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Comparative Analysis of Heat Transfer Through Corrugated and Straight Channels

N. Abbas[1], S. Nazir[2] and M. Hammi[3]

[1]*Department of Mechanical Engineering, University of Central Punjab, Lahore 54000, Pakistan*
[2]*Space and Upper Atmosphere Research Commission (SUPARCO), 75270 Karachi, Pakistan*
[3]*Faculty of Science, University of Mohammed V, BP1014 Rabat, Morocco*
[1]naseem.abbas@ucp.edu.pk

Abstract-This research aimed at conducting thermal analysis to carry out heat transfer comparison between two different heat channels. For this purpose, two 2-D (corrugated and straight) channels have been considered for investigation. Direct numerical simulation has been implemented, in which Reynolds number is varied in an ascending manner (2000<Re>5000), while flow behavior has been maintained in a steady turbulent mode. To undergo analysis, Fluent (ANSYS Workbench 15.0) has been utilized. Air has been considered as a working fluid during analysis, while dimensions like cross section, height and length have been taken as invariant parameters for both channels. For all cases wall flux, has been regarded as a constant measure during heat transfer simulation. After obtaining solution, results have been compared for both channels and it is concluded that transmission of heat is much more prominent in corrugated channel as in comparison with straight channel. In studied geometry, 40% improvement of heat transmission (by average) were obtained in corrugated channel as compared to the straight channelsuccessfully. Moreover, Augmentation of the Reynolds number leads to an increase in velocity due to the sharp corner edges of cavity.

Keywords-Heat Transfer; Nusselt Number, Reynolds Number, Straight Channel, Corrugated Channel

I. INTRODUCTION

The optimum design of heat exchangers is crucial parameter to enhance the energy reserves. The best approach to enhance the overall performances of plate heat exchangers is to perceive productive heat transfer surfaces which do not instigate much pressure drop. Utilizing corrugated plates is an appropriate and most effective method to enhance the compactness of heat exchangers which is required for space, automotive and aeronautic sectors of industries. In this way, the wave like geometries are promising geometries to increase the rate of heat transfer by disrupting and breaking the thermal boundary layer. Therefore, corrugated channel surfaces act as turbulence promoters to enhance the indigenous mass and heat transfer. For instance, corrugated channel plates are most extensively used in food industries. The two key limitations in food industries are (i) to stay away the exhaustion of the fluid due to the heterogeneity of the heat transfer to the wall and (ii) to permit a decent blending of the fluid.

Nomenclature

A	Heat conduction area	K	Thermal conductivity
Ac	Channel cross-section area	Nu	Nusselt number
Cp	Specific heat	Re	Reynolds number
D	Hydraulic diameter	p	Static Pressure
ρ	Fluid density	Q	Heat flux
f	Friction factor	Pr	Prandtl number
h	Average heat transfer coefficient	L	Wavelength of one wavy unit or pitch
H	Channel Depth or Height	S	Chanel Width
Tw	Wall temperature	Tm	Mean (Bulk) fluid temperature
V	Average flow velocity	µ	Dynamic viscosity
x/L	Aspect Ratio	x	Direction of Inlet flow

The literature is rich in both experimental and numerical studies of heat transfer environmental impacts, efficient heat exchangers have become very essential in various equipment's such as automobiles and distributed energy systems. Heat exchangers are the devices whose primarily function is to exchange heat from one medium to another medium. In the start of twentieth century, heat channels (ducts) of dissimilar shapes were introduced in market to fulfill the requirements of dairy industry. Shah and Focke investigated that several types of heat channels have been differentiated from each other based on flow construction, shape of channels, dimensionless numbers and many other parameters [i]. Following the pioneering work of H. M. Ali used a new and original water cooled mini channel heat sinks for microprocessor cooling [ii], multi walled carbon nanotube nanofluids for thermal management of high heat generating computer processors [iii], heat transfer augmentation for car radiator using ZnO-water nanofluids [iv], nanofluids performance for simulated microprocessor [v], pin-fin heat sink on heat transfer performance [vi, vii]. Moreover Ali also explained very well about heat transfer phenomena's in nanofluids industry by applying different novel techniques [v, viii-xvi].

