ISSN 2395-1621

Comparative thermal analysis of sah with artificial roughness

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ABSTRACT

Solar energy is the most promising source of energy, available freely and omnipresent. The most efficient way to extract this energy is its conversion to thermal energy by using solar collectors such as solar air heaters and solar water heaters. These are used for several industrial applications like crop drying, space heating, etc. But the thermal efficiency of solar air heater having smooth plate collector is very low due to low convective heat transfer coefficient between the absorber plate and the air flowing in the duct. The use of artificial roughness on upper and underside of absorber plate surface is an effective way to enhance the heat transfer to the flowing air in the duct, at the expense of pressure drop. Several investigators have investigated that artificial roughness is provided by fixing wires, ribs, wire mesh or expanded metal mesh and by providing roughness in dimple shaped geometry. The thermal performance of solar air heater is increased by providing multiple arc shaped roughness element on the absorber plate of double pass SAH with parallel flow. The optimization is carried out amongst the smooth, one sided and double sided roughened SAH for *(P/e)* relative roughness pitch value equal to 40. The heat transfer enhancement with newly designed artificial roughness is compared with smooth absorber plate. Data reduction of experimental data is carried out. Experimental results are validated by CFD software.

***Keywords*— Artificial Roughness geometry, CFD, Heat transfer coefficient, Double Pass SAH, Solar Energy.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Solar energy is the cleanest source of nonconventional form of energy, available freely almost all parts of the globe naturally. For the efficient use of solar energy it must be first converted into thermal energy. Thus conversion of solar energy into thermal energy can be obtained by the use of solar collectors. Flat plate collectors are type of solar collectors has proved to be used significantly in various industrial applications like space heating, drying agricultural products, drying of seeds, etc. Researchers have shifted their focus to explore various conventional solar air heaters, due to their lower efficiencies. Present investigation is focussed on the use of artificial roughness elements on single side as well as double sides of absorber plate and comparison of their performance with the smooth absorber plate. The values of Nusselt number and friction factor have been obtained for different values of Reynolds number. Validation of experimental results has been done by CFD software Ansys Fluent.

II. MOTIVATION

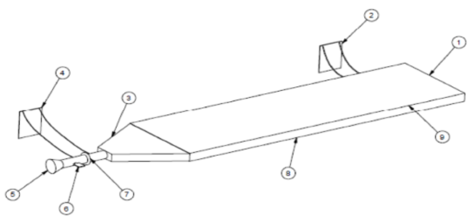
The thermal efficiency of solar air heater having smooth plate collector is very low due to low convective heat transfer coefficient between the absorber plate and the air flowing in the duct. Several investigators have investigated that artificial roughness is provided by fixing wires, ribs, wire mesh or expanded metal mesh and by providing roughness in dimple shaped geometry [1]. In a smooth plate solar air heater a thin viscous sub layer develops adjacent to the wall in turbulent boundary layers where the velocity is relatively low. In this region heat transfer is predominated by conduction and beyond this heat transfer process is dominated by convection [2]. Thus the objective is to increase the heat transfer coefficient between the absorber plate and air flowing over the plate. Although providing roughness element improves thermal efficiency, it also leads to increased frictional losses [3]. Hence, greater power by fan or blower is required. Therefore, in order to keep the friction losses at a minimum level, the turbulence must be created only in the region very close to the duct surface i.e. in laminar sub-layer only.The surface roughness is produced by several methods, such as sand blasting, machining, casting, forming, welding ribs and by fixing thin circular wires along the surface (metal rib grits) [3]. Hence, the chief domain of concern for investigators is to find appropriate geometry of roughness element that would enhance the heat transfer between the absorber plate and flowing fluid with lowering the friction factor.

III.METHODOLOGY

The experimental analysis is done for the solar air heater having the artificial roughness in the form of circular multi-arc shaped ribs on the aluminum plate. The experimental setup, procedure and CFD analysis are explained in subsequent points as follows.

