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"Mathematical Investigation Of Dissimilar Shell Material Pattern OnThermal Presentation Of Solar AirHeater"

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Abstract
This work is concerned with a two-dimensional numerical analysis doneto predict the influenceof transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transferproperties. Solar air heater is a useful device that can be utilized to augment the temperature of airby extracting heat from solar energy. It is a rectangular duct consisting of an absorber plate on itstop and heat falls only on the top of absorber plate. When ribs/baffles are introduced just beneaththe absorber plate, there is a considerable alteration in the thermal performance of air flowingthrough the rectangular duct. A comparison was made between the results of thin (high aspectratio) and square ribs arranged in three patterns, namely, single wall arrangement, staggeredarrangementand in-linearrangement on two oppositewalls. TheNusseltnumbervariationwithReynoldsnumberrange5000-24000wascheckedatafixedribpitch(p)andheight(e)values.Computationalfluiddynamics(CFD)simulationswereperformedusingcommercially availablesoftwareANSYSFLUENTv15.0.Theresultswerecomparedwiththeexistingexperimentaloneswhileperformingsimulationsundersimilarconditions.Two methods were used tocalculatethe average Nusseltnumber inwhichonemethodextractedthelocalNusseltnumberatmanypointsandonaveragingthese,gavetheaverageNusselt number and the other method resembled the one used in the existing experimental work.Theresultsrevealedthat,ascomparedtosmoothduct,theintroductionofribsledtoaconsiderableaugmentationinheattransfer.Goodagreementwasfoundbetweentheexistingexperimentalresultsandnumericaloutput,whenthesecond methodwasadoptedtocalculatetheNusseltnumber.However,theNusseltnumbercalculatedusingmethod1yieldedvalueslowerthantheexistingones.Theresultsrevealedthatthethinribsyieldedbetterperformancethanthesquaredones.Out ofthethreearrangements,thebestthermalperformancewasgivenbythininlineribswhoseconvectiveheattransfercoefficientwas1.83timessmoothduct'sconvectiveheattransfercoefficient.

Keywords:Solarairheater,turbulentflow,Nusseltnumber,ribs,Reynoldsnumber.

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I. INTRODUCTION

Augmentationofconvectiveheattransferofarectangularductwiththehelpofbaffles/ribshasbeena common practice in the past few years. This concept is widely applied in enhancing the thermo-hydrodynamicefficiencyofvariousindustrialapplicationssuchasthermalpowerplants,heatexchangers,airconditioningcomponents,refrigerators,chemicalprocessingplants,automobileradiators and solar air heaters. Solar air heater is a device used to augment the temperature of air withthe help of heat extracted from solar energy. These are cheap, have simple design, require lessmaintenance 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 andcuringofindustrial products.

The shape of a solar air heater of conventional application is that of rectangular duct encapsulating anabsorber 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 plateand absorber for air to flow in.Thedetailed constructional details of asolarair heaterareshownin fig1.1.

Solar air heaters have higher thermal efficiency when the Reynolds number of air flow through theirpassage is 3000-21000. In this range, the duct flow is generally turbulent. Hence, all the researchwork pertaining to the design of an effective solar air heater involves turbulent flow. Conventionalsolar air heaters with all the internal walls being smooth usually have low efficiency. The solar airheater"s internal surface can be artificially roughened by mounting certain ribs/obstacles of differentshapes such as circular wires, thin rectangular bars, etc.

periodically on the lower side of collectorplate. This results in a considerable augmentation in the heat transfer rate, but at the same time leadstoincreasein friction factor therebyenhancingthepumpingpowerrequirements.

