Performance Evaluation of Thermal Attributes in Impinging Jet Heat Sink using Airfoil Pillars with and without Nano Fluid

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Objectives: In the current research three techniques have been operated to enhance the rate of heat transfer in a heat sink. The amalgamation of Impingement of jet, airfoil pillars and Nano fluids are used. Nano fluids has a lot of potential to enhance the heat transportation in contrast to the water. The investigation has been executed with the help of three dimensional numerical model using Computational fluid Dynamics. At the onset the model has been validated with the inspection carried out already in experimental form. The observations in the form of thermal attributes are investigated. From the results the conclusion is made that the use of airfoil pillars and Nano fluids has increased the thermal characteristics of the three dimensional model in the form of heat exchange coefficient by almost 28.2%. The Nano fluid has been utilized for the 0.5% concentration.

Key words: Nano Fluid, Concentration, water, Pitch ratio, Heat sink, Pillar, Height ratio, CFD
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INTRODUCTION

Heat dissipation in most of the components of our daily life is found to be very challenging. This is because the components are subjected to high temperature conditions. Naphon, P. et al. [1] examined experimentally the different schemes to enhance the rate of heat transfer. Impinging jets in a channel of micro nature with titanium oxide Nano fluid were used to enhance the characteristics related to flow and temperature. The suspension, radius of nozzle and the rate of mass flow were selected as variables. The results indicated that with the use of Nano fluid heat transfer attributes were improved. No significant increase was noticed in drop in pressure. The elevation of jet also affected the performance. With the decrease in the elevation the coefficient of heat increased. So the suitable choice of different parameters is very crucial. Izadi, A. et al. [2] used the concept of non – dimensionalization and similarity to solve the Navier – Stokes equations of partial differentiation nature. Copper water based Nano fluid was used in the numerical exploration of fluid movement and heat transport characteristics. Concept of jet impingement with uniformity of velocity and without uniformity was taken care of in the study. Partial differentiation equations are changed in ordinary differential equations. The end result of parameters like suspension of Nano fluid was discussed on the accomplishments. The results were validated with the commercial simulation results. It was noticed from the results that Nano fluid concentration and the rate of heat were in direct relationship. The results of temperature and velocity were executed in non-dimensional form. The performance was found to more in case of non-uniformity as compared to uniformity. Flow and temperature were found to be in inverse relation with porosity. Siavashi, M. et al. [3] scrutinized the heat sink of cylindrical shape and porous nature with flow impingement in the form of Nano fluid. Uniform flow condition was adopted. The conservative equations were solved numerically and supported with the help of CFD simulation. Results indicated enhancement in performance of sink with the adoption of Nano particles. Also the influence of aspect was discussed. In the study non-dimensional variables were formed for the solution. The end result of non-dimensional variables like Reynolds number, Prandtl number, Nano fluid was studied and evaluated. The response variable was selected as Nusselt Number. Re and shear stress were found in positive trend. Inverse trend was found in between aspect ratio and heat. Nano particles increase the Nusselt number. Naphon, P. et al. [4] explored the impingement phenomenon with the application of Nano fluids. Two techniques were employed to study the characteristics. One was computational fluid dynamics and the other one was artificial network. Results were detected in the reasonable limits with the experimental values. Error detected in the solution was about one percent. Different layouts of micro channel were studied. Results indicated for further improvement in performance of heat sink. Yang, L. et al. [5] demonstrated the application of laws of thermodynamics particularly first and second in case of sink with micro channel. Growth was established in terms of surface coefficient with the addition of Reynolds number and concentration of Nano particles. temperature, uniformity and rate of irreversibility found in decrement with the two parameters. But reverse movement was discovered in exhibition of pumping power. The Nano fluid was expressed superior in contrast with base fluid. Miry, S. et al. [6] employed the sink performance using aluminum oxide and titanium oxide based Nano fluids. The achievements were noted for different Reynolds number. With the rate of flow, fourteen percent increment was noticed in the surface coefficient with the use of Nano fluid in contrast to water. The increase in pumping power and resistance could be neglected in balancing with the performance. Eight percent augmentation in Nu was detected with Nano. Also the application of Nano fluid caused the uniformity in temperature for the sink. Shalchi-Tabrizi, A., & Seyf, H. R. [7] deliberated the properties of heat in a micro sink using Aluminum – water as Nano fluid. Two design criterion were selected These were concentration and radius of particle. Numerical interpretation was aimed. It was found from the interpretation that as the radius of particle was decreased, thermal properties increased. Also increasing fashion was noticed when particle concentration was increased. But with the use of Nano fluid negative reaction was the outcome with change in concentration. Disorderness was also noted as surged with growing trend of Reynolds number and concentration. FVM was used to solve the governing equations in three dimensions. Selimefendigil, F., & Öztop, H. F [8] assessed the effectiveness in the name of heat and movement of fluid in JIHSWNF. Hot surface was taken for study which was maintained at a constant temperature along with cylinder which was rotating and adiabatic. The boundary conditions used in the equation were solved with the help of finite volume solver. The relation between the rotation of the cylinder and the cooling performance was investigated. The minimum and maximum limits for the Reynolds number were assumed to be hundred and four hundred. The position of cylinder horizontally also affected the properties. When the two cases i.e with and without rotation, Nu was assessed as increased by twenty percent in case of rotation which was clockwise. The whirl movement was squashed due to rotation. Selimefendigil, F., & Öztop, H. F [9] performed numerical investigation in case of JIHSWNF using two jets. Constant temperature conditions were taken for the surface. Equation were solved with GWR method. It was found from the studies that the convection coefficient deteriorates in the presence of magnetic field. It reduces the thermal attributes of heat sink. The use of Nano particles tried to improve the aspects of fluid and heat. In the absence of field, Nusselt number is higher at higher value of Reynolds number. The problem was solved with steady state conditions. Rehman, M. M. U. et al. [10]

