Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 2, Issue 4, Pages 140-154, Oct-Dec 2018

CFD & Taguchi Analysis for Optimization of Geometrical and Flow Parameters in A Ribbed Channel Duct

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Article Received: 29 May 2018 *Article Accepted: 21 September 2018* *Article Published: 13 October 2018*

ABSTRACT

The thermo hydraulic performance has been carried out computationally for the stationary channels with rib turbulators fixed at ninety degree and then it has been optimized by applying taguchi approach. Ribs have been arranged linearly in an alternate way and numerical values of the friction factor and convective heat transfer coefficient are evaluated. A L_{16} (4^3) orthogonal array has been taken as a motive to optimize for maximization of thermal performance. The idea of thermal performance comprises two types of effects at an identical time i.e. it maximizes the heat transfer coefficient on one hand and on the other hand it minimizes the friction factor issue. Thermal Enhancement Factor is maximized because it is the final goal of the present work. The rib relative pitch (P/e) is numerous from 3, 6, 9 and 12. The inclination angles are converged from square ribs (i.e. 90 degree), 80 degree, 70 degree to 65 degree (equilateral triangle ribs) levels . Different values of heat transfer coefficient and friction factors are calculated by using different Reynolds numbers 4000, 8000, 12,000, 16,000. The validity of this entire analysis has been done by taking square rib (w/e=1) and by comparing the results with standard experimental results. With the help of effective impact of rib relative pitch, inclination angles and flow parameters, the standard cooling design has been achieved. With the help of net effect of inclination angles, rib pitch to height ratio and flow parameters, we can get the optimal cooling configuration. A equilateral triangular shaped rib with optimum parameters (α)=65˚, Re=4000,and p/e=9 is found to have best thermo-hydraulic performance than that of square rib.

Keywords: Heat Transfer, Friction Factor, Thermal Enhancement Factor, Taguchi Method.

1. INTRODUCTION

Expanding interest of electricity required both technology and power or finds an optionally available way which decreases the energy utilization. The trade, utilization and recovery of power in each subject for instance either business or local involve a heat transfer manner. some enormous zones in which pressured convection heat transfer appear are recorded as electricity region, refrigeration and air conditioning, thermal processing of chemicals, electrical machines and digital gadgets, squander heat recovery in production, internal cooling of engine; turbo-machinery frameworks. Ribs are playing a extensive position on this regard.

2. LITERATURE REVIEW

Quite a lot of studies has been devoted to the comprehension of heat transfer and fluid flow in rib turbulated conduits. There are big portions of test and investigative examinations on flows through conduits with a primary go location. The giant majority of these investigations depend on the flows from pipes with either smooth walls or with rib roughened partitions, or with in part roughened partitions or with both smooth and cruel walls. Recently, the researchers have paid unique attention towards numerous geometric parameters of a roughened surface along with varying flows. Some of the investigators with their research are discussed as follows:

In 1978 J.C.Han [1] first examined rib-roughened surface to know the effects of rib shape, angle of attack and pitch to height ratio on friction factor and the evaluation of connective heat transfer coefficient was done. A parallel plate geometery was used for this purpose. A general correlation for friction factor and the nusselt number was evaluated to represent the rib shape, separating and angle of attack in accordance with the law of the wall similarity and the heat momentum similarity which was used by dipprey and sabersky . Ribs with angle 45˚ were found to have more heat enhancement at a given grating force than with ribs at a 90˚ approach angle or when contrasted with sand-grain roughness.

In 1984 J.C.Han [2] carried out an experiment in a square duct with roughened ribbed wall fixed opposite to each other to evaluate the net effect of pitch of the rib-to-height ratio and height of the rib -to equivalent diameter on friction factor and heat transfer coefficient. Value of Reynold number(Re) was taken from 7000 to 90,000.The result illustrated that the Stanton number of the ribbed side wall was about 1.5 to 2.2 times than four-sided smooth conduit for the analysis of the test information. The Stanton number of the other was approximately increased by 25% because of the ribbed wall. The value of mean friction factor varied about 2.1 to 6.0 times of the smooth duct.

In 1988 J.C.Han and J.S.Park [3] carried out an experiment investigating the net effect of angle of attack(α) of ribs and its aspect ratio on the dissemination of convective heat transfer coefficient for generating streams in short rectangular channels with opposite ribbed faced surfaces. Value of Reynold number (Re) was taken between 10,000 to 60,000.The value of angle of attack rose in a sharp manner from 90˚, 60˚,45˚ to 30˚ and the aspect ratio was taken as 1, 2 and 4 respectively. The result showed that the local nusselt number reached a fixed value at X/D > 3 after showing a decrease at α=90˚ but for the other values i.e. at 60˚, 45˚and 30˚ it showed a constant increment after X/D > 3 because of the induction of secondary induced flow created by angle of rib. Also the net impact of angled ribs on heat transfer was accurately observed after X/D > 3 for square channel but this impact was opposite in the case with rectangular channel having high aspect ratios. Results evaluated that angled ribs with angles (i.e. α=60˚, 45˚and 30˚) had more heat transfer rate with an accuracy of 30% than that of transverse ribs (i.e. α=90˚) for the square channel.

In 1989 J F Lockett and M.W.Collins [4] applied different techniques with the use of holographic interferometery for the optimization of thermal flow field. They carried out an experiment with two ribbed shape geometries, one rounded shaped and other square shaped and evaluated that the heat transfer variation was effectively higher for rounded shaped ribs than the square shaped rib and was relied on the local Reynold number (Re).The base of the back opposed rib divider individually. These evaluation pictured the considerable best position of the technique. Their fringes gave fluid isotherms, their closeness indicated accuracy of heat exchange rate that is both quantative(temperature and local heat exchange) and subjective (thermal structure perception) information were accurately viewed from an identical picture and for analysis of three dimensional problems, this method was also applied.

