NUMERICAL INVESTIGATION ON 90 DEGREE TRANSVERSE NOZZLE SHAPED PERFORATED RIBS WITH DIFFERENT NOZZLE ANGLES AND RIB HEIGHT

Surendra Agrawal [1], Dr. Anil Kurchania[2], Dr. Dinesh Kumar Soni[3],
Research Scholar[1],Professor[2,3],
Department of Mechanical Engineering[1,2,3]
UIT, AISECT University Bhopal (M.P.) India

Abstract* — An two-dimensional computational fluid dynamics (CFD) analysis of a solar absorber plate has been carried out using circular nozzle shaped perforated transverse 900 ribs as artificial roughness on the absorber plate. The relative roughness pitch(P/e= 7.14–17.86), nozzle angle (12, 14, 18, 21 degrees), Reynolds number (Re = 3800–18,000) are chosen as design variables for analysis. A uniform heat flux of 1000 W/m2 is maintained on the surfaceof absorber plate. computational code, ANSYS FLUENT 15.0.0 with renormalization group K-epsilon turbulence model was chosen. An enhancement in Nusselt number and friction factor with decrease in circular relative roughness pitch difference ratio (P/e) is presented and discussed with reference to base paper results. The effect of nozzle shaped perforation and Reynolds number on enhancement of Nusselt number and friction factor is also presented. Optimum configuration of roughness element for artificially roughened solar air heater has been determined in terms ofthermo-hydraulic performance parameter. The nozzle angle of 14° on circular nozzle shaped perforated transverse 900 ribs and circular relative roughness pitch difference ratio of 25 providebest thermo-hydraulic performance of 2.047 consideringthe maximum heat transfer and minimum pressure drop.

***Keywords* — Computational Fluid, Artificial roughness, Thermo-hydraulic performance parameter, Friction factor**

I INTRODUCTION

1.1 Solar power

As we all know that the natural resources of fossil energy are limited this is available in the form of oil and solid substance like crude oil, coal and many others. They are used at very large scale due to this they are depleting much faster rate. Hence is the need of the current scenario to find alternative source of energy. Solar energy is finding as the one of the most easily available, most promising and important renewable source of energy. It is available in abundant form at anywhere in earth. It is also very easy to capture and utilized it. The easiest way to utilized and store solar energy is to convert it in to heat energy which is basically utilized for heating purposed. Heating air through solar power form the major component of solar power exercise system. After burning the fossil fuels harmfully greenhouse gases (CO_2, SO_2, NO_x) can remain as byproduct, which causes higher levels of acid rain during the rainy season, it also increases the amount of harmful atoms in air which create air pollution, due to the increase of chlorine atom in atmosphere depletion of ozone layer is also happening and also causing global warming. It is predicted that globally it is going to increase very faster rate in future due to expectations of a considerable increase in power and heat demand. The heated air energy demand relates with different sector is quite significant. Solar power air heaters have been used with the aim to reducing the percentage of consumption of conventional fuels to a very large extent. The residential and industrial sectors are larger consumers of fossil energy. Therefore, the heating system and air conditioning devises of residential and industrial buildings generate an large amount of CO_2 and many other gases which is responsible for global warming. Fossil energy required to heat and energy required to maintain air-conditioning of the buildings can also be reduced by using renewable sources as alternative to fossil energy (Sanjay and Vilas, 2014)[14]. Heating of air using solar radiation is a technology where the radiation coming from the sun, that is solar radiation, is entrapped by an absorbing medium and utilized for air heating. It is a technology that uses inexhaustible energy for conditioning of air or maintaining the temperature of buildings or for different other purposes (Omajaro and Aldabbagh, 2010) [2].

Solar heater is the most economical and efficient solar technologies, which is widely used due to their easiness in space heating, removing the moisture from timber, used for drying the industrial products, vegetables and fruits. They may be also used in combination with photovoltaic solar absorber panels which is used to manufacture photovoltaic thermal hybrid solar energy collectors (hybrid PV/T systems or PVT) to produce heating effect or to generate electricity. The basic advantages of solar power collectors are: the fluid which is flowing inside the collectors does not get freeze or boil, they cannot create noise during flowing, the operating of solar panel system is very safe and the operating cost is also very less, system cannot produce any kind of harmful wastes and the running life of solar system is also long enough life cycle (Abdullah and Bassiouny, 2014).[5] but solar power collectors have some following drawbacks: low density, the thermal absorption capacity of solar panel is low and the thermal conductivity of air is also low which lead to low thermal efficiency, high cost system installation and non-uniform rate of heat generation

1.2 Classification of solar air heater system based on different type's solar power collector

Collectors are commonly classified by their air ducting methods as one of three types

- Through-pass collectors
- Front-pass
- Back-pass
- Combination front and back pass collectors

III SOLAR ENERGY COLLECTORS

Solar collectors are the key component of active solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat, then transfer that heat to water, solar fluid, or air. The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems.

Solar energy collectors are classified as:

(1) Flat plate collectors.
(2) Concentrating collectors.

If the area of interception of solar radiation is same as the area of absorption, the collector is known as flat plate collector.

3.1 Flat Plate Collectors

Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 100°C.

The major components of Flat Plate collectors are:

- The absorber plate used for absorbing solar radiations, normally metallic with a black surface. A wide variety of other materials can be used with air heaters. It is usually one plate or an assembly of metal sheets or plates forming a nearly continuous surface coated with radiation absorbing black paint, black porcelain enamel or a metallic oxide.
- A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet. As the number of covers increases, the loss of heat from top of collector decreases while intensity of radiation incident on absorber plate also decreases.
- Tubes, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid to transfer energy from absorber plate to the fluid.
- Insulation, provided at the back and sides to minimize heat losses.
- The casing or container, which encloses the components and protects them from the weather.

