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Numerical Investigation and Heat Transfer Enhancement of DPHE With Louvered Strip Inserts By Using Metal Oxide Nanofluids.

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Abstract: Thermal conductivity is considered important factor for rapid cooling and heating application. Base heat transfer fluid normally having low thermal conductivity (K), so we preferred Nano fluid for increasing the heat transfer rate. Thermal conductivity of base fluid is increased with increasing concentration of metal particles within critical limit. Thermal conductivity is affected by the following parameters like shape, size, clustering, collision, porous layer, melting point of nano particle etc. In this project, we will use the effect of using louvered strip inserts placed in a circular double pipe heat exchanger on the thermal and flow fields utilizing various types of nanofluids is studied numerically. Two different louvered strip inserts arrangements (forward and backward) are used in this study. The effects of louvered strip inserts is studied by considering the boundary conditions i.e., thermal insulation around outer pipe, gravity effect is negligible and thermophysical properties of fluids are constant Four different types of metal oxide nanoparticles like Al_2O_3, SiO_2, CuO and ZnO with different volume fractions in the range of 1% to 3% are used as the nanoparticles which are dispersed in the base fluid (water). The heat transfer enhancement resulting from various parameters such as nanofluid types, nanoparticle volume fraction, types of inserts, and material used for fabricating the DPHE. Simulation of DPHE with louvered strip is carried out by designing the model in Creo 2.0 (formerly PRO-E) and then exporting the file model to ANSYS R14.5 software where fluid flow simulation is carried out in FLUENT model. Thermophysical properties of nanofluids for different volume fractions, which are used for simulation process is obtained by numerical model. Governing equations like energy equation and K-epsilon 2nd equation for viscous model is used for simulation. Simulation results will show the increase in Heat transfer rate (W), Nusselt number (Nu), Skin friction coefficient (C_f), Heat transfer coefficient (h) and temperature (K) at the outlets of hot and cold fluid is obtained for different volume fractions of metal oxide Nanofluids.

Keywords: DPHE, Nanofluid, Volume Fraction, Heat transfer rate, Skin friction coefficient, Nusselt number, heat transfer coefficient, Thermal conductivity, Temperature and Louvered strip inserts.

1.Introduction

Heat exchangers are widely used in industrial and engineering applications. The reason towards that is not only an accurate assessment of the long-term performance and the regarding financial costs is needed, but a comprehensive investigation of heat transfer, pressure drop, and the effectiveness is also inevitable which all require arduous work. Upon using heat transfer enhancement methods, pressure drop will also be increased which results in a higher pumping power. So, it is firmly stated that some of these heat transfer enhancement methods may just adversely affect the need to an optimum case containing the heat transfer rate and pressure drop. As a result, choosing the methods wisely is of great importance. The engineering cognizance of the necessity to extend the thermal performance of heat exchangers, thereby effecting energy, material, and price

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savings further as an of import mitigation of environmental degradation had led to the event and use of the many heat transfer improvements techniques. Enhancements techniques basically scale reduce thermal resistance during a typical device by promoting higher convective heat transfer constant with or without surface area will increase (as represented by fins or extended surfaces). Forced convection heat transfer in a circular tube had been a subject of interest in many research studies over the past decades. In terms of reducing the size and the cost of the heat exchanger devices and saving up the energy, many engineering techniques had been devised to enhance the heat transfer rate from the wall in heat exchangers. One of these heat transfer enhancement techniques is the passive method. This method includes the insertion of louvered strip and twisted tapes, turbulent/swirl flow devices, coil wire and helical wire coil in a circular tube. In this study, we use louvered strip inserts to enhance the performance of heat exchanger and metal oxides like Al_2O_3, SiO_2, CuO and ZnO with different volume fractions in the range of 1% to 3% are used as the nanoparticles which are dispersed in the base fluid like water.

