EXPERIMENTAL INVESTIGATION AND HEAT TRANSFER ANALYSIS OF A DIMPLE TUBE AND CORRUGATED TUBE BY NATURAL CONVECTION

Sarvesh Kumar Rupa Sinha[1], Dr. Santosh Wankhede[2], Rajesh Kumar[1]

[1]Department of Mechanical Engineering, Alamuri Ratnamala Institute of Engineering and Technology, Shahapur
[2]Department of Mechanical Engineering, Yadavrao Tasgaonkar Institute of Engineering and Technology, Karjat

---***---

Abstract- Heat transfer enhancement of dimple, corrugated and plain tube is done in this study. Here, voltage is varying from 60-100 v. There is wide increase in heat transfer from corrugated tube after 80 Volts. Hence, we have high heat transfer in the corrugated tube at higher voltages. Also, I use dimple tube in this study and I try to find out the heat transfer coefficient of dimple tube and corrugated tube and plane tube. I use natural convection set up for this study and I find out Corrugated tube shows good results as compared to other tubes.

Keywords: Heat Transfer Analysis, Corrugated Tube Heat Exchanger, Dimple Tube

1.INTRODUCTION

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients, which is the heat transfer mechanism called as free or natural convection. Natural convection is the principal mode of heat transfer from pipes, refrigerating coils, hot radiators etc. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. contrast to the forced convection, natural convection phenomenon is due to the temperature difference between the surface and the fluid is not created by any external agency. Natural convection flow pattern for some commonly observed situations is given in Figure 1.as a fuel. Energy and exergy analysis of the engine is done and exhaust analysis is also done in this study.

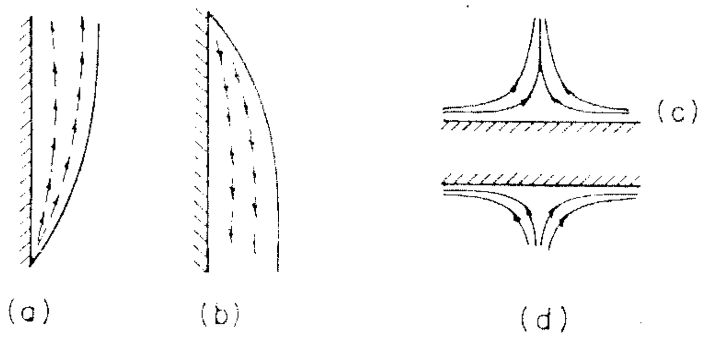


Figure 1. Natural convection flow patterns

1) Heated vertical plate

2) Cooled vertical plate

3) Upper surface of a heated horizontal plate

4) Lower surface of a heated horizontal plate

Convection is the transfer of heat energy through a material by the bodily movement of particles and will occur in fluids (liquids and gases).Convection arises when a fluid is warmed, and thus expanded. The expanded fluid is less dense and therefore rises and is replaced by cooler fluid, which then undergoes the same process. This is called convection current. Convection can be natural or forced. Natural convection is when the fluid movement is caused by the fluid itself, whilst forced convection uses external means (such as a fan) to drive the fluid movement Convection can be natural or forced. Natural convection is when the fluid movement is caused by the fluid itself, whilst forced convection uses external means (such as a fan) to drive the fluid movement.

The rate of heat transfer due to convection is given by; Q = h A(TS - Tα)

Where; h is the convective heat transfer coefficient, in W/m^2K;

A is the surface area, in m^2;

TS is the surface temperature, in K;

Tα is the fluid temperature, in K.

h will depend upon;

the relative velocity of the fluid;

the temperature difference between the surface and the environment; the direction of heat flow;

the surface size and orientation;

the fluid properties (density, viscosity, heat capacity etc); Surface roughness.

Where; R_{conv} is the thermal resistance of convection, in m^2K/W.

Therefore; $Q = (T_S - T_\alpha)/ R_{conv}$

To lower the heat flow due to convective heat transfer you can reduce the area in contact with the fluid, or decrease the convective heat transfer coefficient.

Heat transfer is the area that deals with the mechanism responsible for transferring energy from one place to another when a temperature difference exists. Natural convection is one of the most economical and practical methods of cooling and heating. Natural convection is caused by temperature or concentration induced density gradient within the fluid. Natural convection flow occurs because of influence of gravity forces on fluids in which density gradients have been thermally established.

