Heat Transfer Augmentation of Nanofluid flow in Ribbed Ducts: A Review

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Abstract: *The demand for energy is expected to increase at a faster rate in future years, partly because of the exponential growth of the world's population. Everything that happens in the world can be expressed as a flow of energy. Heat transfer enhancement in heat exchanger tube at low and moderate Reynolds numbers has been a major subject of intensive research over the years. Various techniques, based on both active and passive methods, have been proposed to enhance convective heat transfer in these applications. Using ribbed duct is one of the most effective ways to increase the heat transfer in many engineering applications such as heat exchangers, cooling of turbine blades and heating and cooling devices. Nanofluids with definition of ultrafine particles suspended in a conventional base fluid with high thermal conductivity can considerably assist in this issue. Metallic, non-metallic and polymeric particles suspended in a base fluid with high thermo-physical properties can improve the thermo-physical properties of the mixture and subsequently bring higher heat transfer enhancement compared to conventional working fluids. The objective of this article is to review various studies on nanofluid flow and heat transfer behaviour in which different obstacle turbulence promoter elements were used to enhance heat transfer with a minimum friction loss.*

Keywords-Energy; Heat Exchanger; Fluid Flow; Heat Transfer

NOMENCLATURE

b	Ribbed groove width (mm)
b/H	Rib grooved width ratio (dimensionless)
e	Rib grooved height (mm)
e/H	Rib grooved height ratio (dimensionless)
f_{rs}	Friction factor (dimensionless)
H	Channel height (mm)
Nu_{rs}	Nusselt number (dimensionless)
P	Rib grooved pitch (mm)
p/H	Rib grooved pitch ratio (dimensionless)
Re	Reynolds number (dimensionless)
R/W	Serration width ratio (dimensionless)
w/e	Rib grooved width ratio (dimensionless)
y/w	Aspect ratio (dimensionless)
CFD	Computational flow dynamics

GREEK SYMBOLS

α_a	Angle of attack (degree)
η_p	Thermal hydraulic performance (dimensionless)
ρ	Density (kg/m^3)
μ	Dynamic viscosity (kg/ms)

I. Introduction

Heat transfer improvement is one of the significant regions in engineering investigations. In presents day's fast increase of research activities and manufacturing processes concentrated on economizes the heat transfer by using new processes with elevated efficiency [1-3]. Using grooves and ribs on internal plane of heat exchanger is one of the normal methods to rupture the laminar secondary layer and form restricted wall turbulence because of the flow division and reattachment among consecutive corrugations, which decreases the thermal resistance and effectively improves the heat transfer [4-7]. In place of employing ribbed Chanel to provide a considerable improvement in thermal performance of the dense heat exchangers, this enhancement was inadequate to meet whole industrial requirements. Hence, research on improvement method in such conduits has become very important. For this function, employing nano-fluids as a cooling fluid in ribbed conduits in its place of conventional fluids can improve thermal conductivity of the base fluids and thus a further development in thermal efficiency of heat exchangers among a more condensed design. A number of experimental and mathematical investigations were performed on the stream and thermal descriptions of conventional fluids in variant ribbed channels. One of the methods to improve heat transfer in the divided sections is to use nano-fluids. The nano-fluids are fluids that include pendant nano-particles like metals and oxides. Such nano-scale elements remain pendant in the base fluid. Therefore, it does not cause an enhancement in pressure fall in the stream field [8–15]. In place of employing ribbed passage to supply a considerable improvement in thermal behaviour of the compacted heat exchangers, this enhancement was inadequate to meet every manufacturing need. So, investigation on improvement method in such passage has become extremely significant [16-19]. For this function, employing nano-fluids as a cooling liquid in ribbed passage instead of conventional fluids can improve thermal conductivity of bottom liquids and thus an additional development in thermal behavior of heat exchangers among a much condensed model. Some experimental and mathematical investigations were performed on the fluid flow and thermal behavior of traditional fluids in variant ribbed passages [20]. In current durations, the problems of providing much significant and consistent thermal method in case of decreasing the dimension, economy and of energy have been earned considerable concentration. The current improvement of nanotechnology directed to the theory of employing pendent nano-particle in heat transfer liquids to enhance the convective heat transmission coefficient of the bottom fluids. Heat exchangers are fractions of manufacturing apparatus used to replace or transmit thermal energy from one standard to other at variant temperatures. In some manufacturing methods like chemical and food industries, refrigeration, air conditioning and space purposes, it is needed to raise the temperature of one fluid when cooling the remaining one [21-23].