Use of corrugated channels during analysis results in complicated flow but it increases the heat transfer phenomena by 2 to 3 times as compare to heat transmission process which occurs in conventional straight channel [xvii, xviii]. Same type of heat transfer was also investigated on the corrugated channels utilization to increase the rate of heat transfer. The utilization of Corrugated channels is an appropriate mean to enhance the thermal performance of heat transferring devices because of induced breaking and destabilization parameters in thermal boundary layer [xix]. The pressure drop characteristics of high viscous solution is also an important parameter on the heat transfer [xx]. If the heat does not get its proper pressure for transferring from one to another medium, then it will lose its energy. The corrugated and sinusoidal wavy channels to improve the HT effectiveness by enhancing the surface area and warning the development of vortices in flow [xxi]. This efficiency is associated with the path of HT through designed plates of channels which resulted in formation of turbulent flow at low Reynolds number. The turbulence in channel which is formed by pattern of corrugated channels, is mainly due to compressible flows in narrow streams. These narrow streams have many abrupt variations in the flow velocities and flow direction. So, this kind of turbulence reduces the liquid film resistance which results in more efficient heat transfer as compared to the turbulent path created by high flow pressure and rates.

To improve the liquid film resistance the laminar flow has also been investigated through corrugated heat transfer channel both experimentally and numerically. The solutions for heat transfer and laminar flow in corrugated channels with two bends at angle of 90^0. Then the results are studied by considering the effects on flow characteristics as well as heat transfer by bending angle of corrugated channel [xxii]. While some researchers had numerically analyzed the corrugated flow structures for both laminar and turbulent flows [xxiii] and formulated the approach for heat transfer and laminar flow through corrugated ducts [xxiv]. A finite volume scheme had applied to get fully developed flow model, friction factor and HT coefficients to explain the heat transfer [xxv]. The complete created stream of air and water through distinctive folded structures can be identified as HT qualities [xxvi]. Different relationships of Nusslet number or water and air have been gotten by constituting an area through three indistinguishable folded structures. Layering point is balanced up to 30° while cooled wind stream through center one and boiling hot water is similarly isolated in contiguous channels. Sudden [xxvii] had examined numerically the pressure drop and heat exchange in the corrugated channels and smooth tubes under states of consistent high temperature flux. The inspection and the dissipation of waves of surface in channel, which had folded base and dividers has also been studied to check the heat losses in different heat channels [xxviii, xxix] connected the LDV to focus speed profiles and typical stream that passed through the creased stream conduits which had wavy top and base plats. Sawyers had mulled over numerically the impact of three dimensional hydrodynamic on heat exchange through the creased pipes [xxx]. Methodologies through which HT execution could be improved without huge weight drop punishments and entangled three-dimensional structures that manufacture is taken as an extremely difficult assignment have turned into a subject of extraordinary investment. Decrease in size of high temperature, high stream rates of the coolant build up and finally finish a sharp increment in weight misfortune. Turbulent convective high temperature exchange is not suitable which is considered as a productive mode of hotness exchange. Stream of coolant happens through smaller than expected hotness directs in both laminar and transitional administration while convective heat transfer altogether relies on upon blending of liquids.

To enhance heat transfer, use of Dean Vortices (DV) is an auspicious fluid flow mechanism. When liquid passes through the wavy channels, there is a chance of establishing the secondary flows (DV) established because of centrifugal forces. This secondary flow progresses the rotation of fluid elements in span wise plane, the wavy passage which sequentially increases the folding and stretching of fluid elements. This mechanism is employed by many researches as it is resulted in improvement and enhancement [xxxi-xxxii]for both mixing and heat transfer. Fully-developed viscous flow and heat transfer in curved semi-circular sectors are used to improve the performance of heat transfer through different Channels [xxxiii, xxxiv]. Recently Fletcher had methodically performed numerical investigations of completely created stream and Heat exchange process [xxxiv, xxxviii] in intermittent corrugated channels by considering states of different cross-areas. The HT execution could be significantly improved in straight channels by taking the same measurements of cross-segment; and in the meantime, the rate of heat transfer is much higher than the pressure drop. As previous numerical research work to clarify the HT improvement, the investigated behavior of fluidic's flow and the heat transfer in wavy micro channels. They sort out that the stream [xxxix] field description and dynamical framework system (Poincare segments) are utilized to examine the liquid blending and it is discovered that the amount and area of the DV may alter essentially along the flow of heat stream. For stream in wavy entries, the discriminating Reynolds numbers for stream moves can be brought down fundamentally than if there should arise an occurrence of straight channels. The main concentrated is on [xl] the stream conduct and hotness move in sinusoidal sections by taking huge angle degrees. They watched unstable stream at Reynolds numbers even under 200. The basic Reynolds numbers for onset of instability exceptionally relies on upon the channel geometry and additionally the aggregate divert length in the stream course. The precariousness can be considered as an unsettling influence for liquid and may be brought about improvement of liquid blending and additionally high temperature exchange. Accordingly, it is extremely huge to explore the insecure stream in wavy channels. Direct numerical simulation can give valuable data relating to the spatial and transient transformation of the stream field and the comparing execution of the heat transfer forms.

