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Review on effect of corrugated surface on heat transfer and fluid flow characteristics

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Abstract

Energy crises are one of the increasing problems in industrial engineering. Thermal system is a major part of energy consumption. Therefor it is necessary to increase efficiency of the thermal systems. Heat exchangers are widely used in petrochemical, pharmaceutical, chemical, power and food industry, heat recovery systems, air–conditioning, refrigeration, central heating systems and cooling automotive components. Hence it is necessary to researchers to focus on to increase the efficiency of the thermal system. The expansion of activities focused on the intensification of heat exchange, reducing the weight and dimensions of heat exchangers, increasing their productivity is needed to decrease energy and material consumption as well as saving the cost of heat exchange equipment. Heat transfer enhancement is majorly depends on heat transfer surface area. Heat transfer surface can be increased by various passive methods. The use of corrugated surface is an effective method of intensification of heat transfer in heat exchangers. Corrugations represent a passive technique. In addition, it provides effective heat transfer enhancement because it combined the features of extended surfaces, turbulators and artificial roughness. In this work the analysis of corrugated profiles and effect of geometrical parameters, operating parameters, insertion of thermal conductive barriers on it was studied.

Keywords: Heat transfer enhancement, convective heat transfer coefficient, heat exchanger, corrugated surface, duct channel geometry, Reynold's number

1. Introduction

The severity of the energy crisis is increasing rapidly with the increase in the energy demand for industrial, commercial, and residential sectors. The main obstacle for the industrialization of enzymatic process would be overall cost of production. Therefore it is necessary to work on increment of thermal efficiency of the system with minimum cost of production, reduction in volume of material. Heat exchangers are major part of thermal systems and researchers focused on the enhancement of heat transfer rate with minimum pumping power.

Various methods of heat transfer enhancement are used for enhancing the heat transfer without disturbing the overall realization of the systems and it covers wide range of areas in industrial engineering. Heat transfer enhancement techniques are classified as the; passive methods, active methods, and compound methods. Active method involves some external power input such as insertion of Nano sized, high thermal conductivity, and metallic powder to the base fluid whereas in passive method geometry or surface of the flow channel is modified to increase the thermo–hydraulic performance of the systems. Use of corrugated profile is one of the easiest passive method for enhancement in heat transfer rate. The development of corrugated heat exchangers has been driven by the need for economical, high performance, yet small in size and lightweight equipment, which can be used in a variety of purposes. The heat exchanger made of corrugated plates has significant advantages over a conventional heat exchanger as they have a larger total heat transfer area for their size. Further, the challenge lies in enhancing the heat transfer capacity of the heat exchangers with more compactness. Therefore, the conflicting requirements have given rise to in-depth research in designing and development of the corrugated plate type heat exchangers.

In thermal systems, the heat transfer enhancement rate, pressure drop, Reynolds number, pumping power are important factors to obtain an optimal design condition. It is observed that corrugated surface has the significant effect on the enhancement of heat transfer and pressure drop compared with the flat channels. Also corrugation provides maximum surface area which leads to heat augmentation. Corrugation also increases turbulence intensity. With the insertion of nano-fluids in base fluid also increases heat transfer rate in corrugated duct. This paper focus on to review the analysis carried out by various researchers for heat transfer enhancement in heat exchanger by using various duct geometries, phase shift, different corrugation profiles, various operating parameters and nano-fluid.