Gavara [24] investigated the laminar strained convection of nano fluid within an upright passage among symmetrically accumulated rib heaters on planes of conflicting wall. The heat transfer and fluid stream descriptions are observed for different Re and nano particles volume portions of nanofluid. It was found that a skin f_{rs} coefficient beside the solid fluid boundries raises and reduces abruptly among the base and top surfaces of heaters because of the abrupt increase and decrease in the velocity of fluid at the particular faces. The skin f_{rs} coefficient and Nu_{rs} in the passage, enhance due to improvement in volume part of nano-fluid.

Ahmed and Yusoff [25] studied the three variant kinds of nanofluids, Al_2O_3, CuO and SiO_2 heat transfer and laminar stream descriptions which are pendent in ethylene glycol, within a triangular passage by employing delta winglet group of vortex respectively. They obtained that the standard Nu_{rs} rises among the nano-particles volume portion and Re related with an enhancement in pressure fall. The Nu_{rs} and pressure fall consequences decrease due to enhancing the particle span. A schematic diagram of simulation domain id depicted in Fig. 1 respectively.

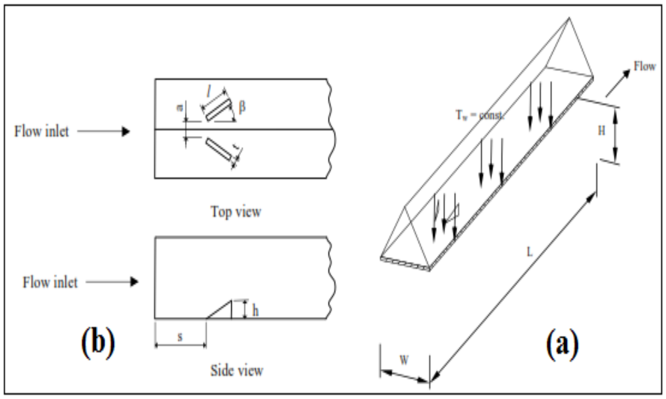

Figure 1. (a) Schematic diagram of problem area, (b) geometric parameters of problem VG (Source, [25])

Ghale, Haghshenasfard and NasrEsfahany [26] examined the strained convective heat transfer of aluminium and H_2O nano-fluids in a straight micro passage by employing Computational flow dynamics (CFD) modeling. They conducted the study in two phases in the first phase, single phase and double phase combination designs has been employed for calculation of Nu_{rs} and hydrodynamics factors of nano-fluids in a plain micro passage heat drop and in the second phase the influence of ribs tabulators on nano-fluid stream and Nu_{rs} performance of micro passage were studied. They revealed that Nu_{rs} and f_{rs} coefficient of nano-fluids in obstacle micro passage are larger as compared to that of simple micro passage, and such improvement raised by enhancing the width of obstacles. Khdher, Sidik, Mamat and Hamzah [27] experimentally and numerically investigated the pressure fall and heat transfer coefficients of Al_2O_3 and H_2O nano-fluids streams in circumferential obstacle pipe among variant rib dimensions. They found that when the numerical values of ribbed pipes were evaluated with smooth pipes it shows Nu_{rs} ranges from 92% - 621% and f_{rs} ranges from 25% - 241% as compared to those achieved in flat tube based upon the circumferential statistical factors, thermal conductivity and mass rate of operational fluid respectively. Yang, Tang, Zeng and Wu [28] performed the mathematical simulation with single and double phase design of nanofluids turbulent strained convection in 3D arc obstacle ribbed passage by steady wall temperature. They revealed that the standard Nu_{rs} of arc obstacle ribbed passage is achieved to be enhancing maximum among less significant obstacle ribbed height ratio and several ratios of arc rib grooved pitch respectively. It was achieved that the aim purpose E is optimal at Re = 10,000 and the arc obstacle groove has an increment of 42.1% respectively. A schematic diagram of 3D arc ribbed grooved passage is presented in Fig. 2