evaluated the behavior of impinging jets on a heated plate. The material of the plate was copper. Different coolants were used for the study. Turbulence model was used for the equations in three dimensions. The properties were found in case of water, Nano fluid and phase change material. Results were correlated with experimental values. Aluminum oxide and phase change material was mixed with water and the results of this mixing were evaluated. The properties were detected best in case of phase change material. Improvement in attributes was also observed in case of Nano fluid but was less as compared to phase change material. The value of stress was more in case of Nano fluid and PCM. Naphon, P., & Nakharintr, L. [11] explored the thermal attributes of a heat sink with mini fins of rectangular shape with the Nano fluid. Aluminum was taken as the sink material. For the preparation of Nano fluid, water and titanium oxide were taken. The results were distinguished for the case with water and with Nano fluid. The characteristics of thermal sink were studied with the design parameters. Higher value of Nu was observed with Nano fluid. Enhancement in drop in pressure was noted. Sarafraz, M. M. et al. [12] prospected the outcome of Reynolds number and heat flux for the GNP –water Nano fluid in a channel. Experimental outcome was studied to measure the surface coefficient, factor of friction and surface coefficient. In this case coefficient was increased by eight percent and same was found in the case of Nusselt number. The accomplishment of the channel system was found to be augmented. This was in spite of the pressure value drop. Hasan, H. A. et al. [13] assessed the execution of collector with impingement of jet in terms of thermal and electrical parameters. Thirty-six jets were used to push the water in the collector. Three cases were taken for study. These were silicon carbide –water, titanium oxide – water and silicon dioxide – water combinations. From the results the efficiency in the first case was detected maximum. Also it was noticed that the efficiency with nanoparticles was increase as compared with a conservative collector. Zahmatkesh, I., & Ali Naghedifar, S. [14] concluded that the response in terms of oscillation depends on the Re, Gr and Dr. It has no relevance for porosity and proportion of nanoparticles. The phenomenon of convection was used in the impingement cooling. The plate was horizontal and heated not completely. But the rate of heat transfer is high with surge in porosity and nanoparticles proportion. Situations was reviewed in the conflicting case between flow jet and buoyancy. Arshad, W., & Ali, H. M [15] deduced from the experimental results that heating power change caused the increase in Nusselt number in the case of titanium oxide – water Nano fluid but the same was not the case in water. Inverse trend was detected in case of heating power and drop in pressure. The case was discussed in a heat sink with mini channel. TiO_2 was used with fifteen percent concentration. Arshad, W., & Ali, H. M. [16] analyzed the hydraulic behavior with water and graphene based nanoparticles in case of sink with integrated fin. The experiential study was performed for different values of heat flux and ten percent concentration of nanoparticles. From the results closest affinity was noticed between heat input and transfer of heat. Same was the case for pumping power. At the lower values Nano fluid attributes were observed better. Lam, P. A. K., & Prakash, K. A [17] presented optimization technique for impingement cooling using Nano fluid. The objective was to maximize rate of heat transfer and minimize generation of entropy. Total three design variables and three response parameters were selected. With an increase in Reynolds number, increasing pattern was seen in Nusselt number and generation of entropy. Similar type of pattern was detected in case of concentration of nanoparticles. Also the flow pattern was investigated. Algorithm was used for the optimization. Karami, N., & Rahimi, M. [18] done experimental investigation to describe the effectiveness of PV cell using Nano fluid. Plate with micro channels of rectangular shape was captured. The effectiveness of the Nano fluid was assessed. An improvement of about twenty-seven percent was noticed at 0.01 % of concentration. In this study friction factor and Reynolds number were determined. The flow is found to be laminar in the channel. Extraordinary results were seen for reduction in temperature due to the presence of nanoparticles. Bahiraei, M. et al. [19] recommended the use of Nano fluid instead of the pure water to increase the rate of heat transport with small increase in pumping power. For this three dimensional numerical study was performed. Higher swirl flow causes high rotational speed which in turn causes high exchange of heat. With the increase in concentration, at a rotational speed of zero radian/sec, almost 16 % improvement was seen in convection coefficient.

Selimefendigil, F., & Öztop, H. F. [20] predicted the flow and heat characteristics for different variables like frequency, Re and concentration of Nano particles. Unsteady state conditions were adopted for the solution using FVM. Heat transfer augmentation was found from the results. The results were found better at a Reynolds number of hundred. Also the Nusselt number was augmented. Radwan, A. et al. [21] adopted a new scheme using MCHSWNF in case of LCPVT systems using aluminum oxide and silicon carbide with water as coolant. Numerical simulations were predicted to determine the cell efficiency. From the outcomes the use of Nano fluids determined to be very effective as compared to the without Nano fluids. This was dependent on the concentration ratio. Nineteen percent increase was predicted in the efficiency and the temperature was reduced to 311 K. Nakharintr, L., & Naphon, P. [22] proposed a heat sink with one jet for the scrutiny of features in terms of heat dissipation for the magnetic field applications. Brass was used for the modelling of thermal sink which was made using EDM for the specifications. Different concentration of titanium oxide particles was used with water for working fluid. Differentiation was made for the studies with and without magnetic field. Nusselt number escalated in the presence of magnetic field and this value increases with increase in the strength of field. Pressure fall not affected with the concentration of fluid. Ambreen, T. et al. [23] demonstrated the plots for temperature and streamlines in a heat sink with pin fin of micro nature along with Nano fluid. Fixed value of flux 300000 W/m^2 was applied at the bottom. It was concluded from the findings that for a constant value of drop in pressure, nanoparticles increased the heat dissipation. For 1% concentration almost 16 % improvement was marked in the value of h. On the upstream and downstream side non-uniform and uniform flow was spotted respectively.

Based on the literature it is noticed that no significant work has been made regarding the use of Nano fluid in combination with air foil pillars. So in the current investigation, a three dimensional model with the CuO Nano particles with 0.5 % concentration is used in conjunction with air foil pillars in a heat based sink to enhance the thermal and fluid characteristics.