2. Literature review

N. Tokgoz and B. Sahin [1] experimentally investigated structures of flow in a corrugated duct using the technique of Particle Image Velocimetry. The aspect ratio of the corrugated channel was taken as 0.3 in this study. The main objective of this study was to understand the influences of phase shift on the augmentation of heat transfer and flow behaviour. The investigation consist of Reynold number values of 2 × 103 and 6 × 103 and two different phase shifts such as 00 and 900 for the available corrugated channel. The experimental results showed that increasing of momentum transfer by corrugated channel and transporting energy caused a better augmentation of the heat transfer rate for both phase shıft angles compared to the smooth channel. Takahiro Adachi and Haruo Uehara [2] numerically investigated relation between heat transfer and pressure drop in periodically rectangular grooved parts by assumption of two–dimensional and periodically fully developed flow. The geometrical parameters of channel were taken as, period of the module (L = 8), length of contracted or expanded groove (l = 4) with upper height of groove (a1 = 2) having 5 different lower height of groove (a4 = 0, 0.5, 1, 2, 3) from the centreline having Prandtl number Pr = 7 with Reynolds number range of 50 – 500. The Nusselt number increases due to vortices inside the grooves resulted in bifurcation from steady–state flow to oscillatory along with pressure drop increment. It was observed that channels with the expanded grooves have more efficient performance than contracted grooves in heat transfer enhancement. Wei Wang et al. [3] studied numerically a double pipe heat exchanger with outward helically corrugated tube under the determined geometry parameters and investigated heat transfer enhancement and complex flow features on the shell side by a multi objective optimization method and compared with the tube side. It was found that with decrement in the shell diameter the heat transfer and pressure drop were increased, and optimum diameter obtained of 38 mm. Due to fluid impact to the wall and spiral flow heat transfer was improved. The structural parameters were taken as inner tube diameter (Dts = 20 mm), tube wall thickness (tl = 2 mm), corrugation width (wl = 10 mm), corrugation height (Hl = 2 mm), and corrugation pitch (pl = 20 mm). The genetic algorithm method was used to obtain optimal solution of the matching flow rates and two equilibrium solutions for the tube and shell sides.

Aydın Durmus et al. [4] has done the experimental study of the effects of surface geometries of three different type heat exchangers called as PHE flat (flat plate heat exchanger), PHE corrugated (plate heat exchanger corrugated) and PHE asteriks (Asterisk plate heat exchanger) on heat transfer, friction factor and exergy loss. The experimental studied were carried out for a heat exchanger with single pass under condition of counter flow and parallel flow. In this study, experiments were conducted for laminar flow conditions. Prandtl number and Reynolds number were in the range of $3 \leq Pr \leq 7$ and $50 \leq Re \leq 1000$, respectively. Friction factor, heat transfer and exergy loss correlations were obtained according to the experimental results. In this experimental study, in order to increase heat transfer in plate type heat exchanger by passive method, rectangular fins are located on the plates. Xuebo Dong et al. [5] numerically investigated thermal hydraulic characteristics of steam air in the vertical corrugated tubes with sinusoidal waveform of various amplitudes and wavelengths. The condensation process enhanced by adding the mass, species, energy and momentum sink terms to the condensing wall as well as due to detached vortex characteristics and accumulated air in waveform domain with argumentation of turbulent flow and heat transfer. It was observed that better thermal hydraulic performance obtained in the corrugated tubes with longer wavelength and higher amplitude waveform condensing wall and the optimum design of geometric parameters obtained as amplitude of basic waveform (A = 0.5, 2 mm) at wavelength of basic waveform (L = 21 mm) with inlet velocity range of (v = 2 to 4 m/s and v = 5 to 12 m/s). In the corrugated tube with (L = 35 mm, A = 3.5 mm at v = 1 m/s) the greatest thermal performance factor ($\phi = 1.18$) was obtained. H. A. Mohammed et al. [6] has numerical investigated forced turbulent convective heat transfer and fluid flow in a corrugated channel of plate type heat exchanger. Using a finite volume method, continuity, momentum and energy equations were solved. The constant heat flux boundary conditions were applied at the top and bottom wall of the corrugated channel. This study consist of the effect of geometrical parameters of corrugation such as channel heights, wavy heights and tilt angles using water as a working fluid. The channel heights were taken as 12.5, 15 and 17.5 mm, wavy heights were 2.5, 3.5 and 4.5 mm and tilt angles of 20°, 40° and 60° were taken for investigation. The heat flux ranging from 0.4 – 6 kW/m2 and Reynolds number was in the range of 8000 – 20,000. It has been observed that the channel height of 17.5 mm, 2.5 mm wavy height and 600 wave angle were found to be optimum parameters and they have a significant effect on enhancement of heat transfer. Kitti Nilpuenga et al. [7] presented new experimental results on plate heat exchanger performance including the pressure drop, heat transfer coefficient, and thermal performance factor under different surface roughness, chevron angles, and working conditions. Roughness of Plate surface ranging between 0.95 μm and 2.75 μm with two chevron angles of 30° and 60° were used and Reynolds number was taken to be from 1200 to 3500 with a hot water temperature of 40°C, and a cold water temperature of 25°C. The experimental results showed that the pressure drop and heat transfer coefficient increase when the chevron angle is decreased and the surface roughness and Reynolds number were found to be increased. It was observed that the average thermal performance factors were 1.09 and 1.02 for 30° and 60° chevron angles, respectively and the optimum thermal performance of a plate heat exchanger was obtained at a chevron angle of 30°, the highest surface roughness, and the lowest Reynolds number.

