"PERFORMANCE PREDICTION OF SOLAR AIR HEATER DUCT HAVING DIFFERENT TURBULATORS."

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ABSTRACT

Solar air heaters have low warm proficiency in light of low convective warmth exchange coefficient between the air and the safeguard plate which prompts higher temperature of the safeguard plate and causes most extreme warm misfortunes. The principle warm protection from warm exchange from safeguard plate to the owing air is development of laminar sub layer on the warmth exchanging surface. It is prescribed to soften this laminar sub layer up request to expand the warmth exchange at the surface.
CFD Analysis of Solar air radiator pipe is completed without and with simulated harsh ness. The impacts of different unpleasantness geometry on warm exchange coefficient and grating element were researched in the extensive variety of Reynolds number between 6000 to 18000. Diverse turbulence models are utilized for investigation viz. RNG k-epsilon, standard k-epsilon, feasible k-epsilon, SST k-omega, and the outcomes are contrasted and systematic outcomes. Among different models, RNG K-epsilon display is observed to be generally proper. It was discovered that as Reynolds number expands Nusselt number additionally increments. Distinctive harshness geometries were endeavored viz. semi-round, rectangular and triangular. The turbulence made because of harshness prompt increment in warm exchange rate and also rubbing factor. Among, different unpleasantness geometries, the outcomes got with triangular geometry were observed to be ideal in setting of warmth exchange and in addition weight drop.

Keyword : - *Heat transfer, Solar air heater duct, Turbulators.*

1. INTRODUCTION

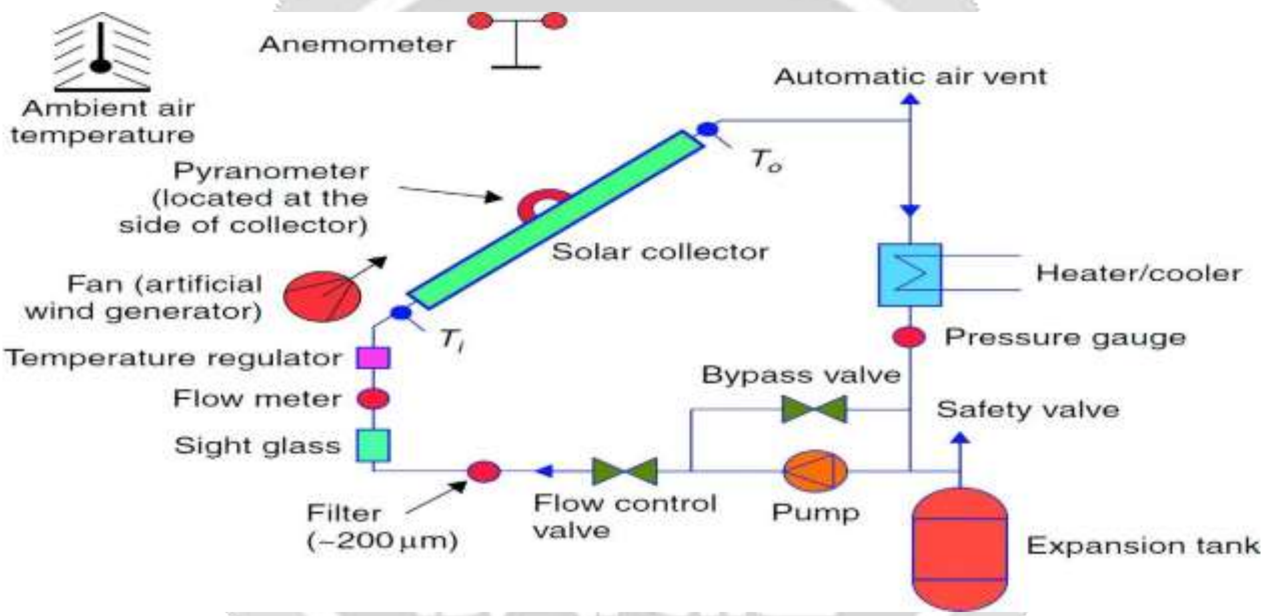
As the name "PERFORMANCE PREDICTION OF SOLAR AIR HEATER DUCT HAVING DIFFERENT TURBULATORS", indicates the main point of our task that is to analyse efficiency of solar air heater duct then increase it with minimal friction factor using various types of turbulators. Solar energy is the prime free source of in exhaustible energy available to all. India is one of the best recipients of solar energy due to its favorable location in the solar belt (40^{o} S to 40^{o} N). The solar energy potential in India is immense due to its convenient location near the Equator. India receives nearly 3000 h of sunshine every year, which is equivalent to 5000 trillion kWh of energy. By January 2014 the installed grid connected solar power had increased to 2208.36 MW, and India expects to install a total of 20,000 MW by 2022. Developing renewable energy may help India to increase its energy security; reduce the adverse impacts on the local environment, which lower its carbon intensity contribute to more balanced regional development; and realize its aspirations for leadership in high-technology industries. At its core, solar energy is actually nuclear energy. In the inner 25% of the Sun, hydrogen is fusing into helium at a rate of about7Ö1011 kg of hydrogen every second. If this sounds like a lot, it is because it is: this is equivalent to the amount of mass that can be carried by 10 million railroad cars. There is no need to fear, though, that we are going to run out of fuel anytime soon, as the Sun has enough hydrogen in the core to continue at this rate for another 5 billion years. This form of heat transport depends greatly upon the surface temperature of an object for the amount and type of energy. Stefan-Boltzmann's Law tells us that the amount of energy that is radiated per unit area of surface depends upon the temperature of the object to the fourth power, i.e. energy/area is proportional to T4. This means that the amount of energy that is emitted by the Sun, and therefore, the amount of solar energy that we receive here on Earth, is critically dependent upon this surface temperature. A change of 1% in the temperature of the Sun (58 K) can result in a change of 4% in the amount of energy per unit area that we receive here. While this might not sound like a lot, it is more than enough to plunge us into brutal ice age or hellish global warming. [1]

