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A NUMERICAL STUDY OF CHEVRON, CORRUGATED-PLATE HEAT EXCHANGER USING CFD TECHNOLOGY

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ABSTRACT

In this paper chevron corrugated plate heat exchanger simulated. A two dimensional plate were modelled in ANSYS 14.0 and CFD analysis is performed for temperature ,velocity & pressure fields at different mass flow rate i.e. 20L/H,40L/H,60L/H,80L/H.Temperature ,velocity and pressure drop increases with the increase of mass flow rate along the direction of flow .A 2D model of plate shows two sides of steam and one side water where temperature of water is higher at higher mass flow rate shows expected heat transfer. Variation of heat flux at both steam side were also observed results are plotted graphically & numerically.

Keywords: *Surgical robotic, Chevron, Corrugated, heat Exchanger etc.*

I. INTRODUCTION

Heat exchangers have been used in a wide variety of applications. Typical among them are the district heating stations, heat recovery systems, HVAC systems, food and chemical process systems, and oil cooling systems. The plate heat exchangers are compact and efficient and their types, structures optimization for better heat transfers and scope of applications are still developing. The core components of the PHE are plates, which are heat transfer surfaces which not only facilitate heat transfer between the cold and hot fluids, but also bear the pressure difference on both sides. Many kinds of corrugated plates have been studied in pursuit of high heat transfer and lower pressure drop. Usually the main parameters in evaluating the performance of corrugated PHEs are the efficiency of heat transfer, flow resistance, and the pressure capacity. It is generally observed that chevron corrugated PHE has high efficiency, large fluid resistance, and large pressure capacity, which is mainly because the flow channel cross section between the plates changes in a very complicated way, likely to cause turbulence. Such a flow, with repeated expansion and contraction of the flow cross section will consume more pumping.

There are considerable effort have been made to understand the behaviour of chevron corrugated PHE's such as in a numerical simulation It was observed that a significant swirling flow, induced by the interaction with the fluid flowing in the conjugate duct, was predicted in the cross-section of each furrow. Its (relative) intensity was found to increase with increasing *Re,* and P/H_i (Pitch of corrugation /internal height of corrugations [1].
In an experiment it was observed that the local heat transfer has been measured using thermo chromic liquid crystals combined with true-colour digital image processing. Part of the novelty is that flexible proprietary sheeting has been successfully applied to curved surfaces. In the range investigated, the average Nusselt number (Nu) was found to increase approximately as $\boldsymbol{Re^{2/3}}$ for all geometries [2].

A detailed mathematical model for the simulation of a PHE in steady-state with a general configuration was developed in algorithmic form. This assembling algorithm made the simulation and comparison of different configurations more flexible. An important feature of the proposed algorithm is that it may be coupled to any procedure to solve the system of differential and algebraic equations. The assumption of constant overall heat transfer coefficient throughout the exchanger, often used for the mathematical modelling, was tested and showed little influence over the main simulation results for heat exchange(thermal effectiveness and outlet temperatures) [3].

II. LITERATURE REVIEW

Y.Y. Hsieh, L.J. Chiang, T.F. Lin (2001) carried an experiment to explore the sub cooled flow boiling heat transfer and the associated bubble characteristics of R-134a in a plate heat exchanger[4].

Yoichi Shiomi , Shigeyasu Nakanishi, Takafumi Uehara (2004) Examined two-phase flow in a channel formed by chevron type plates was examined .The pressure drop was expressed by the function of Reynolds number and increases with the increase in the corrugation angle of the plates in the single-phase flow [5].

ZHANG Guan-minTIAN Mao-cheng (2005) observed by simulation and experiment that the fluid's momentum induced by the change of the inclination angle β is probably the main factor that causes a change of the flow pattern mentioned [6].

Paisarn Naphon (2006) In his another experiment on the heat transfer and pressure drop characteristics in the channel with double V-corrugated surfaces presents that For fluid flowing through the corrugated surface, fluid re-circulation or/and swirl flows are generated in the corrugation troughs. The onset and growth of recirculation zones promote the mixing of fluid in the boundary layer. Therefore, the corrugated surface has significant effect on the enhancement of heat transfer and pressure drop. Effect of relevant parameter on the heat transfer and pressure drop characteristics are also considered [7].