2. Literature Review

Eiamsa-ard et al. [1] investigated experimentally the impact of louvered strip inserts in a double pipe heat exchanger on heat transfer and pressure loss under turbulent flow. Experimental results show that the utilization of louvered strips led to a higher heat transfer rate over the plain tube. And, also investigated experimentally the heat transfer and the pressure drop characteristics in a circular tube fitted with regularly spaced twisted tape elements. The results show that the use of small value of space ratio (S) provided higher heat transfer rate than that of large value of space ratio (S). And, also investigated experimentally the effect of twist- ed tape (TT) with serrated twisted tape (STT) on the heat transfer and pressure drop in a constant heat flux tube with air as a working fluid. The thermal performance factor of the tube with (STT) was found to be better than that of the tube with (TT). Torii et al. [2] studied numerically by using finite difference methods the effect of louvered fins on the heat transfer and air laminar flow distribution. It was found that the heat transfer performance became larger in the high Reynolds number region, different heat transfer rates yielded at both side walls of the louvered fin rear the plate.

Mohammed et al. [3] studied numerically the effect of louvered strip insert installed in a circular double heat exchanger on thermal and flow characteristics using various types of nanofluids. The combination of various slant angle and pitch was investigated in this study. The results show that combination of the highest slant angle (α) of 30° and lowest pitch (S) of 30 mm can promote the heat transfer by approximately 367%–411% over the plain tube. The higher slant angle generates a strong turbulence intensity leading to rapid mixing of the flow. The effects of the louver and delta winglet geometry on the thermal- hydraulic performance of such a compound heat exchanger were performed by Huisseune et al. [4]. A small fin pitch and large louvered angle promote a strong flow deflection and thus has a large contribution of the louvers. The influences of a modification of small pipe insert with various spacer lengths and arc radii with different slant angle on heat transfer enhancement, flow resistance and thermal-hydraulic performance were experimentally studied by Wenbin et al. [5]. A small pipe was formed into an S-shape and installed on a core rode. Tubes fitted with pipe inserts affect the heat transfer coefficient and friction factor. Review article on heat transfer enhancement by using various types of inserts was developed by Tabatabaeikia et al. [6]. The present work investigates the flow of nano fluids (i.e., CuO, ZnO, Al_2O_3, SiO_2) with the base fluid as water (H_2O) at different volume fractions (i.e., 1%, 2%,and 3%) for forward arrangement and backward arrangement of Louvered strips.

3.Calculations of thermophysical properties for Nanofluids

The thermophysical properties of different Nanoparticles are tabulated in the below table 1:

Table 1: thermophysical properties of H_20 and nano particles.

Thermo-physical properties	Water	Al_2O_3	SiO_2	CuO	ZnO
Density **ρ**(kg/m3)	998.2	3600	2200	6500	5600
Dynamic viscosity, **μ**(Ns/m2)	1.00E-03	0	0	0	0
Thermal conductivity, **k**(W/mK)	0.6	36	1.2	20	1.3
Specific heat, **C_P**(J/kg.K)	4182	765	703	535.6	495.2

To find out the volume fraction of nano particles in the nanofluids is done based on mass fraction. The volume fraction is found by the following formulae equation.

$$\varphi_v = \frac{V_{np}}{V} = \frac{V_{np}}{V_{np}+V_{bf}} = \frac{\frac{m\varphi_m}{\rho_{np}}}{\left(\frac{m\varphi_m}{\rho_{np}}+\frac{m(1-\varphi_m)}{\rho_{bf}}\right)} = \frac{\varphi_m}{\rho_{np}\left(\frac{\varphi_m}{\rho_{np}}+\frac{(1-\varphi_m}{\rho_{bf}}\right)}$$

where, φ_v and φ_m are the volume and mass fraction respectively, ρ_{np} and ρ_{bf} are the density of nano particles and base fluids respectively, V_{np} and V_{bf} are the volumes of nano particles and base fluid, V is the volume of the total mixture and m is the mass of the total mixture.

