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Numerical Analysis of Solar Air Heater Roughened with Combination of Multiple Broken arc with Circular Protrusions

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ABSTRACT

The study presents a performance evaluation of a solar collector for heating air roughened with multiple broken arc shaped ribs combined with circular protrusion in arc shape on the back side of absorber plate. Simulation work has been carried out in ANSYS FLUENT (v14.0) platform with RNG k-Ɛ model at constant heat flux 1000 w/m2. The rib roughness has relative roughness pitch of 10 ,20 and 30, height of broken arc rib is 1 mm, pitch space between the broken arc and circular protrusion is 2.5 mm, pitch space between two broken arc ribs is varying from 10 to 30 mm, pitch space between two circular protrusion is also varies from 10 to 30 mm, diameter of circular protrusion is 0.6 and 0.8 mm, Relative channel width to broken arc rib width ratio is 6.67, gap between two broken arc rib varies from 0.8 to 1.2 and relative roughness height of 0.021.It has been observed that above used geometry can significantly improve nusselt number in range (2.08-5.23) and friction factor value ranges from (1.7-3.8) in comparison with smooth duct. Value of friction factor has been reduced compared with other previous research work. The thermal hydraulic performance factor of solar air heater is 3.3113.This new geometry increases nusselt number with very little increase in friction factor and hence longer life and more economical than previous geometries.

Keywords: Thermal-hydraulic performance, Relative roughness pitch.

1. INTRODUCTION

Energy has become indispensable part of everybody's life and most important basic infrastructure for economic evolution of a country. High consumption of traditional energy sources (e.g. coal, petroleum, wood) has made us to use renewable energy resources. As we know solar, hydro and wind are the three major basic sources of new energy, which are long lasting. Researchers are also investing high efficient techniques to harness this energy.India is largest and fastest growing economies in the world, and also having an expansive population of above 1.2 billion people. There is a huge demand for energy and currently this demand is satisfied predominantly by coal, foreign oil and petroleum, these sources are not a continuous source of energy, and therefore not a permanent solution to the energy crisis, it is also harmful to the environment. The conversion, utilization, and recovery of energy in every industrial, commercial, and domestic application involve a heat exchange process. Improved heat exchange can remarkably enhance the thermal efficiency in such cases and also improves the economics of their operation and design. The requirement to enhance the thermal efficiency of heat exchangers, thus affecting energy, type of material, and savings of money as well as a reduction of environmental degradation had led to the growth and use of many heat transfer improvement techniques. The constant and continual requirement of energy led to a broad research work which was accomplished to obtain the maximum advantage of solar energy.

2. LITERATURE REVIEW

Solar energy can be said to be one of those forms which is freely available, and easily accessible and of course is non- polluting in nature. It is considered to be an indispensable source of energy to meet the growing demand for the sustainable development and to control the global climate change. The need to enhance the thermal performance of heat exchangers, consequently, effecting energy, material, and cost savings as well as a consequential mitigation of environmental degradation had led to the development and use of many heat transfer enhancement techniques. There are several devices like solar water heater[1-2] and solar air heater[3-4] are used to harness the solar energy. Many researchers have conducted numerical study of solar air heater [6-7]. CFD is a vital tool to analyze thermal systems [8-9]. Kumar et.al [10] carried out 3D CFD investigation of solar air heater using broken curved ribs and concluded that these ribs augmented thermo-hydraulic performance. Gupta and Varshney [11] carried out CFD study of solar air heater, they concluded that by incorporation of sectioned tapered rib thermal performance of Solar air heater enhances. CFD is vital for study of solar air heaters [12-14].

2.1 Objectives of Present Work

The objectives of the present work are shown as follows:

(1) To study the effect of variation in the Reynolds number (Re = 4000, 8000, 12000, 16000, 20000) on the fluid flow characteristics, heat transfer characteristics, and friction characteristics.

(2) To investigate the consequence variation in the Relative Roughness Pitch p/e = 10, 20, 30and Relative broken arc gap to height ratio g/e= 0.8, 1.2, 1.6, 2on the fluid flow characteristics, heat transfer characteristics, and friction characteristics.

(3) To investigate the consequence of variation in relative roughness height (e/D_h = 0.021).

(4) Diameter of Protrusion dimple D_d= 0.6 and 0.8 mm respectively.