In 1998 G.Rau [5] studied detailed analysis of streamlines and heat exchange factors were carried out in a square channel with ribs picturing a notable blockage proportion ($e/D_h = 0.1$). Value of Reynold number (Re) was taken at 30,000. The effects after close estimations were taken about for three different p/e proportions (6, 9, 12) in a one-sided-ribbed channel. The different values having had taken with a two sided ribbed channel were taken for p/e = 9. For p/e=12 the local heat exchange increament dispersion on the symmetry line evaluated a better and accurate result . For p/e=9 the over all floor information gave unexpected and accurate results. For p/e=9 the maximum acceleration of new boundary layer stream close to the divider behind the reattachment evaluated that the shear power in the shear layer behind the rib was ultimate outcome for this p/e proportion. In 2003 Z.X.Yuan [6] carried out Heat exchange and friction characteristics for another type of rectangular channel with winglets had been evaluated.The result showed that by variation of Reynold number from 5.2×10^3 to 4.8×10^4, characteristic of heat exchange of the improvised conduit with having winglets was perfect in accordance to the enhanced duct with transverse type disturbances. By Comparing under the similar pumping power condition showed that the Nusselt number proportion Nu/Nu_o of the winglet channel in accordance to the smooth pipe shifted from 1.7 to 3.5, while this ratio was normally 1.5 for the new pipes with transverse unsettled outcomes. For condition of same mass flow rate, the ratio of Nu/Nu_o of the winglet channel to the smooth conduit reached in the region of vicinity of 2.7 and 6.0. The time when the aspect ratio shifted from 1:3 to 1:2,the value of friction factor changed by a little portion at a small Reynold number, rather the original change in the heat transfer coefficient was simply around 38%.The two gap of the winglet combine tried was evaluated and it was observed that for both friction factor and nusselt number, the accurate difference between them was only around 5%.

In 2004 Andallib Tariq and P.K. Panigrahi [8] examined the analysis of flow and convective heat transfer coefficient on a mounted rib at the surface along with slit inside the wind tunnel. The open area ratios was taken within the range of 10% (i.e. 10,20,30,40 and 50%) in accordance with the total projected area of the rib and the Reynold number (Re) was taken to be 32,200. The Liquid crystal thermography technique was used to perform nusselt number dispensation. Outcomes of analysis clearly evaluated that thermal performance was increased and friction factor loss was decreased due to the slit inside the rib and within an open region range of 20% the ideal execution was achieved. Within the open range of 30% it was clearly indicated that the flow through the opening slits changed the reattaching shear layer from the highest point of the rib.The reattachment length was shorter, Nusselt number was higher, and the upgradation of the normal heat transfer from the heated surface was performed. The Heat transfer expansion of a strong rib came out to be lower than the slit rib taking within a standard open region range of 20% .

In 2005 Lei Wang and Bengt Sundén [9] conducted number of experiments based on the turbulent heat transfer and friction factor in a square duct with roughened and truncated ribs on one wall. In an intermittent plan, the ribs were placed inversely w.r.t. standard one. The ratio of height of the rib to the hydraulic diameter was 0.15,the height of rib to the height of pitch was 12 and the value of reynold number was taken within range of 8000 to 20000. To show nitty gritty distribution of heat transfer coefficient between a pair of ribs, liquid crystal thermography technique was performed. The experimental results completely evaluated that the shape of the rib completely affected local heat transfer coefficient. At rear corner of the upstream rib , a hot spot was clearly shown for continuous ribs. After the heat transfer rate within the reattachment zone, there was a sharp increase in the nusselt number within the recirculating zone. A decreament of the Nusselt range was shown by excess downstream due to the development of thermo physical phenomenon in thickness. A sharp increase of Nusselt number was obtained in the leading region portion of downstream ribs because of the formation of the secondary recirculation bubbles. For both; truncated as well as continuous ribs , the pattern of flow was completely relied on Reynold number. The Reynold number was varied inversely with augmentation level. The final outcome showed that thermal performance of continuous ribs was better than truncated ribs.

In 2008 R.Kamali and A.R. Binesh [10] explored the CFD analysis of different shaped ribs i.e. triangular, square, trapezoidal rib with escalating height and with diminishing height in accordance with direction of flow.The range of pitch-to-height(p/e) was from 8.0 to 12.0. The final goal of the research was to analysis the various rib shapes effect on thermo-hydraulic performance. For heat transfer distribution between the pair of ribs numerical simulation technique was performed and the recirculation zones were clearly explored . The conclusion was that in the rib distribution of heat transfer coefficient internally the shape of rib was playing an important role. The trapezoidal ribs with lesser height attained maximum heat transfer and the friction factor values were minimum for the trapezoidal ribs with escalating height with respect to flow for Re=20000 and also the maximum heat increament was at p/e=12 for different p/e ratios. In 2009 Kyung Min Kim and Hyun Lee [11] explored an optimum design for improving heat transfer rate and thermal heat performance rate for a stationary channels with angular rib turbulators to find an effective geometery. Only two factors that is angle of attack (α)[$30^\circ \leq \alpha \leq 80^\circ$] of rib and pitch-to-rib height ratio (p/e)[$3.0 \leq p/e \leq 15$], were taken among so many different design factors. By Calculating pitch-averaged Nusselt range ratios it was clearly indicated that it was in accordance with the previous experimental research, totally useful to utilize the optimized process. R.S.M.(Response surface method) was done to optimize the process. At (α)[$50^\circ \leq \alpha \leq 60^\circ$] and)[$6.0 \leq p/e \leq 7$],the maximum value of heat transfer rate and thermal performance rate was achieved. At α=53.32˚ and p/e=6.51, the maximum value of heat transfer rate was evaluated.