Oana Giurgiu et al. [8] has done numerical study for two different models of mini channels, included in plate heat exchangers structure using Computational Fluid Dynamics. The effects of geometric parameters of the two studied plates on the enhancement process of heat transfer was studied comparatively and the temperatures fields, distribution of velocity, and distribution of convection coefficient along the active mini channel. The investigated mini channels had the inclination angles of 30°, 60° and the Reynold flow number was 3500. Experimental measurement have been carried out on the two types of plates, and its numerical simulation shows that mini channels with inclination angle of $\beta = 60^{o}$ provides best heat transfer. It has been observed that the geometry of the plate considerably affects the flow of fluids characteristics through channels formed between the plates, highlighting the performance of thermodynamic characteristics of these devices. E.A.M. Elshafei et al. [9] has experimentally investigated the pressure drop and convective heat transfer characteristics of flow in corrugated channels. Experimental studies were performed on channels of fixed corrugation ratio and uniform wall temperature over a range of Reynolds number, $3220 \leq Re \leq 9420$. The effects of phase shift variations and channel spacing on pressure drop and heat transfer were discussed. It has been observed that corrugated channels flow showed a significant change in enhancement heat transfer accompanied by increased pressure drop. Depending upon the spacing and phase shift, the pressure drop and average heat transfer coefficient were enhanced by a factor of 1.9 to 2.6 and 2.6 up to 3.2 relative to those for parallel plate channel, respectively. Results showed that, the friction factor increases with increasing its phase shift and channel spacing. The effect of friction factor and spacing variations on heat transfer were more pronounced than that of phase shift variation, for high Reynolds number. Q. Xiao et al. [10] numerically studied the effect of asymmetric wavy channel for laminar flow having Prandtl number of 0.707 with Reynolds number range of 100 – 1000 and compared with symmetric wavy channel. Laminar flow and heat transfer in two dimensional asymmetric wavy channel was numerically investigated and coordinate combination method is used for calculation procedure. It is observed that with increment in grid points the difference in friction factor and average Nusselt number decreases hence mesh of 52 × 24 was selected which showed deviation in friction factor nearly 3 – 4% and that for Nusselt numbers was about 1 – 2%. At the same pumping power, the asymmetric wavy channel shows more heat transfer enhancement as compared to symmetric wavy channel at same pumping power.

