Review article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

A Review on Recent Advances in Corrugated Plate Heat Exchangers

Kumar Pradeep[1]*, Gupta Vishal[2] and Kurmi Pradeep Kr.[2]

[1]*Dept. of Mech. Engineering, Radharaman Institute of Research and Technology, Bhopal, India
[2]Radharaman Engineering College (Polytechnic Wing), Bhopal, India.
E-mail: pradeepshaw05@gmail.com, vishalgupta.manit@gmail.com, pradeepkumarkurmi6@gmail.com

ABSTRACT

Heat exchangers are widely used in industries for recovering heat from exhaust fluids to the fluid to be used. This not only improves efficiency of the system rather leads to judicious use of energy. Recently there has been tremendous research in the design of heat exchangers. Corrugation in the heat exchanger increases turbulence in the working fluids leading to improved heat transfer rates. In the present research paper, recent research done for corrugated type heat exchangers has been presented.

KEYWORDS: Corrugated type heat exchanger, turbulence, heat transfer rate, thermal hydraulic characteristics

***Corresponding author**

Pradeep kumar*

M.Tech Scholar,

Department of Mechanical Engineering

Radharaman Institute of Research and Technology, Bhopal, India

E-mail Id: pradeepshaw05@gmail.com Mob: 7415441247

INTRODUCTION

A heat exchanger is defined as equipment which transfers the energy in form of heat from fluid to cold fluid. The efficiency of heat exchanger depends upon the inlet and outlet temperature of working fluids. The heat exchanger should be such that the heat transfer rate should be high and investment is least. Broadly there are two types of heat exchangers: Direct contact type heat exchanger and indirect contact type heat exchanger. Recently corrugated types of heat exchangers have come into picture. Their advantages include increased heat transfer, reduced servicing costs, compact design and minimal fouling. Because of these advantages, corrugated type heat exchangers are gaining popularity. A lot of research is being done in their design field.

REVIEW

Junqi et al.[1] (2018) has experimentally investigated the thermal hydraulic characteristics for three types of fluids (R245fa, glycol & water) on plate heat exchanger surface. To overall evaluate the enhanced heat transfer, concept of pump power is provided. Using multiple regression method, dimensionless correlation equation of Nusselt number & friction factor are given. It is concluded that the plate chevron angle affect thermal hydraulic performance. Heat transfer increases with increase in chevron angle & vice versa.

Goodarzi et al.[2] (2015) experimentally investigated the influence of different functional covalent groups on the thermal physical properties of carbon nanotubes – base fluid. Thermal properties such as convection heat transfer coefficient, Nusselt no., friction loss, pressure drop & pumping power were calculated for corrugated plate heat exchanger. Variation in Reynold’s no. was done & nano-fluids properties were measured experimentally.

Elmaaty et al.[3] developed a corrugated plate heat exchanger. The author has presented review related to plate heat exchanger and further on brazed corrugated plate heat exchanger the authors have been worked upon. The author have concluded that additional work & modelling are needed on visualisation, calculation & measurements of pressure drop and heat transfer using nano-fluids.

Hasanpour et al.[4] (2016) have experimentally studied a double pipe heat exchanger with inner tube corrugated filled with various categories of twisted tapes from conventional to modified types (perforated, V-cut and U-cut). The twist ratio, the hole diameter, the width and depth ratio of the cuts have been varied and the Reynolds number has been changed from 5000 to 15000. Overall more than 350 experiments were carried out. Nusselt number and friction factor for corrugated tube equipped with modified twist tapes are found out to be higher than typical tapes.

Han, Huai-Zhi et al.[5] (2015) developed a double type heat exchanger with inner corrugated tube. Dimensionless parameters corrugation pitch (p/D), corrugation height (H/D), corrugation radius (r/D) and Reynolds number (Re) have been considered for four design parameters. The authors have verified quadratic model for Nuc, fc, Nuc/Nus, fc/fs and h of double tube heat exchangers with inner corrugated tube using the analysis of ANOVA and the confirmation runs which can be used to predict the experimental value within the 98% accurate interval.