Carla S. Fernandes a, Ricardo P. Dias b, c, Joao M. Nobrega d, Joao M. Maia d (2008) The PHEs had different corrugation angles and the area enlargement assumed a value commonly used in the industry. Due to the geometrical complexity of the cross-corrugated chevron-type PHEs passages, the velocity profiles and, therefore, the shear rate behaviour are also complex [8].

Masoud HAGHSHENAS FARD **a*, *Mohammad Reza TALAIE*** **b*, and Somaye NASR*** **(2009)**
In this study the CFD simulations have been developed to predict the overall heat transfer coefficient and heat transfer rate of ZnO/water nanofluid in a plate heat exchangers Single-phase model has been used for prediction of temperature and fluid flow distribution and calculation of heat transfer coefficients and heat transfer rates [9].

Ying-Chi Tsai, Fung-Bao Liu, Po-Tsun Shen (2009)
Investigate hydrodynamic characteristics and flow distribution in two cross-corrugated channels numerically and experimentally the experimental results of pressure drop are 20% higher than the predictions by CFD. The distribution of the fluid from the inlet port into two channels is not uniform by the CFD simulation. The flow rate of the first channel is higher than that of the second channel about 1% in the range of study [10].

III. METHODOLOGY AND PROBLEM FORMULATION

Flow channel is the conduit formed by two adjacent plates between the gaskets. Despite the complex flow area created by Chevron plates, the mean flow channel gap *b*, can be identified as

$$b = p - t$$

Where *p* is the plate pitch or the outside depth of the corrugated plate and *t* is the plate thickness, *b* is also the thickness of a fully compressed gasket, as the plate corrugations are in metallic contact. Plate pitch should not be confused with the corrugation pitch. Mean flow channel gap *b* is required for calculation of the mass velocity and Reynolds number and is therefore a very important value that is usually not specified by the manufacturer.

If not known or for existing units, the plate pitch can be determined from the compressed plate pack (between the head plates), L_c which is usually specified on drawings. Then *p* is determined as:

$$p = \frac{L_c}{N_t}$$

Where N_t is the total number of plates.