3. METHODOLOGY

3.1 MODELLING

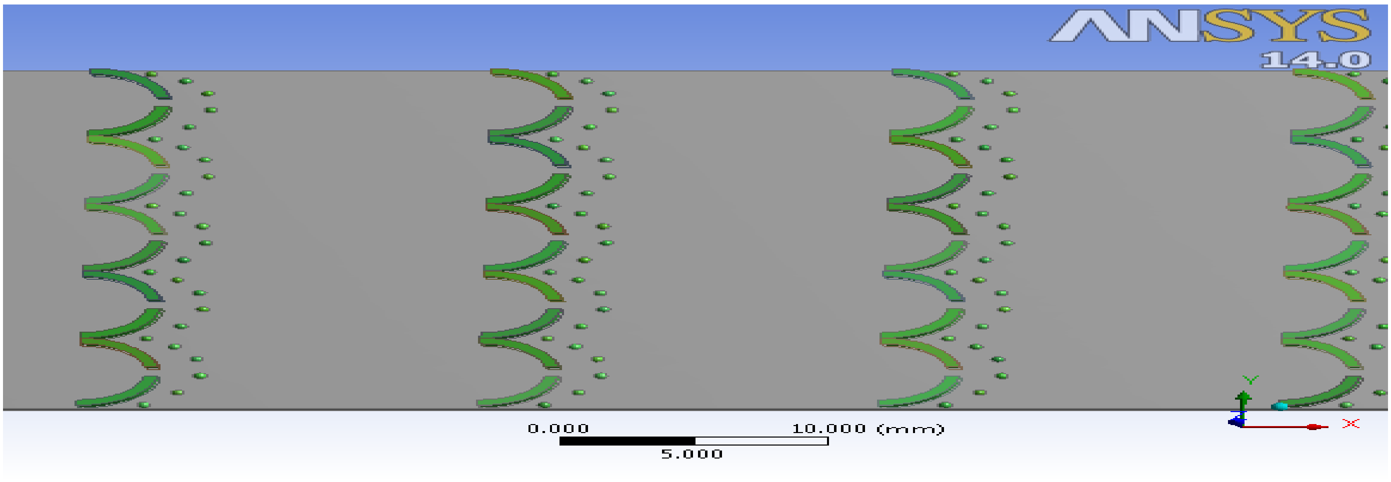


Figure 3.1: Design of solar duct with the Broken Arc and protrusion Dimple Rib roughness.