P. J. Heggs et al. [11] employed an electrochemical mass transfer technique to calculate values of the local transfer coefficients within a corrugated plate heat exchanger channel. The Reynolds number ranging from 150 to 11,500 for the following corrugation angles of 300, 450, 600 and 900. The integral mass transfer results indicates that particularly at low corrugation angles, such as 300, pure laminar flow does not occur within the tested Reynolds number range. The local transfer coefficients for three dimensional maps provide evidence for the nature of the fluid motion. In this studied, it has been clearly showed that a core of fluid flows along the troughs of the corrugations, over the entire Reynolds number range investigated. It has been observed that at high Reynolds numbers, a peak at the base of the corrugation trough supports the theory that these crossing trough wise streams induce swirling flow. Asal Sharif et al. [12] has investigated the effect of the apex angle on the thermal and hydraulic features of triangular cross–corrugated heat exchangers for the Reynolds numbers ranging from 310 to 2064, by using three dimensional computational fluid dynamics approach with the Reynolds stress model. This study includes the influence of the complexity and intensity of the recirculation zones along with the turbulence intensity on those characteristics and corresponding pressure and viscous forces. The investigation revealed that there was less than 5% deviation between the Reynolds stress model and experimental results. It has been found that with increase in the apex angle, pressure drop and heat transfer coefficient increases, due to the increase of the vorticity magnitude and the pressure force along the flow direction. Naznil Singh et al. [13] have done experimental studies on corrugated plate heat exchangers with corrugated plates channel inclination angles for the parallel plates were varied from 00 to 800 in increments of 200 to find the configuration with the optimum heat transfer rate keeping the channel spacing was constant. Water was used in both the hot and the cold channels. The temperatures of the two media between which heat was exchanged were 25.40 C for cold water and 380 C for hot water and flow direction in the heat exchanger was parallel with both the fluids. The flow rate of the hot water was kept constant while flow rate of the cold water was varied. It was observed that the rate of heat transfer increases for all the plate inclination angles with increase in flow rate of cold water. M. Ciofalo et al. [14] numerically investigated heat transfer and hydrodynamic characteristics in cross–corrugated geometry under transitional and turbulent conditions for compact heat exchangers. The finite volume method is used for a variety of approaches ranging from laminar flow assumptions to standard and low Reynolds number turbulence model to obtain three dimensional numerical prediction with direct and large eddy simulation. The geometrical parameters are taken as corrugation angle θ = 300 to 1500 with P/Hi = 2 to 4 (ratio of pitch of corrugation to internal height of corrugation having Reynolds number range of 103 to 104. It is observed that as the corrugation angle θ increases from 00 to 1600 the friction factor and Nusselt number also increases. Also it has been found that corrugation angle geometry shows heat transfer enhancement as compared with straight duct. Sandip K. Saha and A. H. Khan [15] studied numerically the effect of corrugation angles (30° ≤ β ≤ 80°) on thermohydraulic performance of a cross–corrugated plate heat exchanger (PHE) with Reynolds number ranging from 400 to 10000. It was found that pressure drop and Nusselt number increased with increment in Reynolds number and the corrugation angle. It was estimated that friction factor of the PHE with β = 80° was 2.8 times greater and for same Nusselt number was increased by 3 times than flat PHE. It was resulted that flow distribution and heat transfer in the PHE improved in corrugations compared to a flat plate heat exchanger. The average thermal enhancement factor at the same pumping power of a PHE observed with 80° was 34.11%, 16.23%, 10.63% and 8.25% more than that of a PHE with β = 30°, 45°, 60°and 72° respectively.

Ahmed Hamza and Yutaka Hanaoka [16] has done experimental study in laminar flow forced–convection heat transfer for air flowing in a channel having a V–corrugated upper plate heated by radiation heat flux while the other walls are thermally insulated and studied the effects of the operating parameters. The Reynolds number (Re) ranging from 750 to 2050, incident radiation fluxes of 400, 700, and 1000 W/m2, inlet air bulk temperatures ranging from 12.40C to 59.40C and tilting angles of the channel (b) of 00, 150, 300, 450, and 600 have been varied. The results show that, the effects of Reynolds number on local Nusselt number (Nux) are clear and more significant at the channel entrance region. While, changing tilting angles of the channel from 00 to 600 leads to an increase in on local Nusselt number by a ratio ranging from 33% to 67.3% depending on Reynolds number values and other operating parameters. Increasing the qinc values by 175% and 250% leads to an increase in local Nusselt number values by 26% and 50%, respectively. F. Andrade at al. [17] experimentally investigated characterization of the heat transfer and pressure drop of smooth tube and two corrugated tubes that have an internal diameter of 5.75 mm and a heating length of 0.38 m. This work has been conducted in laminar, transitional and turbulent regime, with Reynolds numbers ranging from 429 to 6212, under both diabatic and adiabatic flow conditions and the heat flux imposed on the tube wall ranged from 5.5 kW/m2 to 21.1 kW/m2. It has been observed that the friction factor of the corrugated tubes gives a smoother transition than in the case of the smooth tube, being the diabatic and adiabatic friction factor for the corrugated tubes was found to be similar from laminar to turbulent regime. The result showed that the highest heat transfer augmentation occurs at Reynolds number ≈ 2000, specifically, the Nusselt number augmentation (Nuc/Nus) increases up to 4.7 for the corrugated tube with helical pitch p = 6 mm and up to 3.8 for the corrugated tube with p = 12 mm. Kitti Nilpueng and Somchai Wongwises [18] experimentally investigated heat transfer coefficient and pressure drop of water flow inside a plate heat exchanger with a rough surface and compared with that obtained from a smooth surface. In this study, three different commercial stainless steel corrugated plates with symmetrical chevron angle of 250 were used and the water flow inside the plate heat exchanger was arranged for a single pass and counter flow. The test was performed at Reynolds numbers ranging between 1300 and 3200 and plate surface roughness ranging between 0.936 μm and 3.312 μm. The results showed that the increase in surface roughness resulted in an increase in heat transfer coefficient between 4.46% and 17.95% and an increase in pressure drop between 3.90% and 19.24% with respect to a smooth surface.