In the study of heat transfer, both equilibrium and non-equilibrium processes are encountered. The science of heat transfer allows us to determine the time rate of energy transfer caused by the more practical non-equilibrium processes. With the growing sophistication in technology and with the increasing concern with energy and the environment, the study of heat transfer has, over the past several years, been related to a very wide variety of problems, each with its own demands of precision and elaboration in the understanding of the particular processes of interest. Areas of study range from Atmospheric, geophysical and environmental problems to those in heat rejection, space research and manufacturing systems.

2. LITERATURE REVIEW

2.1 General Literature Review about natural convection.

The correlations are based on the Rayleigh number

$$R_a = Gr_l Pr = \frac{g\beta(T_s - T_\infty) \times L^3}{\vartheta\alpha}$$

The fluid properties are evaluated at the film temperature.

An empirical correlation that may be applied over the entire range of RaL is of the form

$$NuL = \{0.825 + \frac{0.387\ Ra_L^{\frac{1}{6}}}{[1 + (0.498/\mathrm{Pr}\ )^{\frac{9}{16}}]^{\frac{4}{9}}}\}$$

2. 2 Iso thermal vertical plates, Inclined and horizontal plates & The long horizontal cylinder

For laminar flow slightly better accuracy may be obtained by using the following empirical correlation

$$NuL = \{0.68 + \frac{0.67\ Ra_L^{\frac{1}{4}}}{[1 + (0.498/\mathrm{Pr}\ )^{\frac{9}{16}}]^{\frac{4}{9}}}\}$$

This geometry has been studied extensively and Incropera has a reference to a review. A correlation for a wide Rayleigh number range of an iso-thermal cylinder is given by

$$NuL = \{0.36 + \frac{0.518\, Ra_L^{\frac{1}{4}}}{[1 + (0.559/\mathrm{Pr}\,)^{\frac{9}{16}}]^{\frac{4}{9}}}\}$$

$$NuL = \{0.60 + \frac{0.387\, Ra_L^{\frac{1}{6}}}{[1 + (0.559/\mathrm{Pr}\,)^{\frac{9}{16}}]^{\frac{8}{27}}}\}$$

The local Nusselt number is influenced by boundary layer development. The decay of local Nusselt number would be disrupted at Rayleigh numbers sufficiently large to permit transition to turbulence within the boundary layer.The pioneering work on the problem of natural convection in vertical parallel plate is traced back by W. Elenbass [2] (1942) who analysed the laminar natural convection heat transfer in a smooth parallel plate vertical channels without internal bodies & a detailed study of the thermal characteristics of cooling by natural convection was reported. Followed by many experimental, theoretical & numerical investigations for both laminar & turbulent flow regimes. I.H.Toruka [3] performed experimental study free convection from a cylinder array arranged in a vertical line between parallel walls. Empirical formulas were proposed to predict the average heat transfer coefficient. Y.Shen, P.Tong[4][1998], explained light scattering experiment of turbulent convection in water is carried out in a convection cell with rough upper and lower surfaces. The vertical heat flux is found to be increased by ,20% when the Rayleigh number becomes larger than a transition value. .B. Du[5](1998), performed novel convection experiment is in a cell with rough upper and lower surfaces. The heat transport across the rough cell is found to be increased by more than 76%. Flow visualization and near wall temperature measurements reveal new dynamics for the emission of thermal plumes. N.Onur and M.K.Akta[6] performed study on natural convection between inclined plates. The plate inclinations were chosen to be 0^0,30^0,45^0 and measured with respect to vertical position. Hot plate is facing downwards and heated isothermally. The lower plate is insulated and unheated. Ademola A. Dare and Moses O. Petinrin[7](2010) explained diffusion velocity method (DVM), a version of vortex element method(VEM), was used to model the steady state, laminar natural convection flows along isothermal vertical plates and in isothermal vertical channels. A.M.Clausing Professor, Mem. ASME[8](1989),his investigation on natural convection from a heated, upward facing, square, horizontal to surrounding gas medium is described. S.M.Guo,C.C.Lai[9](2000) studied influence of surface roughness on heat transfer coefficient and cooling effectiveness for a fully film cooled three dimensional nozzle guide vane(NGV) has been measured in a transonic annular cascade using wide band liquid crystal and direct heat flux gases(DHFG). Rossano Comunelo[10](2005),his work deals with heat transfer coefficient ―h‖ of a isothermal vertical plate with H = 0.15 m. The neighborhood surfaces influence in that coefficient is aimed with simulation and standard experimentation. A novel technology to measure the heat flux, caling ―Tangential Heat Flux meter‖ is applied and simulation with a CFD commercial code was performing. J.W. Zhou , Y.G. Wang [11](2008) studies that determine the influence of unsteadiness on flat plate impinging jet heat transfer implicitly assume that the effect of unsteadiness found on smooth impingement surfaces also holds on surfaces with certain obstacles on them. P.Kandaswamy, J. Lee, A.K.Abdul Hakeem [12](2007) studies Natural convection heat transfer in a square cavity induced by heated plate numerically. A.A.Walunj, D.D.Palande [13]((2014) studies Steady state natural convection from heat sink with narrow plate-fins having parallel arrangement mounted on inclined base was experimentally investigated.