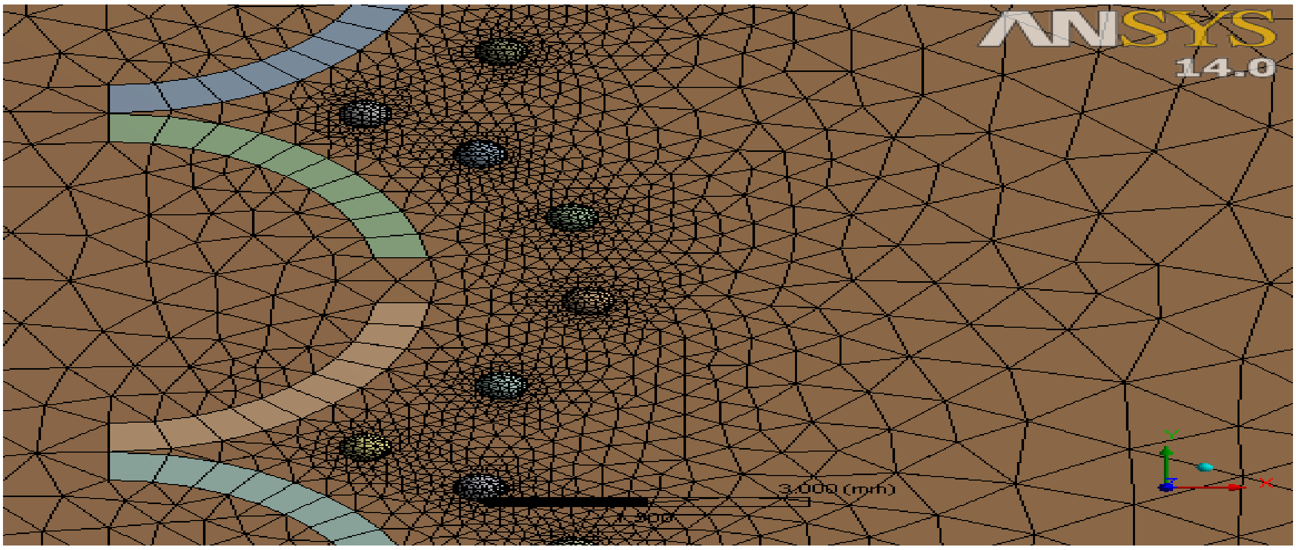
3.2 PARAMETERS RANGE

The Top surface and wall of the test section are provided as absorber solar Duct with constant heat flux 1000 w/m^2 and remaining bottom wall is adiabatic as insulator. This design is performed for heat transfer enhancement and to reduce the friction for experimental working point of view so that we are using number of parameters of rectangular channel. The circular protrusion is mounted on the heated source wall of the channel to improve heat transfer coefficient and drawing the principle that warms air rises between the cold walls and air.

S. NO.	PARAMETERS	RANGE OF VALUES
1	Rectangular channel Total Length, L	2400 mm
2	Channel Entrance Length, L1 Channel Test Length, L2 Channel Exit Length, L3	525 mm 1000 mm 875 mm
3	Channel Width, W	300 mm
4	Channel Height, H	25 mm
5	Relative Roughness Pitch, p/e	10, 20 and 30
6	Hydraulic Diameter, D_h	46.154
7	Relative Roughness Height, e/D_h	0.021
8	Gap of between the Broken Arc, g	0.8, 1.2, 1.6 and 2.0 mm
9	Uniform Heat Flux, I	$1000 w/m^2$
10	Reynolds Number, Re	4000, 8000, 12000, 16,000, and 20000.
11	Prandtl Number, Pr	0.707
12	Height of the all Roughness, e	1 mm
13	Radius of the Broken Arc, R_c	3 mm
14	Pitch space between the Broken Arc and circular protrusion, P_d	2.5 mm
15	Width of the Broken Arc roughness rib, w˙	45
16	Relative channel width to Broken Arc rib width ratio, W/w˙	6.67
17	Diameter of the circular protrusion, D_d	0.6 mm and 0.8 mm
18	Gap between the two circular protrusions, G_d	0.8 mm
19	Relative broken arc gap to height ratio, g/e	0.8, 1.2, 1.6 and 2.0

3.3 MESH GENERATION

Mesh generation is largest analytical aspects of engineering simulation. A larger number of cells are used for accurate results in the model of the rectangular duct with different roughness geometries. Mesh generation necessity and acquire the right mesh for each simulation in the most automated result in long solver runs, and very less may lead to inaccurate results. ANSYS Meshing technology has been built on the strengths of stand-alone, world class meshing tools. The most powerful aspects of these different tools have been brought together in a one environment to design some of the strongest and finest meshing available.

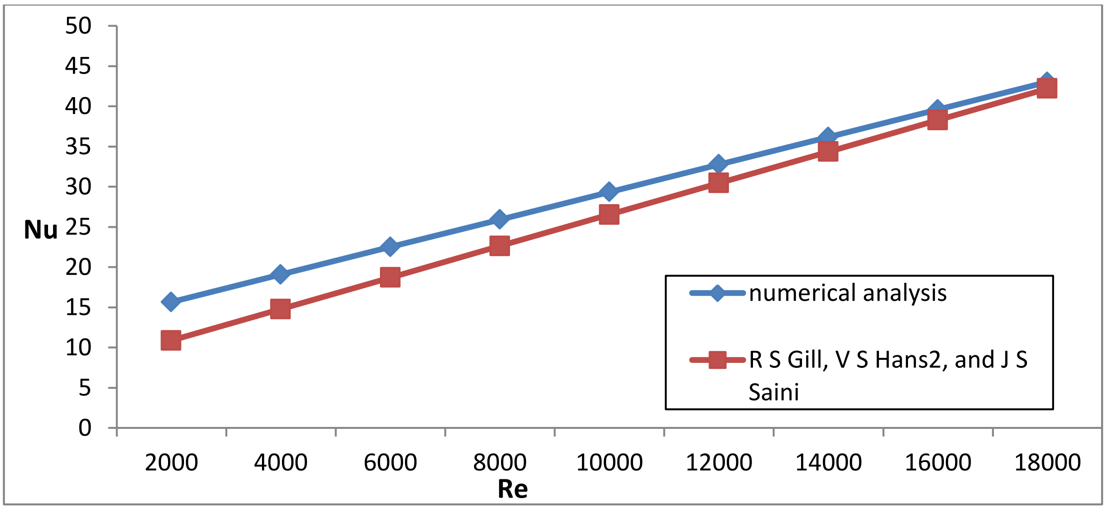


3.4 GRID INDEPENDENCE TEST

Sl. No.	Number of nodes	Number of Elements	Nusselt number
1	86390	157959	24.7790
2	331146	704845	179.6880
3	658973	1250518	43.22131
4	940502	2109124	43.25841
5	1417891	18089903	48.46780