Han, Xiao-Hong et al.[6] (2010) have used chevron corrugated plate heat exchanger to obtain three dimensional parameters- temperature, pressure and velocity fields. It was seen that in the first zone, the temperature gradient increases gradually and got the maximum in the central of the flow, the temperature gradient became smaller again. The highest temperature appeared around the upper port, while the lowest temperature appeared in the cold fluid inflow around the lower port. From the flow field, a dead zone where the fluid flow rate is very low departed from corrugated side. The simulated results have been compared with the experimental values and it was found that results were consistent with those of pressure drop.

Kabeel, A. E et al.[7] (2013) have experimentally tested loop to study the PHE thermal characteristics, heat transfer coefficient, pressure drops etc at different concentrations of nanofluids. The measured heat transfer coefficient results have been compared with theoretical values. An increase in heat transfer coefficient up to 13%, for a nano-fluid concentration of 4% in laminar flow regime, at constant Re number with 9.8% uncertainity is observed. On using nano fluids, power being transmitted is enhanced. But effectiveness of plate heat exchanger decreases.

Kanaris, Athanasios et al.[8] (2006) used a general purpose CFD code to compute the characteristics of the flow field, and the heat transfer of conduits with corrugated walls. The plates were assumed to be of stainless steel of herringbone design. The code has been validated experimentally for counter current flow of water. It is concluded that CFD is an effective & reliable tool for designing of efficient plate heat exchangers.

Khan, T.S et al.[9] (2010) experimentally obtained heat transfer data for corrugated plate heat exchangers for single phase flow configurations. Experimental were carried out for Reynolds number ranging from 500 to 2500 and Prandtl number from 3.5 to 6.5. Chevron angle and Reynolds number had effect on heat transfer coefficient. Correlation between Nusselt number as a function of Reynolds number, Prandtl number and chevron angle has been proposed based on experimental data.

Aslan E et al.[10] (2018) numerically investigated the characteristics of convective heat transfer and friction factor for periodic corrugated channels. The authors used finite volume method (FVM) for three different Reynolds averaged numerical simulation (RANS) based turbulent models (K-ω, shear stress transport- SST model and the transition SST model). The results are compared with previous experimental result. The Reynolds number has been varied within the range of 2000 to 11000, while keeping the Prandtl number constant. Variation in dimensionless quantities such as Nusselt number, Colburn factor, friction factor and goodness factor with the Reynolds number is studied. The SST model is shows slightly better performance. It is conduced that the friction factor decreases with increasing minimum channel height. For the overall performance of turbulence model; the overall performance of the models are observed to be quite similar for all the turbulence models.

Sharif, asal et al.[11] (2018) used Computational Fluid Dynamics approach with the Reynolds stress model to investigated the influence of the apex angle on the thermal and hydraulic features of triangular cross-corrugated heat exchangers. The Reynolds number was varied from 310 to 2064. The numerical results varied by 5% than experimental results. On increasing the apex angle, pressure forces increase which lead to pressure drop along with heat exchanger coefficient. It is concluded that on increasing apex angle from 45^0 to 150^0, vorticity magnitude & pressure forces along the direction of flow increase which lead to higher heat transfer.

Khavin, G.[12] (2018) studied about the different height of corrugation for heat exchangers with a circular plate. For designing of such heat exchanger, use of plates with different corrugation heights along hot and cold side can prove to be very helpful. Due to this design, resistance to contamination increases.

Kondepudi & O'Neal[13] (1991) experimentally investigated fin tube heat exchanger for studying the effects of frost growth on thermal performance of fin tube heat exchangers with wavy and corrugated fins. More frost growth and higher pressure drops were found for higher air humidity & fin density. It was concluded that frost growth was a function of spacing as well as air humidity. The pressure drop was found to be function of frost growth & heat exchanger geometry. Heat exchangers with smaller fins due to reduction free flow area have higher pressure drop.