GEOMETRICAL CONFIGURATION OF THE MODEL

The geometry of the model (JIHSWAPNF) is shown in the figure 1. Model has been designed for the heat sink with jet impingement. Airfoil pillars has been used to increase the rate of heat transfer. The model is first validated with the experimental results. [24,25]. The model has been used in two cases. First case with pure water and second case with water – CuO Nano fluid with 0.5 % concentration. Pitch ratio (ratio of pitch of jet and diameter of jet) and height ratio (ratio of channel height and diameter of jet) are taken as dimensionless variables for the evaluation and performance attributes of JIHSWAPNF.

RESULTS & DISCUSSION

The three dimensional model of heat sink with airfoil pillars has been utilized for the study based on the pure water and water – CuO Nano fluid with 0.5% concentration. Test based on the grid independence has been performed. The comparative execution has been carried out for the water and water CuO Nano fluid in terms of different characteristics parameters like RIMT, OPD, h, Nu, R_T and PP for PR at different values of HR. Four values of HR (1,2,3 and 4) has been taken for the performance evaluation. PR is varied from 6 to 12.

Figure 2 indicated the distinction in rise in maximum temperature (RIMT) with pitch ratio (PR). PR is varied as 6,8,10 and12. The same has been noticed for different values of height ratio (HR). HR is taken as 1,2,3 and 4. RIMT with PR for different values of HR has been compared for water and water –copper oxide (CuO) Nano fluid. The comparative analysis has been made for 0.5 % concentration. For HR = 1 and PR = 6, RIMT = 71.29 and 43.83 for water and Nano fluid respectively. For PR= 8, RIMT = 75.19 for water and 48.2 for Nano fluid. For PR= 10, RIMT = 86.4 for water and 54.53 for Nano fluid. For PR= 12, RIMT = 90 and 55, for water and Nano fluid respectively. As the PR grows, RIMT also grows. For HR = 2,3 and 4, RIMT has been observe in direct proportion with PR. The RIMT is lower in case of Nano fluid as compared to simple water. The same is due to the increase in the thermal conductivity of the working fluid (Nano fluid).

Figure 3 projects the interconnection between overall pressure drop (OPD) with pitch ratio (PR) for different values of height ratio (HR) for water and anno fluid. For HR = 1, PR= 6, OPD was found to be =4811 for water and 20524 for Nano fluid. At PR= 8, OPD = 4166 and 18208 for water and Nano fluid respectively. At PR= 10, OPD = 3553 for water and 17040 for Nano fluid. OPD = 3508 and 16213 for water and Nano fluid respectively corresponding to PR = 12 and HR =1. As PR increases, OPD decreases. For HR = 2 and PR =6, the value of OPD for water and Nano fluid is noticed to be 8069 and 66817 respectively. Similarly, at PR = 8, OPD = 7826 and 59478 for the water and Nano fluid. From the figure 3, it is recognized that with increase in PR for different values of HR, OPD decreases. Also OPD is noticed to be more in case of Nano fluid as compared to the water. The reason for the high pressure drop in Nano fluid is due to increased viscosity of Nano fluid as compared to water.

The interconnection of Heat Transfer Coefficient (h) with Pitch ratio (PR) for water and Nano fluid for various values of HR = 1,2,3 and 4 is projected in the figure 4. For HR = 1and at PR = 6, the value of h is to be noted as 14027 and 22815 for water and Nano fluid respectively. For PR = 8, h = 13299 and 20746 for water and Nano fluid respectively. For PR = 10, h = 11574 and 18338 for water and Nano fluid. Also h is observed to be 18000 for Nano fluid and 11111 for water corresponding to PR = 12. For HR =2, PR= 6, value of h= 20000 and 43122 for water and Nano fluid respectively. For water as the value of PR is increased, h is decreased for constant values of HR. In case of Nano fluid also with increase in PR, h is decreased. The maximum value of h = 36900, at HR= 4 and PR= 6 in case of water while in case of Nano fluid extreme value of h = 62972 at HR = 4 and PR = 6. So the higher value of h is noted in case of Nano fluid as compared to water. The higher value of the h is justified because of the increase in the velocity. Since for a constant Re, viscosity of Nano fluid is more than water, which causes higher velocity of Nano fluid.

In figure 5, the interrelation between Nusselt Number (Nu) and Pitch ratio (PR) is deduced for four different values of height ratio (HR) using water and the same has been compared with the case using Nano fluid as working fluid. For HR = 1, at PR =6, the value of Nu is noticed to be 8.871 for water and 14.93 for Nano fluid. As the value of PR is increased from 6 to 8, Nu is detected to be 8.4 for water and 13.58 for Nano fluid. At PR = 10, the value of Nu is 12 and 7 in case of Nano fluid and water respectively. Nu = 11, at PR= 12 which is higher as compared to Nu = 7 in case of water. For HR = 2, Nu = 6 for water and 14.11 for Nano fluid corresponding to PR = 6. From the figure 5 it is clear that as PR is increased from 6 to 12, Nu gets decreased for both water and Nano fluid. The maximum value of Nu is detected to be 14.93 in case of Nano fluid and the minimum value of Nu is 4.15 in case of water.

The correlation between the thermal resistance (R_T) and pitch ratio is shown in the figure 6. The correlation was discussed for PR values from 6 to 12 at constant values of HR = 1,2,3 and 4 for the water and Nano fluid. AT HR = 1 and PR = 6, R_T is noticed to be 0.0035 and 0.0021 for water and Nano fluid respectively. Lower value of R_T is noticed in case of Nano fluid with 0.5 % concentration. For PR= 8, R_T is detected to be 0.00241 for 0.5 % concentration and 0.00375 for water. R_T = 0.00272 and 0.00432 at PR = 10 in case of Nano fluid and water respectively. Similarly, at pitch ratio = 12, the value of resistance is noted to be 0.0028 in case of 0.5 % concentration and 0.0045 in case of pure water. As the value of PR is increased, increasing trend is seen for resistance in both the cases with water and Nano fluid.