A. Experimental Setup

The wooden rectangular duct of internal dimensions 1750 *mm*x300 *mm*x30 *mm* which consists of an entrance section, a test section and an exit section of length 500 *mm*, 1000 *mm* and 250 *mm* respectively in accordance with the recommendation of *ASHARAE* standard 93–77 [20, 21]. The entry length is taken as $5\sqrt{WH}$ and exit section length is taken as $2.5\sqrt{WH}$. The entry section of length is provided for uniform development of flow at the inlet of the test section. The test section of length 1000 *mm* provided for the testing of smooth and artificially roughened plates. In order to provide the insulation and minimize the heat losses, the thickness of the plywood base of duct is 18 *mm* and side wooden wall thickness is 12 *mm*. The exit section and plenum are attached to minimize the pressure losses from sudden reduction in area of the outlet. A circular pipe is used to pass the air from the plenum to the orifice meter. After that the flow control valve is used. The air is sucked by the induction blower at extreme right end. When the air is passes over the absorber plate heated by solar radiation then heat is transferred from plate to the air. The aluminum absorber plate of 1 *mm* thickness is used for testing. A glass cover is provided so that the solar radiation falls on the upper side of the aluminum plate. The thermocouples are provided for measurement of air as well as the temperature of the plate. A digital multi-point temperature indicator is used for indicating the temperature of the thermocouple. The micro-manometer is provided across the test section for friction factor measurement. The experimental setup is prepared on the roof-top of the building so that the solar radiation should fall on the plate from *9.00 AM* to *3.00 PM*. The instrument used for specific measurement in experimental setup is discussed one by one as follows.



1. Air inlet 6. Flow control valve
2. Micro manometer 7. Orifice Meter
3. Plenum 8. Test section
4. U-tube manometer 9. Upper glass cover
5. Blower

Fig 1: Schematic diagram of the experimental setup

B. Experimental Procedure

The experimentation of the solar air heater having smooth plate and the artificial roughened plate is done on the rooftop of building. The tests are taken on fair weather condition i.e. clear days of the summer February 15- May 15 so that maximum solar radiation available to analyze the performance. The air is induced by the induction blower. The air enters to the entry section and gets developed over the entrance section and then passes on both sides of plate. The inlet air temperature of the test section is measured by two inlet thermocouples. Plate temperatures along the test length are measured by attaching eight thermocouples to the plate along its length. Out of which four thermocouples are set above the plate and four below. Again the two thermocouples are used to measure the outlet temperature at test section.The pressure drop along the test section is measured by micro-manometer which shows the differences in pressure at inlet and exit of the test section. Discharge is measured by the orifice meter by measuring the pressure drop across orifice meter. The hot air comes out at exit of the induction blower.

C. CFD Analysis

The boundaries and continuum as inlet, outlet, heated wall, insulated wall and the fluid zones were defined as per the experimental conditions. Different boundary conditions for the geometries were selected as: air inlet velocity. Both Inlet and Outlet pressure was kept as zero gauge pressure. All the other walls were considered to be completely insulated with zero heat flux except absorber plate. No slip condition was applied to all the ‘walls’. After setting all necessary input conditions the problem was iterated for 600 iterations within which it gives well converged solution so that accurate results were displayed. The contours were displayed by using post processor. The multiple arc shaped elements were used as the roughness elements and were used on both single and double side for the analysis. The volumetric meshing of the duct of smooth duct and roughened one is as shown in Fig. 2 and Fig. 3, respectively.

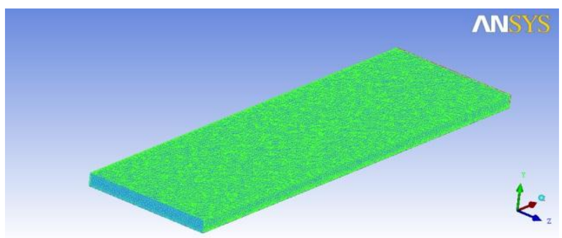


Fig 2: Volumetric Meshing of Smooth Duct

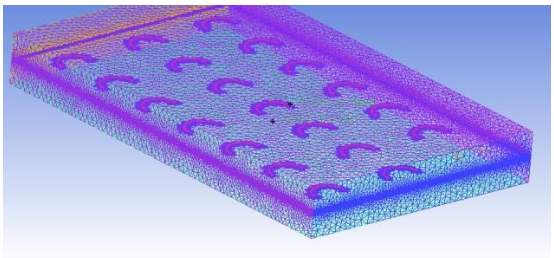


Fig 3: Volumetric Meshing of Roughened Duct

The computational analysis is done by using the following methodologies are as shown in Table 1.