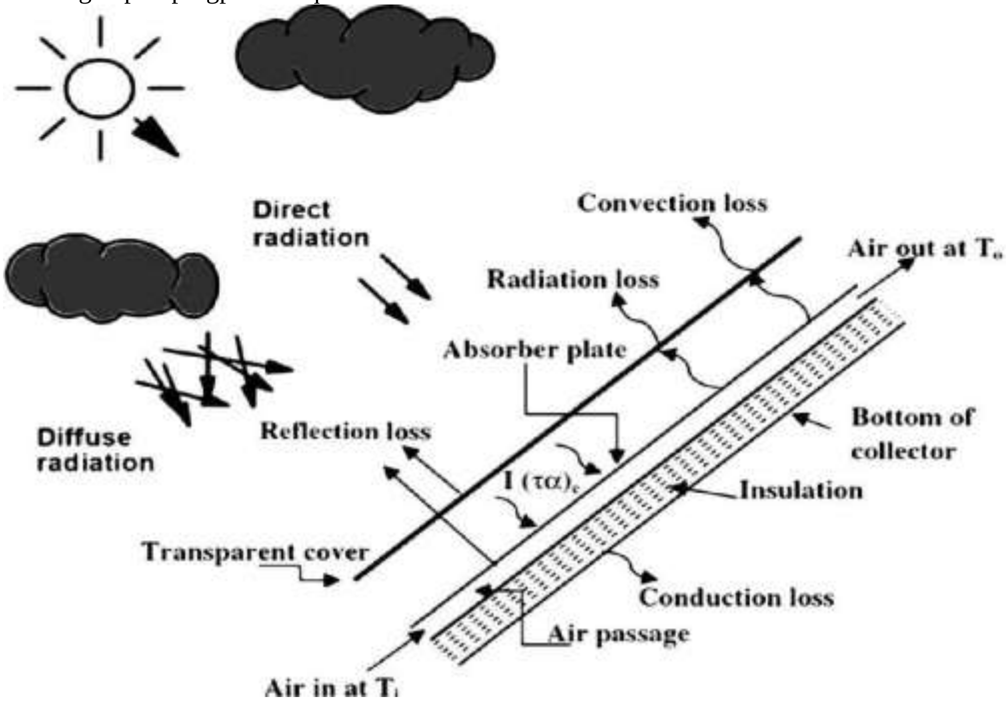


Fig.1.1Solar AirHeaterConstructionalDetails

It is a well-known fact that the friction factor and convective heat transfer coefficient of turbulentflow are highly dependent on the surface roughness of the duct through which they pass [6]. Hence,artificially roughened solar air heaters must be designed in such a manner that their performanceyields higher convective heat transfer rates from absorber plate to air low roughness to air flow.Extensive research is being conducted in this field by many authors, whose work generally involvesperforming experiments or carrying out numerical simulations with different types, sizes and patternsof ribs/ baffles and finding the right parameters at which the heater gives optimal performance(minimum friction loss and maximum heat transfer). Some scientists, after performing research workon solar air heaters, develop a set of correlations for calculating Darcy"s friction factor and Nusseltnumberin terms ofoperatingand roughnessparameters.

The mechanism by which heat transfer, between air and roughenedabsorber plate, increases isbreakage of laminar sub-layer. The introduction of ribs leads to local wall turbulence and breakage oflaminar sub-layers leading to periodic flow reattachment and separation. Vortices are formed nearthesebaffles, which leadsto a significantriseinNusseltnumber.

II. LITERATURESURVEY

2.1RELATEDWORK

[1] FarisAissaoui et al. (2017) developed a mathematical for simulating the influence of fins andbaffles on the thermal performance behavior of single pass solar air collector system working inforced convection. Due to the lack of theoretical work in the case of single pass solar air heatershaving artificial roughness, we have proposed a theoretical model which consists of dividing thecollector into several differential elements along the panel. This model is based on a numericalsolution of energy equations in each component of collector. The results obtained from the presentwork and results of others researches are in good agreement. Using energy analysis, influence ofparameters such as width of baffles, distance between baffles, length of air heater and number offins are presented. The obtained results would be useful to select the most efficient and designparameters.

[2] Asole et.al (2020) In this paper, results of CFD analysis on heat transfer and friction in rectangularducts with broken double arc shape rib with staggered rib roughness has been presented. The ribroughnesshasrelativeroughnesspitchof10,arcangleof30°andrelativeroughnessheightof

0.043.Therelativegappositionwasvariedfrom0.30to0.60.TheeffectsofrelativegappositiononNusseltnumber,frictionfactorandthermo-hydraulicperformanceparameterhavebeendiscussed and results compared with smooth duct under similar conditions. The rough ribs wereefficient enough to transfer the desired heat, but they are not economical and are very complex indesignand construction.Whereas, roughnessgives moreareaofcontact.

[3] **Shreyas P et al. (2021)** Analysis is conducted for configurations of the absorber plate consisting of5mm,8mm,10mmand12mmventdiametersandthenumberofventsisvariedas,24,36and

54. The numerical CFD analysis is conducted for Reynolds numbers ranging from 3000 to 21,000.The CFD analysis is evaluated against the experimental results. The average increase in the thermalefficiency of 23.33% is obtained for the configuration with 8 mm diameter vents and 36 number ofventscomparedtothebasemodelwithouttheabsorberplate.Theaverageincreaseinthermohydraulicefficiencyis21.78%higherfortheconfigurationwith36ventsandaventdiameter of 8 mm compared to the base model. The highest thermohydraulic efficiency of 72.8% isobtained. The thermohydraulic efficiency of the collector is directly proportional to the increase invent diameter. The study infers that the circular geometry and vented absorber plate causes vortexformationresultingin increasein turbulenceinducedheat transfer.