The thermophysical properties of nanofluids used in this study were obtained using the following equations:

The density of nanofluid, ρ_{nf} can be obtained from the following equation 1:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np}$$

The effective specific heat at constant pressure of nanofluid can be calculated from the following equation 2 shown below:

$$\left(C_{p_{nf}}\right) = (1-\varphi)C_{p_{bf}} + \varphi C_{p_{np}}$$

Where, $C_{p_{nf}}$ is specific heat at constant pressure of nanofluid, $C_{p_{bf}}$ and $C_{p_{np}}$ respectively, are the specific heat at constant pressure of base fluid and nano particles. φ is the volume fraction.

The effective thermal conductivity can be obtained by using the following mean empirical correlation. Then effective thermal conductivity is given below in equations:

$$K_{eff} = K_{static} + K_{brownian}$$

$$K_{static} = K_{bf} * \left\{\frac{\left(K_{np}+2K_{bf}\right)-2\varphi\left(K_{bf}-K_{np}\right)}{\left(K_{np}+2K_{bf}\right)+\varphi\left(K_{bf}-K_{np}\right)}\right\}$$

$$K_{brownian} = 5 * 10^4 * \left(\beta * \varphi * \rho_{bf} * C_{p_{bf}}\right) * \sqrt{\frac{k * T}{2}} * f(T, \varphi)$$

Where,

$$f(T, \varphi) = \{(2.8217 * 10^{-2} * \varphi) + 3.917 * 10^{-3}\}\left(\frac{T}{T_A}\right) + \{(-3.0669 * 10^{-2} * \varphi) - 3.3991123 * 10^{-3}\}$$

The values for β in the Brownian thermal conductivity are taken from the below table 1 for different nanofluids and its volume fractions.

Table 2: Values of β for different nanofluids [1]

Nano particles	β	φ concentration (%)	Temperature (K)
AL_2O_3	$8.4407(100\phi)^{-1.07304}$	$1\% \leq \varphi \leq 10\%$	$298\ K \leq T \leq 363\ K$
CuO	$9.881(100\phi)^{-0.9446}$	$1\% \leq \varphi \leq 6\%$	$298\ K \leq T \leq 363\ K$
SiO_2	$1.9526\ (100\phi)^{-1.4594}$	$1\% \leq \varphi \leq 10\%$	$298\ K \leq T \leq 363\ K$
ZnO	$8.4407(100\phi)^{-1.07304}$	$1\% \leq \varphi \leq 7\%$	$298\ K \leq T \leq 363\ K$

The effective viscosity of nano fluid can be obtained by using the following mean empirical correlation. Then the effective viscosity is given in the following equation 3:

$$\mu_{eff} = \mu_{bf} * \left(\frac{1}{1 - 34.87 * \left(\frac{d_{np}}{d_f}\right)^{-0.3} * \emptyset^{1.03}}\right)$$

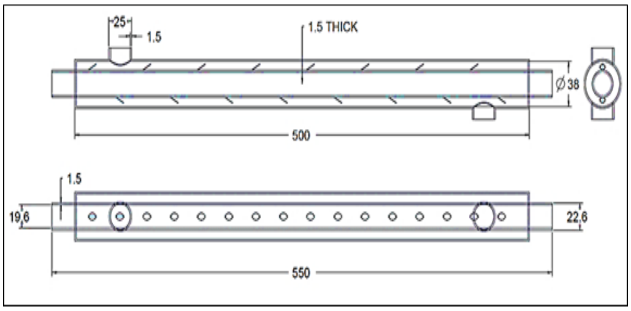
Where,

$$d_f = \left(\frac{6M}{N\pi\rho_{bf}}\right)^{1/3}$$

M is the molecular weight of base fluid, N is the Avogadro number = 6.022*1023 mol^{-1}, ρ_{bf} is the mass density of the based fluid calculated at temperature T_0=293 K.