TABLE I
Computational Analysis

Pre-processor	**ICEM-CFD**
Solver	Fluent
Post-processor	CFD-Post
Pre-processor	ICEM - CFD
Domain	3D
Solver	Pressure-Based
Time	Steady
Model	Energy and RNG *k–ε model*
Fluid	Air
Near wall treatment	Standard wall function
Density	Ideal gas
Plate material	Aluminum
Turbulent Intensity	5 %

IV. RESULT & DISCUSSION

The performance of the SAH with Smooth plate and plate which is artificially roughened has been evaluated in this section. The various parameters involved for the performance analysis are relative roughness pitch *(P/e)*, angle of attack *(α)*, forartificially roughened plates alongwith different values of Reynolds Number. The roughened plates used were both Single and doublesided roughened ones. The values for *P/e* ratios considered as 40 for the Reynolds number values existing from 3000, 6000, 9000, 12000 and 15000. The experimental and CFD analysis has been carried out for the SAH having smooth absorber plate for the sets of Reynolds number mentioned priorly. The performance analysis of smooth plate was marked by various parameters such as Nusselt number, Friction factor and Stanton number. Similar sets of Reynolds Number values ranging from 3,000-15,000 have been used for artificially roughened plates. The plate with single and Double sided roughened with multiple arc shaped roughness elements for relative roughness pitch 40 is used. The lateral pitch of 75 mm was kept constant. The experimental results have been validated with CFD results and shows that roughened plates shows better performance than that of SAH with smooth absorber plate.

A. *Validation of Experimental and CFD results*

The experimental and CFD analysis of Double pass Parallel flow has been carried out for the range of Reynolds number ranging from 3000 -15000. Figure 10 to Figure 13 shows the variation of 'Nu' and 'f' with the increment in the Reynolds number for smooth, single sided roughened and double sided roughened absorber plates respectively.

1) SAH with Smooth Absorber Plate:

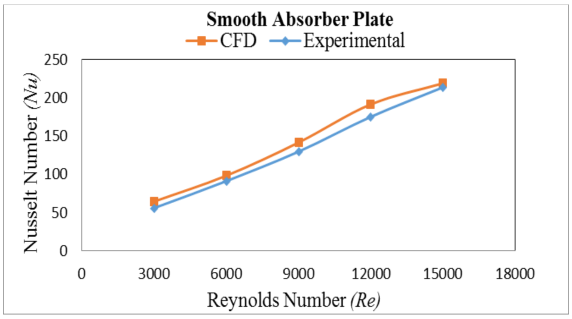


Fig 4: Comparison of *'Nu'* Vs *'Re'* for Smooth Absorber Plate

Fig. 4 shows the variation of *'Nu'* with the increment of *'Re'* for both the experimental and *CFD* values for smooth absorber plate. As the *'Re'* increases there is also the increment in the value of *'Nu'*. The maximum deviation between experimental and *CFD* values is found to be 13.22 % for Reynolds Number 3000. Also the average value of deviation is observed as 7.95 %. Hence, the deviation is less than 10 % and hence it is within permissible limits. Thus the experimental values are validated with the *CFD* values.

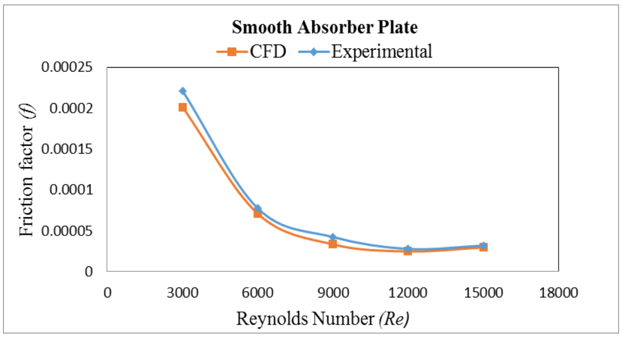


Fig 5: Comparison of *'f'* Vs *'Re'* for Smooth Absorber Plate

Similarly, the values of friction factor determined from experimental data for smooth duct have been compared with the values obtained from the *CFD* analysis as shown in Figure 11. The experimental results show the good agreement of friction factor with the *CFD* results. The maximum variation between *CFD* values and experimental values is observed as 9.01 %, which is within the permissible limits for value of 'Re' equal to 3000. The average of deviation is observed as 9.80 % and is within 10 %, hence acceptable. Thus the *CFD* values are validated with the experimental values.