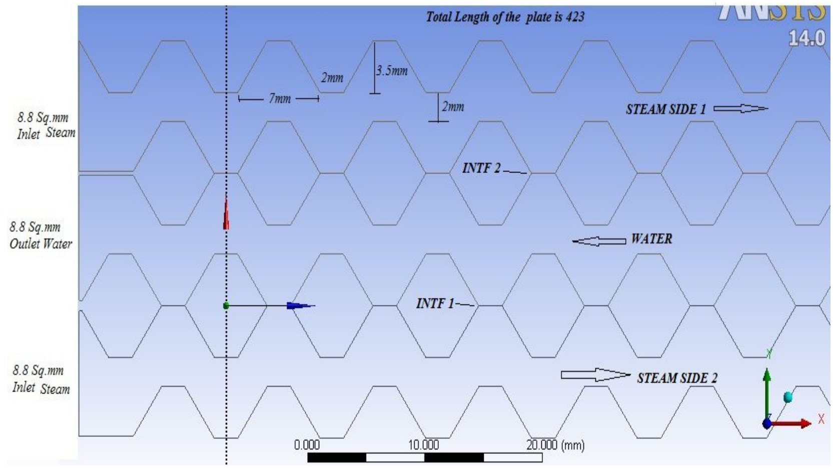


Figure 1: Geometry detail and interface definition

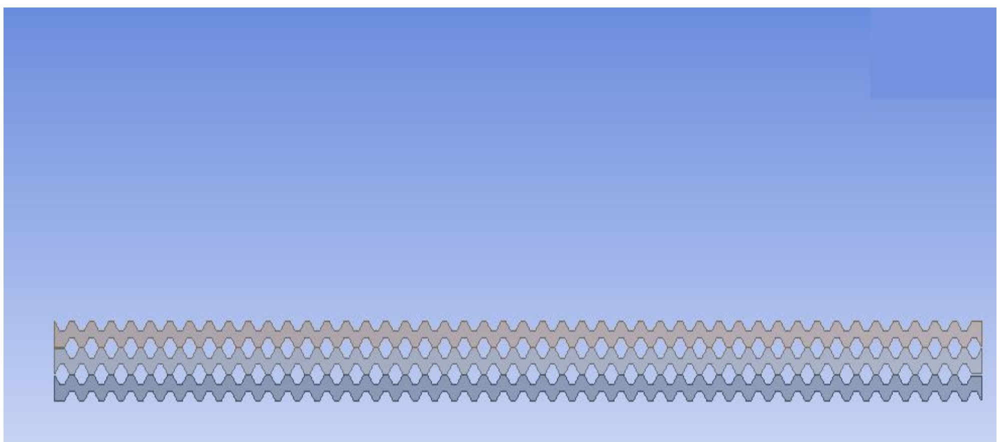
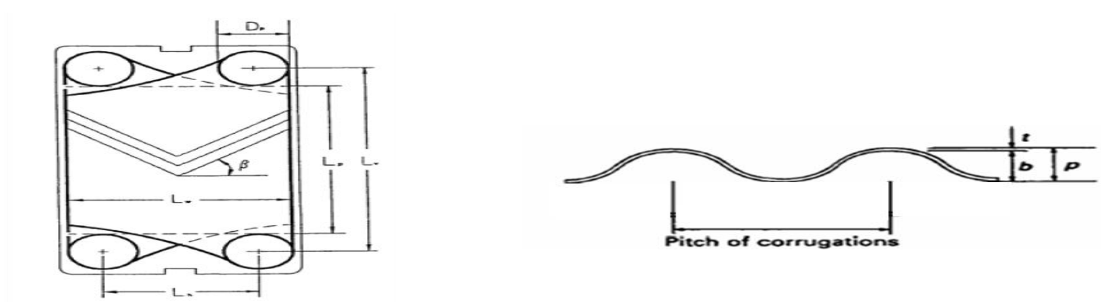


Figure 2: Model of the Corrugated Plate



(a) (b)

Figure 3: (a) Plate Geometry (b) corrugation geometry

IV. CHANNEL FLOW AREA

One channel flow area is given by A_x:

$$A_x = bL_w$$

Where L_w is the effective plate width.

The channel equivalent diameter D_e is given by:

$$D_e = \frac{4(channel\ Flow\ Area)}{(wetted\ surface)} = \frac{4A_x}{P_w}$$

Where,

$$P_w = 2(b + \emptyset L_w)$$

Then,

$$D_e = \frac{4(bL_w)}{2(b+\emptyset L_w)}$$

V. HEAT TRANSFER COEFFICIENT

- With plate heat exchangers, heat transfer is enhanced.
- The heat transfer enhancement will strongly depend on the Chevron inclination angle b, relative to flow direction,
- Both the heat transfer and the friction factor increase with b.
- On the other hand, the performance of a Chevron plate will also depend upon the surface enlargement factor f, corrugation profile, gap b.
- In spite of extensive research on plate heat exchangers, generalized correlations for heat transfer and friction factor are not available.

VI. FLOW REYNOLDS NUMBERS

- The transition to turbulence occurs at low Reynolds numbers and, as a result, the gasketed-plate heat exchangers give high heat transfer coefficients.

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- The Reynolds number, Re, based on channel mass velocity and the equivalent diameter, D_e , of the channel is defined as:
-

$$Re = \frac{G_e D_e}{\mu}$$

$$G_e = \frac{m\dot{m}}{N_{cp} b L_w}$$

Where N_{cp} is the number of channel per pass and is obtained from ,

$$N_{cp} = \frac{N_t - 1}{2N_p}$$

Where N_T is the total number of plates and N_p is the number of passes.