[4] MesutAbuşka et al. (2021) enhance the thermal efficiency and to create proper volume for heatstorage material in terms of the effectiveness of the SAH. The thermal efficiency for the absorberwith conical obstacles was 14.0, 14.6, and 11.8% higher than the flat absorber plate for the massflow rates, respectively. The results show that the number of Nusselt obtained in conical surfaceexperiments was highest for all cases tested regardless of Reynolds number. The experimentalresults are compared with the numerical results obtained by the CFD method. The model resultsindicate good agreement with the experimental results. Also, the results show that the heat transferin front of the conicalelements is high, and the backis low; in the smooth absorber,a linearvelocitydistributionisseenalongthechannel;however,intheconicalsurfaceabsorber,thevelocitydistribution dueto turbulenceis veryvariable.

[5] Study of solar air heater with discrete arc ribs geometry: Experimental and numerical approach (2021) Rajnish Azad ,Sushant Bhuvad,Atul Lanjewarhas investigated that the design of Solar Air Heaters (Sol-AHs) duct, the most efficient way to enhance the heat transfer is by providing artificial roughness on the absorber plate. In the present paper, experimental analyses perform on solar air heater (Sol-AHs) with novel discrete symmetrical arc rib geometry. The studied parameters are ratio of gap width to rib element diameter (g/e) of 2, 3, 4 and 5, ratio of rib diameter height to hydraulic diameter (e/Dh) as 0.045, ratio of rib pitch to rib element diameter as 10, air flow angle of attack as 30°, number of gaps 3 and Re in range of 3000–14000. The performance of novel discrete arc rib solar air heater has been compared with existing staggered V-rib geometry. Maximum enhancement in Nusselt number achieves at g/e equal to 4, which is 3.88 times more compared to the smooth plate, while the highest increment in the thermo-hydraulic performance also observes at g/e of 4. Correlations have been developed for ratio of gap width to rib element diameter and flow parameters. The mathematical model has been developed using a MATLAB code and validates with an experimental study, which further use to design the Solar Air Heater (Sol-AHs) under various operating parameters. Moreover, the new discrete symmetrical arc rib geometry has better performance than the existing best novel V-rib geometry.

[6] A Numerical Study on the Performance of Different Shaped Perforation Hole on the Absorber Duct Insert in a Solar Air Heater (2022) Arunkumar H. S., Shiva Kumar and K. VasudevaKaranthhas investigated that the solar air heater is one of the solar energy applications used to heat the atmospheric air for space heating and drying applications. Due to the formation of the laminar viscous sublayer convective heat transfer coefficient of the absorber plate is low. An attempt is made to improve the efficiency by creating perforation holes of different shapes (circular, triangular and rectangular) on the top surface of the absorber duct insert placed inside the test section of the Solar Air Heater (SAH). The absorber duct insert enhances the heat transfer rate, and perforation causes the cross flow and the flow disturbance in the flow stream. A rectangular-shaped hole configuration shows the highest thermal efficiency of 87.01 %, followed by the circular and triangular hole configurations. Circular hole configuration shows the highest thermo-hydraulic efficiency of 83.01 % at the Reynolds number of 15000.

[7] **The Effect of Roughness in Absorbing Materials on Solar Air Heater Performance (2022) karamveer ,Naveen kumargupta ,jamelorfi**has investigated that the Artificial roughness on the absorber of the solar air heater (SAH) is considered to be the best passive technology for performance improvement. The roughened SAHs perform better in comparison to conventional SAHs under the same operational conditions, with some penalty of higher pumping power requirements. Thermo-hydraulic performance, based on effective efficiency, is much more appropriate to design roughened SAH, as it considers both the requirement of pumping power and useful heat gain. The shape, size, and arrangement of artificial roughness are the most important factors for the performance optimization of SAHs. The parameters of artificial roughness and operating parameters, such as the Reynolds number (Re), temperature rise parameter ($\Delta T/I$) and insolation (I) show a combined effect on the performance of SAH. In this case study, various performance parameters of SAH have been evaluated to show the effect of distinct artificial roughness, investigated previously. Therefore, thermal efficiency, thermal efficiency improvement factor (TEIF) and the effective efficiency of various roughened

absorbers of SAH have been predicted. As a result, thermal and effective efficiencies strongly depend on the roughness parameter, Re and ΔT/I. Staggered, broken arc hybrid-rib roughness shows a higher value of TEIF, thermal and effective efficiencies consistently among all other distinct roughness geometries for the ascending values of ΔT/I. This roughness shows the maximum value of effective efficiency equals 74.63% at a ΔT/I = 0.01 $K \cdot m^2/W$. The unique combination of parameters p/e = 10, e/D_h = 0.043 and α = 60° are observed for best performance at a ΔT/I higher than 0.00789 $K \cdot m^2/W$.