The main objective of this numerical investigation was to deal with the comparative analysis of heat transfer in corrugated and straight heat channels. Direct numerical simulation has been implemented, in which Reynolds number is varied in an ascending manner (2000<Re>5000), while flow behavior has been maintained in a steady turbulent mode. To undergo analysis, Fluent (ANSYS Workbench 15.0) has been utilized. Air has been considered as a working fluid during analysis, while dimensions like cross section, height and length have been taken as invariant parameters for both channels.

II. Material and Methods

Numerical Analysis has been executed to find out the heat transfer rate through the corrugated channel by taking air as a working fluid. Unit channel specifications has been analyzed and are represented in Table I. Angle of the channel is accustomed up to 20º while Reynold number is varied from 2000 to 5000. Similar sort of work has also been done to determine the convective heat transfer coefficient (h) [xli]. The stream has been induced periodically in channel to maintain the heating condition uniformly. Axial distance (L) distinguishes the wall temperature at different points. An appropriate way to measure bulk temperature has been introduced on a straight line with similar set of points. As discussed earlier that The regime for a channel with continuously changing flow has been established thermally and local Nusselt number is calculated by using the given relation after assessing the cycle-average developed (fully) heat transfer coefficient [xlii].

$$h = \frac{Qcycle}{(Tw - Tb)Acycle} \quad (1)$$

The channel`s height is basically represented as characteristic length which is used as hydraulic diameter(Dy). The Reynolds number can be defined as [xxvii];

$$Re = \frac{\rho VD}{\mu} \quad (2)$$

Where V is the average velocity of fluid, fluid density is denoted by ρ, and D is hydraulic diameter of used channel and μ denotes the dynamic viscosity of fluid. The transient and time-arrived at the midpoint of frictional loss (communicated as a frictional factor) and execution of heat transfer of the current corrugated channels (calculated by Nusselt number) are figured. We have examined in contrast, this flow channel with straight channels having the same cross segments. The frictional factor is characterized as[xliii];

$$\rho = -\left(\frac{dp}{dx}\right)\left(\frac{2D}{\rho V^2}\right) \quad (3)$$

The Nusselt number of cycle-average has been calculated by using the following equation[xliv].

$$Nu = \frac{hDy}{K} \quad (4)$$

Illustration of planar corrugated channels has been shown clearly in Fig. 1. Fig. 2 explain the characteristic dimensions for one periodic unit of the corrugated channel. The thermal hydraulic performance of such corrugated V channels has been considered for comparing them with Straight (baseline) channels, by keeping length and cross section as a constant parameter for both types of channel. The geometrical configuration of the corrugated V channel has modeled successfully on the Design Modeler of Workbench 15.0 (Commercial package). It is considered that the heat transfer and flow has happened in a two-dimensional turbulent mode by considering the properties of air as constant values. Sometimes the hydraulic engineers face incredible problems in imagining the stream examples and setting up one-dimensional model. They practically assume to the stream field, then two-dimensional flow channel to be utilized. The preferences of two-dimensional flow incorporate a critical change in figuring pressure driven variables at scaffolds. US Department of transportation has a solid inclination for the utilization of two-dimensional models more than one-dimensional models for complex conduit and/or complex extension water powered examinations. So, two-dimensional heat transfer was taken in our investigation.