3.2 Concentrating Collectors

A concentrating collector utilizes a reflective parabolic-shaped surface to reflect and concentrate the sun's energy to a focal point where the absorber is located. To work effectively, the reflectors must track the sun. These collectors can achieve very high temperatures because the diffuse solar resource is concentrated on a small area. In fact, the hottest temperatures ever measured on the earth's surface have been at the focal point of a massive concentrating solar collector. Concentrating collectors have been used to make steam that spins an electric generator in a solar power station. This is sort of like starting a fire with a magnifying glass on a sunny day..

IV PERFORMANCE EQUATIONS FOR A SOLAR COLLECTOR

The performance of solar collector is described by an energy balance that indicate the distribution of incident solar energy into useful energy gain (Qu) and heat losses like bottom (Qb) and top (Qt) as shown in Fig.1.2. The details of the performance analysis of a solar collector are discussed by Duffie and Beckman [31] and Goswami [41].The heat transfer in a solar collector takes place by simultaneous radiation, convection and conduction. The heat transfer from the top takes place by convection and radiation while from the side and bottom is by conduction. The net rate of useful energy collected per unit area is the difference of the amount of solar energy absorbed and the energy loss by the collector to the surroundings

IV LITERATURE REVIEW

Yadav and Bhagoria (2013) [5] - This investigation the study of heat transfer and fluid flow processes in an artificially roughened solar air heater by using computational fluid dynamics (CFD). The effects of small diameter of transverse wire rib artificial roughness on heat transfer and fluid flow have been investigated. The situation for optimum performance has been determined in term of thermal enhancement factor. A maximum value of thermal enhancement factor has been found to be 1.65 for the range of parameters investigated. We found Nusselt number are also increases with an increase of Reynolds number..

Yadav and Bhagoria (2013) [6] - This investigation is solar air heater is one of the basic equipment through which solar energy is converted into thermal energy. Computational fluid dynamics (CFD) investigation is also carried out to select best turbulence model for the design of a solar air heater. CFD simulation result to found to be in good arrangement with experimental result and with the standard theoretical approaches. A two-dimensional CFD analysis has been carried out to study heat transfer and fluid flow behavior in a rectangular duct of a solar air heater with one artificial roughened wall having circular transverse wire rib roughness.

Yadav and Bhagoria (2013) [7] - This investigation is conducted to analyze the two-dimensional incompressible Navier-Stokes flows through the artificially roughened solar air heater for relevant Reynolds number ranges from 3800 to 18,000.Atwo-dimensional CFD model of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate has been proposed and used to predict the heat transfer and flow friction characteristics. Further, we found the Nusselt number tends to increase as the Reynolds number increases in all cases.

Yadav and Bhagoria (2014) [8] - A numerical investigation on the heat transfer and fluid flow characteristics of fully developed turbulent flow in a rectangular duct having repeated transverse square sectioned rib roughness on the absorber plate has been carried out.The two-dimensional fluid flow and heat transfer processes in a rectangular duct of a solar air heater with one artificial roughened wall having square sectioned transverse rib roughness are analyzed numerically, and a detailed description of the average heat transfer and flow friction factor, i.e. Nusselt number and friction characteristics, are obtained. Further, we found the Nusselt number tends to increase as the Reynolds number increases in all cases.

V COMPUTATION FLUID DYNAMICS

5.1 Introduction

Computation Fluid Dynamics (CFD) is the branch of fluid science which deals with a variation occurs on fluid flow, basically computational fluid dynamics opt an finite volume method as methodology and for base equation it follows the Eulerian equation, i.e. when gravity forces were not considered, pressure force and viscous force are used to simulate the desired fluid flow problem.

5.2 Fluent Solver

Computation Fluid Dynamics consists of several domains to solve fluid flow problem like CFX, fluent (poly flow), fluent (blow moulding), fluent, fluent solver works under computational fluid dynamics, it obeys the three governing equation with respect to base equation (Eulerian equation) i.e. energy equation, momentum equation and continuity equation by applying or solving through this algorithm, the further results were obtained and variation could be determine.

5.3 Finite volume method

Finite Volume Method is used to solve the fluid flow problems by obtaining the convergence of Eulerian equation and governing equation, this method works on volume of fluid or volume of fraction, it consists of energy equation, momentum equation and continuity equations with respect to pressure force, viscous force or gravity force to solve the fluid flow problem, in case of heat exchanger, radiation, turbulence, laminar flows, acoustics and also deals with aerodynamics, HVAC

5.4 Governing equations:

5.4.1 Continuity equation:

$$A_1V_1=A_2V_2$$

A_1 = area of inlet
V_1= velocity at inlet
A_2= area of outlet
V_2= velocity at outlet

This equation shows the flow is pressure based or density based i.e. if a flow is pressure based the vortices and stream line of fluid is normal, if the flow is density based the fluid flow and stream line is in a high pressure.

5.4.2 Momentum Equation

This equation justified that the flow of fluid consists of definite mass and product of velocity with respect to mass to determine the momentum of fluid flow.

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_i}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} \quad (4.1)$$

5.4.3 Energy Equation

This equation works on present simulation model when heat flux and radiation were applied on boundary condition to determine the temperature variation on fluid flow and on heat transfer solid element to determine temperature variation.