[8] **Analysis on Heat Transmission and Fluid Flow Attributes in Solar Air Accumulator Passage with Diverse Faux Jaggedness Silhouettes on Absorber Panel (2019) ShivasheeshKaushik, Satyendra Singh** has investigate the heat transmission and fluid cascade peculiarities of solar air convectors using varying faux irregular surface and shapes on absorber sheet, so that the solar devices utilize maximum amount of available solar radiated heat energy during day time. These artificial roughness shapes are use for the enhancement of thermal performance. This need arises from the fact that the heat circulation and liquid cascade trait have been investigated by the previous investigators only for the cases that differ considerably from those relevant to solar air brazier having different screen matrix placed in the planes parallel to the flow direction and that the radiant energy being absorbed in depth. In our present research paper we investigating experimentally the behavior of artificial irregularities located over absorber platter of solar air heater vessel of varying shapes like trapezoidal, sin wave, rectangular, alternative elliptical shape pattern etc, with different Reynolds Number range 4000 to 24000, mass flow rate on Nusselt Number and Friction Factor and also find the suitable optimum shape for heat transmission enhancement. The results indicated the best heat transfer enhancement results for the alternative elliptical shape pattern among other artificial roughness with range of 0.0786kg/s – 0.475kg/s mass flow rate with thermal efficiency near about 78%. Index Terms: Aluminum sh

[9] **Solar Crop Drying-A Viable Tool for Agricultural Sustainability and Food Security(2018) J.T Liberty , W.I Okonkwo , S.A Ngabea**has investigate that the solar drying of agricultural products. Losses of fruits and vegetables during their drying in developing countries are estimated to be 30–40% of production. The postharvest losses of agricultural products in the rural areas of the developing countries can be reduced drastically by using well-designed solar drying systems. Solar drying is becoming a popular option to replace mechanical thermal dryers owing to the high cost of fossil fuels which is growing in demand but dwindling in supply. This paper presents the viability of solar dryer for agricultural sustainability and food security. Detailed description, fundamentals and preceding research work performed on solar dryers and solar air heaters, as the vital element for the indirect and mixed modes of solar dryers, were presented in the present review paper. For sustainability and climate change, it is important to use renewable sources of energy as much as possible. Solar energy applications were divided mainly into two categories: the first is the direct conversion to electricity using solar cells (electrical applications). The second is the thermal applications. The latter include solar heating, solar cooling, solar drying, solar cooking, solar ponds, solar distillation, solar furnaces, solar thermal power generation, solar water heating, solar air heating. Among the different types of solar dryers, the indirect mode forced convection solar dryer has been demonstrate to be superior in the speed and quality of drying. Incorporating of sensible and/or latent heat storage media within the solar drying systems accelerate the drying process during the night time and low intensity solar radiation periods and exclude the need for using auxiliary heat sources during low solar radiation seasons. The latent storage media is preferable compared to the sensible store media to achieve nearly constant drying air temperature during the drying process. Since the solar air heater is the most important component of the indirect solar drying system, improvement of the solar air heater would led to better performance of the drying system.

[10] **Investigating the different process parameters and design of solar air heater -A review (2020) Abhishek Gupta, Dr. A.R. Jaurker** has investigate that the Solar energy is the most promising field for the coming generation for power generation. Researcher are finding different means of conventional fuels, in that solar energy is the cheapest and easily available source of energy. Solar air heaters are basically used to convert solar energy in useful application like air and water heater. The performance of solar air heater depends on different process parameters like solar air heater duct design, fluid flow behaviour, flow speed and many other. In order to further increase the heat transfer from solar air heater, it is necessary to understand the working of solar air heater. This paper includes the working and different process parameters of solar air heater. It mainly focuses on the research work carried out so far for the enhancement of heat transfer.

III. RESEARCH METHODOLOGY

3.1 PROBLEMFORMULATION

The present work is concerned with carrying out two-dimensional simulations on an artificiallyroughened solar air heater, through which air of air flows. The air heater internal surface wasroughened with the help of transverse-square and thin (high aspect ratio) ribs. The ribs werearranged in different patterns namely one wall only, staggered and in-line on both lower and upperfaces.