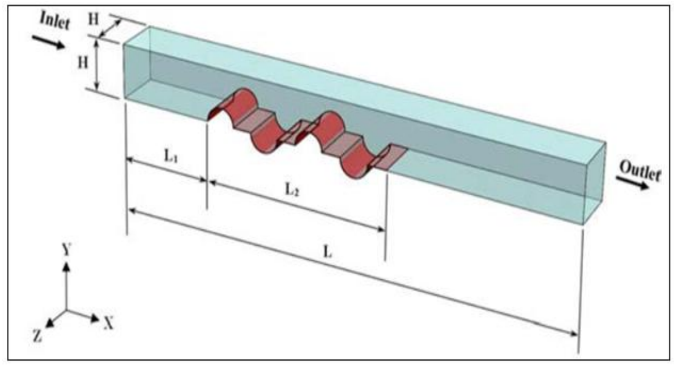

Figure 2. Schematic diagram of 3D arc ribbed grooved passage (Source, [28])

Vanaki and Mohammed [29] studied the influence of variant rib profiles and turbulent nano-fluid stream on thermal and flow fields via diagonally roughened rectangular passage among Re lies within 5000–20000 and consistent heat flux of $10kW/m^2$ respectively. The outcomes depicts that the obstacle passage performance was significantly effected through rib profiles their experimental factors. It was obtained that the H_2O-SiO_2 demonstrates the maximum Nu_{rs} improvement evaluated with other examined nanofluid and Nu_{rs} through the obstacle passages were increased due to the enhancement of Re, particle volume fraction and with reduction of nano-particles diameter respectively. Shamani et al. [30] investigated the Nu_{rs} due to turbulent stream of nano-liquids through obstacle groove passage with four variant obstacle profiles and four different nano-particles respectively. They revealed that the SiO_2 nano-fluid has maximum data of Nu_{rs} as compared to remaining nano-fluids and Nu_{rs} enhanced when the volume fraction raises and then reduced when the nano-particle diameter increased respectively. They also depicts that such trapezoidal obstacle grooves employing nano-fluids has the probability to significantly enhance Nu_{rs} descriptions and hence can be superior for the enhancement of proficient heat exchanger apparatus. A schematic diagram of rib groove passage for geometrical design is depicted in Fig. 3

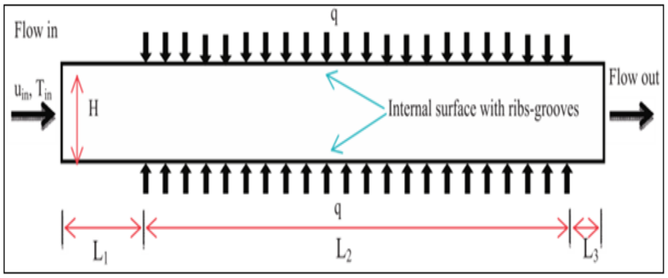

Figure 3. Schematic diagram of rib groove channel (Source, [30])