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_i}{\partial x_i}\right) \quad (4.2)$$

5.5 Procedure for solving problem with fluent:

- Pre- processor
- Solver
- Post- processor

5.5.1 Pre-processor

It is a process on which model is created for simulation, meshing of the domain is done and boundary conditions were applied i.e. inlet, outlet, heat flux, wall, etc.

5.5.2 Solver

It is used to apply the governing equation and base equation on pre-processor to determine the variation on fluid flow.

5.5.3 Post processor

It is used to determine the results obtaining from fluent solver in a form of contour plots, in a form of a velocity and stream line contour plots etc.

5.5.3 Turbulence Modeling

Turbulent flows are characterized by fluctuating velocity fields. These fluctuations mix transported quantities such as momentum, energy, and species concentration, and cause the transported quantities to fluctuate as well. Since these fluctuations can be of small scale and high frequency, they are too computationally expensive to simulate directly in practical engineering calculations. FLUENT provides the following choices of turbulence models:

- Spalart-Allmaras model
- k-ε models
  - Standard k-ε models
  - Renormalization-group (RNG) k-ε models
  - Realizable k-ε models
- k-ω models
  - Standard k-ω models
  - Shear-stress transport (SST) k-ω models
- v2-f model (addon)
- Reynolds stress model (RSM)
  - Linear pressure-strain RSM model
  - Quadratic pressure-strain RSM model
  - Low-Re stress-omega RSM model
- Detached eddy simulation (DES) model
  - Spalart-Allmaras RANS model
  - Realizable k- ε RANS model
  - SST k- ω RANS model
- Large eddy simulation (LES) model
  - Smagorinsky-Lilly subgrid-scale model
  - WALE subgrid-scale model
  - Kinetic-energy transport subgrid-scale model

5.5.4 Choosing a Turbulence Model

It is an unfortunate fact that no single turbulence model is universally accepted as being superior for all classes of problems. The choice of turbulence model will depend on considerations such as the physics encompassed in the flow, the established practice for a special class of problem, the level of accuracy required, the available computational resources, and the amount of time available for the simulation.

VI MODELING AND ANALYSIS

Geometry is framed in demonstrating programming UNIGRAPHICS and its foreign made to the ANSYS workbench where lattice is finished, and sends out the work to FLUENT 15.0. The limit conditions, material properties, and including properties are set through parameterized case records. Familiar tackles the issue until either as far as possible is met, or the measure of emphases determined by the client is accomplished. The procedure for resolving the problem is:

- Create the geometry.
- Meshing of the domain.
- Set the material properties and boundary conditions.
- Obtaining the solution

6.1 PREPARATION OF THE CAD MODEL

The measurements of the computational area sun based pipe depended on the work by Rajesh Maithani, J.S. Saini. After this procedure the imperative are connected and along these lines the model is accomplished in demonstrating programming UNIGRAPHICS The accompanying section (4.1.1) demonstrates the parameters of sun based air radiator channel roughened misleadingly with V-ribs and Semicircular V-ribs.

6.1.1 Modeling of duct with smooth absorber plate

The geometry of conduit with smooth safeguard plate is made and coincided on UNIGRAPHICS. At that point subsequent to putting the limit conditions this fit record is keep running on FLUENT 15.0 and the outcome acquired from familiar are utilized for approval of the outcome with the base paper.

6.1.2 Solver setting and Boundary Conditions

In CFD examination before the running of geometry on FLUENT 15.0, solver defining and limit conditions are given. In the present case taking after solver defining and limit conditions are connected

VII RESULT AND DISCUSSION

Table-7.1 Base paper results and Simulation Results of Nusselt no. for the Smooth absorber plate

Reynolds no.	Base Paper Results	Simulation Results
3800	16	15.02
5000	20.05	18
8000	29	27.5
12000	40	38
15000	44	46
18000	52.5	58.5

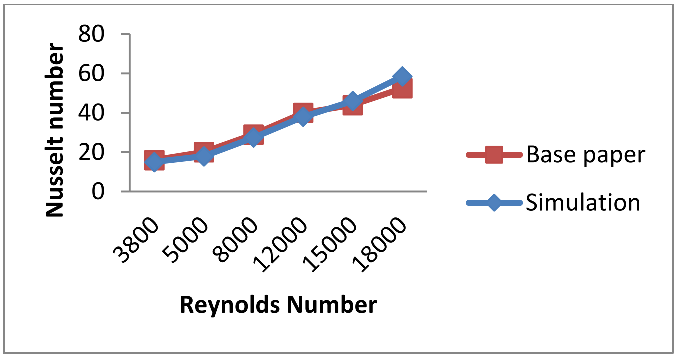

Figure 7.1 Graph shows Base paper results and Simulation Results of Nusselt no. for the Smooth absorber plate

The graph represents the validation of present study with respect to base paper results reynolds no. from 3800 to 12000 shows average convergence, between reynolds no. 12000 to 15000 fluctuation seems to be high due to effect of thermal boundary layer the kinematic viscosity shows maximum due this thermal diffusivity gradually decreases shows variation in graph with same boundary conditions