J.H. Lin et al. [19] experimentally studied the flow characteristics and optimum channel geometry to enhance heat transfer performance by using Buckingham Pi theorem. The dimensionless correlations were resulting characteristics of the heat transfer performance of the corrugated channel in a plate heat exchanger. The correlations were obtained by omitting the less impact factors. Dimensionless correlations for local Nusselt number and average Nusselt number have been developed based on experimental results and the

Buckingham Pi theorem. Compared with the experimental results, the accuracies of the dimensionless correlations were found to be acceptable. It was observed that the average and local Nusselt number increases with increment in corrugation angle. Since corrugation angle causes transition of laminar flow to turbulent flow at lower value of Reynolds number results in heat transfer enhancement. Van Quan Hoang et al. [20] studied numerically effect of corrugation on convective heat transfer and pressure loss characteristics of flow using large eddy simulation (LES) under pulsating inlet conditions which were amplitude (A) of the imposed pulsation did not exceed 100% of the mean velocity while dimensionless frequency (St) was ranged from 0.0 to 0.79. The heat transfer enhancement occurred due to imposed unsteadiness of flow structures with continuous oscillation between laminar and turbulent performance. It was found that thermal performance factor increased from 0.9 to 1.17 under constant flow condition and for pulsating corrugated channel reached from 1.3 to 1.4. Nehir Tokgoz [21] investigated both experimentally and numerically the flow characteristics in a duct with circular corrugated channel with aspect ratio (a/R) taken as 1 using the Particle Image Velocimetry (PIV) technique. The four different Reynolds numbers Re = 2000, 3000, 4000 and 5000 was taken for findings. It was observed that due to corrugation transporting energy and momentum transfer enhanced which results in increment of heat transfer rate. The thermal boundary layer of the corrugated channel was thinner as compared with the straight channel which leads to increment in concentrations of vorticity results in enhancement of heat transfer. Due to negative pressure gradient and kinetic energy along the direction of flow cavity zones were created which grounds augmentations in heat transfer area and flow turbulence at low Reynolds numbers. Paisarn Naphon [22] has presented the results of the pressure drop and heat transfer characteristics in the corrugated channel under constant heat flux. The experimental test section is the channel with two opposite corrugated plates which all configuration peaks lie in an in–line arrangement. The corrugated plates with three different configuration corrugated tile angles of 20°, 40°, and 60° were tested keeping the height of the channel of 12.5 mm. This experimental studied were done for the Reynolds number and heat flux in the ranges of 500 – 1400 and 0.5 – 1.2 kW/m2, respectively. The effect of relevant parameters on the pressure drop and heat transfer characteristics were discussed. It has been seen that the corrugated surface has significant effect on the enhancement of heat transfer and pressure drop, due to the presence of recirculation zones. Shubham et al. [23] numerically investigated thermo–hydraulic transport characteristics of non–Newtonian fluids flowing through corrugated channels using power law model to study performance of fluid and compared with straight channel. It was observed that heat transfer enhancement in corrugated channel was effective only for greater amplitude while with increment of power law index the heat transfer enhancement in straight channel was decreased. Also for all consider parameters the enhancement in heat transfer (Nu/Nu straight) was smaller as compared to the ratio of pressure drop (Δp/Δp straight) but due to use of shear thinning fluids heat transfer enhancement occurred at minimum pressure drop. It was concluded that the ratio of heat transfer enhancement increases as compared to the ratio of pressure drop increases at a faster rate with Reynolds number, power law index and amplitude of the wall waviness of the channel.