1.1 Aim and Objects

Aim: We chose the solar energy conservation as a renewable power source. We are going for CFD analysis in ANSYS software and after analysing we will select suitable turbulator profile.
Objects: The main objective of this project is to increase heat flux with minimum friction factor in solar air heater duct. The role of CFD analysis is major.

1.2 Performance of solar air heater

Performance of any system represents the degree of utilization of input to the system. It is required to analyze 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 within the collector and hydraulic performance concerns with pressure drop in the duct. A conventional solar air heater (Fig. 1) is considered for brief analysis of thermal and hydraulic performance in the following sub-sections. [2]



1.3 Thermal Performance of Solar air heater

Thermal performance of a solar air heater can be computed with the help of HottelWhillierBliss equation reported by Du-e and Beckman [2]

$$Q_u=A_cF_R[I(\tau\alpha)_e-U_L(T_i-T_a] \quad (1.3.1)$$

$$q_u=Q_u/A_c=F_R[I(\tau\alpha)_e-U_L(T_i-T_a] \quad (1.3.2)$$

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

$$Q_u=mC_p(T_o-T_i)=hA_c(T_{pm}-T_{am}) \quad (1.3.3)$$

The value of heat transfer coefficient(h) can be increased by various active and passive augmentation techniques. It can be represented in non-dimensional form of Nusselt number (N_u)

$$N_u=hl/k \tag{1.3.4}$$

Further, thermal efficiency of a solar air heater can be expressed by the following equation

$$\eta_{th}=q_u/I=F_R[I(\tau\alpha)_e-U_L(T_i-T_a)] \tag{1.3.5}$$

Hydraulic Performance of Solar Air Heater

Hydraulic performance of a solar air heater concerns with pressure drop (ΔP) p in the duct. Pressure drop accounts for energy consumption by blower to Propel air through the duct. The pressure drop for fully developed turbulent flow through duct with Reynolds number up to 50,000 is given as follows equation P. [2]

$$\Delta P = (2f\rho lV)^2/D$$

where f = $f = 0.0085Re^{-0.25}$, Where f is friction factor.

1.4 Advantages of solar air heater

Freezing of working fluid does not exit
Pressure of fluid inside collector is not very high
Corrosion and leakage Problem are less.

1.5 Disadvantages of solar air heater

Heat transfer coefficient between absorber plate and air is very low.

1.6 Application of solar air heater

Heating of Building
Drying of agriculture Product
Heating Green Houses.

2. LITERATURE REVIEW

Forced convection heat transfer in smooth and roughened ducts has been investigated by several investigators.

Hans et al. [6] carried out experiments to determine the effects of the rib angle of attack on the distributions of the local heat transfer coefficient and on the friction factors in short rectangular channels of narrow aspect ratios with a pair of opposite rib roughened walls for Reynolds numbers from 10,000 to 60,000. The channel width-to-height ratios were 2/4 and 1/4; the corresponding rib angles of attack were 90 ^{o}, 60^{o}, 45^{o}, and 30^{o}, respectively. The maximum heat transfer enhancement has been found to occur for a relative roughness width (W/w) value of 6 while friction factor attains maximum value for relative roughness width (W/w) value of 10. It has also been found that Nusselt number and friction factor attain maximum corresponding to angle of attack value of 60 ^{o}. Maximum enhancement of Nusselt number and friction factor has been observed corresponding to relative roughness.

Out experiments to determine the effect of non-circular perforation holes in term of circularity of V-Alam et al. [7] carried shaped blockages attached to one heated wall of a rectangular duct of solar air heater. Five different hole shapes ranging from circular to square to rectangular in the circularity range of 10.6 have been used with varying relative pitch of 412, relative blockage height of 0.41.0, open area ratio of 525% and angle of attack of $30^{o}75^{o}$ and Reynolds number of flow was varied between 2000 and 20,000, Non-circular perforation holes has been found to result in higher heat transfer as compared to circular holes. The highest increase in the value of Nusselt number has been observed at a relative pitch of 8, however the highest observed value of friction factor corresponding to relative pitch of 4mm.Non-circular perforation holes was being found to result in higher heat transfer as compared to circular holes with same open area ratio; and there is optimum non-circular shape that corresponds to a circularity of 0.69.