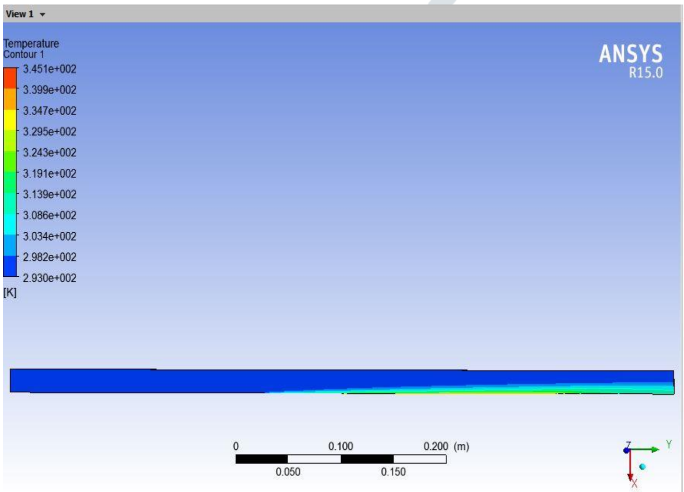

Figure 7.2 Temperature distribution in smooth plate duct with 3800 Reynolds number

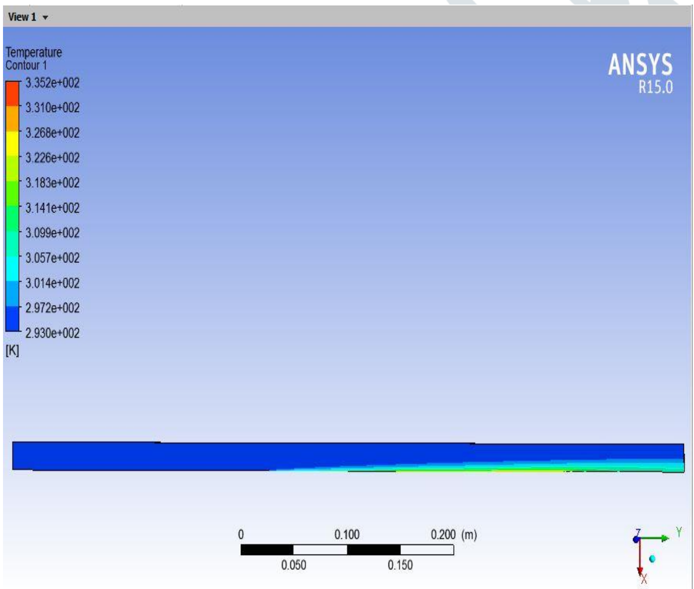

Figure 7.3: Temperature distribution in smooth plate duct with 5000 reynolds number

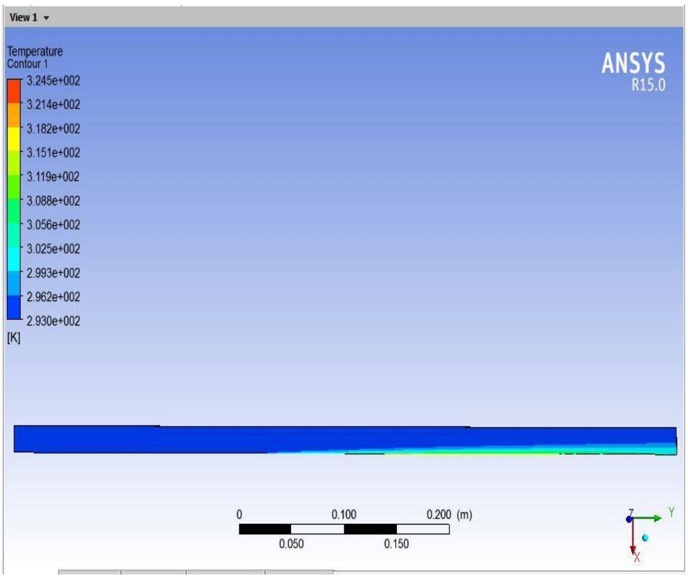

Figure 7.4: Temperature distribution in smooth plate duct with 8000 reynolds number

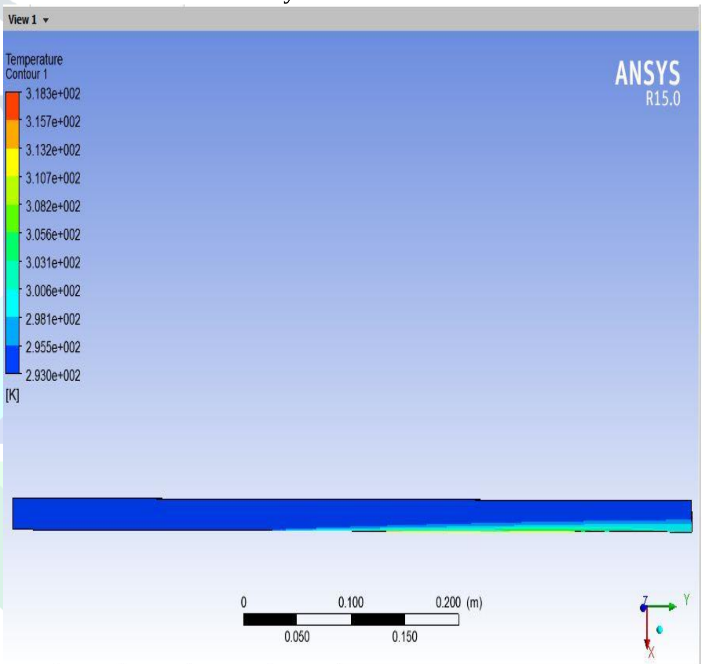

Figure 7.5: Temperature distribution in smooth plate duct with 12000 reynolds number