3. MATERIALS AND METHODS

From the early research work and literature survey it is clear that, there is establishment of tubes with modifications for lengthwise. There is rectangular enclosure for entry of air in case of natural convection. The air coming inwards gets heated as it moves towards the end of the tube, as well as it rises due to decrease in density. This thing is checked for other tubes like dimple and corrugated. With this view point, it is proposed to investigate the following types of tubes configurations which are shown in Fig. 3.1 (a) Dimple (b) Corrugated (c) Plane. Following methodology is decided to investigate thoroughly the possibility of optimization of tube surface.

- Modification of the tubes shapes for maximum heat transfer enhancement.
- Evaluating performance of such different types of tubes.
- Comparison with the plane and other shapes of tubes.

- Study of flow patterns for dimple shapes tube.

Proposal of optimum shape of tube for the given range of base heat flux, based on numerical results and experimental validation of the same.

Fig 3.1 Types of tubes

An experimental setup is designed and developed to carry out the heat transfer enhancement of dimple and corrugated tube. The details of the test set up are given below.

1. Enclosure- .Square pyramid
2. Tubes- a. Plain Cylindrical brass tube
    b. Corrugated brass tube
    c. Brass tube with Dimples
3. Cartridge heater
4. Thermocouples
5. Ammeter
6. Voltmeter
7. Dimmerstat
8. Temperature indicator
9. Toggle switches
10. Stand

These all are the components of the test set up. The line diagram of the test set up is shown in fig. 3.2.

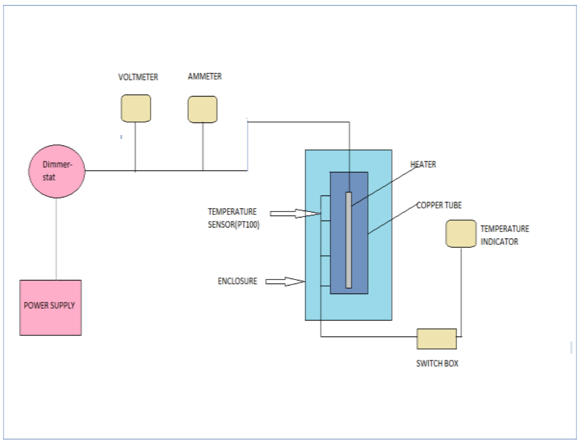


Fig 3.2 Schematic of experimental set up

4. EXPERIMENTATION

4.1 Experimental Assumptions

The experimental analysis is based on following assumptions

1. The temperature on steady state readings at any point does not vary with time.
2. The material is homogeneous throughout and neglect losses.
3. The temperature of the air is uniform.
4. The average temperatures of tube after achieving steady state are used for calculating experimental results.

4.2 Experimental Procedure

1. Put ON the supply and adjust the dimmerstat to obtain the required heat input - (Say 60W, 80 W, 100 W etc.)
2. Wait till the steady state is reached, which is confirmed from temperature readings- (T1 to T4).
3. Measure surface temperature at the various points i .e. T1 to T4.
4. Note the ambient temperature i. e. Ta .
5. Repeat the experiment at different heat inputs **(Do not exceed 150W).**

4.3 Observations

1. O.D. Cylinder = 38 mm.
2. Length of Cylinder = 400 mm.
3. Input to heater = V x I Watts.

1. For plane tube**:**

Table 4.1 Observation Table for plain tube

SR.NO	Volt	Amp	Temperature °C				
			T1	T2	T3	T4	Ta
1	60	0.621	85.3	84.7	79.5	73.6	23.1
2	80	0.834	114.7	117.2	102	90.4	24.7
3	100	1.045	149.3	144.4	124.7	104.5	25.3