4. Modelling and Analysis of DPHE with Louvered strips

Two-dimensional view of DPHE's with louvered strips is designed in solid works. The below figure 1a represents the front, top and side view of DPHE's with forward arrangement of louvered strips making slant angle α=30° and pitch between two strips is 40 mm. Same as the above geometry repeat the procedure with the backward arrangement of louvered strips, the length of the inner tube is 550mm and length of outer tube is 500mm. The diameter(D_1) of inner tube is 19.6 mm, and the diameter(D_2) of the outer tube is 38mm. Thickness of each tube is taken as 1.5mm. the length of louvered strip is 10mm and the width of the louvered strip is 6mm. slant angle α=30° and pitch between two strips is taken as 40mm. The below figure 1b represent the geometry of DPHE with backward arrangement.



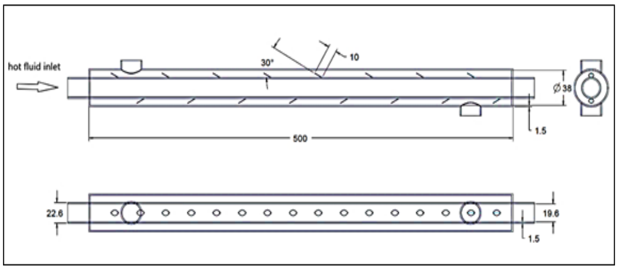
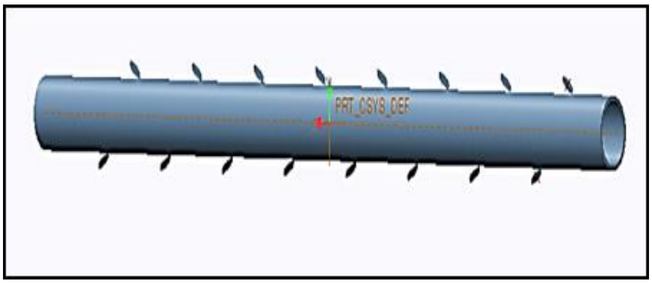


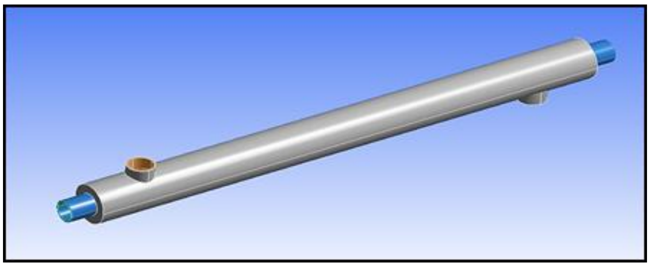
Figure 1: a) & b) Diagram of DPHE with Backward and forward arrangement of louvered strips.

4.1 3D Model and Meshed Geometry

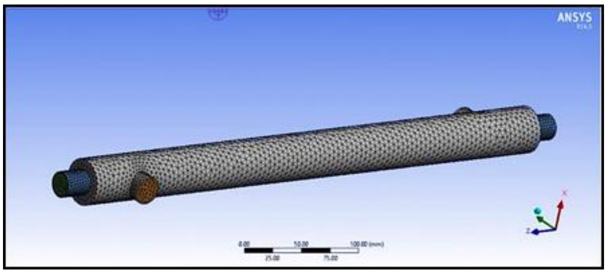
The DPHE with louvered strip inserts model that is generated in Creo 2.0 is then converted into Initial Graphics Exchange Specification (IGES) format because, model can be import in to Ansys. For CFD simulation of DPHE is done on ANSYS FLUENT R14.5 software. In Ansys software R14.5 version on opening the workbench of the Ansys and selecting the analysis system as fluid flow (FLUENT) model to simulate the DPHE. In fluid flow model geometry section import the Creo 2.0 converted model by browsing the file location and double click on the file and importing of file to Ansys is done successfully. The figure 3.13 shows the fluid flow (fluent) tab analysis system overview.