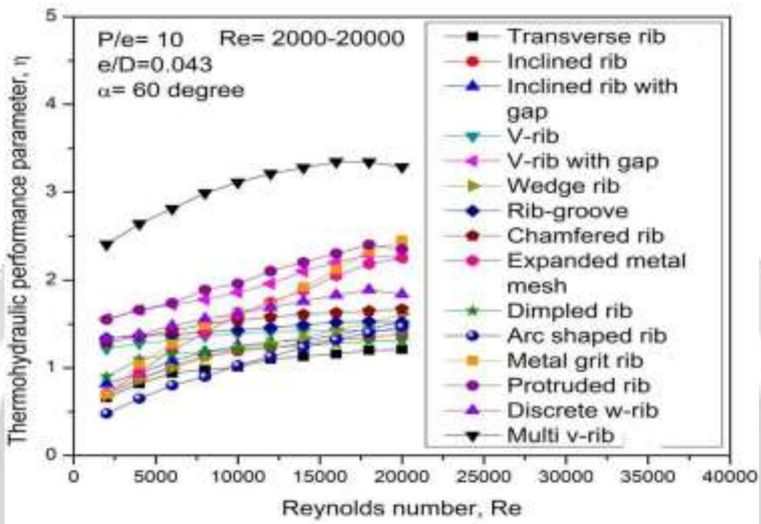


Figure 2.2: effect of different artificial roughness geometries on Thermodynamic Performance

Saini et al. [8] investigated Heat and fluid flow characteristics of roughened solar air heater ducts, various studies have been carried out to determine the effect of different artificial roughness geometries on heat transfer and friction characteristics in solar air heater ducts. Author Reported Multi v-shaped rib roughness geometry has also been shown to be thermohydraulic better in compared to other roughness geometries as shown in Fig.2.2. Transverse rib roughness enhances the heat transfer coefficient by flow separation and generation of vortices on the upstream and downstream of rib and reattachment of flow in the inter rib spaces. Angling of transverse rib further enhances the heat transfer on account of the movement of vortices along the rib and formation of a secondary flow cell which results in high heat flow region near the leading end. V-shaping of a long angled rib helps in the formation of two secondary flow cells as compared to one in case of an angled rib resulting in still higher heat transfer rate.
Saini and Verma [9] studied the effect of roughness and operating parameters on heat transfer and friction factor in a roughened duct provided with dimple-shape roughness geometry for the range of Reynolds number (Re) from 2000 to 12,000, relative roughness height (e/D) from 0.018 to 0.037 and relative pitch (p/e) from 8 to 12. For the range of parameters investigated, Nusselt number was found to be maximum corresponding to relative roughness height (e/D) value of 0.0379 and relative roughness pitch (p/e) value of 10. For xed value of relative roughness pitch (p/e) of 10, friction factor attained the maximum and minimum values corresponding to relative roughness height (e/d) values of 0.0289 and 0.0189, respectively. Correlations for Nusselt number and friction factor have been developed.

A schematic diagram of the experimental setup including the test section is shown in Fig.2.3. The flow system consisted of an entry section, a test section, an exit section, a flow meter and an air blower. The duct having the dimensions of inner cross-section as 2400 mmX300 mmX25 mm was made of wooden panels. The test section having a length of 1000 mm was provided. The length of entry and exit section was provided as 900 mm and 500 mm, respectively. These lengths were taken as per ASHRAE Standard 9397. An electric heater having a size of 1500mmX290mm was fabricated by combining series and parallel loops of heating wire on a 5-mm-thick asbestos sheet. A mica sheet of 1 mm thick was placed on the electric heater wire, in order to get uniform radiation between the electric heater and absorber plate. The heat flux may be varied from 0 to 1000 W/m^2 with the help of a wire connected across it. A 50 mm thick layer of glass wool as an insulating material and a 12mm thick wooden panel was provided in order to minimize the heat losses from the topside of the heater assembly. A 4-mm-thick galvanized iron (GI) sheet having roughened surface on its underside was provided as heat absorber plate. This plate formed the top wall of the duct. The top of the entry and exit sections of the duct was covered with 8-mm-thick wooden panels. In order to ensure that no heat losses occur due to conduction effect, the duct was insulated properly by providing glass wool at the outer surface of the duct covering entry length, test length and exit length

Mittal et al. [10] studied efficiency of solar air heaters having different types of roughness elements on the absorber plate. The effective efficiency has been computed by using the correlations for heat transfer and friction factor developed by various investigators within the investigated range of operating and system parameters and compare effective efficiency of smooth and artificially roughened solar air heater. Solar air heater having inclined ribs as roughness elements is found to have better effective efficiency in the higher range of Reynolds number. The investigation covered a Reynolds number range of 250018 000, relative rough-ness height of 0.020.034 and angle of attack of flow of 30 $^\circ$90° for a xed relative pitch of The correlations for heat transfer and friction factor developed by these investigators for different geometries of roughness.