SR.NO	Volt	Amp	Temperature °C

			T1	T2	T3	T4	Ta
2	60	0.628	81.8	78.1	75.1	71.8	23
3	80	0.892	87.9	84.8	83.9	82.1	24.9
4	100	1.094	113.8	105.9	94.3	71.3	25.8

2. For corrugated tube

Table 4.2 Observation Table for corrugated tube

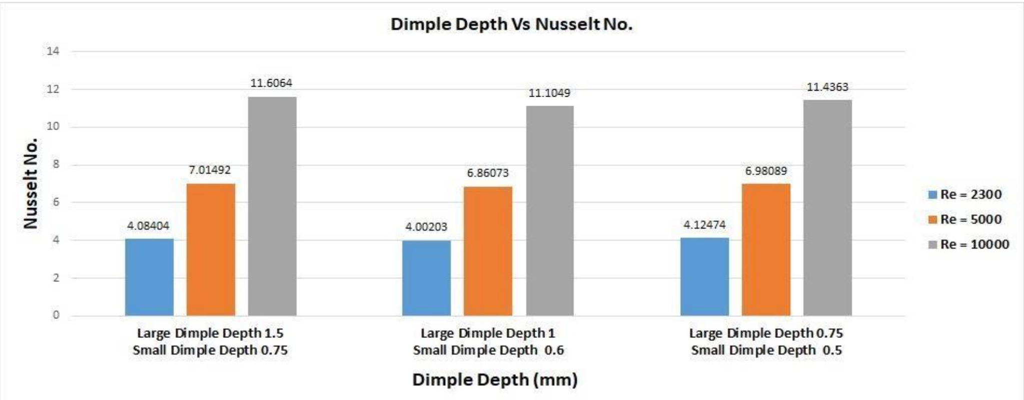
3. For Tubes with dimples:

Table 4.3 Observation Table for dimple tube

SR.NO	Volt	Amp	Temperature °C				
			T1	T2	T3	T4	Ta
1	60	0.632	76	73.8	71.5	64.9	23
2	80	0.845	105.2	95.1	91.78	98.35	25
3	100	1.061	124.9	129.3	117.8	115.1	26

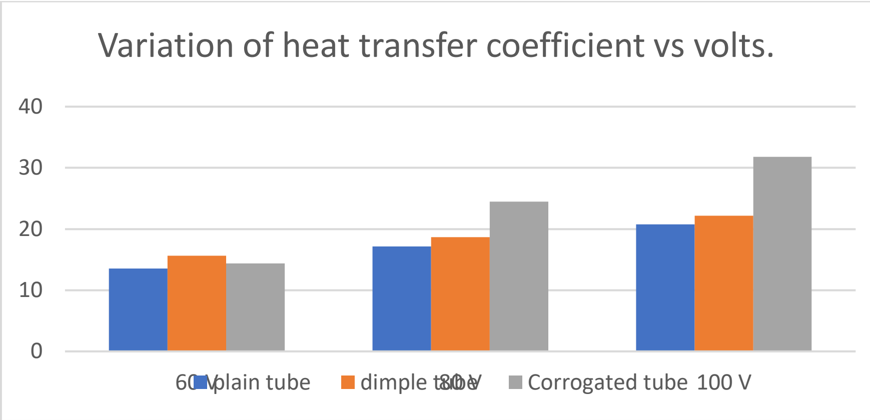
5. RESULTS AND DISCUSSION

To provide further insights into the evolution of the flow pattern, a succession of vector diagram was presented. The results of the vector diagram are shown in above figures. As we have developed protrusions on surface, we can clearly observe increase in amount of heat transfer. As flow increases there is enhancement in heat transfer due to presence of larger depth dimples. As, we can clearly observe that at the ends the red arrows quantity gets decreased and orange arrow quantity increased. With the continuous increase in Reynolds number recirculation increases more and more. At the highest Reynolds number, the inertial losses are dominant.