In 2010 K.R. Aharwal and J.S. Saini [12] took research analysis to evaluate the nature of fluid flow and heat transfer rate with the help of the variation in the gap between a couple of inclined ribs. A rectangular conduit with aspect ratio of 5.84 was taken for research. The range of width of gap was from 0.5 to 2.0 and the range of Reynold number(Re) was from 3000 to 18,000 and this research was given utmost importance to calculate the optimum width of gap in the inclined ribs for the outcome of best thermal performance. The value of nusselt number was maximum when compared with other values of g/e for relative gap width (g/e=1). In 2011 Giovanni Tanda[13] explored forced convection heat transfer on an inclined ribbed geometry fixed at 45˚ inside the rectangular conduit with aspect ratio=5.The final goal was to study the effect of spacing of the rib on thermal heat enhancement factor. Value of Reynold number (Re) was taken to be in the range of 9000 to 35,500. The ratio of the height of rib -to-hydraulic diameter(e/D_h =0.09) was taken and the value of relative pitch (p/e) was taken as 6.67, 10.0, 13.35 and 20.0. By using LCT(Liquid Crystal Thermography) in the inter ribbed region the local convective heat transfer coefficient was evaluated. At p/e=6.66-10(two-ribbed wall channel)and p/e=13.33(one ribbed channel) the maximum heat transfer rate was calculated. In 2012 Md Shaukat Ali, A Tariq[14] examined the rectangular duct channel comprising the trapezoidal ribs and in the range of Re=9400-61,480,the variation of flow was taken and also different chamfering angles in the gap of 5˚(α=5˚,10˚, 15˚ and 20˚) was taken to analyse the research. The aim was to study the thermal enhancement characteristic and nature of flow field by using LCT(Liquid Crystal Thermography) and PIV(Particle Image Velocimetry).The final outcome of this research was that in downstream of ribs large recirculation bubbles were produced. At higher Reynold number,the optional distribution rise was reduced to a great extent which blured advance concerning the expansion in trapezoidal angle, and it is the main reason for the hotspots in the leeward region of the sold rib. As the Nusselt number was increased it clearly indicated the pictures of partitions, reattachments and recirculation bubble as far as spatial HTC was concerned.

In 2014 Yue-Tzu Yang and Peng-Jen Chen [15] carried out numerical analysis along with optimization by using G.A.(genetic algorithm) and R.S.M (Response Surface Method) for the two dimensional ribbed channel to achieve maximum heat transfer rate.The ultimate goal of this research was to study the 3 geometrical parameters wiz. Height of rib (4 mm < e < 10 mm), pitch of rib (25 mm < t < 40 mm) and thickness of rib (5 mm < p < 25 mm).Value of Reynold number was taken in the range of 5000,10,000 and 15,000.The ribs greatly affected the friction factor rate and the heat exchange rate .By using G.A. and R.S.M. method it was clearly evaluated that for the in-line ribbed channel,the numerical value of thermal enhancement factor changed from 1.2to 1.6 after the standard plan.The thermal performance factor was obtained around 2.7 for the case of unsteady ribbed channel.

In 2015 Alireza Zamani and Asghar B. Rahmini [17] carried out numerical investigation on the ribbed channel solar air heater system along with optimization by applying Taguchi approach Their main aim was to produce such rib having maximum heat transfer characteristic and minimum friction loss that is best thermal hydraulic performance. Four major factors were taken to be very important for this research ; rib pitch-to-height (p/H), rib relative height (e/H), rib front projection(s) and rib relative tip width (a/H) and CFD simulations were carried out at fixed Reynold number(Re) as 10,000.The result demonstrated that (e/H) and (p/H) played the most important role for thermal enhancement.

In 2016 Eiamsa-Ard Petpices [19] conducted numerical investigation on a 3-d-square channel with broken V-ribs (B-VR).The calculations were dependent on the finite quantity approach, and the simple calculation with quick plan became accomplished. The B-VR brought the two aspects of a plate which turned into askew set in a square channel to create longitudinal vortex actions through the examined area. Influences of numerous open nook proportions (d/H= zero, 0.01, 0.02, 0.03, 0.04 and zero.05) on convection coefficient and strain drop in the channel and the after results of the B-VR had been considered. The pitch ratio (PR = p/H) and blockage proportion (BR = b/H) of B-VRs had been taken at 1.0 and 0.15. As contrasted and the channel with out V-rib, the only with B-VRs had considerably higher heat exchange and friction factor. It turned out that separated from the ascent of Reynold number, the lowering of the open corner proportions brought about an expansion inside the Nusselt wide variety and friction aspect because of the weaker turbulence and lower resistance from the stream. As per the computational outcomes for B-VRs, the precise thermal enhancement aspect was found at d/h=0. The outcomes established that the B-VRs incited longitudinal vortex streams towards the channels, which introduced about maximum heat transfer development joined by low friction loss. The growth was associated with advanced escalating friction penalty going from 28.03-37.89 times over the smooth channel. The thermal enhancement element for VRs with d/H=zero (the ribs with out open nook) became around 1.6 better than that for the smooth channel.