Parsazadeh et al. [31] performed a strained convection turbulent nano-fluid flow simulation to determine the influence of variant kinds of nanoparticles among variant nano-particle factors in an entirely separated obstacle passage. The conclusion shows that the maximum Nu_{rs} improvement is obtained among SiO_2 nano-fluids and f_{rs} did not significantly alter by employing variant kinds of nanoparticles in the support fluids. Moreover, increase of nano-particles absorptions and Re has constructive impact on Nu_{rs} improvement due to enhancement of speed and thermal conductivity of mixtures. Mohammed et al. [32] examined the hydraulic and thermal descriptions of turbulent nano-fluids streams in a ribbed passage by using nine different ribbed profiles and four variant kinds of nano-particles respectively. It was achieved that the rectangular obstacle triangular groove has maximum Nu_{rs} among former obstacle groove profiles. The SiO_2 nano-fluid has maximum Nu_{rs} than that of other kinds of nano-fluid and the Nu_{rs} increased when the nano-particle y/w, Re and volume fraction enhanced, however it reduced when nano-particle diameter enhanced respectively. Manca et al. [33] studied the strained convection of nano-fluids, created via H_2O and Al_2O_3 nano-particles, in 2D and passage. A one phase technique is used to design nano-fluids and the liquid properties are assumed stable among temperature. They revealed that the Nu_{rs} improvement rises among the particle volume absorption however it is accompanied with the rising pumping energy. The Nu_{rs} enhances when the Re and pumping power increases respectively. Navaei et al. [34] performed a numerical investigation to study the influence of variant geometrical factors and different nano-fluids on the thermal behavior of rib grooved passage below consistent heat flux. They obtained that the partially spherical rib groove among height of 0.2 and pith equivalent to 48 mm has maximum Nu_{rs} and the nano-fluid consists SiO_2 has maximum Nu_{rs} as compared to rest of nano-fluids. It was also found that in terms of employing nano-fluids with varying factors like volume fraction, skin f_{rs} and nano diameter has no considerable variations. Haridas et al. [35] depicts the performance estimation of two kinds of nano-fluids in effecting the heat transfer occurrence in condensed condition passage with three different kinds of nano-fluids and variant ranges of Re. It was found that the Al_2O_3 nanoparticles have superior capability in distracting the thermal edge layer shapes and tends to maximum fraction decrease in width of thermal boundary layers. It has been achieved experimentally the increase in boundary layer interruption and thermal conductivity influence the mainly controlled heat transfer velocities in smaller array of Re. A rectangular assembly of testing setup is shown in Fig. 4.

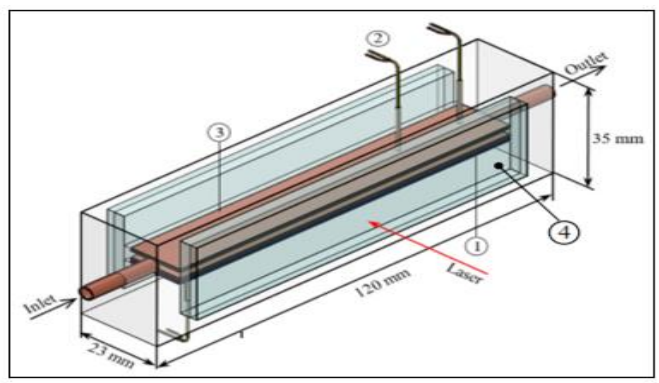

Figure 4. Schematic diagram of rectangular test setup assembly(Source, [35])

Boonloi and Jedsadaratanachai [36] studied the turbulent strained convective heat transfer and different flow parameters in square passage among crimped ribs placed in diagonally. They revealed that by employing wavy ribs highest Nu_{rs} and f_{rs} loss above the flat passage has been achieved. The Nu_{rs} improvements were about 1.97 to 5.14 and 2.04 to 5.27 times as compared to flat passage for α_a of 30^0 to 45^0 respectively. In terms of friction values the equivalent f_{rs} loss data are about 4.26 to 86.55 and 5.03 to 97.98 times as compared to flat passage for α_a of 30^0 to 45^0 respectively. Wang et al. [37] performed a mathematical study on turbulent force convection stream in a particular phase passage among 2D ribbed inner plane in the array of Re from 20,000-60,000 respectively. The experimental results shows that the symmetric curve could considerably decrease the pressure fall up to 28%, but the highest discharge velocity is 7.9% lower as compared to triangular rib on a Re of 60,000. However in case of compound rib at a value of d/e = 0.6, the enhancement of heat discharge is 6.3% higher as compared to triangular rib and the pressure fall is decreased up to 18% respectively. Evaluated to triangular ribs, the best compound ribs could significantly reduce pressure drop and enhance the heat discharge. A channel with inlet and outlet portions is shown in Fig. 5 respectively.