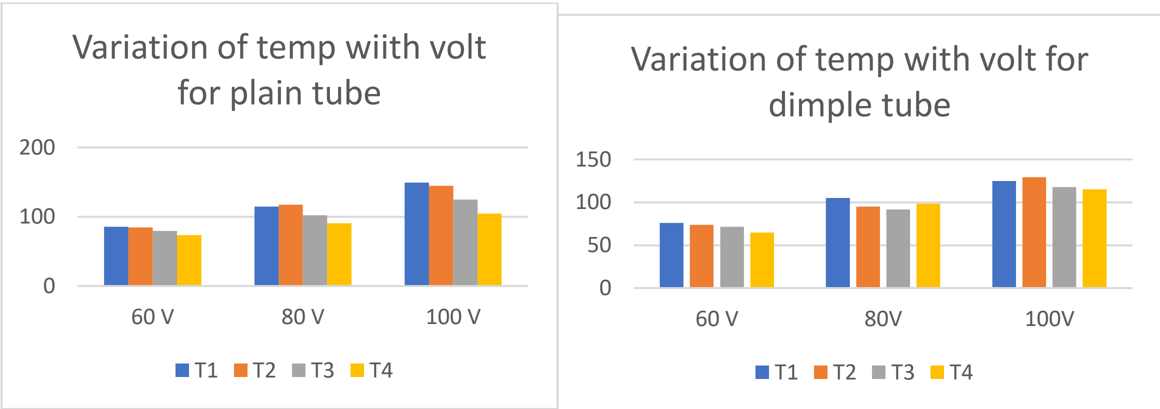


Graph 5.1 Dimple depth vs Nusselt no

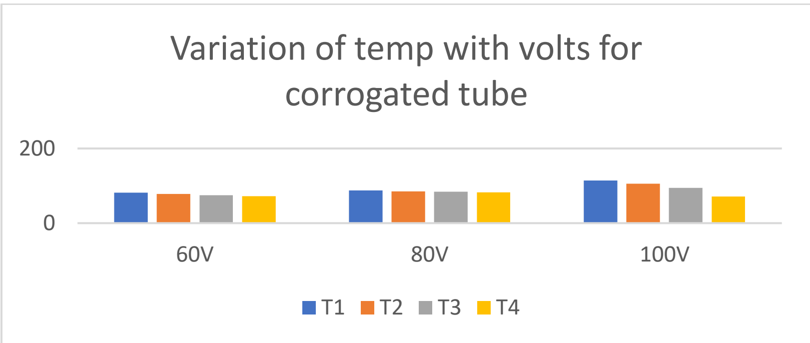
It is evident from above result that heat transfer coefficient for corrugated tube is highest.As we go on increasing the voltage the heat transfer rate goes on increasing but there is wide increase in heat transfer in corrugated tube after 80 volts.so hence we can have high heat transfer if we use corrugated tube and at higher voltages.From graph 5.2 it is observed that as the voltage increases the temperature is also increases and it is higher for corrugated tube at 100 V.



Graph 5.2 Variation of heat transfer coefficient vs volts.



Graph 5.3 Variation of temperature with volts for plain tube and dimple tube



Graph 5.4 Variation of temperature with volt for corrugated tube

6. CONCLUSION

The Heat transfer enhancement of dimple tube, corrugated tube and plain tube is done in this done. Here, voltage is varying from 60 V to 100 V. It is seen that as the voltage increases the heat transfer is also increases. From the experiment outcomes we can conclude that the heat transfer is more from the corrugated tube as compared to others tube, this is because of the material property and small reduction in area as compared to dimple tube. It is seen that there is wide increase in heat transfer from corrugated tube after 80 Volts. Hence, we have high heat transfer in the corrugated tube at higher voltage.