Sun M. & Zeng M.[14] (2018) performed experimental and numerical study to determine the heat transfer and pressure drop characteristics of corrugated tubes. Three kinds of corrugated tubes were considered for measurement and simulation. The numerical results are found to be in good agreement with experimental results. It was concluded that the corrugated tube have a good synergy than plain tubes and heat transfer performance is high.

Faizal M.& M.R. Ahmed[15] (2012) performed experiments on a corrugated plate heat exchanger for small temperature difference applications. Plates were arranged parallel on a single corrugation pattern. The spacing between the plates was varied to determine the configuration that gave the optimum heat transfer. Water was used as working fluid. The flow was kept parallel. The cold side flow rate and the inlet temperature of the hot and cold water were kept constant whereas hot water flow rates were varied. The optimum heat transfer between the two streams was obtained for the minimum spacing of 6mm. The pressure losses were found to increase with increasing flow rates. The overall heat transfer coefficient, the temperature difference between the two stream at outlet, and the thermal length have been also presented for varying hot water flow rates and spacing of plates.

Islamoglu Y. & A. Kurt[16] (2004) used artificial neural networks (ANNs) for heat transfer analysis in corrugated channel. Experiments were conducted for processing with the use of neural networks. Back propagation algorithm was used in training and testing the network and an algorithm using C++ has been developed to solve it. The results of ANN approach & experimental varied by about 4%.

Khairu et al.[17] (2014) used nano fluids to study the effect of water and CuO/water nano fluids on heat transfer coefficient, heat transfer rate, frictional losses, pressure drop, pumping power and exergy destruction in the corrugated plate heat exchanger. The heat transfer coefficient of CuO/water nanofluids increased by about 18.50% to 270.20% with the enhancement of nanoparticles volume concentration. Improved in heat transfer rate was observed where as exergy losses reduced. It was conduded that analytically it is revealed, CuO/water nanofluids reduces exergy destruction.

Min & et al.[18] (2009) reviewed use of heat exchanger into gas turbines. The authors discussed the work of other researches about the design of a heat exchanger matrix, material selection, manufacturing technology and optimization. A potential heat exchanger designs for an aero gas turbine recuperator, intercooler and cooling air cooler has been suggested based on previous research. It is included that primary surface heat exchanger have relatively larger effectiveness.

S.D. Pandey & V.K. Nema[19] (2012) experimentally found out the effects of nano fluid and water as coolant on heat transfer, frictional losses and exergy loss in a counter flow corrugated plate heat exchanger. The required properties of the nanofluid were found out. It was observed that the heat transfer characteristics varied with variation in Reynolds number, Peclet number and nano fluids concentration. It is found out that approximately 21% more heat can be transferred with 2 Vol% nanofluids as that of water for any combination of volume flow rates.

J.A. Stasiek[20] (1998) developed liquid crystal technique and applied it to study six element shapes of rotary air heat preheaters. A complete mapping of temperature, heat transfer coefficient and pressure drop has been obtained at every angle and Reynolds number. It is concluded that the presented corrugated-undulated geometry (CU) can be considered as a generalised of the crossed-corrugated geometry.

Tsai Ying-chi et al.[21] (2009) investigated the hydrodynamics characteristics and distribution of flow in two cross-corrugated channel of plates heat exchangers. The numerical results have been validated with experimental results obtained in laboratory. Pressure drop and flow distribution in two cross-corrugated channels of plate heat exchangers has been investigated. Unstructured tetrahedral mesh has been used for numerical simulation due to the complex geometry.

Vicente & et al.[22] (2004) studied corrugated tubes using experimental techniques to obtain their heat transfer and isothermal friction characteristics. Water and ethylene glycol were used as working fluids. 10 corrugated tube with rib height ranging from 0.02 to 0.06 & spiral pitch from 0.6 to 1.2 were manufactured using cold rolling. It is concluded that heat transfer increases with increase in Prandtl number. Also at low Reynolds number, tubes with height severity index are most advantageous ones.