3.2 COMPUTATIONALDOMAIN
A rectangular section was considered. It consisted of three sections, test section of length L2,entrance section of length L1 and exit length of length L3. The domain on which numericalsimulationswereperformedwastwo-dimensional.Itisbecausetheyperformednumericalsimulations on their solar air heater of aspect ratio 7.5. They compared two dimensional resultswith three dimensional results on the same geometry and did not find any considerable differencebetween the two. They explained their observation by claiming that for continuous transverse ribs,thesecondaryflow effect was negligibleat higherduct aspect ratios.

The geometry taken is similar to that of Skullongetal‟s rectangular duct. Their rectangular ductwasof length 2000 mm, width300 mm and 30 mm witha test section length of440 mm.

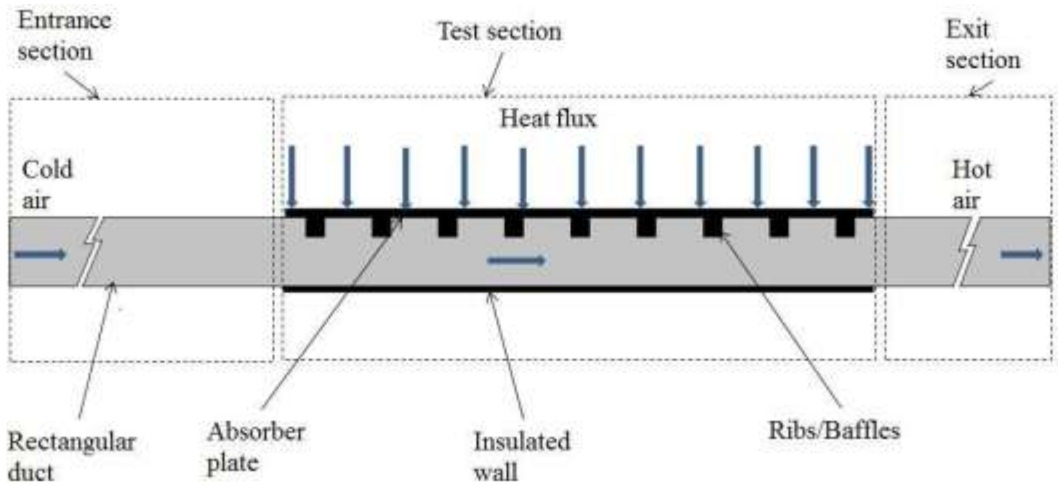


Fig.3.1SketchofComputationalDomain

Hence our domain test section length was 440mm and its entrance and exit length dimensionswere selected on the basis of ASHRAE recommendations, according to which an exit length morethan2.5$\sqrt{WH}$andentrancelengthmorethat5$\sqrt{WH}$werecompulsorytoestablishafullydeveloped flow in the test domain. The geometry of the computational domain. The different ribarrangementsemployed forsimulation areindicated

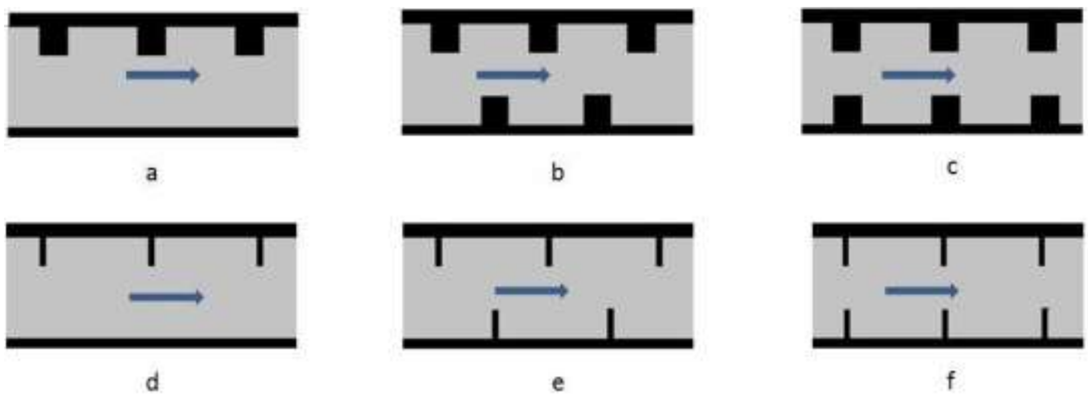


Fig. 3.2 Different Arrangement of Ribs Namely (A) Single Square Ribs, (B) Staggered Square Ribs, (C) In-Line Square Ribs, (D) Single Thin Ribs, (E) Staggered Thin Rib And (F) In Line Thin Ribs