2) SAH with One Sided Roughened:

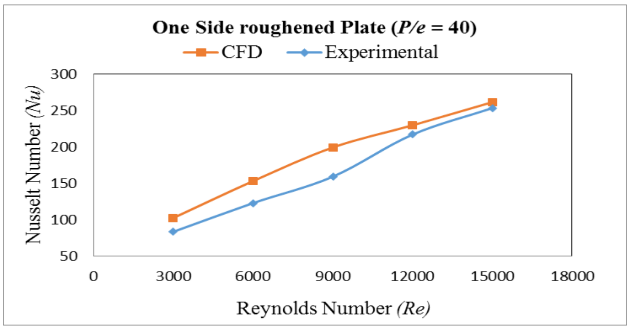


Fig 6: Comparison of *'Nu'* Vs *'Re'* for One Side Roughened Plate

Fig. 6 shows the comparison between the experimental and CFD values of *'Nu'* for one side roughened absorber plate for Double pass parallel flow. The maximum value of *'Nu'* is found to be 264 and 235 with *'Re'* of 15000, for both *CFD* and experimental, respectively. It is also observed from the graph that the value of the *'Nu'* increases with the increase in the value of the *'Re'*. The maximum deviation is found to be 7.8 % and the average deviation is observed as 8.6 %. As the average deviation is found to be lesser than 10 %, the results obtained are validated with the *CFD* values.

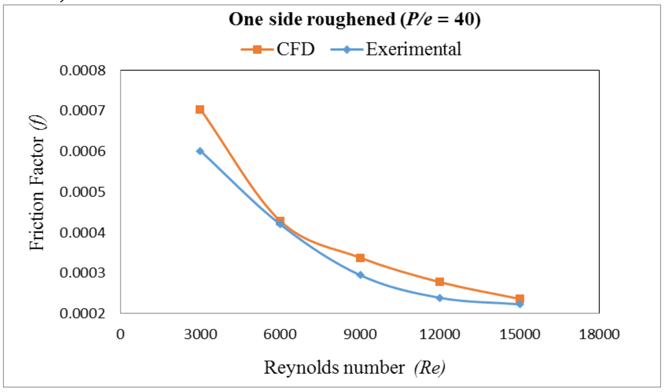


Fig 7: Comparison of *'f'* Vs *'Re'* for One Side Roughened Plate

Fig. 7 shows the comparison between the experimental and CFD values of *'f'* for one side roughened absorber plate for Double pass parallel flow. The maximum value of *'f'* is found to be 0.00075 and 0.0006 with *'Re'* of 3000, for both *CFD* and experimental, respectively.The maximum deviation is found to be 8.76 % and the average deviation is observed as 9.78 %. As the average deviation is found to be lesser than 10 %, the results obtained are validated.

3) SAH with Double Sided Roughened Plate:

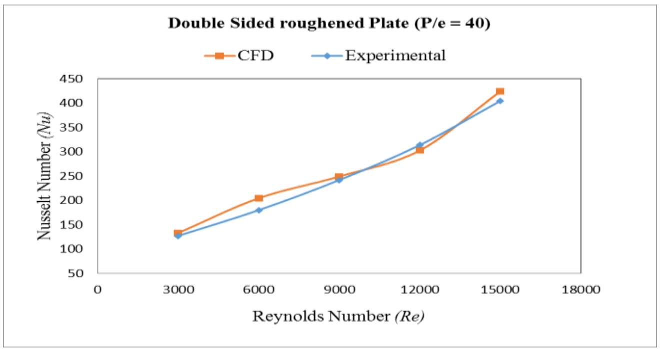


Fig 8: Comparison of *'Nu'* Vs *'Re'* for Double Sided roughened Plate

Fig. 8 shows the variation of *'Nu'* with the increment of *'Re'* for both the experimental and *CFD* values for smooth absorber plate. As the *'Re'* increases there is also the increment in the value of *'Nu'*. The maximum deviation between experimental and *CFD* values is found to be 9.22 % for Reynolds Number 6000. Also the average value of deviation is observed as 8.18 %. As the deviation is found to be less than 10 % and is within permissible limits, the experimental values are validated with the *CFD* values.