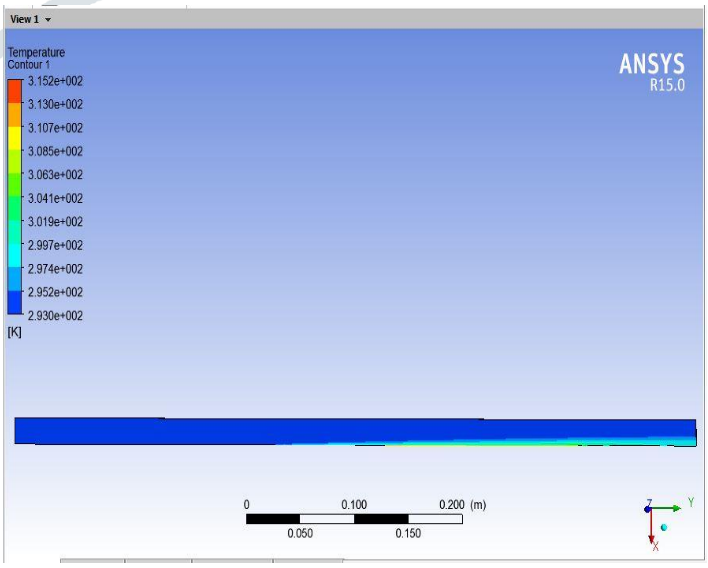

Figure 7.6: Temperature distribution in smooth plate duct with 12000 reynolds number.

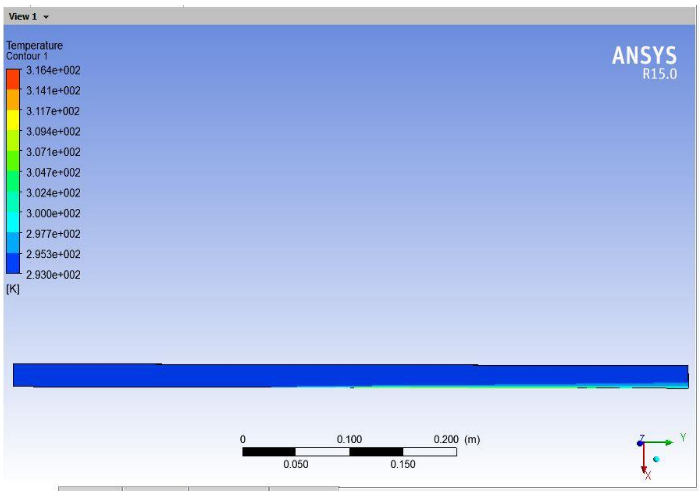

Figure 7.7: Temperature distribution in smooth plate duct with 15000 reynolds number.

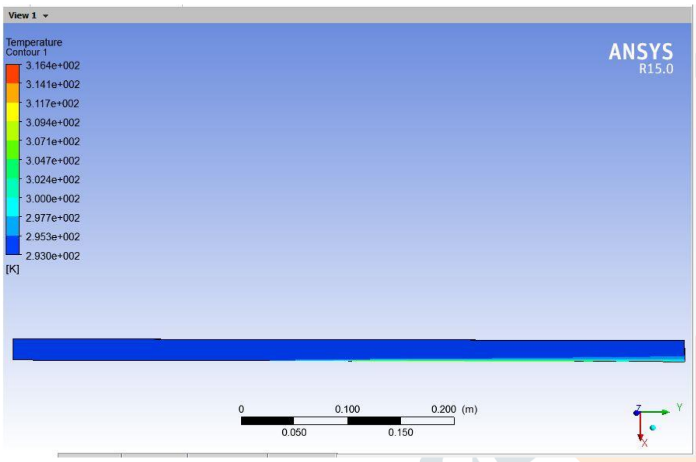

Figure 7.8: Temperature distribution in smooth plate duct with 18000 reynolds number

Table no. 7.2 Base paper result and Simulation Result of Friction Factor for the Solar Duct

Relative Gap Width	Experimental Result	Simulation Results
3800	0.01025	0.0101
5000	0.0095	0.0094
8000	0.0081	0.0083
12000	0.00725	0.00752
15000	0.00709	0.0072
18000	0.00675	0.00676

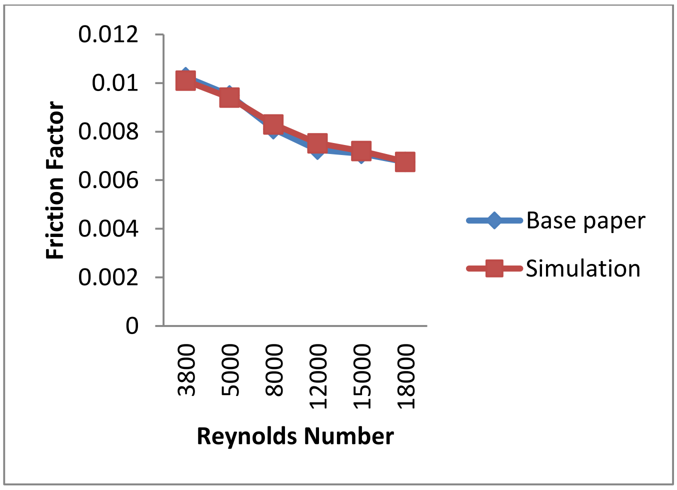

Figure 7.9 Graph shows Base paper result and Simulation Result of Friction factor for the Solar Duct

Results of Nusselt number for different angle of nozzle perforation on solar absorber plate.

Table 7.3: Optimization results for the nozzle perforated 90^0 transverse ribs : Nusselt no. vs. Reynolds no.