3.5 VALIDATION

The present numerical method and model is validated with respect to the result of numerical study carried out by **R S Gill, V S Hans, and J S Saini [15]**.The validation is used for finding the new inserts results and effect of the meshing in our results and design.



4. RESULTS AND DISCUSSION

4.1 VELOCITY CONTOURS

The velocity contour is used for describing the properties of the fluid in the form of the average discharge and velocity condition at area of the model which is flowing in the solar rectangular duct with different inserts. In the figure 4.2 the velocity contour shows the increment of the velocity from 6.351020408 m/s to approx. 58 m/s. this increment at the lowest Reynolds number, Re = 20000 and p/e = 30, e/D_h = 0.022, the gap between broken arc g/e = 0.8 mm and diameter of the circular protrusion d= 0.6 mm that is main condition to increase the velocity in the solar duct. It is seen that in the figure the velocity decreases after striking the roughness shaped which is used to increase the heat transfer enhancement and to warm the trapped air in the duct. So the maximum Nusselt number is achieved in these variation.

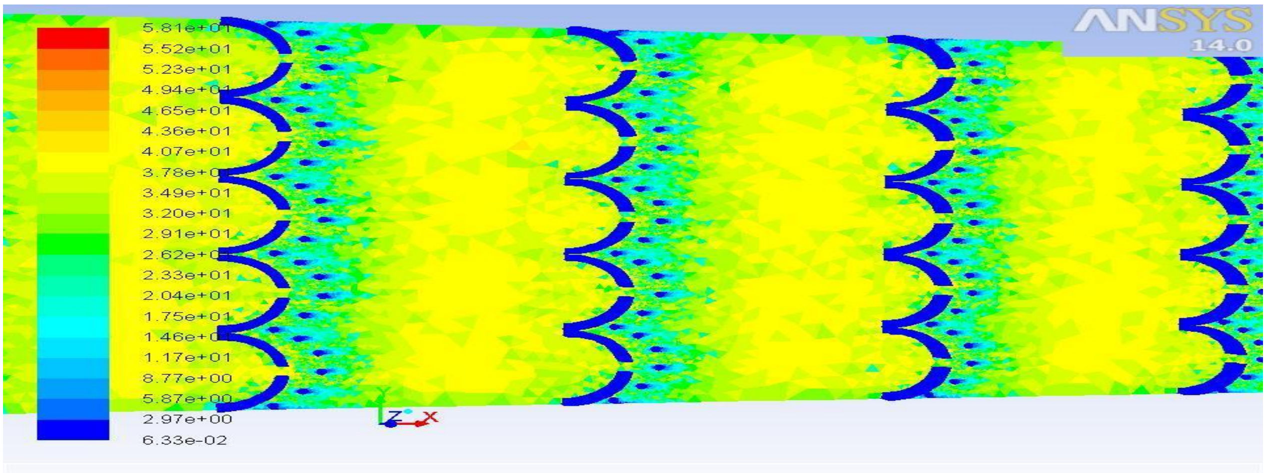


Figure 4.1 Variation of velocity magnitude aruond the solar rectangular duct with combination of broken arc and circular protrusion atg = 0.8 mm, d = 0.6 mm, p/e = 30 and Re = 20000 for maximum value.