For Re ≤ 400

$$Nu = \frac{2hb}{k} = 0.44\left(\frac{\beta}{30}\right)^{0.38} Re^{0.5} Pr^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$f = \left(\frac{\beta}{30}\right)^{0.83}\left(\left(\frac{30.2}{Re}\right)^{5} + \left(\frac{6.28}{Re^{0.5}}\right)^{5}\right)^{0.2}$$

Table no1.- Boundary Conditions for Corrugated Plate

Mass Flow Rate (Lt/hr)	20	40	60	80
Water inlet temperature(K)	294	294	294	294
Steam inlet Temperature (K)	326	326	326	326
Steam inlet Velocity(m/sec)	0.6	1.2	1.8	2.5
Water inlet Velocity (m/sec)	5.292874	10.58575	15.87862	22.05364
Steam Inlet	0.00294373	0.00588746	0.00883119	0.01226554

Water outlet Pressure & Temperature	P=0,T=300K	P=0,T=300K	P=0,T=300K	P=0,T=300K
Steam outlet Pressure & Temperature	P=0,T=300K	P=0,T=300K	P=0,T=300K	P=0,T=300K
Density of water	998	998	998	998
Density of steam	0.5542	0.5542	0.5542	0.5542
Steam to Water side Heat flux		-12620 (-ve flux represent cooling of the system)		
Heat Transfer Coefficient		680 [Reference Data Book]		

VII. RESULTS

1. Pressure drop under different flow rates

Analysis is based on back pressure and mass flow rate Outlet pressure is set to zero (static) in boundary conditions with the flow the pressure head is converted into kinetic energy and hence pressure drop is been considering during the flow through channels .

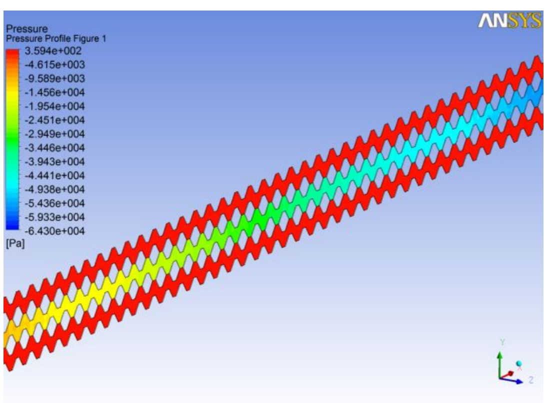


Figure 4: Pressure drop at 20L/hr

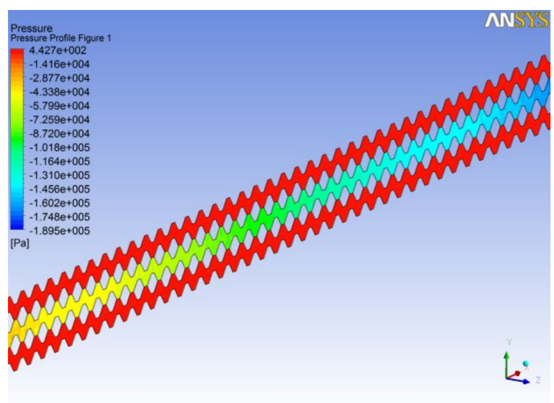
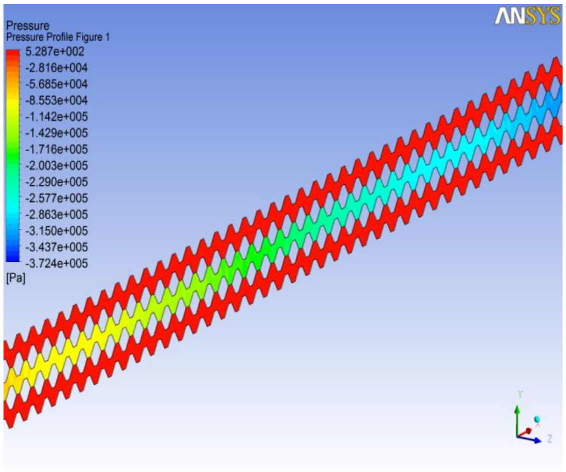