Laohalertdecha S. & Wongwises S.[23] (2010) experimentally investigated the heat transfer coefficient and pressure drop of R-134a inside a horizontal smooth tube and corrugated tubes. The experiment has been done for three values of pitches to discuss their effect on the condensation heat transfer coefficient and pressure drop. It is found that the average heat transfer coefficient and pressure drop increase with increasing mass flux as well as average quality. The results of corrugated tubes have been compared with smooth pipe and it is concluded that 50% higher heat transfer coefficient ratio is found out for corrugated tubes.

Chang Y. J. & Wang C. C.[24] (1997) developed a generalised heat transfer correlation for louver fin geometry 91 samples louvered fin heat exchanger with different geometrical parameters, like louver angle, tube width, louver length, louver pitch, fin length and fin pitch. It is concluded that the inclusion of the plate and tube louver fin data in the heat transfer correlation results in a mean deviation of 8.21%.

Webb R.L.[25] (1981) has extended previous work of Bergles and Webb to establish a broad range of Performance Evaluation Criteria (PEC) applicable to single phase flow in tubes. Detailed procedure have been outlined to calculate the performance improvement and to select the 'optimum' surface geometry. PEC are presented for four design cases: (1) Reduced heat exchanger material; (2) increased heat duty; (3) reduced long mean temperature difference; and (4) reduced pumping power. The cases discussed included fixed flow area and flow area. Appropriate PEC for two phase exchangers area have been also discussed. It is concluded that modified PEC is applicable to heat exchangers having two-phase flow.

CONCLUSION

Corrugated type heat exchangers have high rate of heat transfer because of increased turbulence due to design factor. CFD is an efficient tool for prediction of efficiency of heat exchangers in design phase only. Various non-dimensional parameters can also be found out using CFD which is very difficult experimentally. Use of nano-fluids increases the efficiency of corrugated type of heat exchangers. Any change in the shape of corrugation leads to variation in the performance of heat exchangers.

REFERENCES

1. 1 .Junqi, Dong, Zhang Xianhui, and Wang Jianzhang. "Experimental Study on Thermal Hydraulic Performance of Plate-Type Heat Exchanger Applied in Engine Waste Heat Recovery." Arabian Journal for Science and Engineering 2018; 43(3): 1153-1163.
2. Goodarzi Marjan, Ahmad Amiri, Mohammad Shahab Goodarzi,et al.. "Investigation of heat transfer and pressure drop of a counter flow corrugated plate heat exchanger using MWCNT based nanofluids." *International communications in heat and mass transfer* 2015; 66: 172-179.
3. Elmaaty, Talal M. Abou, A. E. Kabeel,et al.. "Corrugated plate heat exchanger review." Renewable and Sustainable Energy Reviews 2017; 70; 852-860.
4. Hasanpour A., M. Farhadi, and K. Sedighi. "Experimental heat transfer and pressure drop study on typical, perforated, V-cut and U-cut twisted tapes in a helically corrugated heat exchanger." *International Communications in Heat and Mass Transfer* 2016; 70; 126-136.5
5. Han Huai-Zhi, Bing-Xi Li, Hao Wu. et al. "Multi-objective shape optimization of double pipe heat exchanger with inner corrugated tube using RSM method." *International Journal of Thermal Sciences* 2015; 90; 173-186.
6. Han Xiao-Hong, Li-Qi Cui, Shao-Jie Chen, et al. "A numerical and experimental study of chevron, corrugated-plate heat exchangers." International Communications in Heat and Mass Transfer , 2010; 37(8): 1008-1014.
7. Kabeel A. E., T. Abou El Maaty, and Y. El Samadony. "The effect of using nano-particles on corrugated plate heat exchanger performance." *Applied Thermal Engineering* 2013; 52(1) :221-229.
8. Kanaris Athanasios G., Aikaterini A. Mouza, and Spiros V. Paras. "Flow and heat transfer prediction in a corrugated plate heat exchanger using a CFD code." *Chemical Engineering & Technology: Industrial Chemistry-Plant Equipment-Process Engineering-Biotechnology 2006;* 29(8): 923-930.
9. Khan T. S., M. S. Khan, Ming-C. Chyu,et al. "Experimental investigation of single phase convective heat transfer coefficient in a corrugated plate heat exchanger for multiple plate configurations." Applied Thermal Engineering 2010; 30(8-9): 1058-1065.
10. Aslan E, Taymaz I, Islamoglu Y,et al. Computational investigation of the velocity and temperature fields in corrugated heat exchanger channels using RANS based turbulence models with experimental validation. Progress in Computational Fluid Dynamics, an International Journal. 2018; 18(1): 33-45.