4.2 TEMPERATURE CONTOUR

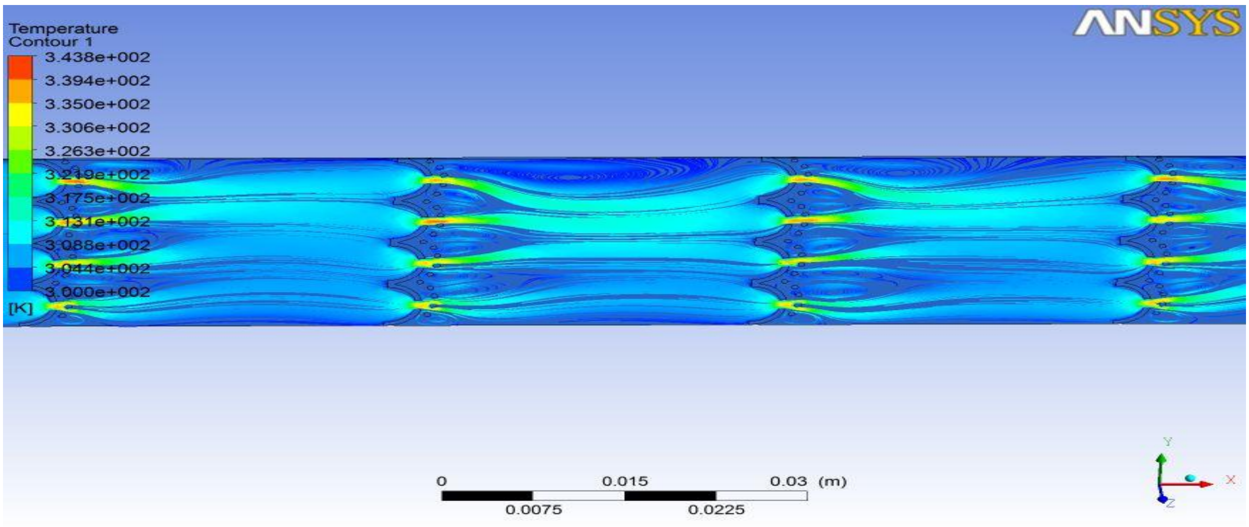


Figure 4.2 Variation of Temperature contour aruond the solar rectangular duct withcombination of broken arc and circular protrusion atg = 1.2 mm, d = 0.6 mm, p/e = 30 and Re = 20000 for maximum value.