Figure 5: Pressure drop at 40L/hr



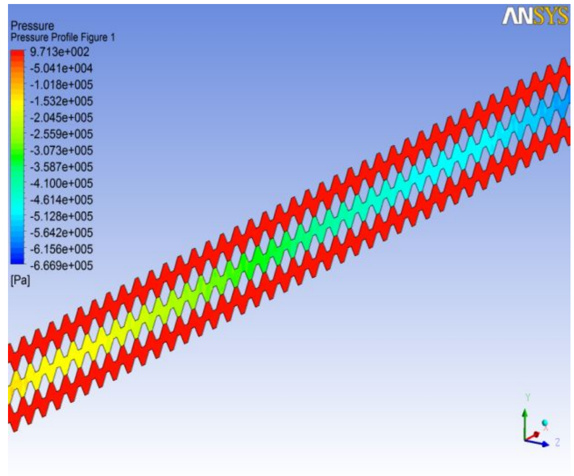


Figure 6: Pressure drop at 60L/hr

Figure 7: Pressure drop at 80L/hr

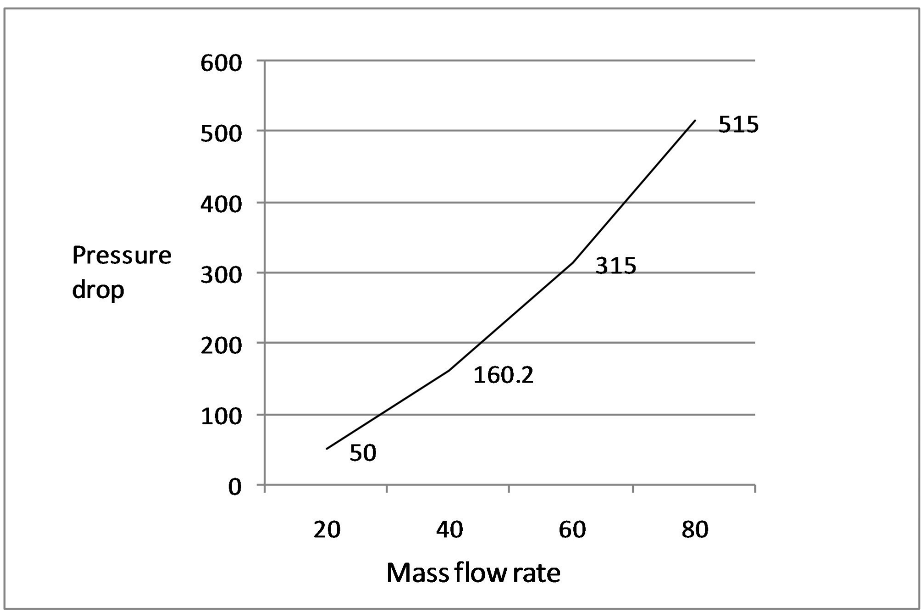


Figure 8: Variation of Pressure drop with respect to mass flow rate

Observation

At low mass flow rate [20 L/hr.] corrugate plates shows the less pressure drop , it is around 50kPa through the flow direction, which is increases for the higher mass flow rate [80L/hr] where we observe the pressure drop is around 515kPa.