CFDMODELLING
CommerciallyavailableANSYSFLUENTv15.0wastheCFDsoftwareemployedtosolvetheconcerned general differential equations numerically. This software numerically simulates usingFINITEVOLUME METHOD

CONSTRUCTIONOFGEOMETRY
The geometry was constructed in commercially available software ANSYS Design Modeler v15.0.Firstly,anoutlineofthegeometrywithoutribswascreatedinx-yplanewithappropriatedimensions (in mm) and

then surface was generated from the "built sketches" option. Then anothersketch that involved the interface between absorber plate and fluid was developed. The surfaceinitially created was splitinto two faces withthe helpof "face-split"option by choosing thesecond sketch as the tool geometry. The face-splitting option was followed by the generation ofsurfaces from the faces with the help of "create surface from faces" option. Finally, all the edgesandsurfaces werenamedaccordingly.

MESHINGOFTHEDOMAIN

The meshing work was accomplished on commercially available ANSYS meshing software. ThegeometrycreatedwasimportedinANSYSmeshing.Therequirednumberofdivisionsandthetype of "bias" were assigned to each edge. In order to obtain regular rectangular shaped mesh cellswith the best orthogonal quality, mapped facing option was activated. Finally, mesh was generatedbyclickingon"Generate Mesh"button.Fig.4.4showsthemesheddomainfordifferentcases.

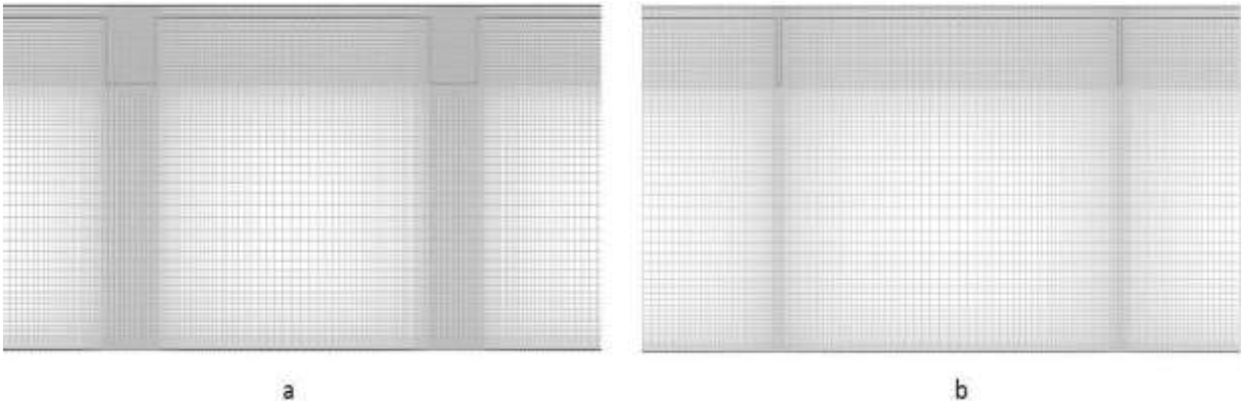


Fig.3.4Detailsof Two-DimensionalMeshingOf(A)SingleSquareRibs

IV. RESULT&DISCUSSION

In this project, a computational model was constructed to measure a solar air heater‟s thermalperformance.Itconsistedofbaffles/ribsjustbelowitsabsorberplate.Thissectionpresentsdetailedresults of theaverageconvectiveheat transfer characteristics.

4.1 SELECTIONOFMOSTAPPROPRIATETURBULENTMODEL

For the smooth duct, the number of mesh cells was varied from 26280 to 186880 at a Reynoldsnumber of 22500. It was observed in simulation results using SST-k-omega and RNG-k-epsilonturbulent model, there was less than 2% alteration in average Nusselt number after 143080 numberofmeshcells.WhentheturbulentmodelwasRealizable-k-epsilon,therewaslessthan2%alterationinaverageNusseltnumberafter105120numberofmeshcells.Hencefurthersimulations for different Reynolds number were performed using 143080 mesh cells with SSTkomega and RNG-k-epsilon turbulent models and 105120 with Realizable-k-epsilon turbulencemodel.TheGrid independencetestresults arerepresented in Fig.4.1