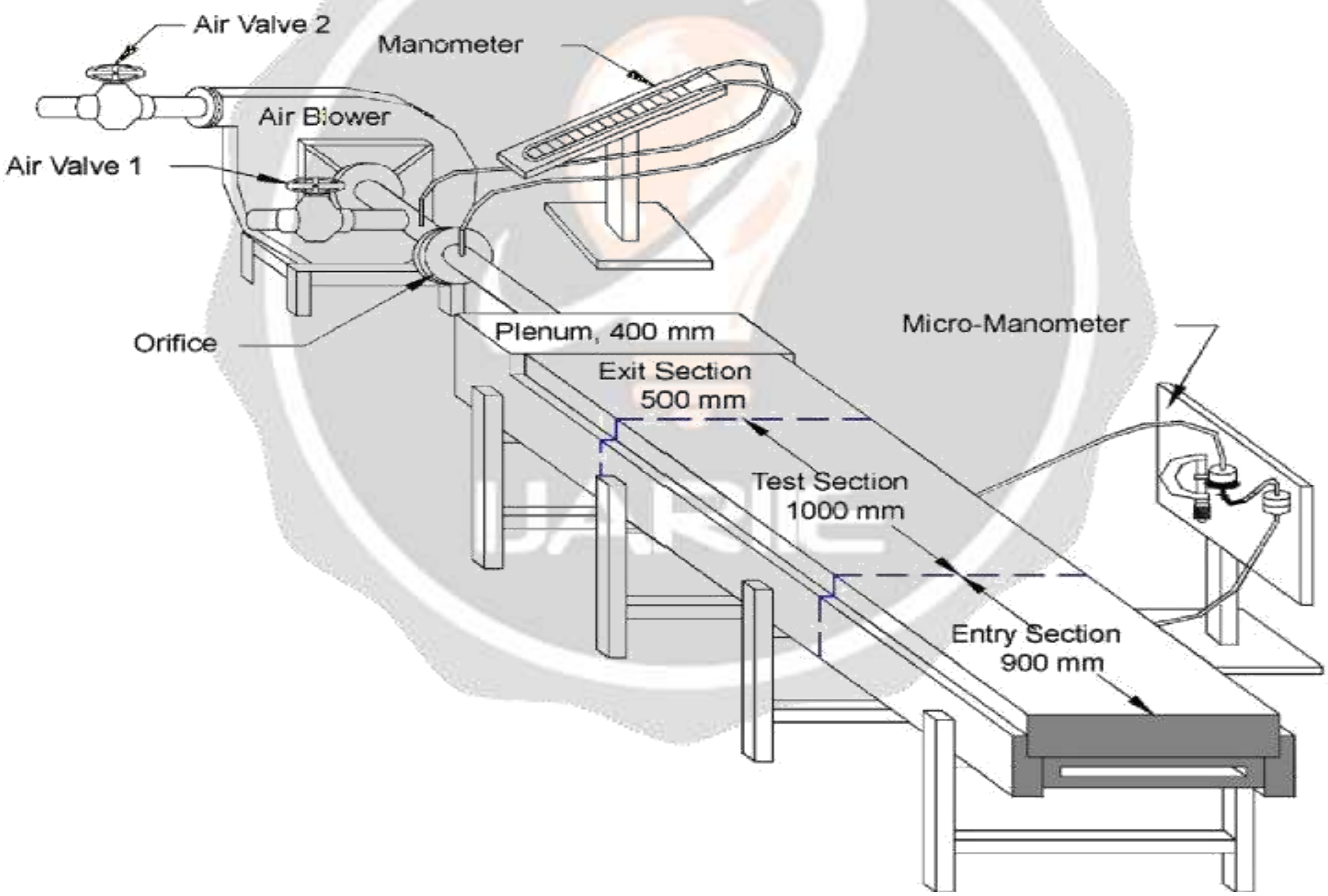


Figure2.3 : Experimental setup of solar air heater

Kumar et.al [11] carried out experimental investigation of heat transfer and friction in the flow of air in rectangular ducts having multi v-shaped rib. It was found that as compared to the smooth duct the presence of multi v-shaped rib with gap artificial roughness yields Nusselt number up to 6.74 times while the friction factor rises up to 6.37 times in the range of parameters investigated. The maximum Nusselt number enhancement occurs at the relativegap distance of 0.69 with the relative gap width of 1.0 for the relative roughness height of 0.043, relative roughness width of 6.0, angle of attack of 60 and relative roughness pitch of 8.0. The value of Nusselt number and friction factor is more for multi v-shaped with gap rib than that for continuous multi v-shaped rib. The maximum value of friction factor occurs for multi v-shaped with gap rib with relative roughness width of 10.

Saini et al. [12] carried out experimental study for enhancement of heat transfer coefficient of a solar air heater having roughened air duct provided with artificial roughness in the form of arc-shape parallel wire as roughness element. The effect of system parameters such as relative roughness height (e/d) and arc angle (a/90) have been studied on Nusselt number (Nu) and friction factor (f) with Reynolds number (Re) varied from 2000 to 17000. Considerable enhancement in heat transfer coefficient has been achieved with such roughness element Based on the experimental values, correlations for Nusselt number and friction factor have been developed. The good agreement has been found between calculated and experimental values. It was found that enhancement in Nusselt number has been obtained as 3.80 times corresponding the relative arc angle (A/90) of 0.3333 at relative roughness height of 0.0422.

Alam et al. [13] studied Heat and flow characteristics of air heater ducts provided with turbulators in different forms of ribs, baffles, delta winglets, obstacles, vortex generator, rings and perforated blocks. It was found that perforated baffles are considered to be thermo- hydraulically better in comparison to solid baffles because perforation in ribs/blocks/baffles enhances the heat transfer due to elimination of hot spot just behind the ribs. Turbulators in the form of winglets, rings, twisted rings, Z shaped baffles vortex generator, obstacles and wiglet were used in air heaters and found suitable to create turbulence to increase the heat transfer rate.

Hans et al. [14] studied Performance of artificially roughened solar air heaters, using computational fluid dynamics (CFD) models, analysis of heat transfer and flow characteristics of roughened solar air heaters needs to be carried out to predict optimum roughness element parameters. it was found Thermohydraulic performance of inclined broken rib geometry has been found to be better in comparison to other roughness element geometries for Reynolds number range between 3000 and 14,000.