Figure 7 presents the relation between pumping power (PP) and pitch ratio for different value of height ratio (1,2,3 and 4). At HR = 1 and PR = 6 for water the value of pumping power is found to be 0.00044. For the same condition PP = 0.0028 in case of Nano fluid. At HR= 1 and PR = 8, PP = 0.00036 and 0.00239 for water and Nano fluid respectively. PP = 0.000294 and 0.0021 at HR= 1, PR = 10 For water and Nano fluid respectively. AT HR = 1, PR = 12, PP is noted to be 0.0002838 and 0.001987 for simple water and Nano fluid respectively. Higher value of pp is found in case of Nano fluid which is due to the increase in the velocity and frictional resistance. Figure 8 presents the fashion of streamlines corresponding to PR =6 and HR= 1 in case of water – CuO Nano fluid. The fashion of streamlines before and after the jet position is represented. The fashion of stream lines gets affected in the vicinity of jets. Vortices have been noted after the jet.

In the figure 9, for the water and CuO Nano fluid the velocity vector is represented for PR= 8 and HR = 1. The magnitude of velocity is also shown in the contours. The maximum and minimum value is shown in the figure. Figure 10 and figure 11 represents the temperature contours in case of water and Nano fluid. The same has been presented for the same conditions (HR = 1 and PR = 6). The temperature of the substrate is reduced with the use of Nano fluid. The temperature is reduced from 384.3 in case of pure water to 356.8 in case of Nano fluid.

CONCLUSION

The model of JIHSWAPNF is investigated for different response parameters with design parameter pitch ratio corresponding to height ratio for water and water – CuO Nano fluid. The analysis was executed for 0.5 % concentration. Following conclusions can be drawn from the results.

1. With the use of water – CuO Nano fluid the temperature of the substrate base is reduced in differentiation with the pure water case. Maximum reduction in temperature is deduced at PR = 6 and HR = 2.
2. Coefficient of heat transfer is increased in case of 0.5% concentration of Nano fluid as compared to the pure water case. Highest surge is noticed at HR = 2 and PR =6 combination. Almost 28.2 % enhancement is detected.
3. Nusselt number is also increased in case of water – CuO Nano fluid in differentiation to pure water. Also the highest value of Nu is deduced at PR = 6 and HR= 2.
4. Thermal resistance is lower in case of water – CuO Nano fluid as compared to pure water. Maximum reduction in thermal resistance is detected at PR = 6 and HR = 2.
5. Pumping power and drop in pressure is surged in case of water – CuO Nano fluid.

Conflicts of Interest Disclosure Statement

The authors declare no conflict of interest in the authorship or publication of this work. The authors declare no sponsored financial sources for the undertaken study.

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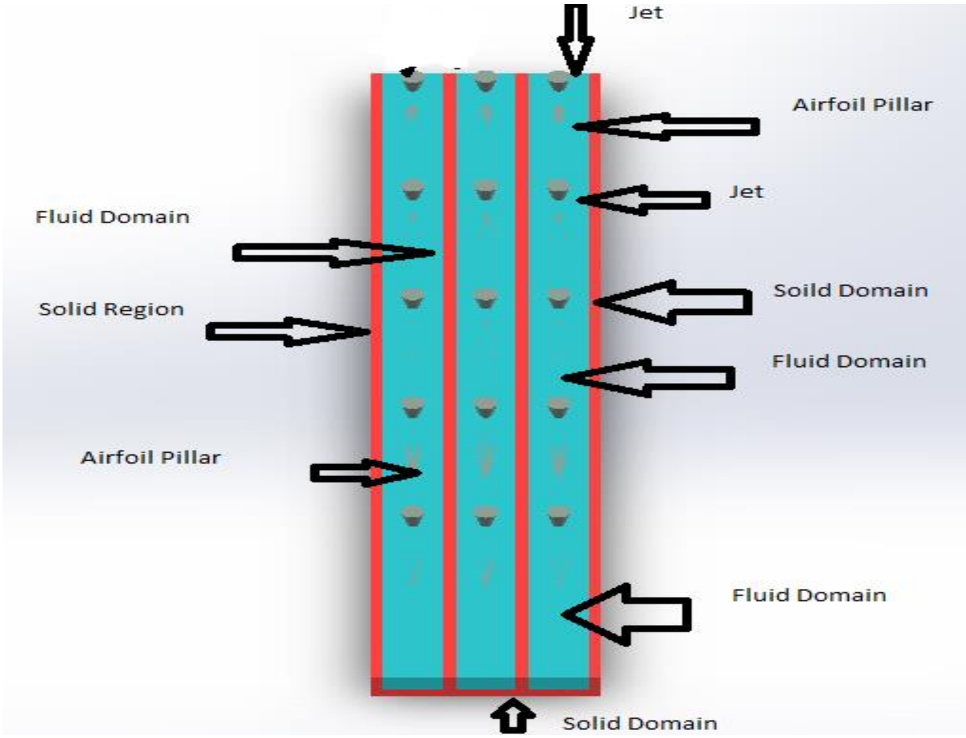