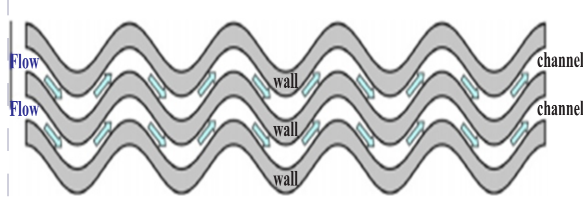

Fig. 1. Illustration of planar corrugated channels

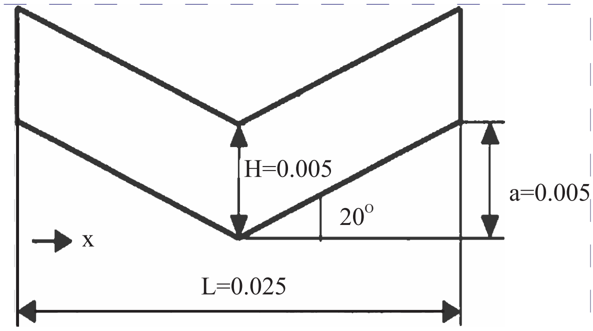

Fig. 2. Characteristic dimensions for one periodic unit of channel

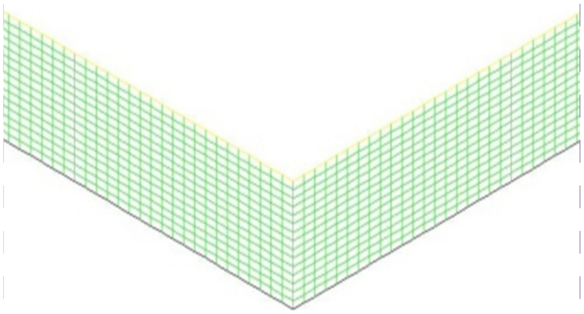

Fig. 3. Schematic representation of the solution domain mesh

The inlet, exit and along the sides of a channel are considered as the boundary conditions. The criteria to categorize every computational liquid progress are breaking points of starting and boundary conditions. For the better use of boundary conditions, during development of stunned lattice, an extra node is included to achieve physical limits. Node outside the gulf of framework is used to transfer the inlet conditions. The limits for scalar volume can match with the physical limits, which allow us to show the boundary conditions and attain to watchfulness comparisons for nodes close limit with small variations. The size of mesh of the duct has been considered as 31and 80. FLUENT (Workbench 15.0) [xlv, xlvi] is used for two-dimensional analysis, while temporal discretization has been done by using second-order implicit scheme. For the spatial discretization, the standard scheme has been adopted to undergo pressure discretization. The 2nd order up wind scheme is used to solve equations for energy and momentum [xlvii]. A constant numeric digit for mass flow rates have been used, while at the inlet and exit of the channel, periodic boundary condition has been defined. Along the walls there is no application of slip conditions while at inlet, constant velocity profile has been used. Along the length of wall, a constant heat flux has been applied, while the relative pressure gradient at outlet is zero.

TABLE I
SPECIFICATIONS OF CORRUGATED CHANNEL

Sr	Specification	Dimension
i)	Characteristic Length (D)	0.005m
ii)	Corrugation Angle	20°
iii)	Aspect ratio (x/L)	$0.10 \leq AR \leq 1.0$
iv)	Pitch (L)	0.025m