12 degree	14 degree	18 degree	21 degree	Smooth	Reynolds no.
10	15	14	13	10	3800
50	55	50	40	20	5000
65	90	70	70	30	8000
125	150	130	120	40	12000
190	200	180	160	45	15000
230	240	230	210	50	18000

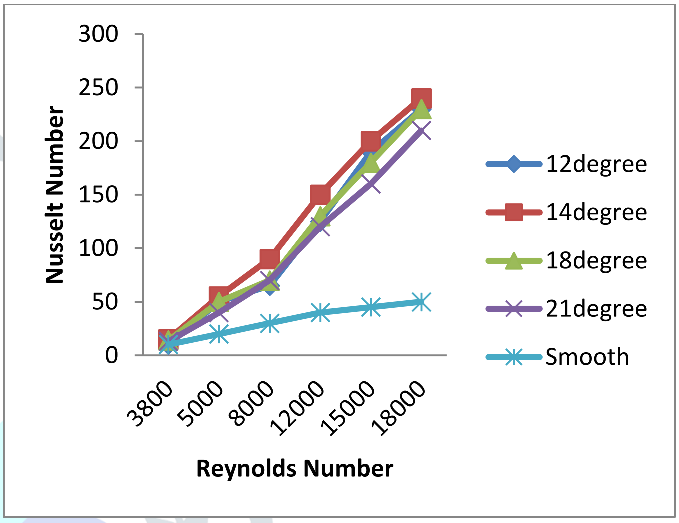

Figure 7.10: Optimization results for the nozzle perforated 900 transverse ribs : Nusselt no. vs. Reynolds no.

Results of Friction Factor for different angle of nozzle perforation on solar absorber plate

Table 7.4 Friction Factor for different angle of nozzle perforation on solar absorber plate

Friction Factor				
12degree	14degree	18degree	21degree	Reynolds no.
0.17	0.153	0.145	0.139	3800
0.175	0.16	0.15	0.143	5000
0.172	0.155	0.148	0.141	8000
0.168	0.149	0.142	0.135	12000
0.164	0.145	0.141	0.132	15000
0.164.52	0.140.66	0.141.23	0.132.85	18000

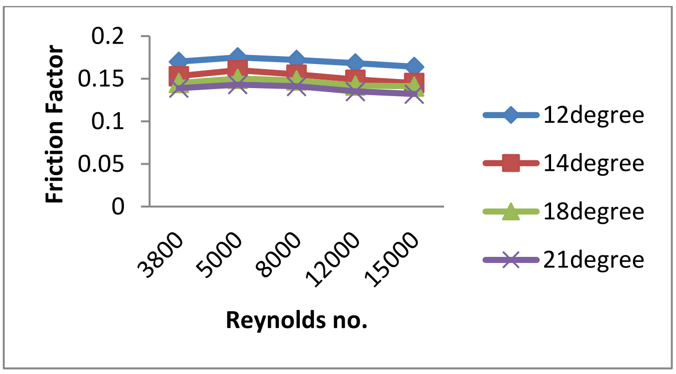

Figure 7.11 Friction Factor for different angle of nozzle perforation on solar absorber plate

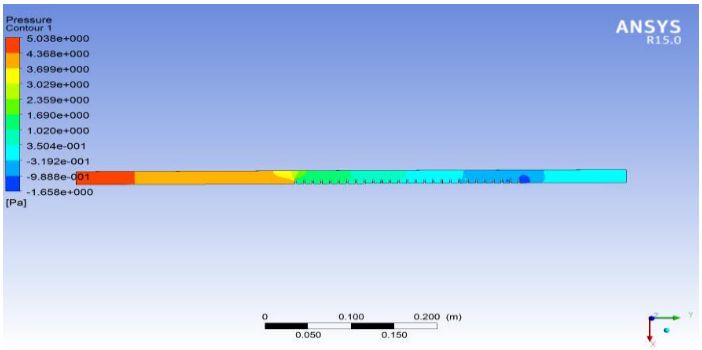

Figure 7.12 Pressure distribution in nozzle perforated 900 transverse ribs plate duct with 3800 reynolds number.

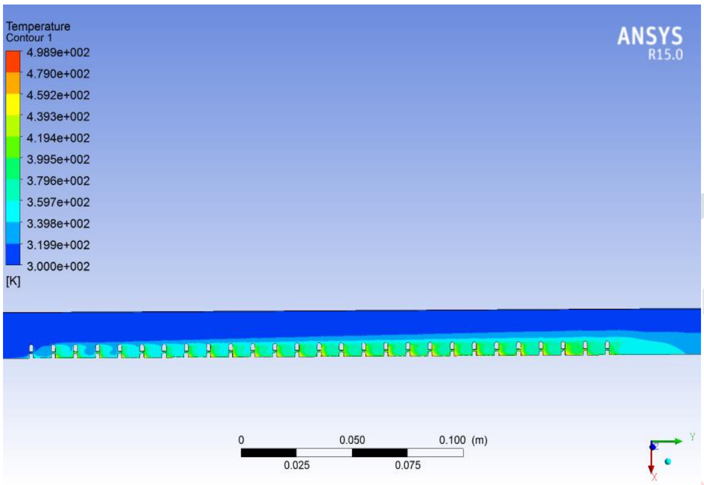

Figure7.13 Temperature distribution in nozzle perforated 900 transverse ribs plate duct with 3800 reynolds number.