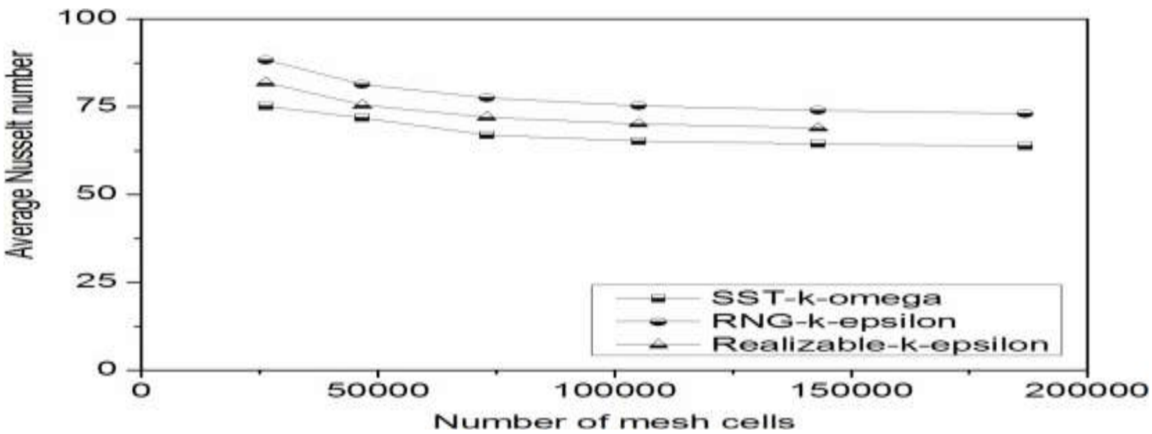


Fig. 4.1 Grid Independence Test Results for Selection of Most Appropriate Turbulence Model

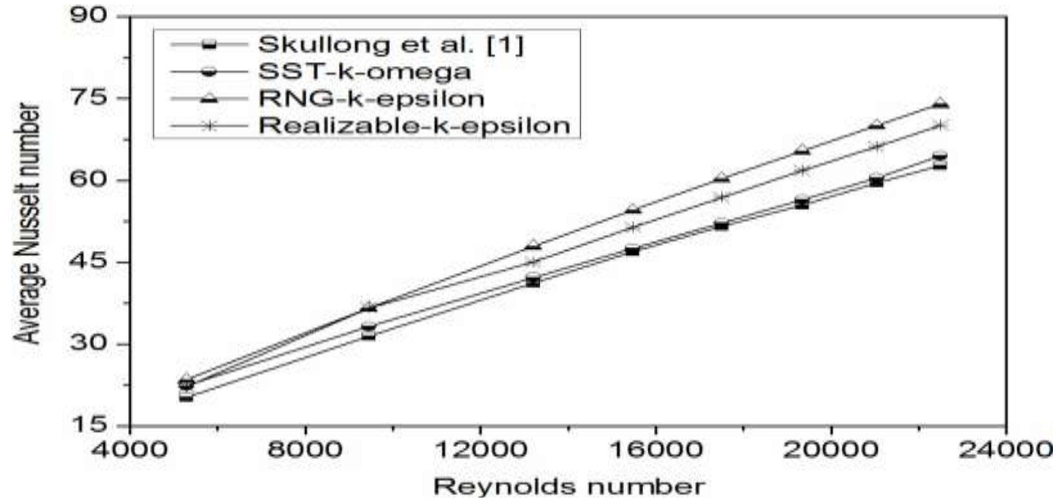
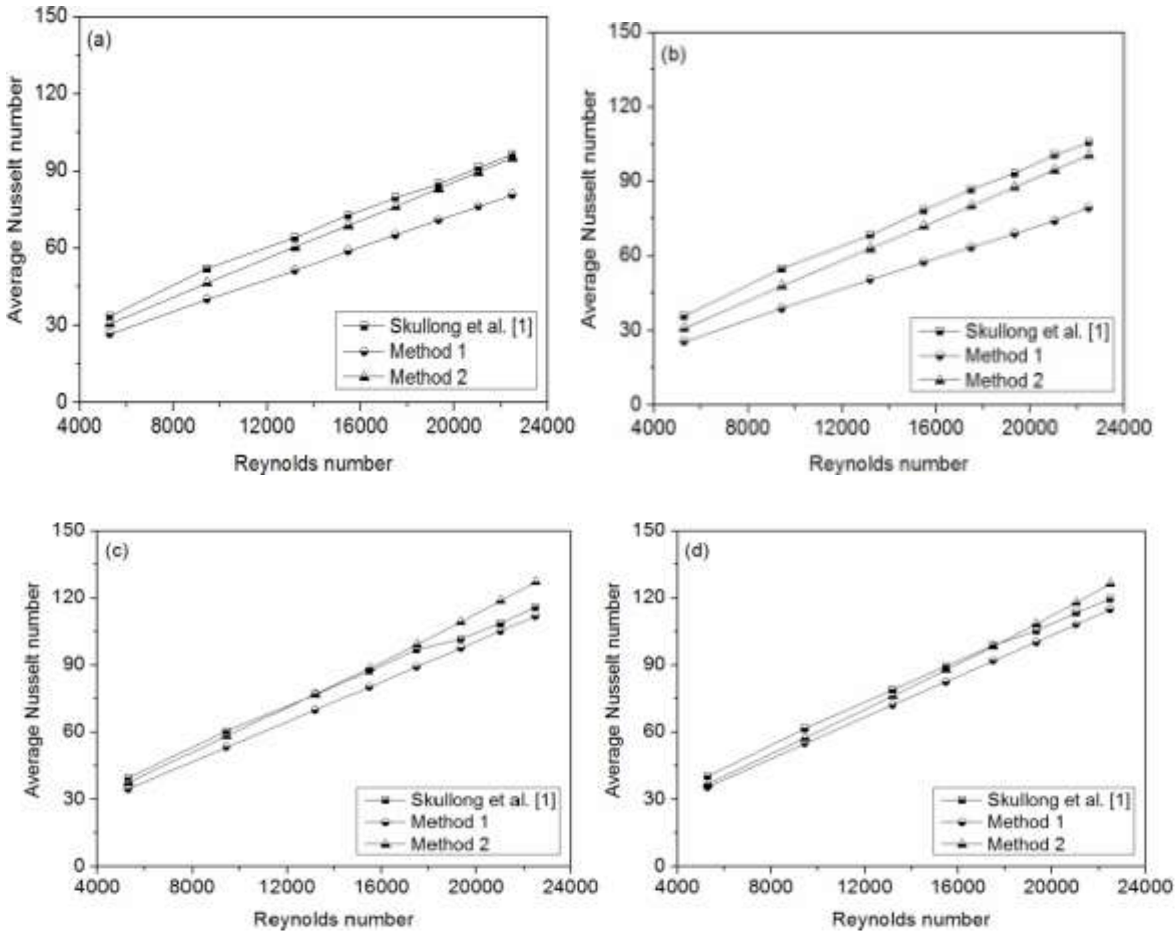