Karwa and Chitoshiya [15] presented the results of an experimental study of thermo- hydraulic performance of a solar air heater with V-down discrete rib roughness on the airflow side of the absorber plate along with that for a smooth duct air heater. The enhancement in the thermal efficiency due to the roughness on the absorber plate was found to be 12.520% depending on the air flow rate; higher enhancement was at the lower flow rate. The results of a detailed thermo-hydraulic performance study of solar air heater with v-down discrete rib roughness using the mathematical model were also presented along with the effect of variation of various parameters on the performance.

Chamoli et al. [16] studied enhance rate of heat transfer to owing air in the duct of solar air heater and in heat exchanger or in cooling of turbine blade various turbulence generators viz. ribs, baffles and delta winglets are considered as an effective technique. Author reported with high roughness height generally called baffles and they show high rate of heat transfer but baffle blockage increases the pressure drop which is a serious concern thus investigators must look to reduce the pressure drop which can attained by desecrating the geometry or to find the geometry which will be thermo-hydraulically better.

Chauhan and Thakur [17] investigated the thermo hydraulic performance of impinging jet solar air heater. It was found that High heat transfer rates are achieved using impinging jets in solar air heater duct but at the cost of increased friction power penalty, It was found that enhancement in thermo hydraulic performance of about 34.54 to 57.89% has been achieved compared to that of conventional solar air heater.

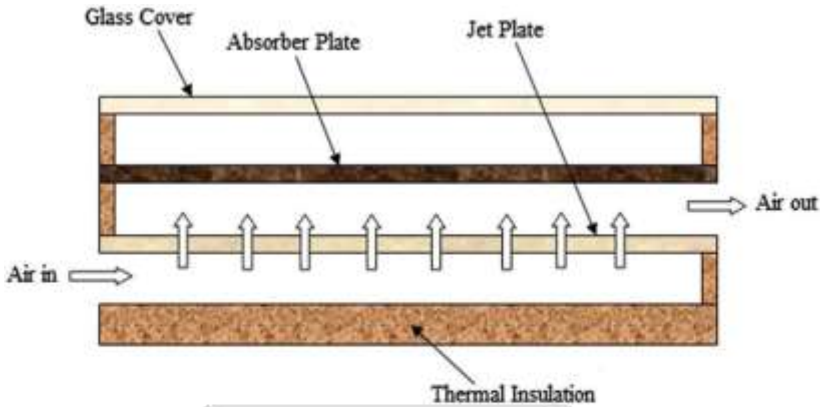


Figure 2.4: impinging jet solar air heater

Patil studied [18] heat transfer mechanism and energy efficiency of artificially Roughened solar air heater. it was found that Transverse rib roughness produces maximum heat transfer enhancement while the roughness pitch lies between 810 times than that of the roughness height. Since the laminar sub layer region is thick at the low Reynolds number, thus the roughness height of the order laminar sub layer thickness at lowest operational Reynolds number is suitable to attain higher heat transfer enhancement at the cost of moderate friction.

Prasad et al. [19] studied thermo hydraulic performance in three sides artificially rough-ened solar air heaters.it was found that Optimal thermo hydraulic performance of such solar air heater is both quantitatively and qualitatively better than one side roughened solar air heaters.

Sharma and kalamkar [20] studied thermo hydraulic performance of Solar air heater, it was found that dimple shape elements offers minimum friction factor value when compared to increase in the Nusselt number value at the optimum value of parameters selected than other rib elements. High aspect ratio values have better heat transfer efficiency.

Kumar and Saini [21] carried out CFD based analysis of fluid flow and heat transfer characteristics of a solar air heaters having roughened duct provided with artificial roughness in arc shaped geometry. The heat transfer and flow analysis of the chosen roughness element were carried out using 3-D models. The ribs were provided on the absorber plate whereas other sides of the duct were kept smooth. FLUENT 6.3.26 commercial CFD code was used for simulation. Different Turbulent Models Namely Shear stress transport keu, Standard k-epsilon, Renormalization group (RNG) k- epsilon and Realizable k-epsilon were tested for smooth duct having same cross-section of roughened duct in order to find out the validity of the models.

Yadav and Bhagoria [22] carried out CFD based Heat transfer and fluid flow analysis of solar air heater. It was found that It was found that from the performed calculations that the Renormalization-group k model yields the best results for two- dimensional flow through conventional solar air heaters, It was found with increase in Reynolds number enhancement of nusselt number.

Yadav and Bhagoria [23] carried out CFD analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate. numerical investigation is conducted to analyze the two-dimensional incompressible NavierStokesfows 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 = 7.1435.71 and e/d = 0.0210.042) have been used as roughness element. It was found that for a given constant value of heat flux (1000 W/m^2), the performance of the artificially roughened solar air heater is strong function of the Reynolds number. The maximum enhancement in the Nusselt number has been found to be 3.073 times over the smooth duct corresponds to relative roughness height (e/D) of 0.042 and relative roughness pitch (P/e) of 7.14 at Reynolds number (Re) of 15,000 in the range of parameters investigated. The average friction factor tends to decrease as the Reynolds number increases in all cases. The average friction factor tends to decrease as the relative roughness pitch increases for a xed value of relative roughness height and it tends to increase as relative roughness height increases for a given value of relative roughness pitch.

Yadav and Bhagoria [24] carried out two dimensional CFD analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate. The effects of small diameter of transverse wire rib roughness on heat transfer and fluid flow have been investigated. The Reynolds number, relative roughness pitch (P/e) and relative roughness height (e/D) are chosen as design variables. It was found that It is apparent that the turbulence created by small diameter of transverse wire ribs result in greater increase in heat transfer over the duct. Average Nusselt number increases with an increase of Reynolds number. The maximum value of average Nusselt number is found to be 117 for relative roughness pitch of 7.14 and for relative roughness height of 0.042 at a higher Reynolds number, 18,000. The maximum enhancement of average Nusselt number is found to be 2.3 times that of smooth duct for relative roughness pitch of 7.14 and for relative roughness height of 0.042.