REFERENCES

1. Tribus, M. and J. Klein., “Heat Transfer Symposium”, University of Michigan Press, pp. 211, 1953.
2. Cess R. D., “Applied scientific research”, vol.10 (1), pp 430-438, 1961.
3. Szewczyk, A. A., “J. Heat Transfer”, 86(4), 501-507, 1964.
4. Whitaker, S., “AIChE Journal”, vol.18 (2), 1972.
5. Shah, R. K., and London, A. L., “Academic Press”, San Diego, CA. 1978.
6. Cooper, P.I. Sheridan, J.C. and Flood, G.J., “Int. J. of Heat and Fluid Flow”, Vol.7 (1), pp61-68, 1986.
7. Copeland, D., “Synopsis report”, Sumitomo precision products, Dec-1998.
8. Kim, S. J., and Kim, D., Journal of heat transfer, vol.121, pp.639-645, 1999.
9. Cheng, W., T, and Lin. H.T., “International Journal of Heat and Mass Transfer”, 01,2002.
10. Sartori, E., Solar Energy, Vol.80 (9), pp-1063–1071, 2006.
11. Abreu, C.R.A., Alfradique, M.F., and Telles, A. S., Chemical Engineering Science, Vol. 61(13), pp. 4282–4289, 2006.
12. Yao, L.S., and Molla, M., “International Journal of Heat and Mass Transfer”, Vol.51 (21– 22), pp. 5154–5159, 2008.
13. Seyyedi, S.M., Bararnia, H., Ganji, D.D., Gorji-Bandpy, M. and Soleimani, S., “Int. J Thermal Sciences”, Vol. 61, pp 1–14, 2012.
14. Pantokratoras, A., “Journal of Mechanical Science and Technology”, 28 (5), pp.1909-1915, 2014.
15. L.A. Asmantas, M.A. Nemira, V.V. Trilikauskas, Coefficients of heat transfer and hydraulic drag of a twisted oval tube, Heat Tran Sov Res 17 (1985) 103–109.
16. L. Yang, Z.X. Li, Numerical analysis of laminar flow and heat transfer in twisted elliptic tubes, Eng Mech 20 (2003) 143–148.
17. Patil, P. and Deshmukh, P., 2014. Numerical study of flow and heat transfer in circular tube with almond shape dimple. International Journal of Engineering and Research, 3(8), pp.21-29.
18. Huang, Z., Yu, G.L., Li, Z.Y. and Tao, W.Q., 2015. Numerical study on heat transfer enhancement in a receiver tube of parabolic trough solar collector with dimples, protrusions and helical fins. Energy Procedia, 69, pp.1306-1316.
19. Wang, Y., He, Y.L., Li, R. and Lei, Y.G., 2009. Heat transfer and friction characteristics for turbulent flow of dimpled tubes. Chemical Engineering & Technology: Industrial Chemistry- Plant Equipment- Process Engineering- Biotechnology, 32(6), pp.956-963.
20. Rao, Y., Li, B. and Feng, Y., 2015. Heat transfer of turbulent flow over surfaces with spherical dimples and teardrop dimples. Experimental Thermal and Fluid Science, 61, pp.201-209.
21. Cheraghi, M. H., Ameri, M., & Shahabadi, M. (2020). Numerical study on the heat transfer enhancement and pressure drop inside deep dimpled tubes. International Journal of Heat and Mass Transfer, 147, 118845.
22. Albanesi, A.W., Daish, K.D., Dally, B. and Chin, R.C., 2018, December. Investigation of heat transfer enhancement in dimpled pipe flows. In 21st Australasian Fluid Mechanics Conference, Adelaide, Australia.
23. Wang, Y., He, Y.L., Lei, Y.G. and Zhang, J., 2010. Heat transfer and hydrodynamics analysis of a novel dimpled tube. Experimental thermal and fluid science, 34(8), pp.1273-1281.
24. Yadav, R.K. and Jain, V.N., 2016. Thermal Analysis of Heat Exchanger with the Help of Taguchi Method. International Journal of Advanced Research in Engineering and Technology, 7(1), pp.01-06.
25. Li, P., Xie, Y. and Zhang, D., 2016. Laminar flow and forced convective heat transfer of shear-thinning power-law fluids in dimpled and protruded microchannels. International Journal of Heat and Mass Transfer, 99, pp.372-382.
26. Ji, W.T., Fan, J.F., Zhao, C.Y. and Tao, W.Q., 2019. A revised performance evaluation method for energy saving effectiveness of heat transfer enhancement techniques. International Journal of Heat and Mass Transfer, 138, pp.1142-1153.
27. Kim, K.Y. and Choi, J.Y., 2005. Shape optimization of a dimpled channel to enhance turbulent heat transfer. Numerical Heat Transfer, Part A: Applications, 48(9), pp.901-915.
28. Mahmood, G.I. and Ligrani, P.M., 2002. Heat transfer in a dimpled channel: combined influences of aspect ratio, temperature ratio, Reynolds number, and flow structure. International Journal of Heat and mass transfer, 45(10), pp.2011-2020.
29. Liang, Z., Xie, S., Zhang, J., Zhang, L., Wang, Y. and Ding, H., 2019. Numerical investigation on plastic forming for heat transfer tube consisting of both dimples and protrusions. The International Journal of Advanced Manufacturing Technology, 102(1-4), pp.775-790.
30. Maithani, R. and Kumar, A., 2019. Correlations development for Nusselt number and friction factor in a dimpled surface heat exchanger tube. Experimental Heat Transfer, pp.1-22.