11. Sharif Asal, Bernd Ameel, Ilya T'Jollyn,et al. "Comparative performance assessment of plate heat exchangers with triangular corrugation." Applied Thermal Engineering 2018;
12. Khavin G. Simulation and Design of Welded Plate Heat Exchangers with Channels of Different Corrugation Height. In Design, Simulation, Manufacturing: The Innovation Exchange 2018; 453-462.
13. Kondepudi, S. N., & O'Neal, D. L. Frosting performance of tube fin heat exchangers with wavy and corrugated fins. Experimental Thermal and Fluid Science, 1991; 4(5): 613-618.
14. Sun, M., & Zeng, M. . Investigation on turbulent flow and heat transfer characteristics and technical economy of corrugated tube. Applied Thermal Engineering, 2018; 129, 1-11…
15. Faizal, M., & Ahmed, M. R. Experimental studies on a corrugated plate heat exchanger for small temperature difference applications. *Experimental Thermal and Fluid Science*, 2012; *36*: 242-248.
16. Islamoglu, Y., & Kurt, A. Heat transfer analysis using ANNs with experimental data for air flowing in corrugated channels. *International Journal of Heat and Mass Transfer*,2004; *47*(6-7), 1361-1365.
17. Khairul M. A., M. A. Alim, I. M. Mahbubul, et al. "Heat transfer performance and exergy analyses of a corrugated plate heat exchanger using metal oxide nanofluids." International Communications in Heat and Mass Transfer 2014; 50; 8-14.
18. Min, June Kee, Ji Hwan Jeong, Man Yeong Ha, and Kui Soon Kim. "High temperature heat exchanger studies for applications to gas turbines." Heat and mass transfer 2009; 46(2): 175.
19. Pandey S.D. and Nema, V.K. Experimental analysis of heat transfer and friction factor of nanofluid as a coolant in a corrugated plate heat exchanger. *Experimental Thermal and Fluid Science*, 2012; *38*: 248-256.
20. Stasiek, J. A. Experimental studies of heat transfer and fluid flow across corrugated-undulated heat exchanger surfaces. *International Journal of Heat and Mass Transfer*, 1998; *41*(6-7): 899-914.
21. Tsai Ying-Chi, Fung-Bao Liu, and Po-Tsun Shen. "Investigations of the pressure drop and flow distribution in a chevron-type plate heat exchanger." *International communications in heat and mass transfer* 2009; 36(6): 574-578.
22. Vicente Pedro G., Alberto Garcıa, and Antonio Viedma. "Experimental investigation on heat transfer and frictional characteristics of spirally corrugated tubes in turbulent flow at different Prandtl numbers." *International Journal of Heat and Mass Transfer* 2004; 47(4): 671-681.

23. Laohalertdecha, S., & Wongwises, S. The effects of corrugation pitch on the condensation heat transfer coefficient and pressure drop of R-134a inside horizontal corrugated tube. *International Journal of Heat and Mass Transfer*, 2010; *53*(13-14), 2924-2931.
24. Chang, Y. J., & Wang, C. C. A generalized heat transfer correlation for Iouver fin geometry. *International Journal of heat and mass transfer*, 1997; *40*(3): 533-544.
25. Webb, R. L. Performance evaluation criteria for use of enhanced heat transfer surfaces in heat exchanger design. International Journal of Heat and Mass Transfer,1998; 24(4), 715-726.