Figure – 1: Model under Investigation

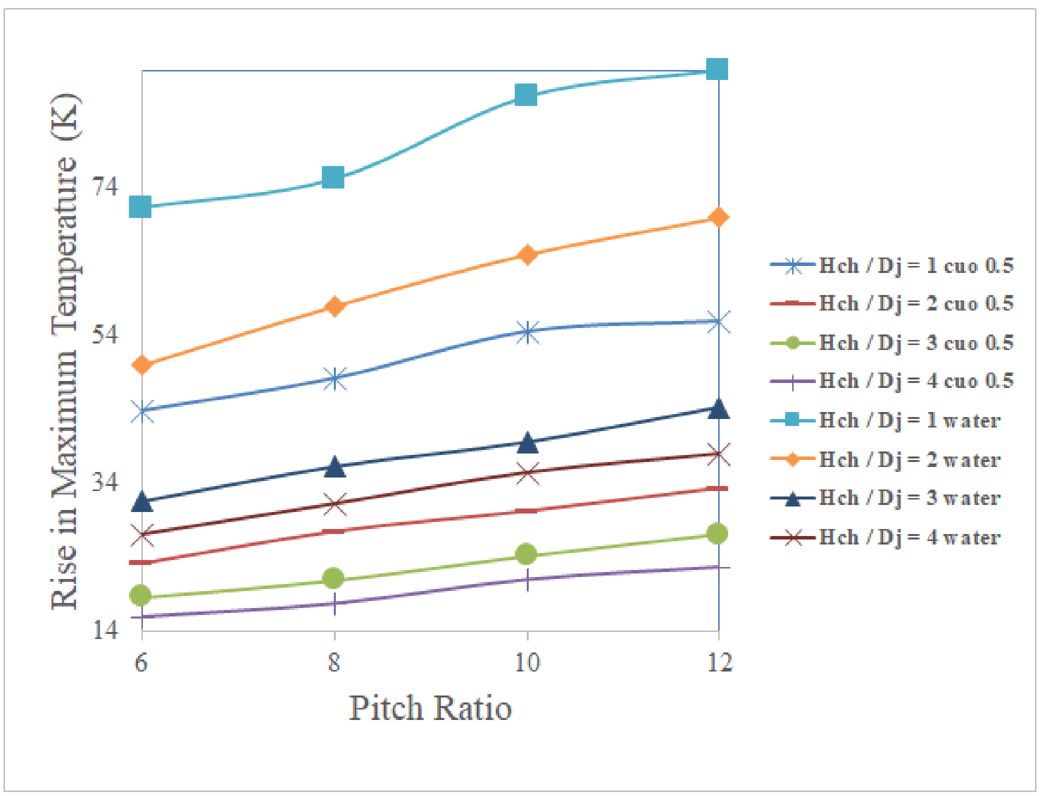

Figure 2: RIMT Vs PR

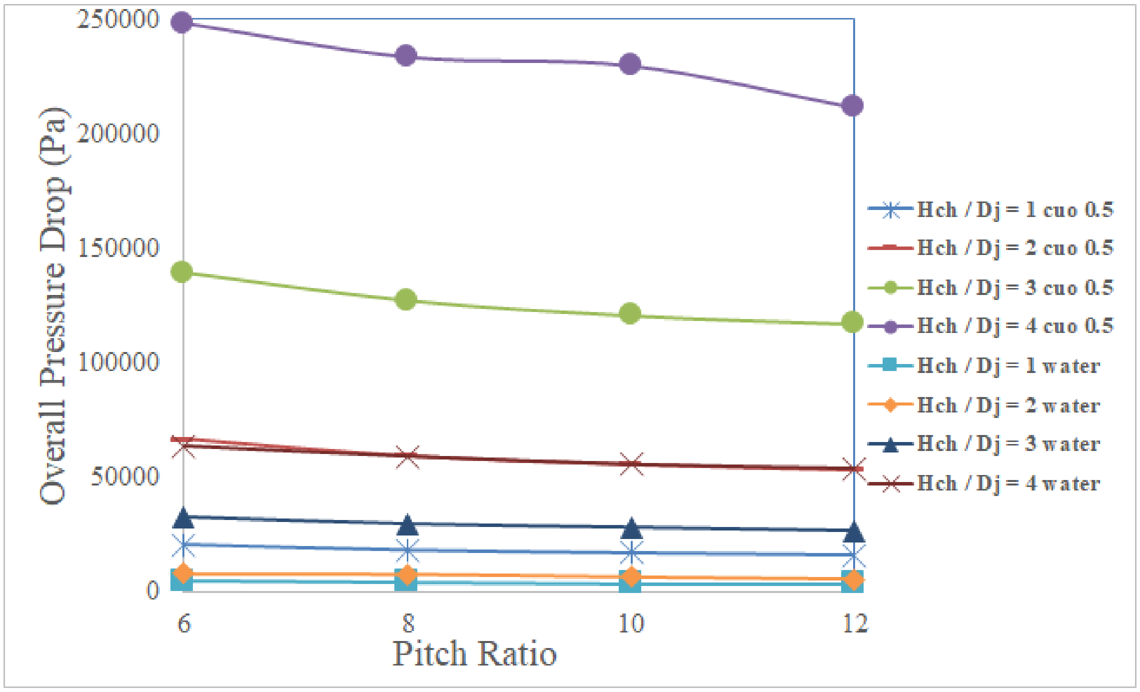

Figure 3: OPD Vs PR

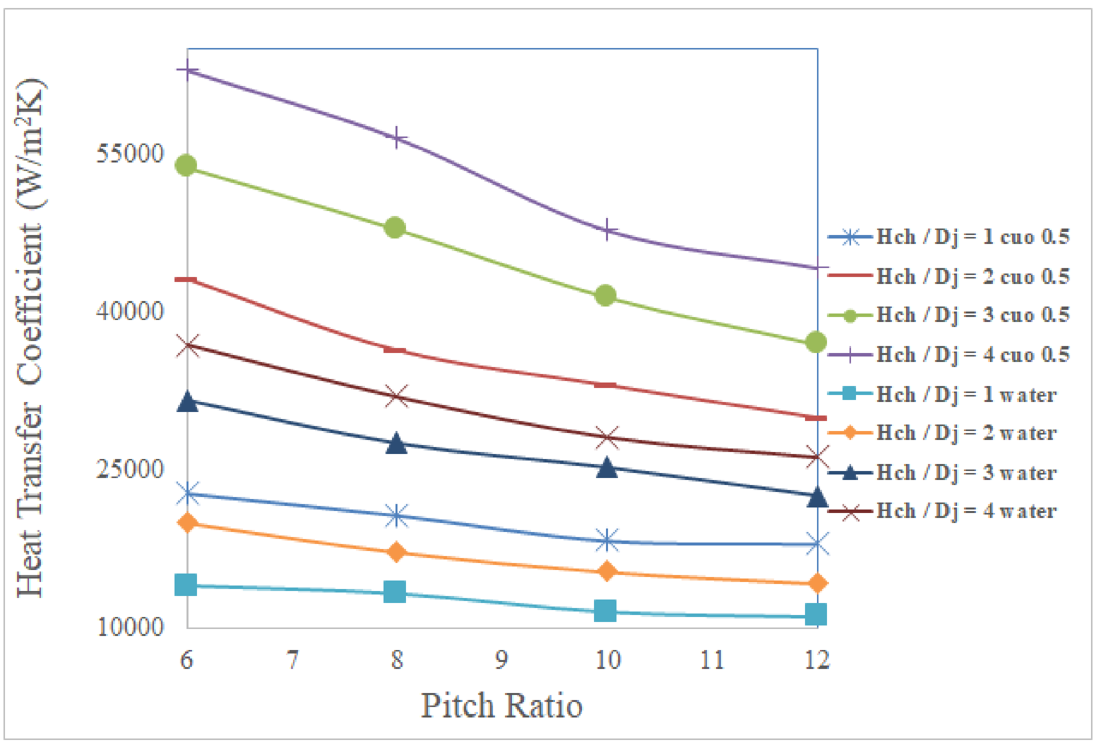

Figure 4: h Vs PR

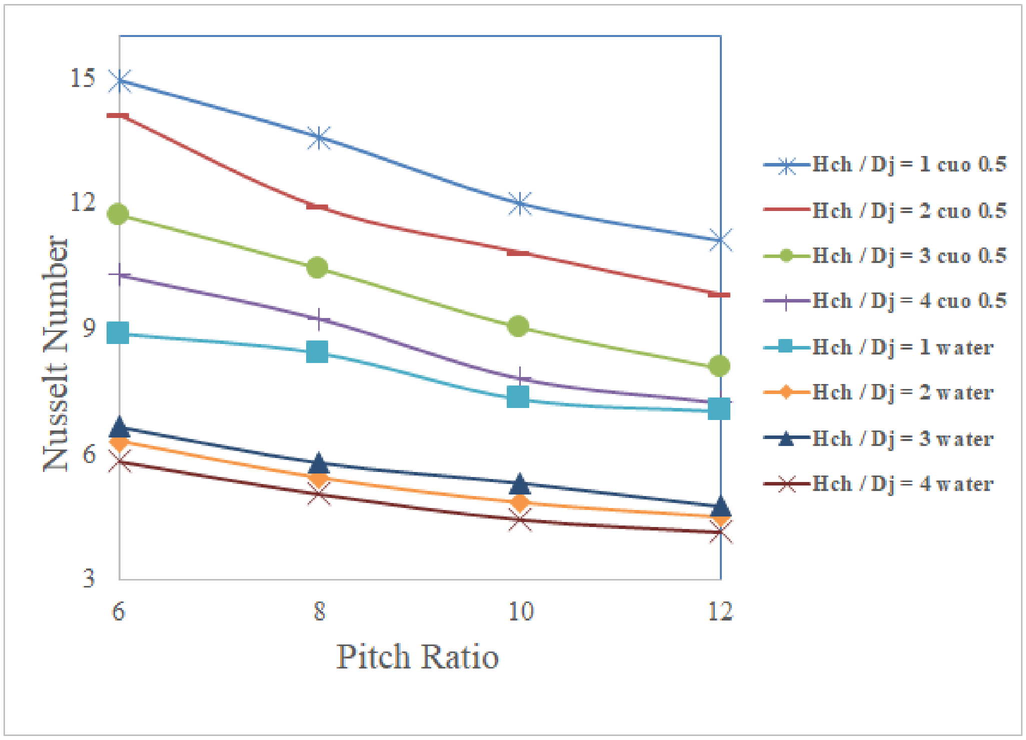

Figure 5: Nu Vs PR

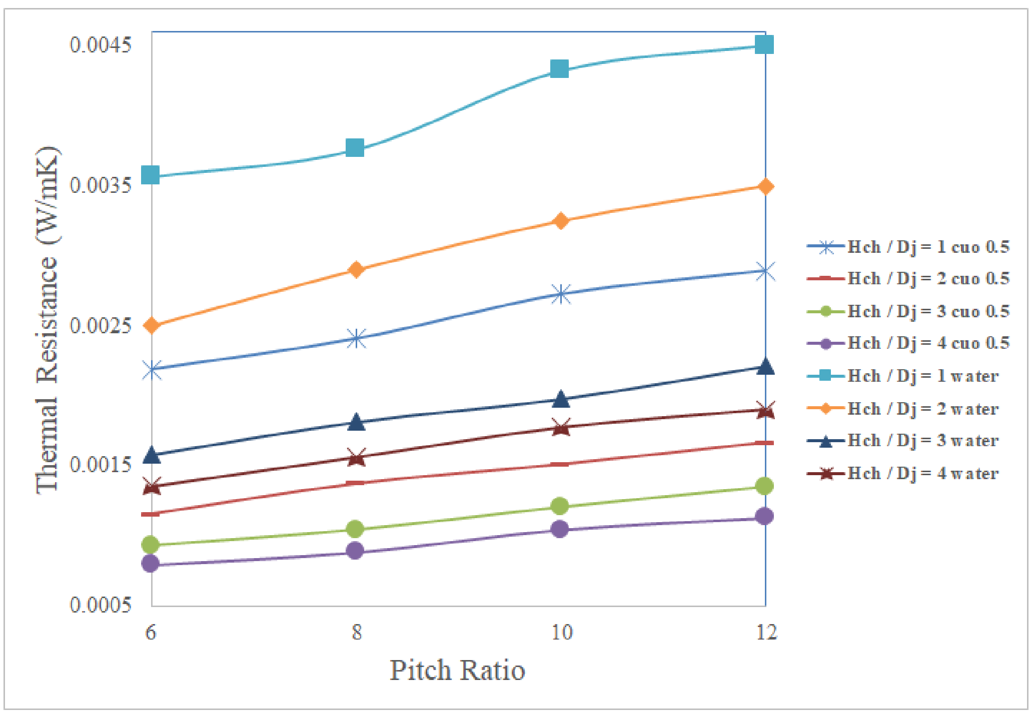

Figure 6: R_T Vs PR

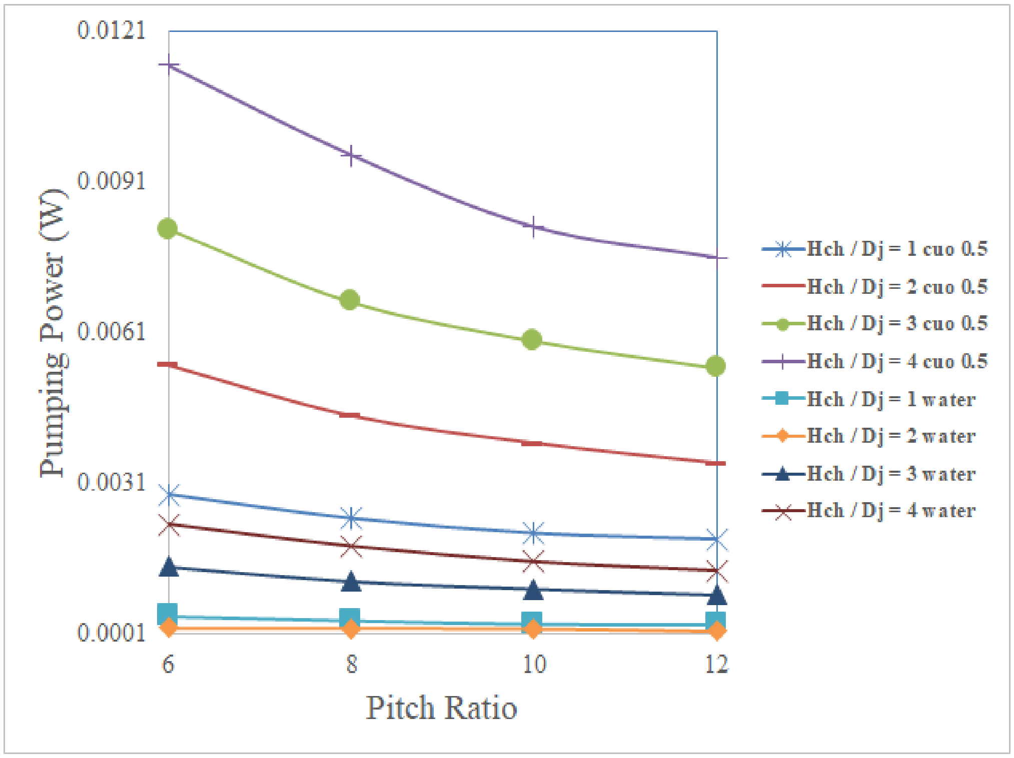