Zohre Taghizadeh Tabari et al. [24] experimentally investigated thermal parameters in plate heat exchanger (PHE) as an important thermal equipment in dairy industries. The nanoparticles of titanium dioxide were added with distilled water to prepare stable nanofluid with weight concentration of 0.25%, 0.35% and 0.8% as the working media in order to capability of heat transfer enhancement of distilled water as a hot stream in PHE. It has been experimentally found that, nanofluid at all concentrations showed higher heat transfer rate (advantage) and pressure drop (disadvantage) than that of the distilled water, resulting from higher thermal conductivity of the nanoparticle loaded in base fluid. To evaluate the positive and negative aspects of the nanofluid applications in the plate heat exchanger simultaneously, parameter of performance index was introduced and the results confirmed the potential of this type of nanofluid in PHE, by looking at the ratio of convective heat transfer enhancement to the pressure drop. Raheem Kadhim et al. [25] numerically studied flow structure and heat transfer characteristics of curved–corrugated channel having L–shaped baffles with presence of ZnO–water nanofluid using cooling techniques passive methods with the effect of thermal–hydraulic performance. The parameters were taken as corner angle (γ = 30◦, 45◦, 60◦ and 90◦), blockage ratio (BR = 0.25, 0.3. 0.35, and 0.4), and volume fraction of ZnO particles (0 to 4%) with Reynolds number ranging from 8000 to 32000 at constant temperature condition (T = 355 K). It was observed that due to corrugations and baffles the turbulence of flow causes leads to vortex flow formation which enhanced heat transfer performance and it was highest for inline arrangement of baffle than staggered arrangement at an angle 300. The optimum thermal–hydraulic performance obtained was 1.99 at blockage ratio of 0.25 and corner angle of 30. Raheem K. Ajeela et al. [26] performed numerically and experimentally effect of alumina oxide (Al2O3) in water nanofluid combined with corrugated surfaces of shape semicircle (SCC), trapezoidal (TCC), and straight (SC) on development of compact heat exchangers for effective and reliable thermal systems. The parameters were taken as Reynolds number ranging from 10,000 to 30,000 with nanofluid Al2O3 volume fractions of 0%, 1%, and 2%. It was observed from velocity and isotherms contours, with increasing the volume fraction of nanoparticles heat transfer enhancement takes place and trapezoidal corrugated channel showed highest performance factor. It was found that corrugations operated the fluid path of the main flow, which creates secondary flow vortexes that improve heat transfer. It was found that at Reynolds number Re = 10,000 and volume fraction 2% the trapezoidal–corrugated channel has maximum enhancement ratio of 2.84.