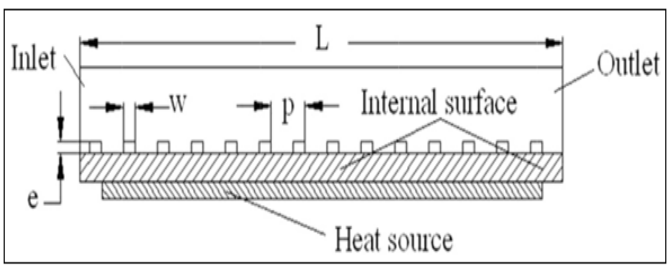

Figure 5. Diagram of channel shape (Source, [37])

Manca et al. [38] performed a numerical examination on strained convection in passages heated with a stable heat flux. The ribs of equivalent material of passage walls are initiated and the examination is carried out by the means of smooth system. They found that the highest value of Nu_{rs} and f_{rs} has been obtained for dimensionless pitches equivalent to 12-10 for square and 8-10 for triangular ribs respectively. Abed et al. [39] studied the influence of variant kinds of nano-particles on a completely developed heat transfer and turbulent stream performance in trapezoidal passages with variant diameters and volume fractions beneath a stable heat flux. They revealed that while the nano-fluids are employed in forced convection the standard Nu_{rs} is observed to be enhanced up to 10% with a volume fraction of 4% and diameter of 20 mm respectively. The optimal improvement depicts that the CuO nano-fluid, nanoparticles minimum absorption ratio and pitch = 6 mm are the most popular factors for energy saving. Ahmed et al. [40] examined the heat transfer and laminar stream descriptions of CuO-H_2O nano-fluids in ribbed and straight passage above Re and volume fraction array of 100 to 800 and 0 to 0.05 respectively. They observed that the standard Nu_{rs} and η_p (Thermal hydraulic performance) parameters raises with rise in nanoparticles Re and volume portion of for every passage profile. The dimensionless pressure drop enhance with improvement in nanoparticles volume fraction, however it reduces when the Re increases for every passage geometries. Shamsi et al. [41] investigated the laminar and CFD stream of non-Newtonian fluid with 0.5% of carboxy methyl cellulose and water as a cooling fluid. The influence of triangular ribs having angle of attack α_a = 30^0-60^0 was examined on flow factors and they found that the triangular rib with α_a = 30^0 had maximum Nu_{rs} and minimum pressure reduction beside the micro channel. Moreover with rise in α_a an unexpected contact is achieved within the ribs and fluid which decreases the length of rib and cause a reduction in heat transfer through the fluid in parts that are away from the solid wall. The investigation has been performed upon a 2D rectangular micro channel as shown in Fig. 6 respectively.

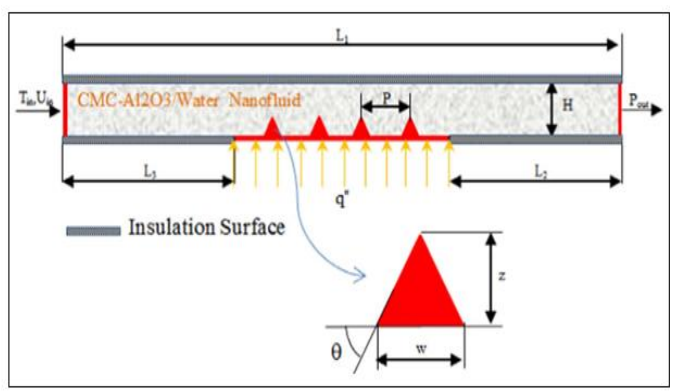

Figure 6. Schematic diagram of experimental setup (Source, [41])