2: Temperature distribution under different flow rates

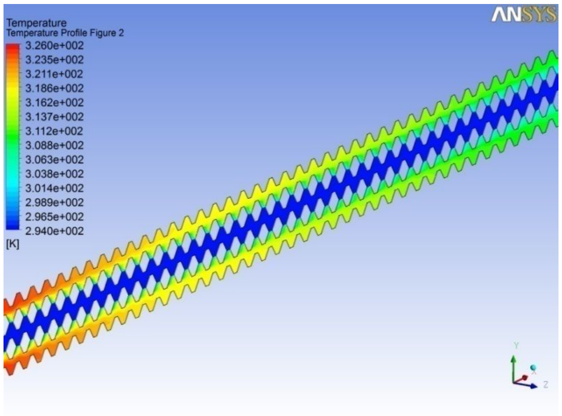


Figure 9: Temperature Contour on XY Plane for 20 L/hr

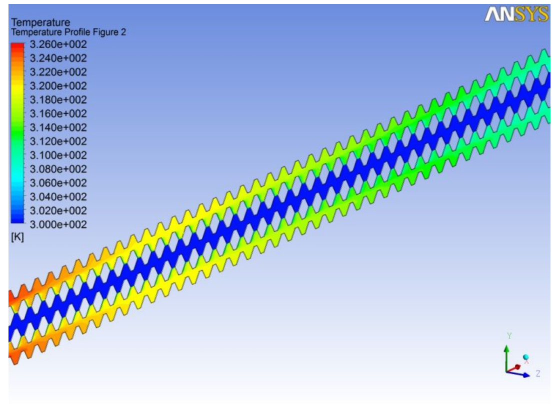


Figure 10: Temperature Contour on XY Plane for 40 L/hr

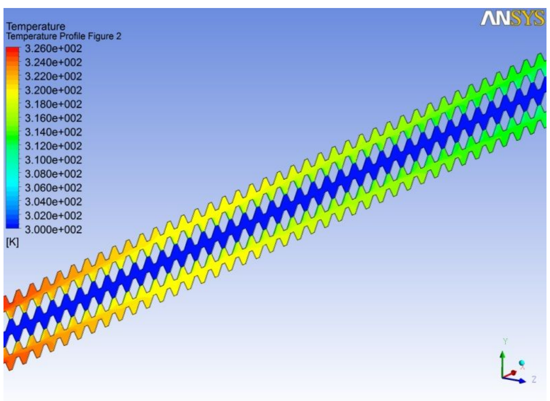


Figure 11: Temperature Contour on XY Plane for 60 L/hr

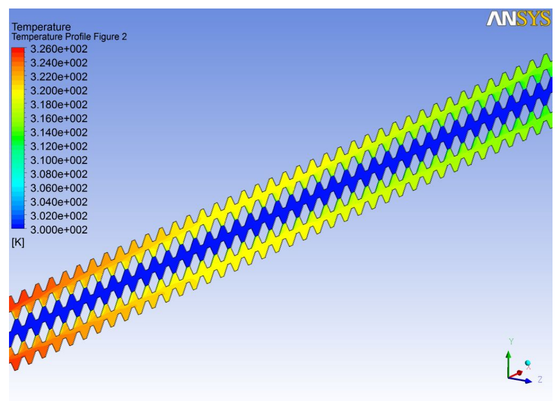


Figure 12: Temperature Contour on XY Plane for 80 L/hr

Observation

At low mass flow rate [20 L/hr.] corrugate plates shows the less heat transfer from the plate, it is around 295.5 Kelvin, through the flow direction, which is increases for the higher mass flow rate [80L/hr] where we observe the higher heat transfer coefficient and higher temperature at exit around 298.5 K.

Table no. 2

Mass Flow Rate	Water Outlet Temperature

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20L/hr	295.5228 K
40L/hr	296.7821 K
60L/hr	297.7379 K
80L/hr	298.5387 K

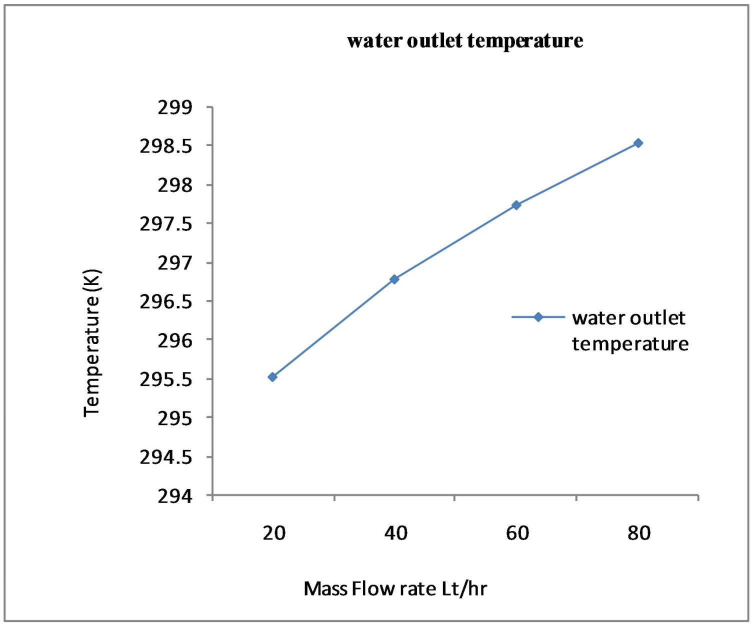
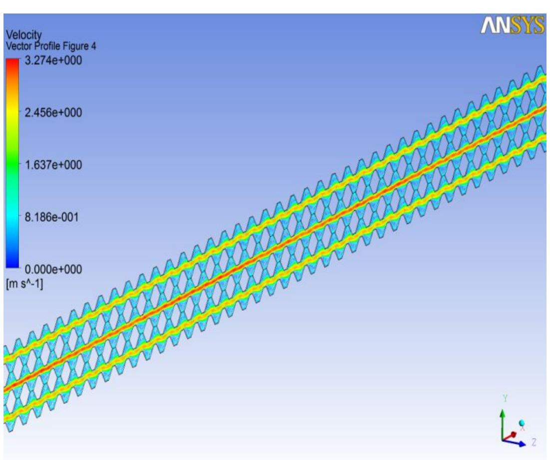