In 2017 Jian Liu [21] numerically investigated the 3-D turbulent flow and convective heat transfer coefficient round a rectangular channel with distorted cylindrical ribs with purpose of gaining quality thermo-hydraulic overall performance. The incoming Reynold quantity was taken from 10,000 to 25,000. He studied 6 specific configurations that have been: Cylindrical ribs with rounded transition of 5mm radius, Cylindrical ribs with rounded transition with most displacement of 3mm, Cylindrical ribs with rounded transition with highest displacement of upstream groove with the aid of 3mm, Cylindrical ribs with rounded transition with clean wall and levelled base, amalgamation of distorted cylindrical ribs and groove with equal pitch and regular ribbed channel. His concluding feedback enlightened higher thermal overall performance of rounded transitioned cylindrical ribs over normal ribs for the reason that former become ensuing in effective reduction in re-circulating drift and higher re-attachment strains. Additionally groove structure resulted best thermal enhancement aspect. Ultimately the rounded transition cylindrical ribs comes out to be first-rate appearing both in terms of heat transfer enhancement as well as minimizing pressure loss penalty.

In 2018 Arjumand Rasool [24] carried out numerical investigation on two-pass square ribbed channel to get the maximum thermo-hydraulic performance. The variation of ribs at relative rib pitch of 10mm and Reynold number within the range of 5000 to 52,000 were considered important geometrical parameters. Their final results stated 1.19 times increment in Nusselt quantity of investigated rib in accordance with square rib and decrement in friction penalty via 1.3 . Finally first-rate thermal enhancement was carried out by boot-shaped ribs. These works have been helpful in concentrating the impact of rib spacing, rib width and the flow parameters on the heat transfer enhancement. The work gave a concept on how the heat transfer changes whilst the channel is roughened.

2.1 OBJECTIVE OF PRESENT RESEARCH

1-To analyse the effect of variation in rib pitch-to-height proportion, rib geometery and Reynold number on flow structures.

2- To analyse the effect of variation in rib pitch-to-height proportion, rib geometery and Reynold number on general Nusselt number and friction factor qualities.

3- To analyse the strength of Taguchi Method to know the standard plan parameters in the event of ribbed duct.

4- To expect the define parameter i.e. geometrical and flow parameters which have the quality impact on heat transfer and friction aspect.

3. METHOD

3.1 Mathematical Modelling

The movement inside the computational space has been thought to be 2-D, turbulent, in- compressible and steady in nature. In Cartesian tensor framework, the simple governing equations which include the continuity equations, Reynold-Averaged Navier– Stokes (RANS) momentum equations, and electricity equations are as:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0$$

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right)$$

$$\frac{\partial}{\partial x_i}[u_i(\rho E + p)] = \frac{\partial}{\partial x_j}\left[\left(k + \frac{C_p \mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_j}\right]$$

Where turbulent viscosity$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}, C_\mu = 0.009,$, E is the total energy, Pr_t is the turbulent Prandtl number for energy.

A 2-Dimensional CFD study of fluid stream and heat transfer characteristics during a re-duct with tetragon ribs of accelerating height in flow course mounted on top and bottom surfaces. Those 2 wall areas subjected to a continuous heat flux, whereas the staying walls unbroken insulated. During this article, choosing appropriate turbulence model is going on the foremost basic of the literature review. The procedure model of this current physical domain has been developed in GAMBIT 2.4 and analysis has been transported out on business computer code ANSYS FLUENT 6.3.

The beginning stage of any numerical technique is to create scientific model having an arrangement of fractional differential conditions with introductory and boundary conditions.

Following suspicions have been considered amid the numerical simulation:

1] Regular flows
2] Sress variant in y dir. is zero.
3] Shear force in y dir. is zero.
4] body force because of gravity has been not noted.
5] Incompressible fluid go with the flow.
6] On the inlet of check section,the flow has been absolutely advanced float.
7] The axial warmth conduction inside the fluid became negligible.
8] The residences of air had been consistent at atmospheric strain and temperature.

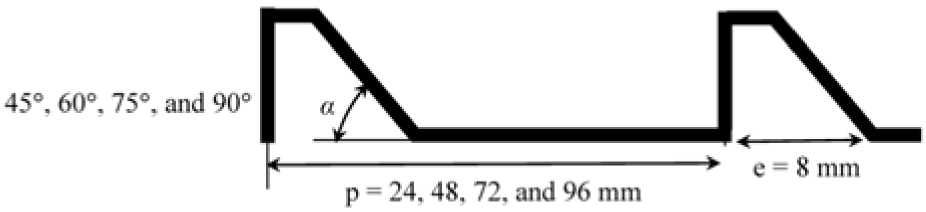
3.2 Numerical Method

3.2.1 Geometry and Computational grid

A square geometry with side (e=8mm) is taken and the inclination angle (α) is varied thereby resulting in different configurations wiz. Square, trapezoidal and equilateral triangle as these are most studied geometries. The meshing of the geometry has been performed utilizing GAMBIT 2.3.16. Surface cross sections were created by triangular and quads work components. For grid independence test, a solution adaptive refinement strategy is utilized. At the point when adaption is utilized properly the subsequent work is most good for the stream arrangement, after 20, 8815 quantities of cells, the variety in the estimation of heat transfer coefficient is irrelevant. Subsequently, the further investigation utilizing networks with 20, 8815 number of cells.

3.2.2 Solution Procedure

The design of rectangular channel rib turbulators with square ribs is created in the FLUENT WORKBENCH 15.0. A 2-Dimensional CFD study of fluid flow and heat transfer characteristics in a rectangular duct with square ribs of changing shapes from square, trapezoidal to equilateral angled triangle a long flow direction mounted on bottom surface. The bottom wall is provided with to a constant heat flux, while the remaining walls kept insulated.



The Realizable k-ε display is generally late improvement and not the same as the other model. Since it is probably going to give better execution than stream including pivot, boundary layer under strong pressure gradient, separation and recirculation. Henceforth, this model has been selected for the present examination.