Akbari et al. [42] examined the convective heat transfer of Al_2O_3 nanofluid with a flat rib-micro channel by adjusting the center part of the bottom wall of micro channel at minor temperature rather than the inlet fluid. They revealed that with rise in volume section and height of ribs the, heat transfer velocity, coefficient of friction and Nu_{rs} of ribbed micro channels tends to increase. The results shows that by varying the ribs height and solid volume portion a considerable variation is achieved in dimensionless rate and temperature along the centerline of stream, through ribbed part.

Alipour et al. [43] studied the effect of T-semi closed rib on heat transfer and turbulent stream factors of silver water nanofluid among variant volume ranges in 3D trapezoidal microchannel. The above results shows that as the Re and volume ranges of solid nano particles were raised the convective heat transfer coefficient of fluid was also increased respectively. The results also shows that at R/W = 0.5 a highest heat transfer coefficient was achieved for whole volume ranges of nanoparticles and variant Re as compared to other related R/W conditions. The schematic diagram of experimental setup is depicted in Fig. 7 respectively.

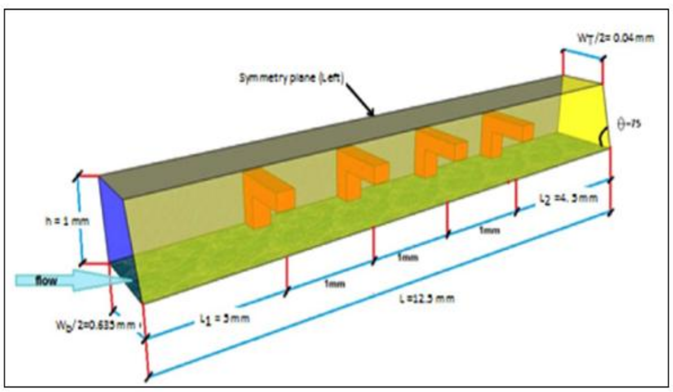

Figure 7. Schematic diagram of experimental setup (Source, [43])

In this investigation, the Nu_{rs} and pressure fall for ribbed curved sinks are 4% to 128% and 8% to 185% larger as compared to flat curved sinks, tends to η_p index within 0.93 and 1.75 respectively. It has been also obtained that the nanofluid provides a maximum heat transfer coefficient and pressure fall as compared to H_2O, and moreover their values enhanced if the value of weight increases [44].

Andreozzi et al. [45] performed a numerical simulation on turbulent strained convection in nano-fluid combination, H_2O-Al_2O_3 in a heated passage among top and bottom wall. They proposed that the rate of heat transfer is enhanced when the Re and nano-particle volume fraction raise and large amount of pumping powers are needed. A rib of rectangular and trapezoidal form depicts the optimal performance on a pitch rib height = 10 respectively.

Behnampour et al. [46] performed a numerical simulation to examine the influence of variant ribs on laminar heat transfer of H_2O-Ag nano-fluid within a ribbed triangular passage under a stable heat fluctuation by employing finite volume approach. The above results shows that enhancement in solid nano-particles volume fraction tends to increase in convectional Nu_{rs} of cooling fluid, however the pressure drop and coefficient of friction decreases with increase in Nu_{rs} respectively. From all the examined rib shapes the triangular shape shows the optimum thermal performance difference criterion values. The schematic diagram of investigated micro channels is depicted in Fig. 8