(a)



(b)



(c)

Figure 2: a) No. of strips created on the hot pipe by using pattern tool on both sides, b) Imported DPHE model from Creo 2.0 in Ansys R14.5, and c) Meshed geometry of DPHE of louvered strips

Hexagonal fine mesh for effective simulation or finite element analysis (FEA) purpose and select the inflation layer and give it to the inner pipe of the DPHE as 2 layers for water and solid interface and also provide the details of no of divisions and click on generate the mesh. The results show that it obtained 380253 nodes and 298520 elements by considering the minimum size is 0.13mm, maximum size is 2mm. the final generated meshed geometry is shown in the figure 2c.

4.2 Boundary Conditions

After the model, next step is selection of materials. In material, select the contact region of DPHE and specify the material as copper alloy (C70600) and specify the properties of material i.e., density of material as 8978 kg/m^3, Specific heat of the material as 381 J/kg.k, and thermal conductivity 387.6 W/m-k. After specifying the material and its properties. Now, select the hot fluid (Nanofluid) material and its properties in the fluid selection tab. Here we select the nanofluids such as Al_2O_3, SiO_2, CuO, and ZnO in each case for simulation and specify properties for every volume fractions. Also,

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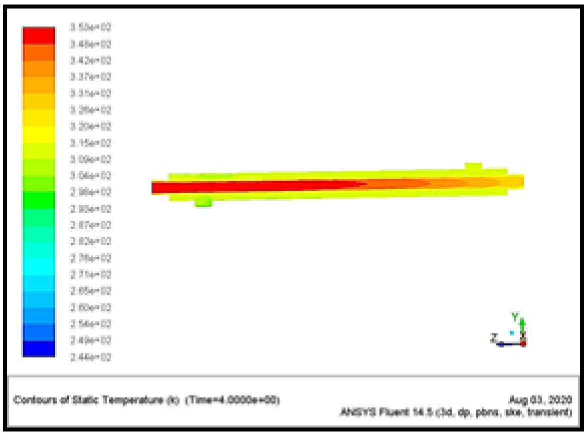
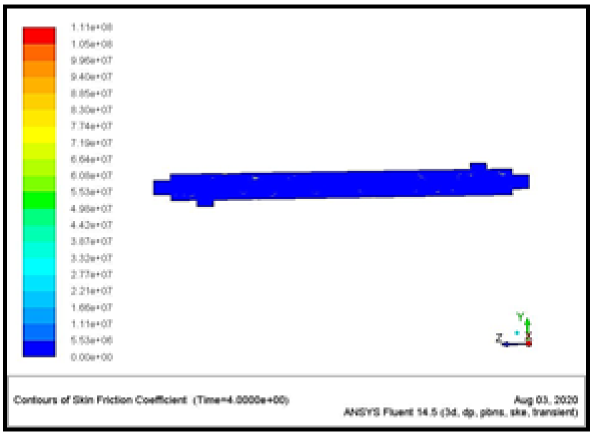
specify the density, effective specific heat, effective thermal conductivity, and effective viscocity of the nanofluids. Now select the boundary conditions options and select inlet and specify the mass flow specification as "Mass flow rate" and specify whether it is a hot fluid or cold fluid inlet and mention the mass flow rate as 0.099 Kg/sec and mention the inlet temperature of cold fluid and hot fluid in 353Kelvin (K). Similarly, mention the mass flow rate of cold fluid inlet as 0.103Kg/sec and specify the temperature of cold inlet in 298 kelvin degrees. Then run the solution for the above DPHE model.