The average Nusselt number is being calculated as:

$$\boldsymbol{Nu = \frac{1}{L}\int \frac{h(x).D_h}{k}\, dx} \tag{4}$$

Where h(x) is local heat transfer coefficient, D_h being hydraulic diameter (64mm), L is being test duct length. Friction factor (f) is also calculated by the below equation:

$$\boldsymbol{f = \frac{\Delta P.D_h}{\frac{1}{2}\rho u^2 L}} \tag{5}$$

Where ΔP stands for pressure drop across the duct, u being average flow velocity over entire test section length L. The Thermal enhancement factor (η) shows the two fold effect of Nusselt number and friction factor being calculated by:

$$\eta = \frac{\frac{Nu}{Nu_s}}{\sqrt[3]{\left(\frac{f}{f_s}\right)}} \tag{6}$$

Where the subscript s shows respective value for smooth channel. Also friction factor for smooth duct is calculated using Modified Blassius equation; $\boldsymbol{f_s = 0.085Re^{-0.25}}$ and Nusselt number for smooth flow is calculated by using Dittus Boelter equation i.e. $\boldsymbol{Nu_s = 0.024Re^{0.8}Pr^{0.4}}$ for prandtl value of 0.7.

a. Taguchi Method

The Taguchi method is widely used in various industrial and engineering applications for optimizing the design parameters, i.e. flow and geometrical parameters. This methodology is based on two fundamentals concepts of statistical engineering; First, the quality losses must be defined as deviations from the targets, not conformance to arbitrary specifications, and the second, achieving high system quality levels economically requires quality to be designed into the product. In the Taguchi method the orthogonal array facilitates the experimental design process and caters a method for fractional factorial experiments. The orthogonal array contributes to study the effect of main and interacting parameters via minimizing the number of experimental trials. Taguchi analysis is performed with **Minitab 18.0** software. In the current work, a L_{16} (4^3) orthogonal array is used, which implied carrying out 16 tests with 3 factors of 4 levels that listed in Table 3.1 and Table 3.2 respectively. As indicated in the table, the observed values of the Reynolds number (A), rib pitch to height ratio (B), and Inclination angle (C).

Table 3.1 Chosen L_{16} (4^3) Experimental Plan

Number of test	**Control factors and their levels**		
	A(Re)	**B(p/e)**	**C(α)**
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

Table 3.2 Parameters and Their Values Corresponding to Their Levels to be studied in Experiments

Code	**Parameters**	**Levels**			
		1	**2**	**3**	**4**
A	Reynolds Number, (Re)	4000	8000	12000	16000

B	Rib pitch to height ratio, (p/e)	3	6	9	12
C	Inclination angle, (α)	65	70	80	90

Taguchi strongly recommends the use Signal-to-Noise (S/N) ratios. By maximizing the S/N ratio, the loss associated with the process can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The experimental observations are transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The S/N ratio characteristics can be divided into three categories given by Equation below when the characteristic is continuous:

Smaller is the better characteristic: $\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y^2\right)$ (7)

Nominal the better characteristic: $\frac{S}{N} = -10\log\frac{1}{n}\left(\sum\frac{\overline{Y}}{S_Y^2}\right)$ (8)

Larger the better characteristic: $\frac{S}{N} = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$ (9)

Where $\overline{Y}$ the average of observed data, S_Y^2 is the variation of y, n is the number of observations, and y is the observed data. "Higher is better" characteristic and "Lower is better" characteristic, respectively, with the above S/N ratio transformation is suitable for maximization of Nusselt number and minimization of friction factor.

4. RESULTS AND DISCUSSIONS

From the literature, it is clear that most of the experimental/computational investigations were executed with array of ribs both square or rectangular, but the investigations related to single ribs are confined. For the validation of present version, the Nusselt number outcomes received with single rectangular rib at Re = 12000 from the prevailing investigation has been compared with the outcomes suggested by Tariq et al (2004) at Re=13400.

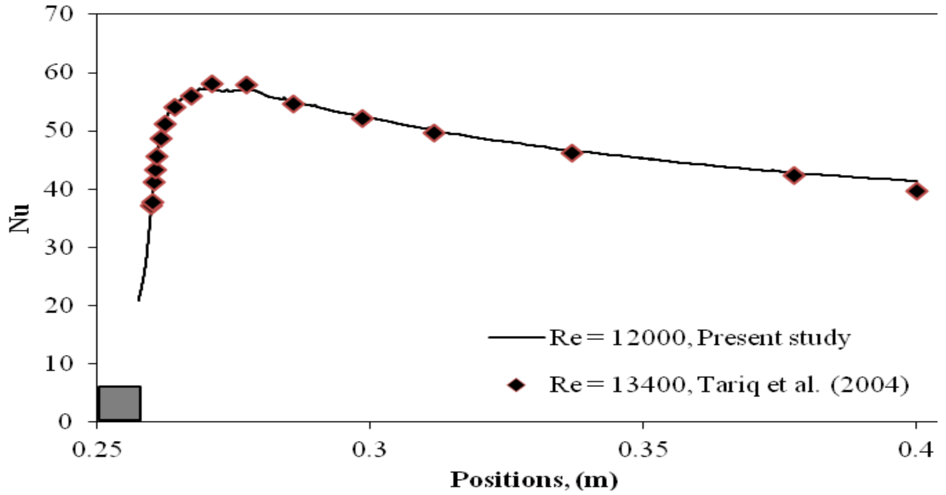


Figure 4.1 Validation of numerical analysis with Experimental results Tariq et al. (2004).

Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 2, Issue 4, Pages 140-154, Oct-Dec 2018

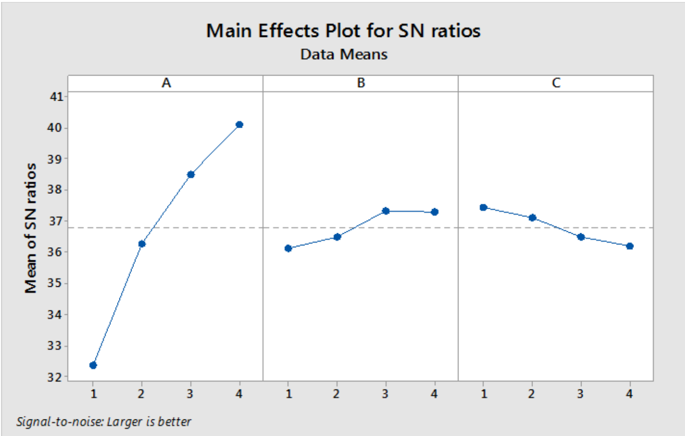
The response table of SNR for individual parameters at different levels, after implementing the Taguchi Method, in the case of heat transfer is presented in tabular form. These tables and figures successfully illustrate the importance of the design factors on the heat transfer, friction factor and thermo-hydraulic performance, and their respective rank is reported in the penultimate row of the tables. The factors with the higher difference between maximum and minimum values of SNR have the higher influence.

4.1 Effect on Nusselt number

For parameter A (Re), the Nusselt number increases with the increase of mean fluid velocity, as expected (Fig. 4.4). The Nusselt number increases with increasing B (p/e), because with increasing rib pitch to height ratio the flow reattaches on the heat transferring, which leads to high heat transfer rate. For parameter C (α), the Nusselt number decreases with increase in inclination angle of the front face of the rib.

Table 4.1 Response Table of S/N ratios for Nusselt number and Main effects Plot

Level	A	B	C
1	32.35	36.12	37.43
2	36.28	36.47	37.09
3	38.48	37.32	36.48
4	40.08	37.29	36.18
Delta	7.73	1.2	1.26
Rank	1	3	2
Contribution ratio, (%	75.86	11.78	12.37



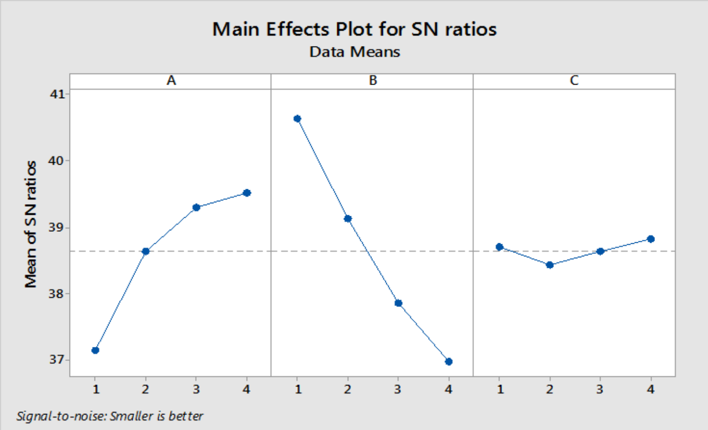
The analysis of the results gives the combination factors resulting in maximum heat transfer rate among the investigated test plate configurations are as follows: Re = 16000 (A4), p/e = 9 (B3), and α = 65°(C1). Therefore, $A_4B_3C_1$ is the optimum set of design parameters associated with heat transfer as per the “higher is the better” condition.

4.2 Effect on friction factor

Table 4.2. illustrates the effect of control parameters on friction factor. Friction factor increases with increase in control factor A (Re). The friction factor tends to decrease with the increase of parameter B (p/e). The values of friction factor slightly decreases with increase the control factor C (α). The optimum values of the control factors for minimum friction factor condition as follows: Re = 16000 (A4), *p/e* = 3 (B1), and α = 90° (C4). Therefore, $A_4B_1C_4$ is the optimum set of design parameters associated with friction factor as per the “lower is the better” condition.

 Online ISSN: 2456-883X

Table 4.2 Response Table of S/N ratios for friction factor and Main effects Plot



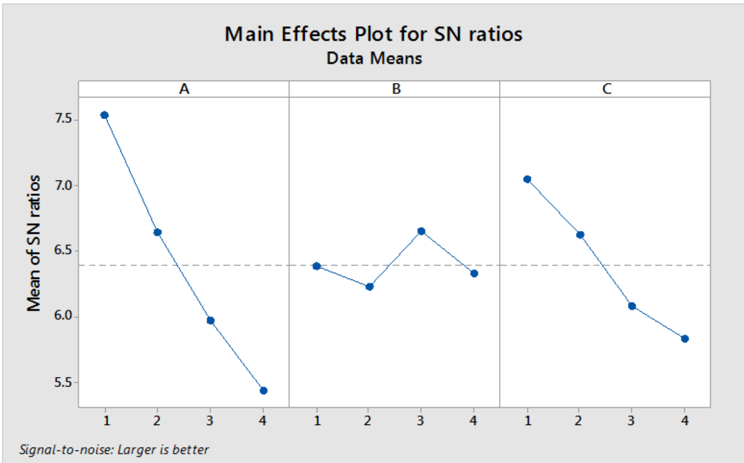
Level	A	B	C
1	37.14	40.64	38.7
2	38.62	39.12	38.44
3	39.3	37.85	38.63
4	39.52	36.97	38.82
Delta	2.38	3.66	0.38
Rank	2	1	3
Contribution ratio, (%)	37.07	57.01	5.92

4.3 Effect on thermo-hydraulic performance

Table 4.3 shows the influence of control parameters on thermohydraulic performance factor. Thermohydraulic performance decreases with increase in control factor A (Re). While no particular trend of thermohydraulic performance factor has been observed for parameter B (p/e). The value of thermohydraulic performance significantly decreases with increase in the control factor C (α). The optimum values of the control factors for maximum thermohydraulic performance are as follows: Re = 4000 (A1), *p/e=9* (B3), and α = 65° (C1). Therefore, $A_1B_3C_1$ is the optimum set of design parameters associated with friction factor as per the "higher is the better" condition.