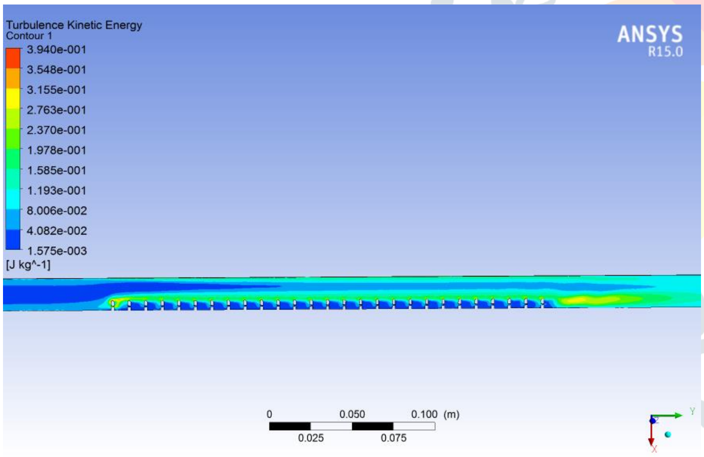

Figure 7.14 Turbulent Kinetic Energy distribution in nozzle perforated 900 transverse ribs plate duct with 3800 reynolds number.

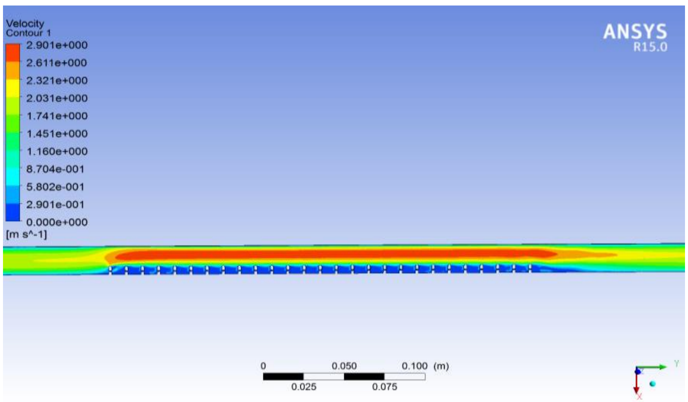

Figure 7.15 Velocity distribution in nozzle perforated 900 transverse ribs plate duct with 3800 reynolds number.

Table no.7.5: Nusselt Number for different Nozzle angle of perforated 900 transverse ribs

12 degree	14 degree	18 degree	21 degree	Reynolds number
55	125	190	265	3800
58	130	205	270	5000
57	126	200	269	8000
50	120	180	255	12000
51.1	120.6	182.6	255.8	15000
53.88	121.8	183	256.69	18000

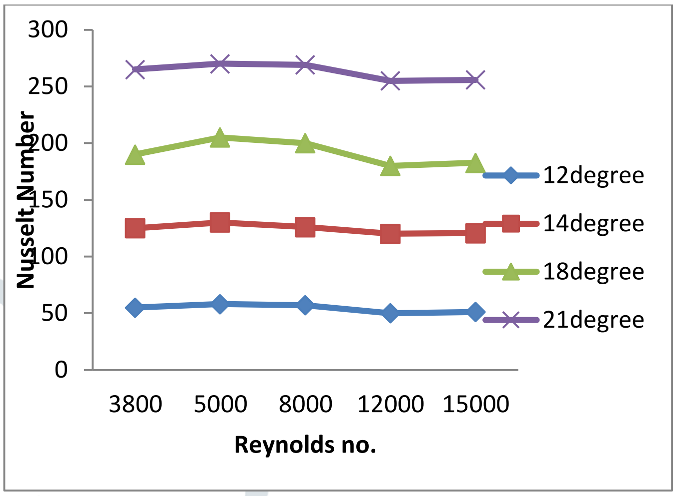

Figure 7.16 Graph shows Nusselt Number for different Nozzle angle of perforated 900 transverse ribs

Table 7.6 Circular Relative Roughness Pitch Difference (Nusselt Number) 14 Degrees

Smooth plate	P/h =10.71	P/h =9.375	P/h =8.33	P/h=7.5
15	43.66	44.8	43.3	45.2
19	53.88	58.25	59.7	61.2
28	74.85	88.6	89.25	96.52
38	111.8	126.58	123.52	124.22
42	132.5	142.69	144.85	145.74
50	153.9	164.5	186.88	187.96

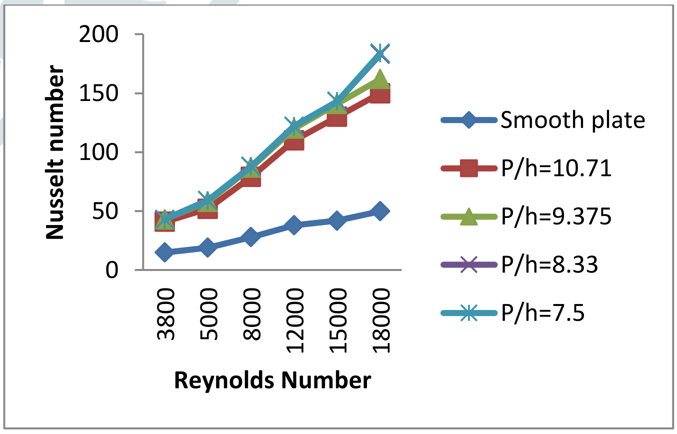

Figure 7.17 Graph shows Circular Relative Roughness Pitch Difference (Nusselt Number) 14 Degrees

Table 7.7 Circular Relative Roughness Pitch Difference (Friction Factor) 14 Degrees

Smooth plate	P/d =10.71	P/d =9.375	P/d =8.33	P/d=7.5
0.01	0.042	0.035	0.0315	0.030
0.009	0.036	0.032	0.0303	0.02
0.0082	0.0335	0.02	0.024	0.024