4.3 VARIATION OF NUSSELT NUMBER WITH REYNOLD'S NUMBER

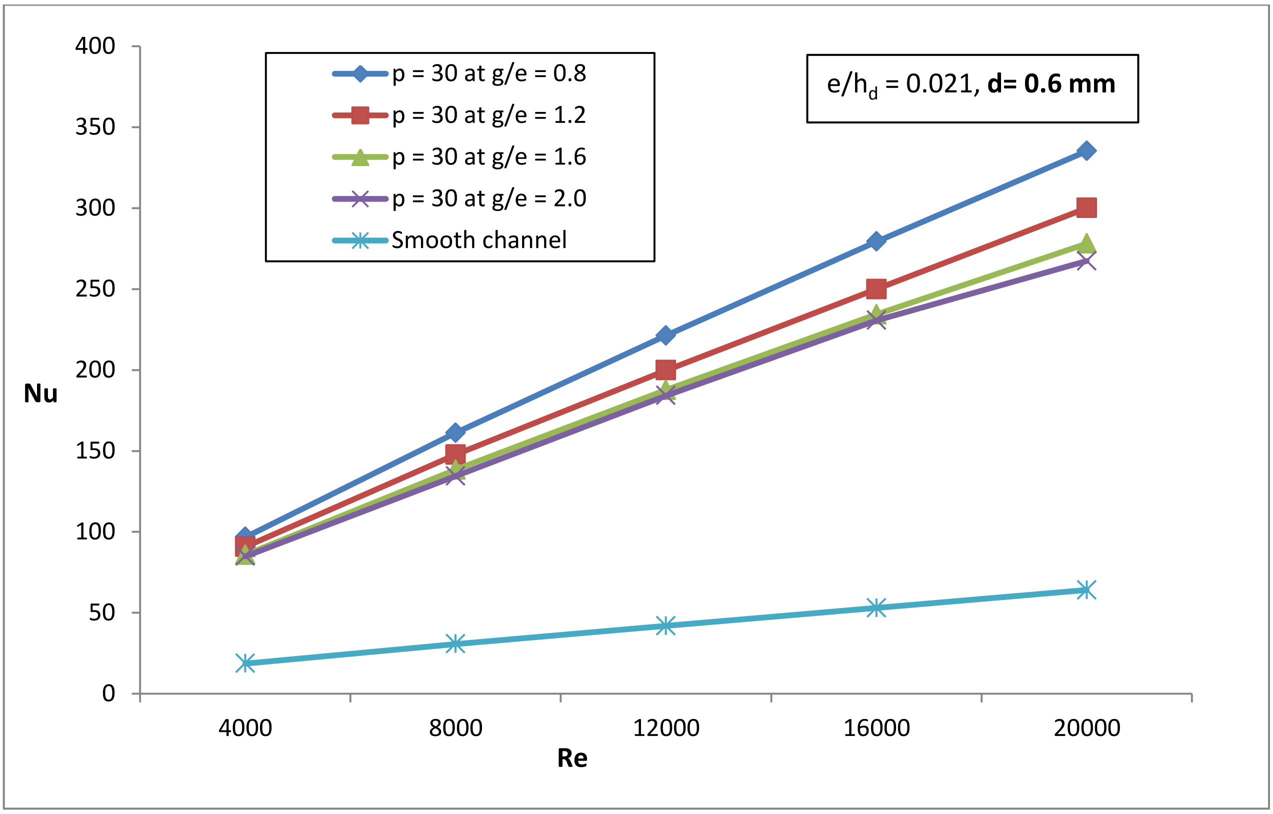


Figure 4.3 Variation of Nusselt number with Reynolds number (4000 - 20000) for different gap pitch roughness (g/e = 0.8, 1.2, 1.6 and 2.0) at e/D = 0.021 and at diameter of the circular protrusion d = 0.6 mm.

4.4 FRICTION FACTOR CHARACTERESTICS

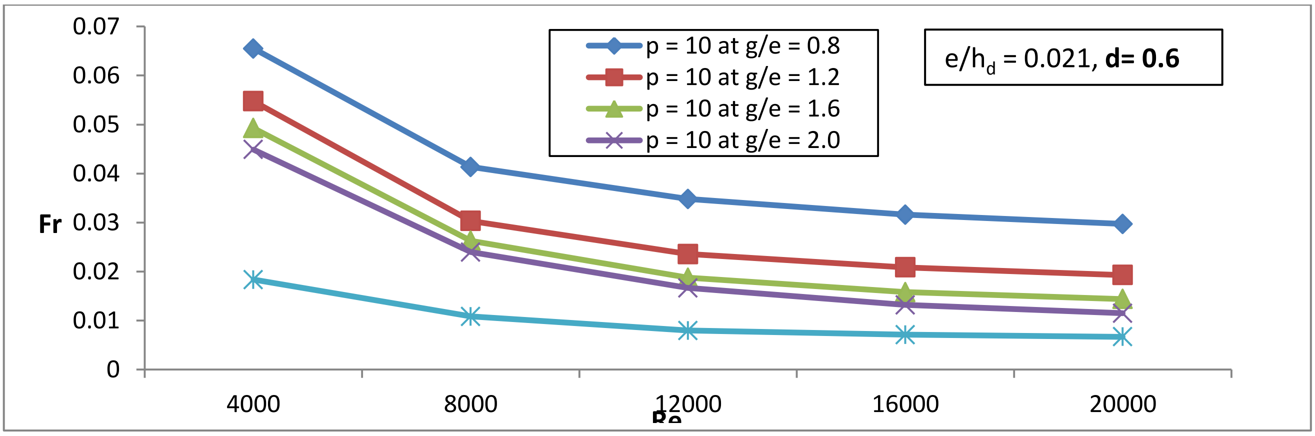


Figure 4.4 Variation of friction factor with Reynolds number (4000 - 20000) for different relative gap between the broken arc roughness (g/e = 0.8 mm, 1.2 mm, 1.6 mm and 2.0 mm) at d = 0.6 mm.

4.5 THERMO-HYDRAULIC PERFORMANANCE

Overall performance of the solar air heater has evaluated by heat transfer rate and friction factor in solar rectangular channel with or without roughness. When the roughness used in the solar duct, the velocity of the flowing fluid in straight line immerged into turbulent flow which was acted as nusselt number as well as friction factor on the surface of the channel. The heat transfer enhancement was very high as compared to smooth tube so that in the solar rectangular duct the overall hydraulic performance is 3.311322476.