Table 4.3 Response Table of S/N ratios for Thermo-Hydraulic Performance and Main effects Plot

Level	A	B	C
1	7.541	6.38	7.051
2	6.645	6.222	6.623
3	5.965	6.652	6.077
4	5.43	6.327	5.831
Delta	2.11	0.43	1.22
Rank	1	3	2
Contribution ratio (%)	56.12	11.44	32.45



The delta is the difference of the maximum and minimum of the SNR for every control factor. The contribution ratio is equal to the ratio of the delta values of each factor to the total delta value of all factors, as presented in last row of Tables 4.1, 4.2, and 4.3. The contribution ratio of each control factor to Nusselt number is shown in Table 4.1. It is seen from the figure that the Reynolds number contributes to 75.86% of the total effect. This means that the parameter A (Re) is the most effective one on heat transfer. Based on the Table 4.1, it can be concluded that the second (B) and third (C) parameters have almost same effectiveness on heat transfer. Table 4.2 clearly evident that parameter B is the most dominant factor that controls the friction factor with a contribution ratio of 57% of the total effect. The factors A and B contribute to 37% and 5.92% of the total effect on friction factor, respectively. As seen from Table 4.3., the parameter A is the most significant having a contribution ratio of 56.12% of the total effect. The factors B and C contribute to 11.44% and 32.45% of the total effect on thermohydraulic performance factor, respectively.

The optimum level of control factors for Nusselt number, friction factor and thermohydraulic performance factor are $A_4^a B_3^c C_1^b$, $A_4^b B_1^a C_1^c$ and $A_1^a B_3^c C_1^b$, as shown in Table 4.4. Here the coefficients a, b, and c symbolize the importance level of each parameter and indicate the first, second, and third effective parameter, respectively.

Table 4.4 Optimum conditions and performance values, where superscript a,b,c are the sequence of effective parameters.

Parameters		Factors			Value
		A (Re)	B (*p/e*)	C (*α*)	
Nusselt number(Nu)					
	Optimum level	4^a	3^c	1^b	114
	Optimum value	16000	9	65°	
Friction factor(f)					
	Optimum level	4^b	1^a	4^c	0.00824
	Optimum value	16000	3	90°	
Thermal enhancement factor(η)					
	Optimum level	1^a	3^c	1^b	2.81
	Optimum value	4000	9	65°	

5. CONCLUSION

(1) For Nusselt Number, the outcomes indicated that Reynold Number (Re) played important role contributing (75.86%) of the total effect. Also, Nu was increasing with rib pitch-to-height(p/e) ratio due to the reattachment of flow achieving most optimum value at Re=16000, p/e=9and α=65˚.

(2) For friction factor, the pitch -to-height ratio of the rib becomes the primary contributing factor (57%) and optimum parameters or optimum values are at Re=16000, p/e=3 and α=90˚.

(3) For overall thermo-hydraulic performance, it shows a declination nature as the Re values are increasing and became nearly unaffected by changing the p/e values and pondered a descending fashion as the inclination angle (α) turned into growing. Greatest parameters for maximum overall performance are at Re=4000, p/e=9 and α=65˚.

(4) The above outcomes indicated that with the change in value of p/e, α and Re, there does no longer exists a completely unique rib configuration which furnished the maximum heat transfer enhancement with minimum friction penalty and the high-quality thermo-hydraulic overall performance in comparison to that of square rib but

it is clearly indicated from the above outcomes that the equilateral angled ribs performs better than square ribs for the above taken parameters.

REFERENCES

[1] Han, J. C., Park, J. S., and Lei, C. K., Heat Transfer Enhancement rate in Channels with Turbulence Promoters, Asme Journal of Engineering for Gas Turbines and Power, vol.107, no. 3, pp. 628–635, 1978.

[2] J.C. Han., and Tao, W. Q., Experimental Study on Heat Transfer in Ducts with Winglet Disturbances, Heat Transfer Engineering, vol. 24, no. 2, pp. 76–84, 1984.

[3] J.C.Han.,and J.C. Park, A Comprehensive Numerical Study on Thermo-hydraulic Performance of Fluid Flow in Triangular Ducts with Delta-winglet Vortex Generators, Heat Transfer Engineering, 2017. DOI: 10.1080/01457632.2017.1288046,1988.

[4] J.F. Lockett and M.W. Collins Thermal Behavior in Rectangular Channel Duct Fitted with V-Shaped Perforated Baffles, Heat Transfer Engineering, vol. 36, no. 5, pp. 471-479, 1989.

[5] Han, J. C., G. Rau., and Ekkad, S., Gas Turbine Heat Transfer and Cooling Technology, 2nd ed., CRC Press, Taylor and Francis group, New York, 1998.

[6] Han, J.C. and Z.X.Yuan., Developing Heat Transfer in Rectangular Channels with Rib Turbulators. International Journal of Heat and Mass Transfer, vol. 31, no. 1, pp. 183–195, 2003.

[7] P.R. Chandra and J.C.Han, Heat Transfer-Friction Characteristic Comparison in Rectangular Ducts with Slit and Solid Ribs Mounted on One Wall, ASME Journal of Heat Transfer, vol. 120, no. 3, pp. 709–716, 2003.