Karmare and tikekar [25] carried out CFD analysis of rib grit roughened surface solar air heater. Lower side of collector plate is made rough with metal ribs of circular, square and triangular cross-section, having 60^{o} inclinations to the air flow. The grit rib elements are xed on the surface in staggered manner to form defined grid. The system and operating parameters studied are: e/D = 0.044, p/e = 17.5. It was found that square cross-section ribs with 58^{o} angle of attack give maximum heat transfer.

Chaube et al. [26] carried out two Dimensional CFD analysis of solar air heater by providing rib type roughness. Author Reported that It is observed that the 2D analysis model itself yields results, which are closer to the experimental ones as compared to 3D models. The 3D model requires much higher memory and computational time compared to 2D ones. It may be because of negligible effect of secondary flow in transverse ribbed duct surface. Hence, it is sufficient to employ a simpler 2D model which being more economical with the memory and computational time requirement. The highest heat transfer is achieved with chamfered ribs but the best performance index is found with rectangular rib of size 315 mm.

Tagliaco [27] Studied Dynamic thermal models and CFD analysis for at-plate thermal solar Collectors and compare all dynamics models. Author reported The transient lumped models able to reproduce the dynamic behavior introducing an overall thermal capacitance of the whole solar collector. Presented a model to evaluate the short-term dynamic behavior of unglazed solar collectors installed on the roof at various flow rates.

Arulanandam et al. [28] investigated heat transfer and ow characteristics for a representative element of an unglazed transpired-plate absorber with holes in a square pitch arrangement under no wind conditions using CFD. The study was completed using TASC flow, a state-of-the-art CFD code. A mathematical model was developed with the relevant boundary conditions and interfacial (solid fluid) conditions specified. It is reported that if transpired-plate absorbers were to be made from lower conductivity materials, such as plastics, acceptable efficiencies could still be achieved.

3. METHODOLOGY

3.1 Selection of Method:

System selection is mainly based on their performance as well as our requirement. According to that we choose Computational Fluid Dynamics (CFD). It is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyse problems that involve fluid flows.

- PCs are utilized to play out the counts required to reproduce the connection of fluids and gases with surfaces characterized by limit conditions. With fast supercomputers, better arrangements can be accomplished.
- Progressing research yields programming that enhances the exactness and speed of complex recreation situations, for example, transonic or turbulent streams.

- Introductory exploratory approval of such programming is performed utilizing a breeze burrow with the last approval coming in full-scale testing, e.g. flight tests.

CFD analysis done with help of ANSYS 9.1 software. Apart from that various software of ANSYS used for a lot of different analysis, such as Fluent and Gambit.

With the help of computer software, we generated graphs and able to compare them individually. Eventually, we got the best turbulent profile from the graphs. Name of efficient turbulent NACA 0030mm is having moderate heat transfer rate and minimal friction factor. Which can easily observe from the below graphs.