III. RESULTS AND DISCUSSION

To evaluate the difference of heat transfer between the V and straight channel, analysis has been performed for the range of Reynolds number between 2000 to 5000.The range of Reynolds number is selected by considering the hydraulic diameter of the channels. The geometric parameter of channels and the aspect ratio, is defined by the ratio called L/D. Ten different ARs are considered for Simulation (0.1, 0.2, 0.3, 0.4 up to 1.0). The aspect ratio of channel is varied as $0.10 \leq AR \leq 1.0$. The steady flow numerical analysis has been done by the commercial package of ANSYS Workbench (Fluent) 15.0 on straight channel. Reynolds number comparability is utilized when viscous force is prevalent. Fig. 4, 5 and Figure 6demonstrate the varying trend of local Nusselt number which is based on the diameter, along the aspect ratio of the straight and corrugated channel. The effect on heat transfer by aspect ratio and eccentricity from a cylinder in a cavity has already been explained but in corrugated and straight channel comparison has not been studied yet per our knowledge. Fig. 3 clearly shows the mesh of unit corrugated channel. Fig. 4 shows that corrugated channel gives higher response to Nusselt number as compared to the straight channel when the Reynold number is 2000. Initially with the increase in aspect ratio the Nusselt number decreases more in both channels but from aspect ratio of almost 0.6 to 1.0 there is very less deduction of the Nusselt number in Fig. 3. As the Nu number is directly proportional to heat transfer coefficient. So, by the enhancement of Nu number the heat transfer will be increased which also testify our results.

In the same manner, numerical analysis on V channel has been verified by the work of Yasar Islamoglu [xxii]. The same package of software has been utilized for the analysis on corrugated channel. corrugated channel is also called as V channel. As already mentioned the working fluid, move through channels totally in submerged stream, flowing through venture meter and orifice meter. This simulation is done for the narrow channels where heat transfer is the main priority and Pressure drop does not matter a lot. The variations of Nusselt number along both channels have been shown in Fig. 5 and Fig. 6. Fig. 5 demonstrate the relationship between Nusselt number and aspect ratio when the Re number is 3000 and similarly Figure 6 also represents the relationship between Nusselt number and aspect ratio when the Re number is 4000. In Fig. 4, 5, 6 and Fig. 7, the corrugated channel gives higher heat transfer as compared to the straight channel. The difference of heat transfer between the both channels at Re numbers values from 2000 and 5000.It is evident from the numerical results that HT is more in corrugated V channel than straight base line channel.

Fig. 3 has shown the varying trend of Nu with the aspect ratio of channel. While comparing the corrugated channel with straight channel, it has been clearly observed that Corrugated channel show excellent response, when the value of Reynolds number is 2000. As shown the variation of HT between both the channels on three different Re. In the case of different Reynolds number there is no change in behavior in both of channels under consideration. Result shows that the value of HT has direct relation with Re, HT increases as the value of Re increased as shown in Fig 6and Fig 7. Fig 8 explains clearly the relationship between Nu and Re in both channels. There is a considerable difference of HT rate in corrugated channel and straight channel, but no change has been observed on higher Re. So, after obtaining solution, results have been compared for both channels and it is concluded that transmission of heat is much more prominent in corrugated channel as in comparison with straight channel.