Figure 13: water outlet temperature at different flow rate

3: Velocity distribution under different flow rates



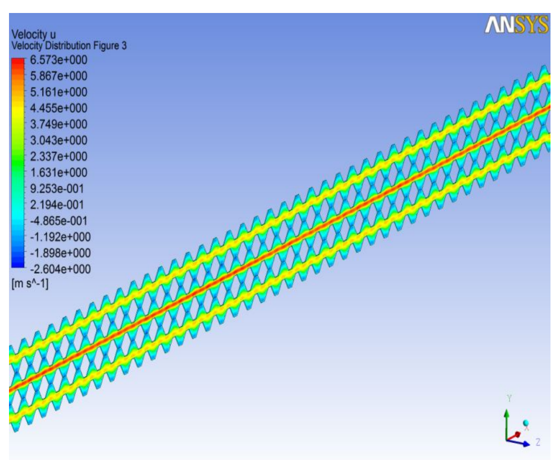
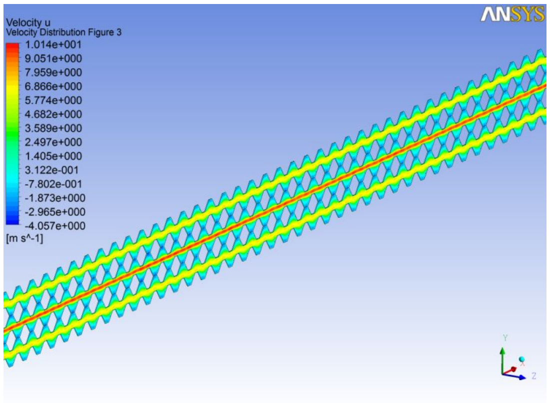


Figure 14: Velocity Contour on XY Plane for 20 L/hr **Figure 15: Velocity Contour on XY Plane for 40L/hr**



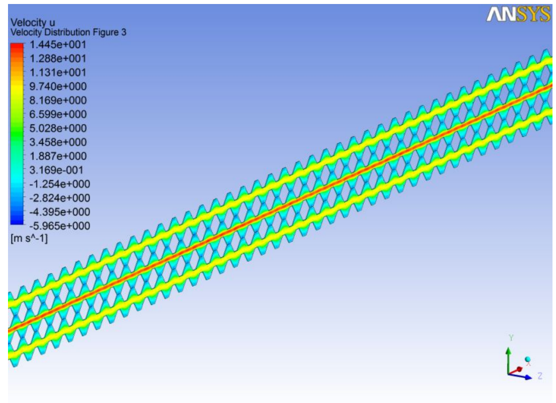


Figure 16: Velocity Contour on XY Plane for 60L/hr **Figure 17: Velocity Contour on XY Plane for 80L/hr**

Observation

Velocity increases as the mass flow rate of the steam and water increases; resultant is Nusselt number and heat transfer coefficient increases.