Figure 7: PP Vs PR

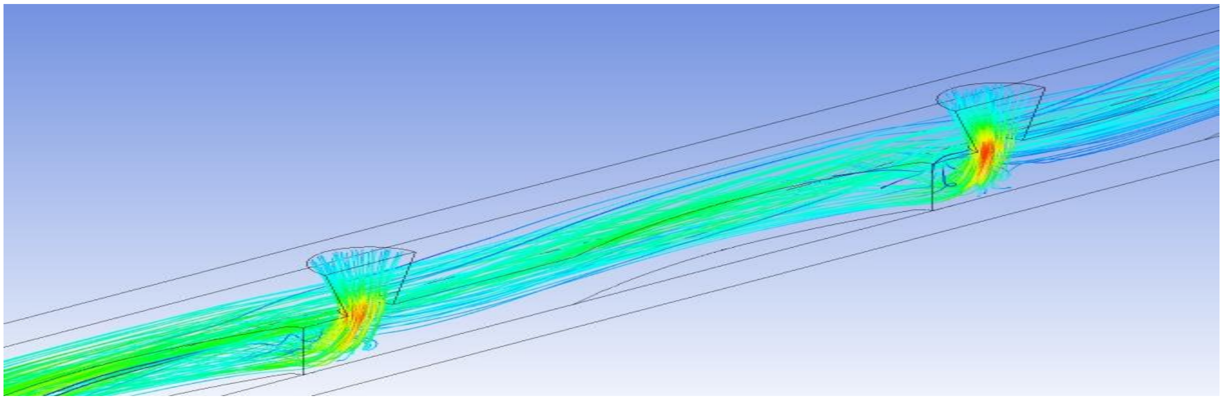

Figure 8: Streamlines at PR = 6, HR = 1

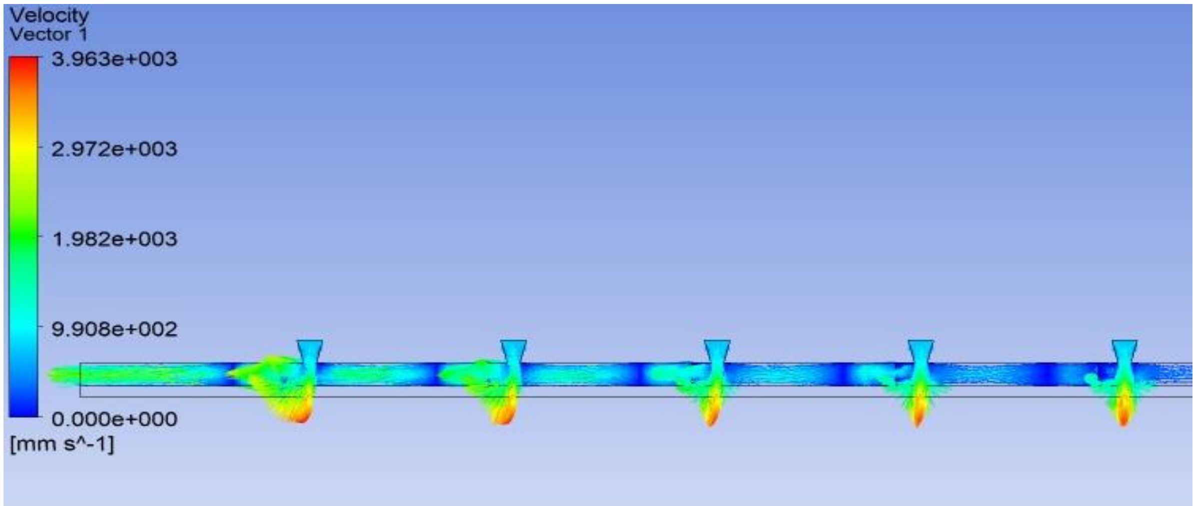

Figure 9: Velocity Vector at PR = 8, HR = 1

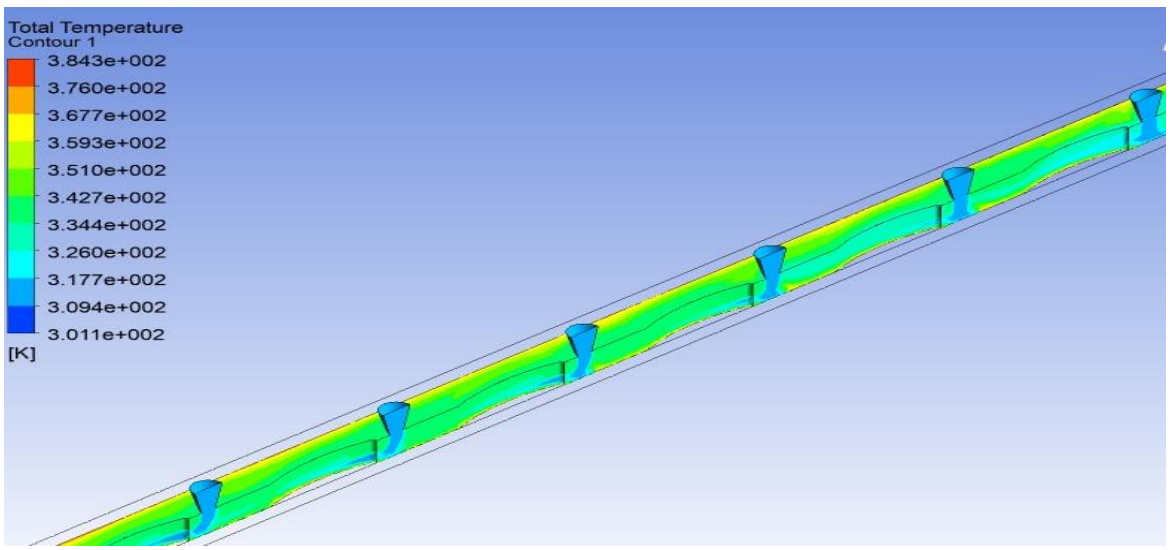

Figure 10: Temperature contour at PR = 6, HR = 1 for water

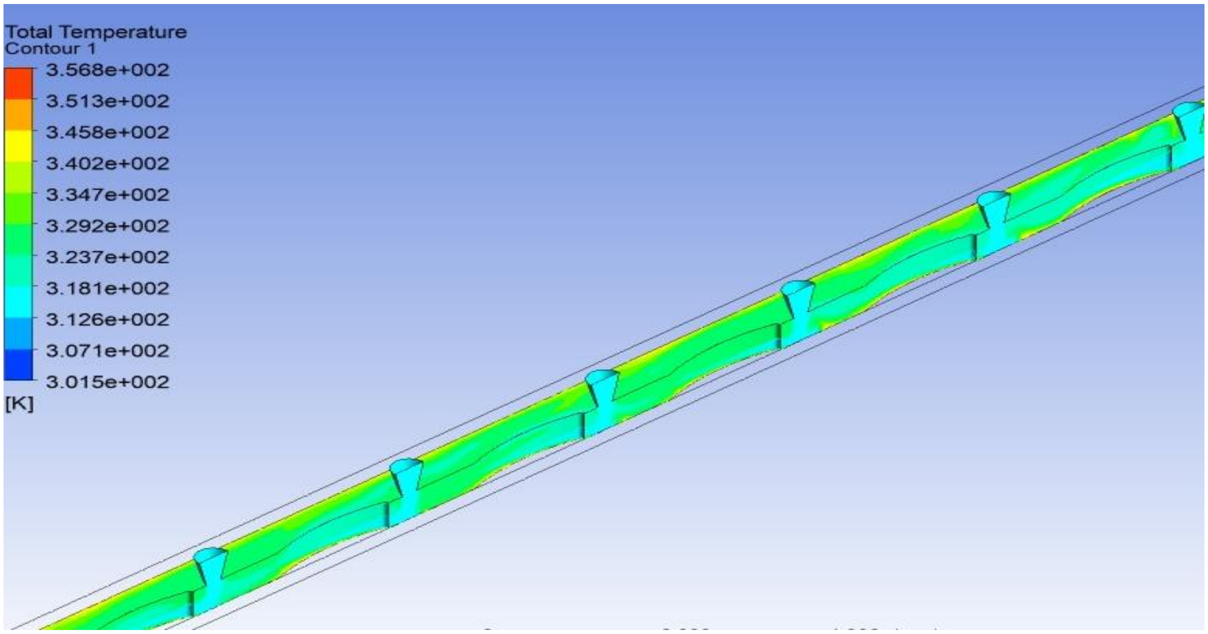

Figure 11: Temperature contour at PR = 6, HR = 1 for Nano fluid

Nomenclature

D_j	Diameter of jet	D_{pr}	Diameter of pillar
Dr	Darcy number	Gr	Grashof's number
h	Coefficient of Heat Transfer	H_{ch}	Height of Channel
K	Thermal Conductivity	Nu	Nusselt Number
Pr	Prandtl number	Pt	Jet pitch
R_e	Reynolds Number	R_T	Thermal Resistance
ρ	Density of fluid	μ	Dynamic Viscosity
$\frac{Pt}{D_j}$	Pitch ratio	$\frac{H_{ch}}{D_j}$	Height ratio

Abbreviations

FVM	Finite volume method
GNP	Graphene Nano plates
GWR	Galerkin weighted Residual
HR	Height ratio
JIHSWNF	Jet impingement heat sink with Nano fluid
JIHSWAPNF	Jet impingement heat sink with airfoil pillars and Nano fluid
MCHSWNF	Microchannel heat sink with Nano flu
OPD	Overall pressure drop
PCM	Phase change material
PP	Pumping power
PR	Pitch ratio
RIMT	Rise in maximum temperature
CFD	Computational fluid dynamics