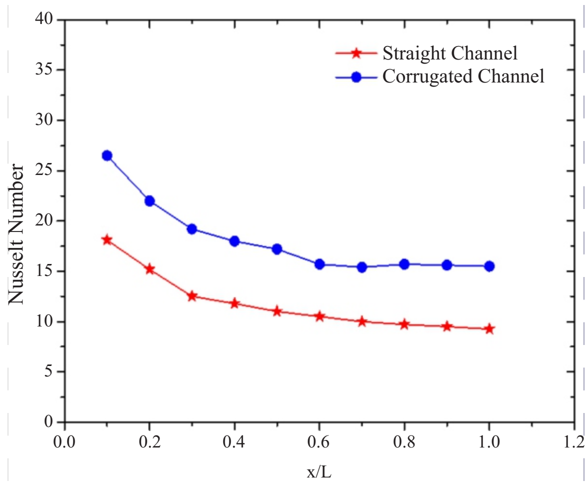

Fig. 4. Variation in Nusselt Number with Aspect Ratio when Re=2000

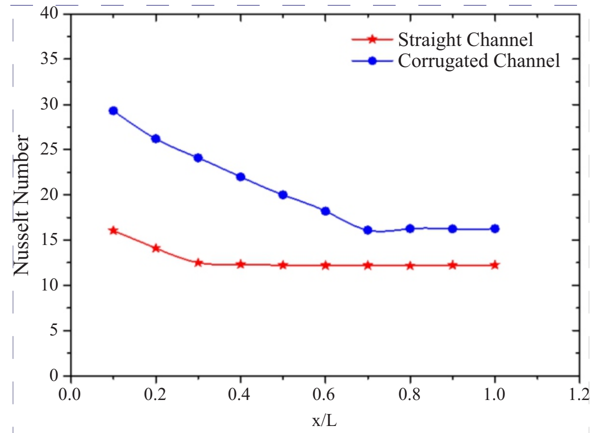

Fig. 5. Variation in Nusselt Number with Aspect Ratio when Re=3000

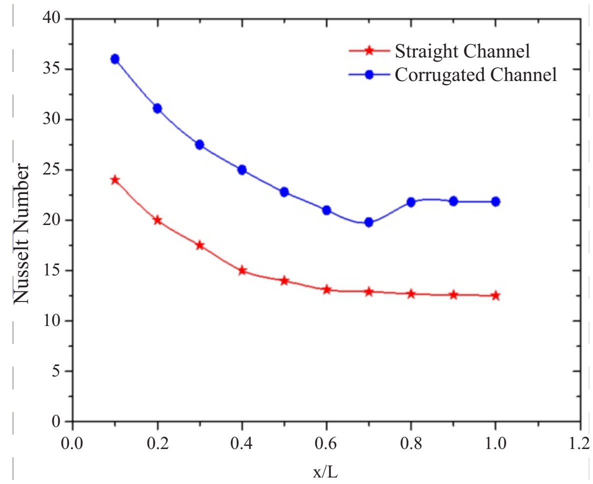

Fig. 6. Variation in Nusselt Number with Aspect Ratio when Re=4000

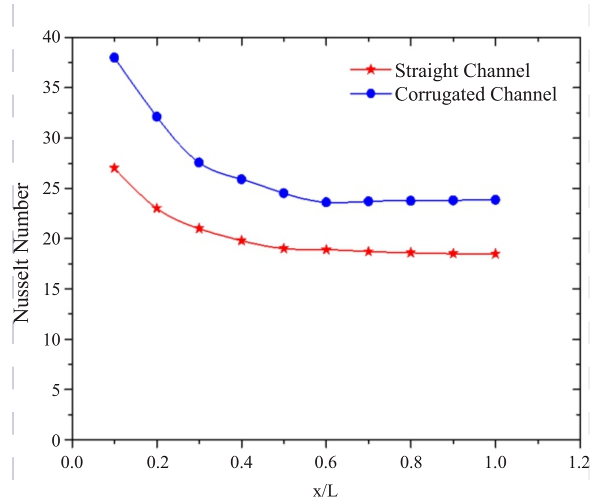

Fig.7. Variation in Nusselt Number with Aspect Ratio when Re=5000

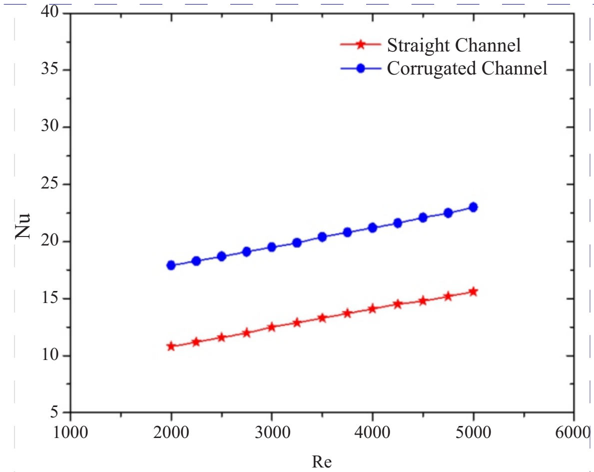

Fig. 8. Variation in Average Nusselt Number with Renylod Number

IV. Conclusions

Numerical investigation is carried out on the corrugated and straight channels through transferring of heat. The results show due to the efficient mixing and more contact time of fluid with the wall gives higher Heat Transfer in corrugated channels than base line straight channels. In studied geometry, ~40% improvement of heat transmission (by average) were obtained in corrugated channel as compared to the straight channel successfully. Moreover, Augmentation of the Reynolds number leads to an increase in velocity due to the sharp corner edges of cavity. The channel `section used in this section is compact and efficient. These channels are ideal for the cases where pressure drop is not the main consideration. These channels are good choice for the heat transferring devices.

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