Raheem K. Ajeel et al. [27] studied numerically and experimentally effect of a corrugated surface and nanofluids on thermal systems and developed compact heat exchangers having more efficiency using forced convective turbulent flow of SiO2 – water nanofluid. The corrugation shape was taken semicircle corrugated channel (SCC) and trapezoidal corrugated channel (TCC) and compared with straight channel (SC) having Reynolds number ranging from 10000 to 30000 with particle volume fractions (1% and 2%). It has been seen that as the volume fraction of SiO2 increased Nusselt number, pressure drop, and enhancement ratio also increased. It is found that trapezoidal corrugated channel (TCC) has maximum enhancement ratio of 3.1 at Reynolds number (Re = 10000) and particle volume fraction (ϕ = 2.0%). Also, enhancement ratio increased from 2.82 to 3.1 when particle volume fraction increases from 1% to 2%. Raheem K. Ajeel et al. [28] studied numerically heat transfer and flow characteristics of the symmetry trapezoidal–corrugated channel with silicon dioxide (SiO2) – water as nanofluid and influence of geometrical parameters (height to width ratio (h/W) and pitch to length ratio (p/L)) on it and obtained optimum parameters for design of thermal devices and make them more compact. The parameters were taken as Reynolds number ranging from 10,000 to 30,000 and volume fraction of SiO2 was 0.08. It was observed that as the (h/W) ratio increases from 0.0 to 0.05 there was increment in average Nusselt number (Nuav) about 99.45% whereas on decrement of (p/L) ratio from 0.175 to 0.075 the average Nusselt number increases about 16.63% at Reynolds number 30000 which concluded that ratio of h/W was more effective than p/L ratio in term of thermal performance factor. Raheem K. Ajeel et al. [29] studied numerically heat transfer and flow characteristics of the symmetry semicircle corrugated channel with silicon dioxide (SiO2) – water as nanofluid and influence of geometrical parameters (height to width ratio (h/W) and pitch to length ratio (p/L)) on it and obtained optimum parameters for design of thermal devices and make them more compact. The parameters were taken as Reynolds number ranging from 10,000 to 30,000 and volume fraction of SiO2 was 0.08. It was observed that as the (h/W) ratio increases from 0.0 to 0.05 there was increment in average Nusselt number (Nuav) about 78.84% whereas on decrement of (p/L) ratio from 0.175 to 0.075 the average Nusselt number increases about 13.59% at Reynolds number 30000 which concluded that ratio of h/W was more effective than p/L ratio in term of thermal performance factor. Dan Zheng et al. [30] analyzed heat transfer and fluid flow characteristics of various nanofluids (Al 2O3 – 30 nm, SiC – 40 nm, CuO

– 30 nm and Fe_3O_4 – 25 nm) into the base fluid with particle volume concentration (0.05 wt. %, 0.1 wt. %, 0.5 wt. % and 1.0 wt. %) of corrugated plate heat exchanger at flow rates in the range of 3 to 9 L/min. It was observed that the convective heat transfer coefficient was increased by 21.9% and pressure drop by 10.1% when 1.0 wt. % Fe_3O_4 – water nanofluid was used as the working fluid which have the best thermal performance whereas CuO – water nanofluid have poorest thermal performance as compared to other tested nanofluids. Also for 1.0 wt. % Al_2O_3 – water and Fe_3O_4 – water nanofluids have higher pressure drop than other 0.5 wt. % nanofluids at same pumping power and high volume flow rates.

3. Conclusion

The literature survey shows that heat exchangers have many applications in the industry and therefore it is necessary to enhanced heat transfer coefficient of heat exchangers. The performance parameters of thermal devices depend on its design, heat transfer rate, type of medium, pressure drop etc. Heat transfer rate can be enhanced by changing the fluid flow inside heat exchanger, by placing the obstacle in the flow called as insert, by changing the surface geometry, by insertion of thermal conductive particles or by combination of techniques. The researchers have challenge to design heat exchanger which should have maximum thermal efficiency at minimum pumping power, minimum pressure drop and friction factor.

From the above discussions it gives the clear idea that enhancement of heat transfer surfaces has developed over years. Enhancement of heat transfer surface can be easily possible by treating the surface. Corrugating the heat exchanger walls for enhancing the system efficiency is the main focus of researchers. Also, changing the common working fluids with Nano–fluids is one of the most interesting topics in the field. The enhancement of heat transfer is achieved by corrugated surface geometry. There are various corrugation profiles like rectangular, triangular, and sinusoidal and the effect of phase shift was analysed in this work. It was observed that corrugation provides better heat transfer as compared to flat channels. Flow parameters also affect the heat transfer rate. Also Nano-fluid increase heat transfer as compared to distilled base fluid. Combinations of corrugated surface and Nano-fluid have great impact on heat transfer augmentation.

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