5 Simulation Results

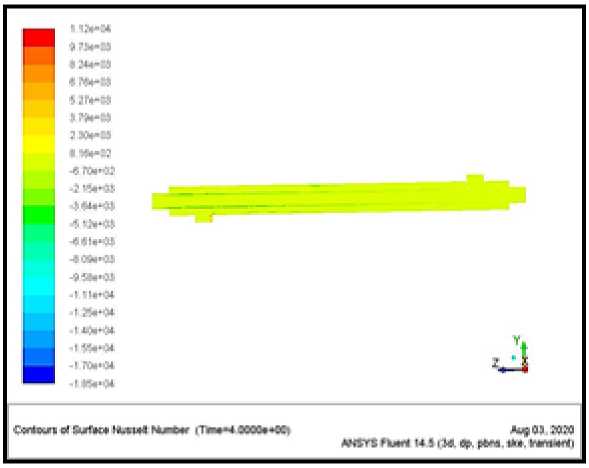


(a)



(b)

(c)

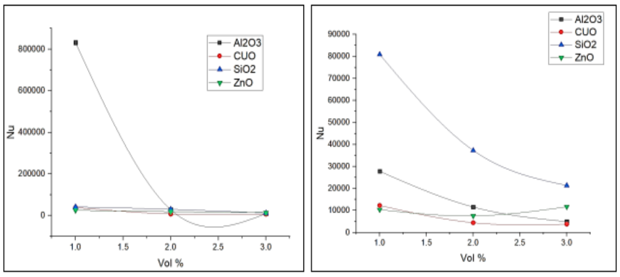


(d)

Figure 3: a) Contours of static Temperature (T), b) Contours of skin friction coefficient (C_f), c) Contours of Heat transfer coefficient (h) and d) contours of surface Nusselt number at 3% volume fraction of Al_2O_3 Nanofluid.

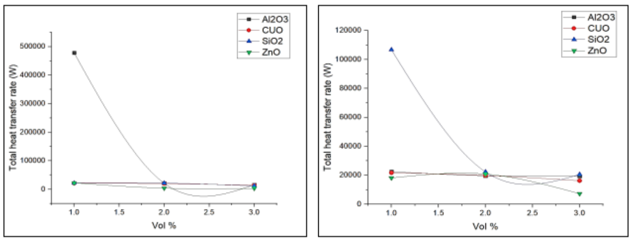
Similarly, the simulation results for SiO2 CuO, and ZnO for 1%, 2% and 3% volume fractions are represented in following Graphs for forward and backward arrangement and temperature at the outlets.

5.1 Graphical results



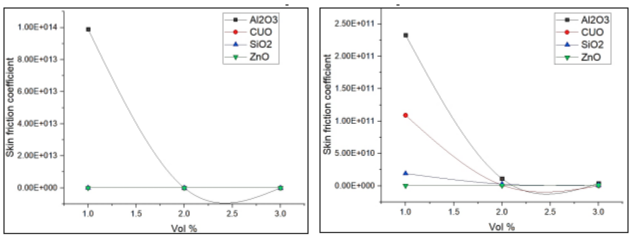
(a) (b)

Graph 1: Comparison of different volume fraction of nanofluids with Nusselt number – (a) forward arrangement and (b) backward arrangement of louvered strip in DPHE.



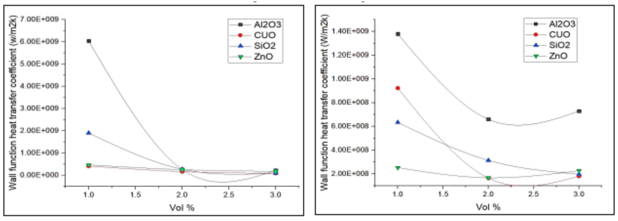
(a) (b)

Graph 2: Comparison of different volume fraction of nanofluids with Total heat transfer rate (W) – (a)forward and (b) backward arrangement of louvered strip in DPHE.



(a) (b)

Graph 3: Comparison of different volume fraction of nanofluids with skin friction (Cf) – (a) forward and (b)backward arrangement of louvered strip in DPHE.



(a) (b)

Graph 4: Comparison of different volume fraction of nanofluids with wall function heat transfer coefficient [h] (w/m2k) – (a) forward and (b) backward arrangement of louvered strip in DPHE.