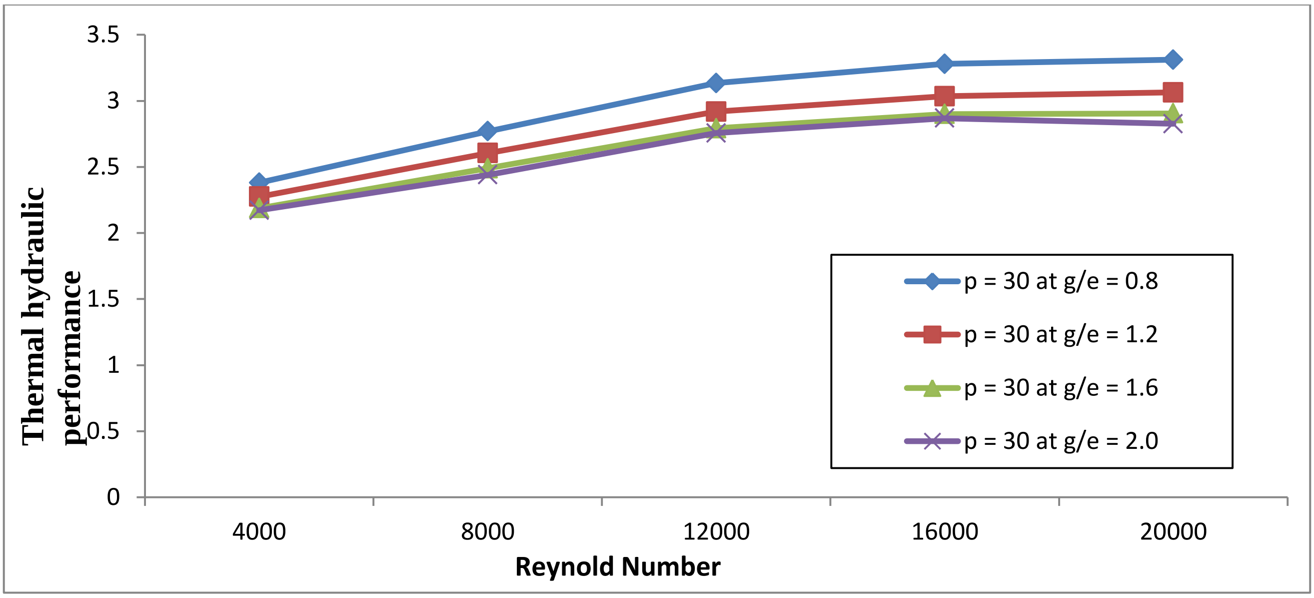


Figure 4.5 Variation of thermo-hydraulic performance of the solar air heater with roughness combination of broken arc and circular protrusion, Reynolds number variation for different values of the gap between the Arc ribs.

5. CONCLUSION

The main conclusions can be summarized as follows:

1. From the results, it is clear that k-ε standard model could provide results with acceptable engineering accuracy for the analysis of flow and heat transfer patterns in rectangular solar duct with inserting the combination roughness as broken arc and circular protrusion which increase the thermal performance of solar air heater.
2. The heat transfer increases and friction factor decreases with the increasing in the Reynolds number and decreasing in the gap between the broken arc and the circular protrusion. The maximum nusselt number is observed at the gap g = 0.8 mm and d = 0.6 mm.
3. The variation in the gap of the broken arc ribs increase the nusselt number and friction factor in the range of 2.0852 – 5.2342 and 1.718119 - 3.805833 times of smooth duct respectively at the variation in the Reynolds number Re = 4000 – 20000. Maximum nusselt number increases 5.2342 times and maximum friction factor increases 3.805833 times of smooth duct.
4. The Nusselt number decreases with the increase in the gap between the arc ribs g = 0.8, 1.2, 1.6 and 2.0 respectively.
5. The highest Nusselt number (Nu =335.1824) is obtained at broken arc gap g = 0.8 mm, diameter of the circular protrusion d = 0.6 mm, Reynolds number Re = 20000 and pitch ratio p/e = 30.

6. The lowest friction factor (Fr = 0.01116879) is obtained at the value of gap between the Arc rib g/e = 2.0 mm, p = 10 and Re = 20000.
7. Highest hydraulic thermal performance (THP = 3.311322476) was observed at Re = 20000 where g/e = 0.8, diameter of the circular protrusion d = 0.6 mm, space between the roughness p = 30.
8. From above discussion, it is clearly seen that this design is performance wise as well as economically the best. Due to lesser friction compare than other previous results, life of this design is longer and due to more value of nusselt number, thermal hydraudic performance is also improved from previous designs.

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