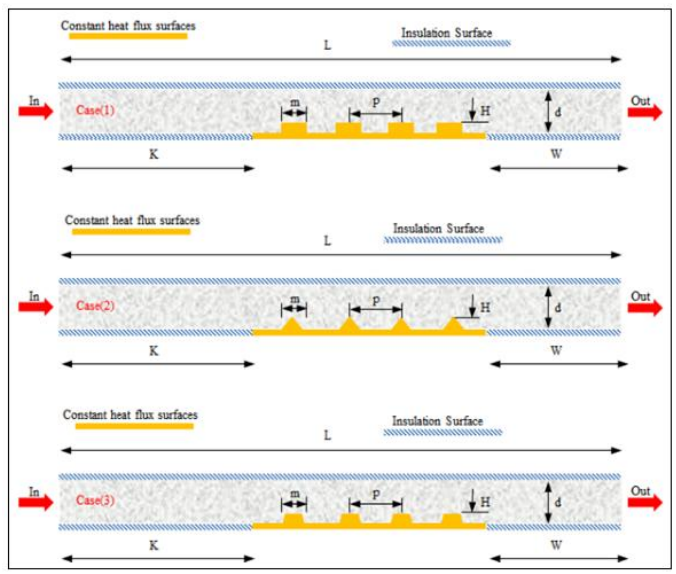

Figure 8. Schematic of studied micro channels (Source, [46])

Kumar et al. [47] performed a numerical simulation for array of methods and operational factors in order to determine the influence of protrusion ribs on Nu_{rs} and fluid flow descriptions of Al_2O_3 nano-particle in mini square passage. The analysis results depicts that, an improvement of 3.73 times in Nu_{rs} and 4.25 times improvement in pressure fall has been achieved with selected set of geometric parameters respectively. The mini square channel among protrusion ribs fixed in the heated wall has been depiocted in Fig.9 respectively.

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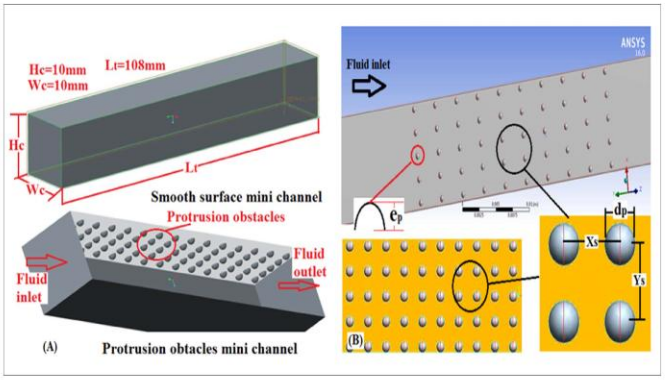

Fifure. 9 (A) Domain solution of CFD analysis (B) Protrusion rib parameters(Source, [47])

Authors	Nano-fluid used	Experimental parameters	Optimal functional parameters
Gavara [24]	H_2O-Al_2O_3	Re = 100-500	Re = 500
Ahmed and Yusoff [25]	Al_2O_3, CuO and SiO_2	ρ = 1114.4-1157.2 Re = 100-1300 μ = 0.0157-0.0164 u = 1.45-1.95	ρ = 1146.9 Re =1300 μ = 0.01959 u = 1.53
Ghale et al. [26]	H_2O-Al_2O_3	Re = 100-1000 W = 0.1-0.14	Re = 900 W = 0.14
Khdher et al. [27]	Al_2O_3	Re = 10000-50000 Circumferential depth = 0.5-1.0 Pitch distance = 5-15	Re = 40000 Circumferential depth = 0.7 Pitch distance = 10
Yang et al. [28]	Al_2O_3	b/H = 0.325-0.775 e/H = 0.1875-0.6525 Re = 5000-20000 p/H = 0.25-075	b/H = 0.325 e/H = 0.1875 Re = 10000 p/H = 0.75
Vanaki and Mohammed [29]	H_2O-SiO_2, Al_2O_3, CuO, ZnO	y/w = 0.5 – 4 Re = 4000-24000	y/w = 4 Re = 10000
Shamani et al. [30]	H_2O-SiO_2, Al_2O_3, CuO and ZnO	Re = 10000-40000	Re = 39000
Parsazadeh et al. [31]	SiO_2, Al_2O_3, CuO and ZnO	Re = 10000-50000 d_p = 20-50	Re = 50000 d_p = 50
Mohammed et al. [32]	SiO_2, Al_2O_3, CuO and ZnO	Re = 5000-20000 w/e = 0.5-4.0	Re = 10000 w/e = 2
Manca et al. [33]	H_2O and Al_2O_3	Re = 20000-60000 w/e = 0.5-4.0	Re = 60000 w/e = 2.0
Shamsi et al. [41]	H_2O-Al_2O_3	$\alpha_a = 30^0$-60^0 d_p = 25-100	$\alpha_a = 30^0$ d_p = 25
Alipour et al. [43]	H_2O- H_2O	R/W = 0-5 Re = 10000-16000 φ = 0-4	R/W = 0.5 Re = 16000 φ = 2