0.0075	0.0255	0.0249	0.023	0.0215
0.007	0.0245	0.026	0.0215	0.0205
0.0067	0.0208	0.023	0.0205	0.0196

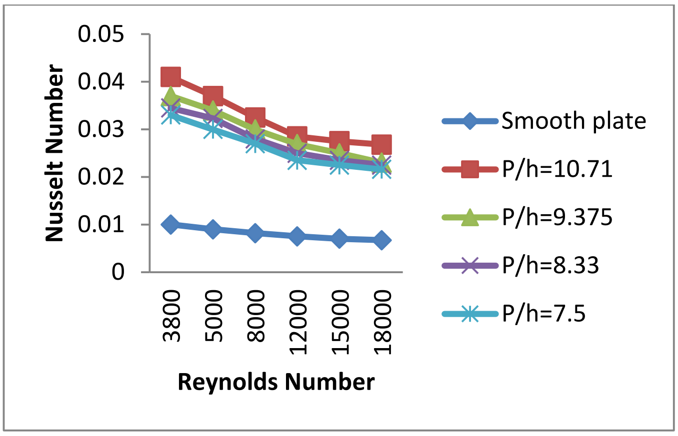

Figure 7.18 Graph shows Circular Relative Roughness Pitch Difference (Friction Factor) 14 Degrees.

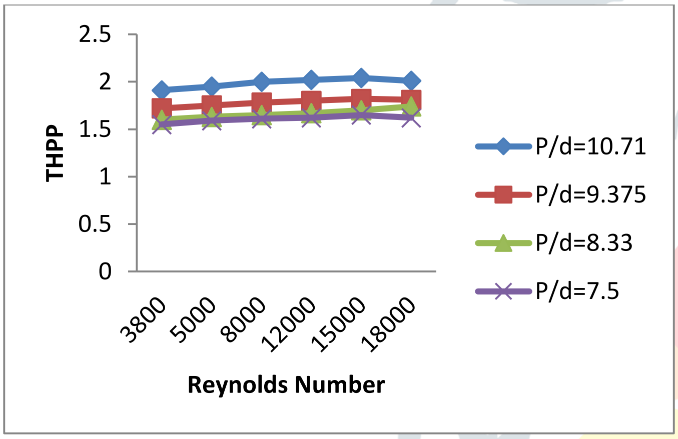

Figure 7.19 Graph shows Thermohydraulic Performance Parameter for Circular Relative Roughness Pitch Difference (14^0)

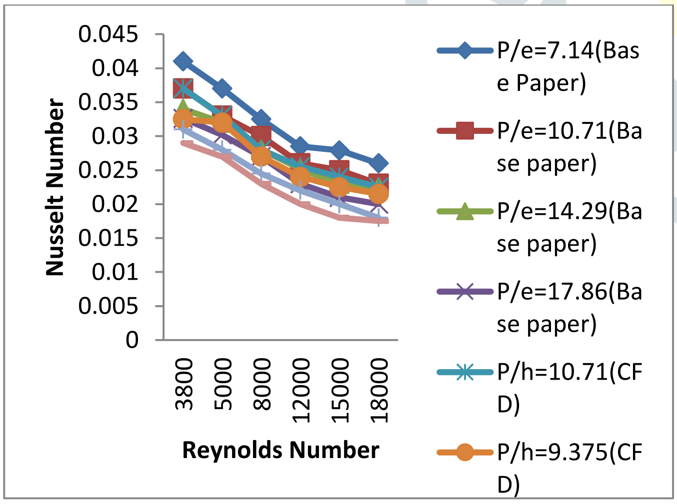

Figure 7.20 Graph shows overall comparison of nusselt number and friction factor with different circular relative pitch difference ratio w.r.t. Reynolds number

VIII CONCLUSION

8.1 CONCLUSION

Perforated circular nozzle shaped transverse 900 ribs blockages developed on 2 – dimensional computational domain which is exposed to uniform heat flux in heat wall section have been investigated with respected to heat transfer and friction factor and thermohydraulic performance characteristics. The effect of nozzle angle of perforation holes, relative pitch difference ratio, pitch difference on Nusselt number and friction factor has been studied for flow Reynolds number range of 3800–18,000. The major findings of this study are given below:

(1) Perforated circular nozzle shaped transverse 900 ribs roughness was been found to result in higher heat transfer as compared to smooth absorber plate with same open area ratio.

(2) Maximum enhancement in Nusselt number and friction factor is found to correspond to a circular relative pitch difference ratio value of p/h=7.5.

(3) The maximum increment in the value of Nusselt number has been observed at a nozzle angle perforation of 14 degrees, however the highest observed value of friction factor corresponding to circularrelative pitch difference of 25.

5. Providing the perforation in 900 transverse ribs results in considerable enhancement in Nusselt number. Average enhancement in Nusselt number for perforated circular nozzle shaped blockages is found to be 31.4% higher over smooth absorber plate while friction factor of perforated blockages gets decreased by 33% of the value as found in perforation.

6. In comparison to smooth duct, the presence of transverse 900 perforated blockages with nozzle shaped holes yields Nusselt number up to 7.76times while friction factor rises up to 27.84 times.

7. Maximum enhancement of Nusselt number occurs at open area ratio (b) of 20%, circular relative pitch difference ratio (p/h=7.5), and pitch difference (P) of 10 and 25, while maximum friction factor is found corresponding to circular relative pitch difference ratio of 5%.

8. Approximately, 50% improvement in thermohydraulic performance is achieved by using Perforated circular nozzle shaped transverse 900 ribs blockages over Smooth absorber plate.

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