4. Velocity curve on the length of the plate

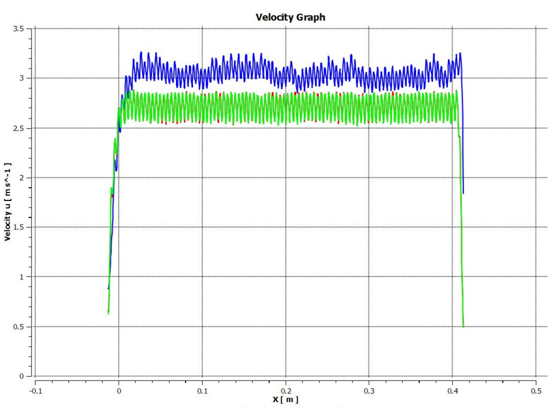


Figure 18: Velocity profile at 20L/hr

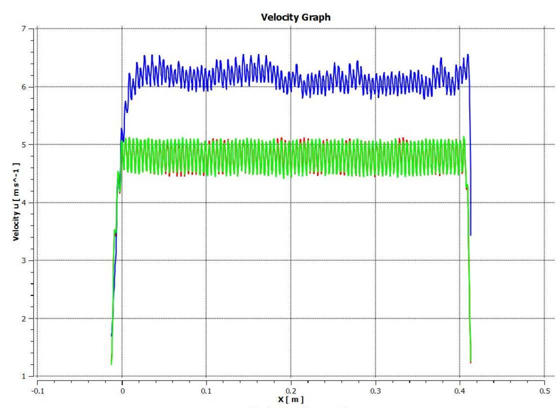


Figure 19: Velocity profile at 40L/hr

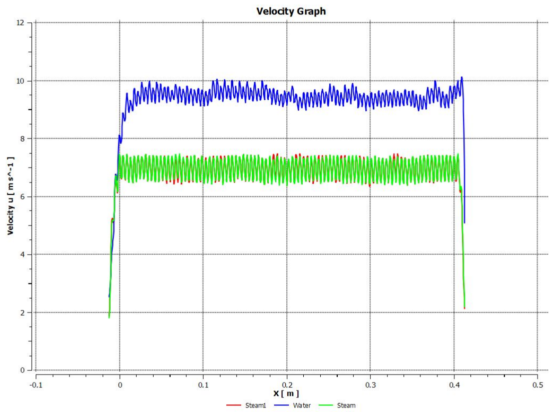


Figure 20: Velocity profile at 60L/hr

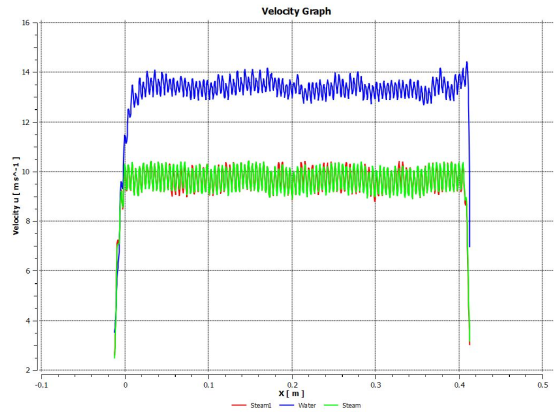


Figure 21: Velocity profile at 80L/hr

Observation

The fluctuation of velocity vector across the section is observed due to irregularity of the geometry of corrugated plate heat exchanger.

VIII. CONCLUSION

The corrugated chevron PHE, which is used in a wide range of industrial applications, was simulated, and the 2D-dimensional temperature, pressure and velocity fields were obtained through numerical simulation [CFD]. From the temperature field, we can see that the temperature gradient is very small in the inlet or outlet terminals. When the fluid enters the first zone, the degree of fluid turbulence is increased and heat transfer is enhanced. In central zone of the flow, the temperature gradient again becomes smaller. As the fluid continues downstream, the temperature gradient also begins to increase when the temperature differences become larger. The highest temperature appears around the upper terminal whereas the lowest temperature appears in the cold fluid inflow around the lower side, temperature gradient is larger, and effect of heat transfer is more acceptable. From the pressure field, we can see fluid pressure gradually reduced along the flow direction. In the diversion zone, the change of the fluid pressure gradient is less significant than that of the first zone. When the fluid enters the first zone, the change of the fluid pressure is more homogeneous. From the flow field, no matter the fluid inflows or outflows the port, there is a marked “dead zone” departed from the corrugated side of the port where the fluid flow rate is very small, even not to contribute in the basic flow, and the temperature maintained at inlet temperature. In adding together, the fluid also flows the side of the port and appears a minor's “uneven distribution” observable fact, but in the first zone it is improved. This non-uniform distribution phenomenon of the fluid is a main factor which affects the performance of PHE, which can be weakened by rolling guide area in the corrugated board. From analysis, it is known that there are a large number of contact points in chevron corrugated PHE. When the fluid flows through the contact points, the size of the speed and direction will change dramatically. In addition, it is found that the experimental results have a good conformity with the simulated ones, which indicates the CFD is an efficient way for the PHE design optimization.

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