Hassan et al. [48] performed a numerical simulation to examine the influence of heat transfer and fluid flow by employing different nano-fluids on impingement gap jet over a smooth plate with ribbed plane. They proposed that the y/w increases with variation in Re and channel height. However Nu_{rs} reduces at significant Re and heat transfer respectively. Zheng et al. [49] investigated the turbulent flow descriptions and heat transfer behaviour in a rib grooved heat exchanger passage. The author depicts that the Nu_{rs} ratio are ranges up to 1.58-2.46 when the f_{rs} ratio are about 1.82-5.03 hence the performance evaluation alternative values ranges from 1.19-1.68 respectively.

CONCLUSION

In this article, reviewed the investigations carried out by numerous investigators to enhance the heat transfer and nanofluid flow using obstacles of different shapes, sizes, and orientations to produce artificial roughness in flow ducts. Improving heat exchangers with viewpoint of maximum convective heat transfer enhancement and reduced size, weight and cost is still taken into consideration. Using ribbed square channel is one of the most effective ways to increase the heat transfer in many engineering applications. Apart from appearance and geometric parameters of a roughened channel, working fluid plays a significant role on the heat transfer enhancement. Nanofluids with definition of ultrafine particles suspended in a conventional base fluid with high thermal conductivity can considerably assist in this issue. Metallic, non-metallic and polymeric particles suspended in a base fluid with high thermo-physical properties can improve the thermo-physical properties of the mixture and subsequently bring higher heat transfer enhancement compared to conventional working fluids. The influence of triangular ribs having angle of attack of 30^0-60^0 was examined on flow factors and they found that the triangular rib with flow attack angle value of 30^0 had maximum heat transfer and minimum pressure reduction beside the micro channel. In case of compound rib at a value of d/e of 0.6, the enhancement of heat discharge is 6.3% higher as compared to triangular rib and the pressure fall is decreased up to 18% respectively. Evaluated to triangular ribs, the best compound ribs could significantly reduce pressure drop and enhance the heat discharge. Influence of variant kinds of nano-particles on a completely developed heat transfer and turbulent stream performance in trapezoidal passages with variant diameters and volume fractions beneath a stable heat flux. While the nano-fluids are employed in forced convection the standard heat transfer is observed to be enhanced up to 10% with a volume fraction of 4% and diameter of 20 mm respectively. The performance estimation of two kinds of nano-fluids in effecting the heat transfer occurrence in condensed condition passage with three different kinds of nano-fluids and variant ranges of Re. It was found that the Al_2O_3 nano-particles have superior capability in distracting the thermal edge layer shapes and tends to maximum fraction decrease in width of thermal boundary layers. The SiO_2 nano-fluid has maximum heat transfer than that of other kinds of nano-fluid and the heat transfer increased when the nano-particle y/w, Reynolds number and volume fraction enhanced, however it reduced when nano-particle diameter enhanced respectively.

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