging behind the changes disturbing the turbulence production and dissipation balance.

VIII. CONCLUSION

The present study proposes the inverse method and the commercial software of FLUENT in conjunction with the experimental temperature data to determine the average heat transfer coefficient h, heat transfer coefficient based on the Solar Duct base temperature and duct efficiency for various duct roughness spacing's. An interesting finding is that the calculated duct temperatures obtained from the commercial software are in good agreement with the experimental temperature data at various measurement locations. The inverse results of h and b also agree with those obtained from the commercial software or the correlation. This implies that the present results have good accuracy. It is worth mentioning is that the selection of approximate grid points may not be negligible in order to determine a more accurate numerical result. The total number of grid points may increase with the different relative gap width spacing. Thus the commercial software in conjunction with the inverse method and experimental temperature data may help to the future development of the Solar Duct.

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