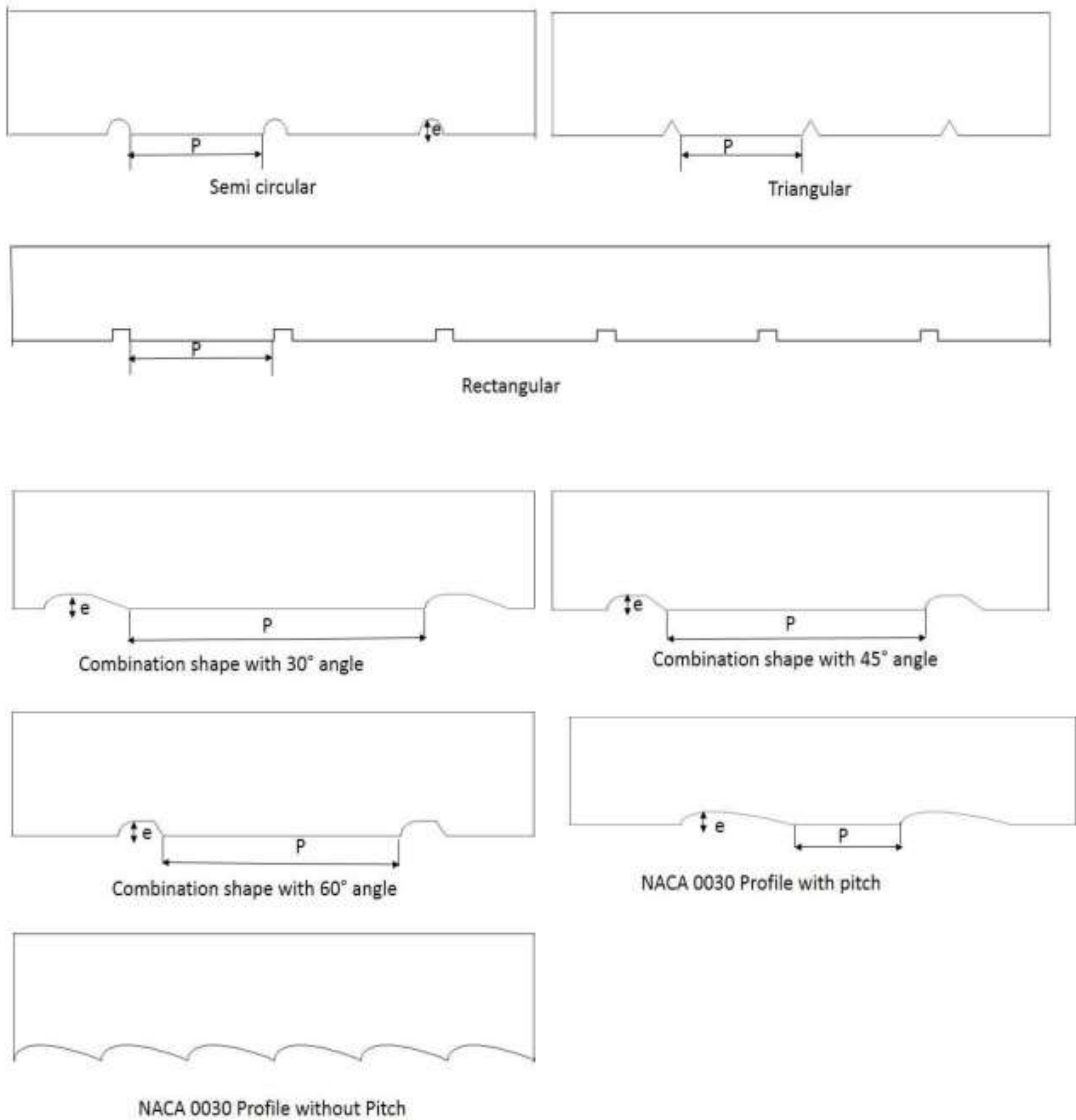


Figure 3.1: Different Roughness Geometries used in Computational Domain

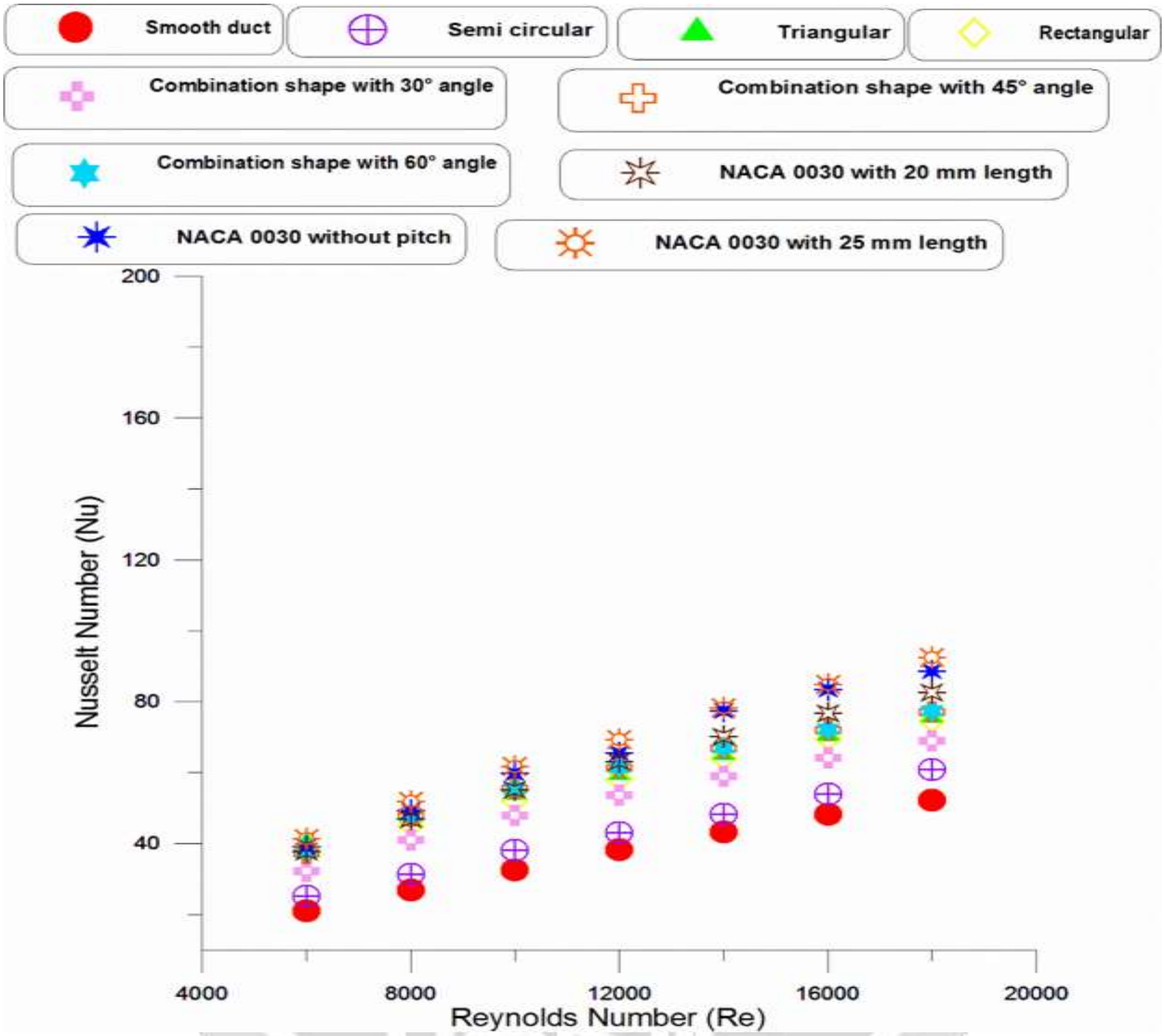


Figure 3.2 Comparison Between Nusselt number Predictions of Different CFD models

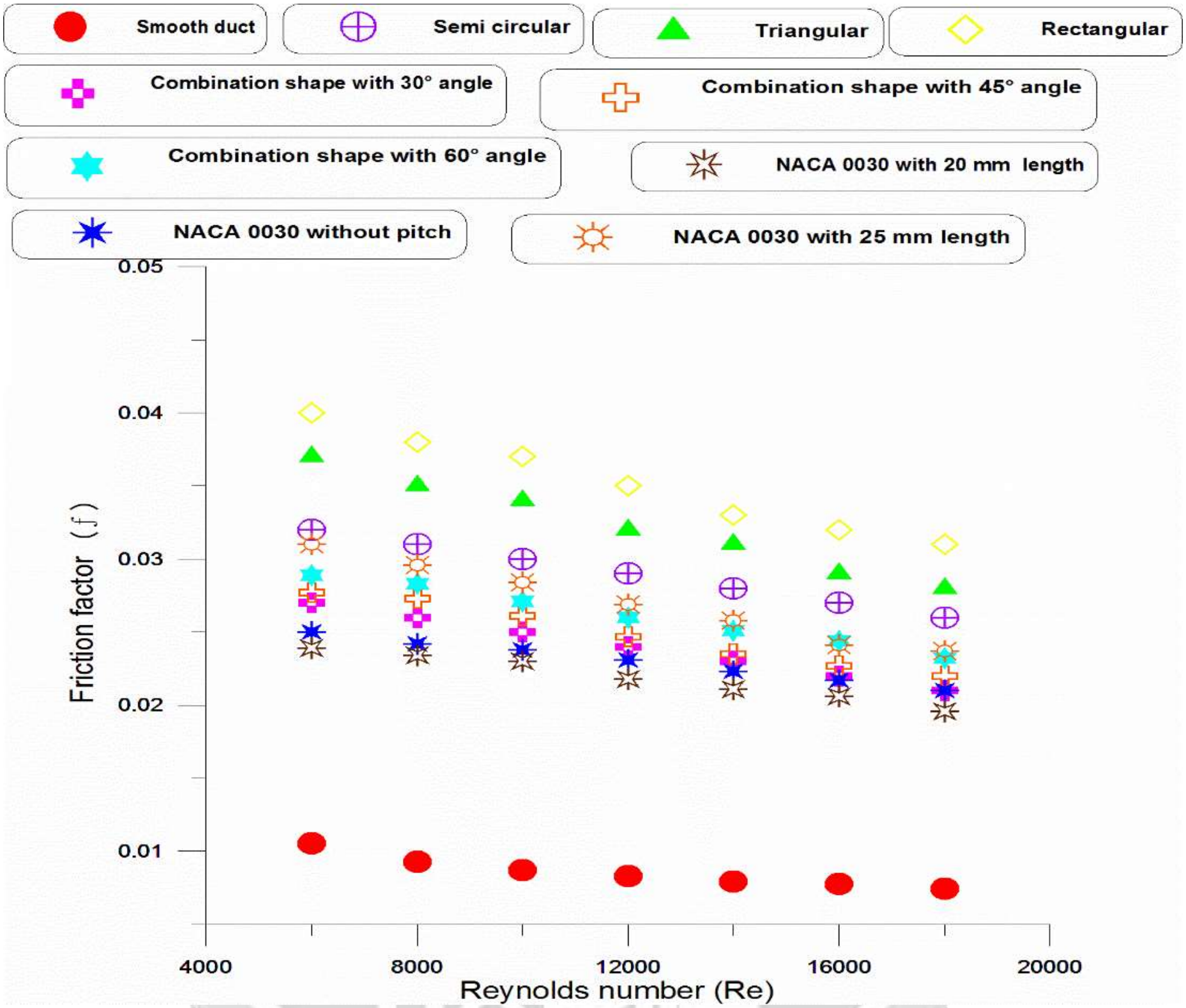


Figure 3.23 Comparison Between Friction Factor Predictions of Different CFD models

5. CONCLUSIONS

In the present study, CFD analysis of smooth duct and artificially roughened solar air heater duct was carried out in the wide range of Reynolds number viz. 6000 to 18000, and results are compared with analytical results. The conclusions made from study are as under:

- Among various turbulent models viz. RNG k-epsilon, Realizable k-epsilon, Standard K- epsilon, SST k-omega; the results obtain with RNG k-epsilon model were found closest to the analytical results.
- It was found that as Reynolds number increased Nusselt number increased and friction factor decreased for smooth and roughened duct.
- The CFD results predicted for smooth duct in terms of Nusselt number and friction factor were compared with Dittus-Boelter empirical correlation and modified Blasius equation respectively and percentage deviation were found to be 2% and 1.5% respectively. This shows very good agreement between two approaches.

- To improve the performance of solar air heater, different roughness geometries viz. semicircular, rectangular, and triangular were attempted, in all the cases, Nusselt number improved but friction factor also increased.
- Among various roughness geometries. The performance of solar air heater was found to be optimum with triangular geometry in terms of Nusselt number and friction factor. due to this modification, the Nusselt number increase 47% and friction factor increase 71% in comparison with smooth duct.

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