Fig.4.2Comparison of SmoothDuct ResultsforDifferentTurbulentModels



V. CONCLUSION

A two-dimensional numerical analysis is done to predict the influence of transverse rectangularcrosssectioned ribs on a solar air heater‟s convective heat transfer properties. A rectangular ductwas constructed and numerical analysis was carried out on square and thin (high aspect ratio) ribshapes arranged in different fashion, namely single wall, staggered andin-line ribs arranged ontwo opposite walls including the absorber plate. Air was the working fluid and constant heat fluxwas applied only on the absorber plate‟s top surface. The output of numerical simulations drew thefollowingconclusions

- On comparing simulation results, pertaining to smooth duct‟s average Nusselt number, fordifferent turbulent models, it was found that SST-k-omega can best predict the thermalperformanceof thesolar air heater.
- Forallthecasesconsideredinthiswork,increaseinReynoldsnumberleadstoaugmentationin Nusselt number.
- When ribs/baffles are introduced just beneath the collector plate, there was a considerablealterationin theheat transfercoefficient of air.
- TwomethodsisusedtocalculatetheaverageNusseltnumberinwhichonemethodextracted the local Nusselt number at many points and on averaging these, gave the averageNusselt number and the other method resembled the one used in the existing experimentalwork. Good matching between existing experimental results and numerical outputs wasspotted, when the second method was adopted to calculate the Nusselt number, therebyproving that CFD can be effectively applied for the design of solar air heaters. However theNusseltnumbercalculated usingfirst methodyielded valueslowerthantheexistingones.
- ThestaggeredribsgavelowerNusselt numberthanthe in-lineones.
- Out of the three arrangements, the best thermal performance was given by thin inline ribswhoseconvectiveheattransfercoefficient was1.83 times thatofsmooth duct.

FUTURESCOPE

Since, itisobserved thathigh aspectratio ribsallow higher convectiveheattransfer, hence itwould be interesting to conduct research work on triangular shaped ribs having very low apexangles.Thepresent workis expected tobeveryhelpfulforcarryingout the new futureproject

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