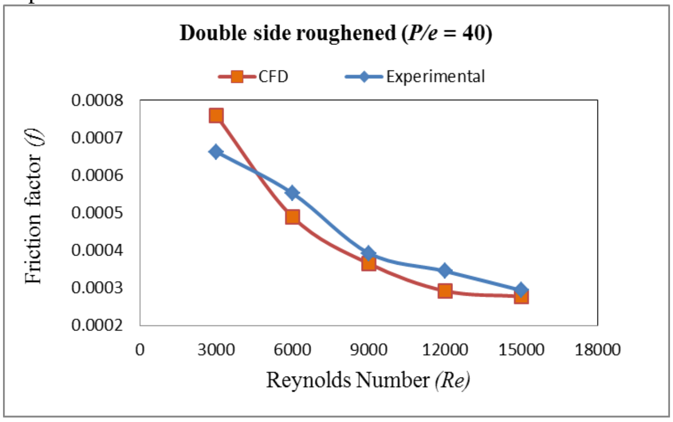


Fig 9: Comparison of *'f'* Vs *'Re'* for Double Sided roughened Plate

Fig. 9 shows the comparison between the experimental and CFD values of *'f'* for Double side roughened absorber plate for Double pass parallel flow. The maximum value of *'f'* is found to be 0.00079 and 0.00065 with *'Re'* of 3000, for both*CFD* and experimental, respectively.The maximum deviation is found to be 9.63 % and the average deviation is observed as 8.62 %. As the average deviation is found to be lesser than 10 %, the results obtained are validated.

B. *Contours of Smooth Absorber Plate*

Fig. 10 and Fig.11 shows temperature and pressure contours of SAH. Fig. 10 shows temperature distribution on plate and along the SAH. As flow proceeds from inlet to outlet, temperature of air increases. Plate gets heated because of solar radiations which transfer heat to the air by convection. Fig. 11 shows Pressure is negative at the entrance of air, hence the air sucks into the duct. Thereby from pressure contour it shows the negative pressure at entrance and positive at the duct exit.

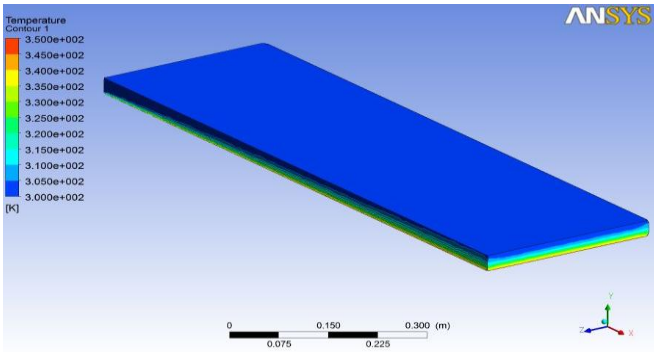


Fig 9: Temperature Contour for Smooth Absorber Plate

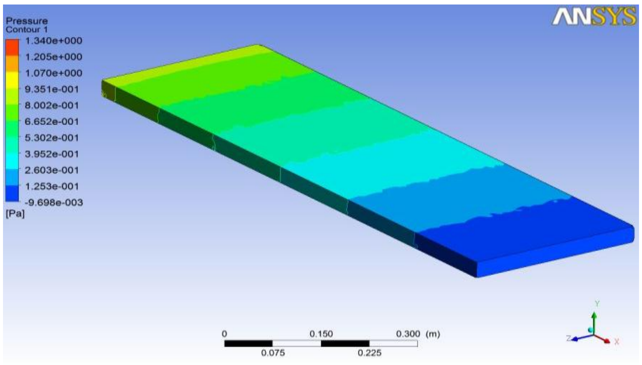


Fig 10: Pressure Contour for Smooth Absorber Plate

V.CONCLUSION

From the present investigation the following conclusions can be marked-

1) The thermal performance of conventional solar air heater is lower as compared to that of artificially roughened solar air heaters.
2) There is increase in the value of Nusselt number with an increase in the Reynolds number, and its maximum experimental value was found to be 244, 264 and 422 for Smooth, one sided and double sided roughened ducts, repectively.
3) The experimental values for smooth absorber plate with double sided parallel pass has been validated with the CFD results and the deviation was found to be less than 10 %, hence acceptable.
4) All experimental results for Nusselt number Vs Reynolds number are validated.
5) All experimental results for Friction factor Vs Reynolds number are validated.
6) The friction factor for Double sided roughened is higher than that of smooth and One sided roughened Absorber plate.

ACKNOWLEDGMENT

I offer my sincere thanks to **Prof. V. N. Kapatkar**, PG Co-ordinator (Heat Power Engineering) for his motivation and help during the experimentation work. I am thankful to **Prof. Dr. H. V. Vankudre**, Head, Mechanical Engineering Department, SinhgadCollege of Engineering, **Prof. Dr. Y. P. Reddy**, Vice-Principal & Head PG Studies, and **Prof. Dr. S. D. Lokhande**, Principal for their cordial support.

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