[8] P.K.Andallib, P.k. panigrahi , Alexander, C. R., and Han, J. C., Heat Transfer and Friction Behaviours in Rectangular Channels with Varying Number of Ribbed Walls, International Journal of Heat and Mass Transfer, vol. 46, no. 3, pp. 481–495, 2004.

[9] Chang, S. W., Lei wang,Bengt Sunden Yang, T. L., and Wang, W. J., Heat Transfer in a Rotating Twin-Pass Trapezoidal-Sectioned Passage Roughened by Skewed Ribs on Two opposite Walls. Heat Transfer Engineering, vol. 27, no. 10, pp. 63–79, 2005.

[10] R.Kamali.,and A.R,Binesh., Holographic Interferometry applied to Rib-Roughness Heat Transfer in Turbulent Flow. International Journal of Heat and Mass Transfer, vol. 33, no. 11, pp. 2439–2449, 2008.

[11] Kyung Min Kim and Hyun Lee, Liou, T. M., and Hwang, J. J., Tieyu Gao and Junxiong Zenga effect of Ridge Shapes on Turbulent Heat Transfer and V Friction in a Rectangular Channel. International Journal of Heat and Mass Transfer, vol. 36, no. 4, pp. 931–940, 2009.

[12] Wang, L.and Sunden, B., K R Aharwal and J S Saini , Experimental Investigation of Local Heat Transfer in a Square Duct with Various-Shaped Ribs. Heat and Mass Transfer, vol. 43, no. 8, pp. 759–766, 2010.

[13] Ali, M. S., Tariq, A., and Gandhi, B. K., Giovanni Tanda Flow and Heat Transfer Investigation behind Trapezoidal Rib using PIV and LCT Measurements. Experiments in Fluids, vol. 54, no. 5, pp. 1520:1–15, 2011.

[14] Sharma, N., A Tariq, MD Shaukat Ali , M., Arjumand Rasool and Adnan Qayoyu , Detailed Heat Transfer Investigation inside a Rectangular Duct with an Array of Ventilated Rib Turbulators, in Fluid Mechanics and Fluid

Power – Contemporary Research, Eds. Saha, A.K., Das, D., Srivastava, R., Panigrahi, P. K., Muralidhar, K., Book Chapter-73, Springer, India, 2012.

[15] Sharma, N., Tariq, A., Mishra, M., Yue-Tzu Yang and Peng-Jen Chen Detailed Heat Transfer and Friction Factor Characteristics in a Rectangular Duct With Rib Turbulators, Proc. 42nd National Fluid Mechanics and Fluid Power Conf., NITK Surathkal, Karnataka, India, FMFP 2015-69, December 14-16, 2014.

[16] Tanda, G., A.Boulem Effect of rib spacing on heat transfer and friction in a rectangular channel with 45 angled rib turbulators on one/two walls. International Journal of Heat and Mass Transfer, vol. 54, no. 5–6, pp. 1081–1090, 2014.

[17] Sharma, N., Tariq, A., Mishra,Ashgar B. Rahmani M., Effect of Pentagonal Ribs on Local Heat Transfer and Friction Factor in a Rectangular Channel, Proc. 23rd Natl. Mass Transfer Conf. & 1st Intl. ISHMT-ASTFE Heat Mass Transfer Conf., Thiruvananthapuram, India, Paper 671, December 17-20, 2015.

[18] Yang, Y. T., Chen, P. J., Sunil Chamoli Numerical Optimization of Turbulent Flow and Heat Transfer Characteristics in a Ribbed Channel, Heat Transfer Engineering, vol. 36, no. 3, pp. 290–302, 2015.

[19] Park JS, Han JC, Huang Y, Ou S. Eiamsa-Ard Petpices, Heat transfer performance comparisons of five different rectangular channels with parallel angled ribs. Heat Mass Transfer 1992;35(11):2891–903, 2016.

[20] Chandra PR, Alexande CR, Han JC., Hamed Safikhani and Smith Eiam Heat transfer and friction behaviours in rectangular channels with varying number of ribbed wall. Heat Mass Transfer 2003; 46(3):481–95.[34] Lau SC, Rd Mcmillin, Han JC. Turbulent heat transfer and friction in a square channel with discrete rib turbulators. J Turbomach 1991;113(3):360, 2016.

[21] Lau SC, Rd Mcmillin, Han J.C. Jian Liu Heat transfer characteristics of turbulent flow in a square channel with angled discrete ribs. J Turbomach 1991;113(3):367–74, 2017.

[22] Zhang YM, Gu WZ, Han J.C., Andallib Tariq and Manish Mishra heat transfer and friction in rectangular channels with ribbed or ribbed-grooved walls. J Heat Transfer 1998;116(1):58–65, 2017.

[23] Tieyu Gao and Junxiong Zenga Effect of roughness shape on heat transfer and flow friction characteristics of solar air heater with roughened absorber plate. WIT Trans Eng Sci 2008;53:43–51, 2017.

[24] Karmare SV, Tikekar AN., Arjumand Rasool, Analysis of fluid flow and heat transfer in a rib grit roughened surface solar air heater using CFD. Sol Energy 2010;84(3): 409–17, 2018.

[25] Gandhi BK, Singh KM. Experimental and numerical investigations on flow through wedge shape rib roughened duct .Inst Eng (India) J MC 2010;90 (January):13–8.

[26] Sharma AK, Thakur NS. CFD based fluid flow and heat transfer analysis of a V-shaped roughened surface solar air heater. Int J Eng Sci Technology 2012; 4(5):2115–21.