The maximum outlet temperature of cold fluid is maximum for 3% volume fraction of CuO nanofluid for forward arrangement of louvered strips and very less temperature difference between hot outlet and cold outlet is obtained at backward arrangement of louvered strips at 3% volume fractions. Later Al_2O_3 has the highest temperature outlet of cold fluid.

The maximum Nusselt number is obtained for Al_2O_3 such that higher the Nusselt number higher is the heat transfer between hot fluid and cold fluid. The maximum heat transfer rate is for Al_2O_3 at 3% volume fractions for backward arrangement. There is a less Temperature difference between cold and cold fluid in case of Al_2O_3 Nanofluid.

Table 5: Temperatures of hot and cold fluid for forward and backward arrangement

		Temperature (K) at outlets			
Nano fluid	Volume fraction (φ)	Forward arrangement		Backward arrangement	
		Cold outlet	Hot outlet	Cold outlet	Hot outlet
Al_2O_3	1	310	334	312	330
	2	312	328	315	326
	3	315	324	318	321
CuO	1	314	332	315	329
	2	317	330	318	327
	3	320	328	319	326
SiO_2	1	309	328	304	331
	2	313	326	309	328
	3	315	322	310	326
ZnO	1	304	336	306	333
	2	306	332	308	330
	3	308	327	311	329

6. Conclusion

From the results, the following conclusions are drawn from the above work.

1. Al_2O_3 at 3% volume fraction at the backward arrangement gives more heat transfer rate and less difference between

hot and cold fluid. Lesser the difference between cold and hot fluid more is heat transfer rate (w) between two fluids. The maximum heat transfer is obtained at the backward arrangement of DPHE by using Al_2O_3

2. The temperature outlet for the cold fluid is maximum for CuO nanofluid at 0.3% volume fraction due to its thermal conductivity at forward arrangement and very less difference is obtained at backward arrangements. Later Al_2O_3 has next highest temperature outlets found from the results. SiO2 and ZnO are follows the Al_2O_3
3. The maximum heat transfer rate (W), wall function heat transfer coefficient (h), skin friction coefficient (C_f) and Nusselt number (Nu) for the Al_2O_3 nanofluid is also obtained at 0.1% volume fraction at both backward and forward arrangements when compared with other nanofluids and volume fractions.

From above discussions it is concluded that Al_2O_3 and CuO nanofluids are preferred for DPHE for maximum heat transfer rate and it also depends up on the thermal conductivity (K) material used for fabricating the DPHE. Plethora of factors that affect the performance of the DPHE. Replacement of base fluid Water with 1-3% of Nanofluids will results in performance of heat exchanger.

NOMENCLATURE:

DPHE	Double pipe heat exchanger
Al_2O_3	Aluminum Oxide
SiO_2	Silicon Oxide
CuO	Copper Oxide
ZnO	Zinc Oxide
Nu	Nusselt number
C_f	Skin friction co-efficient
h	Heat Transfer Co-efficient (W/m^2K)
T	Temperature in kelvin (K)
ρ_{np}	Density of nanoparticles (kg/m^3)
ρ_{bf}	Density of Base fluid (kg/m^3)
φ_v	Volume Fractions (%)
C_{pnf}	Specific Heat of Nanofluid at Constant Pressure (J/kg.K)
C_{pbf}	Specific Heat of Nanoparticles at Constant Pressure (J/kg.K)
K_{eff}	effective thermal conductivity (W/mK)
K_{static}	static thermal conductivity (W/mK)
$K_{brownian}$	Brownian thermal conductivity (W/mK)
K_{bf}	thermal conductivity of base fluid (W/mK)
K_{np}	thermal conductivity of base fluid (W/mK)
k	Boltzmann constant [$k = 1.3807 * 10^{-23}\ J/K.$]
T_a	Ambient Temperature (K)
φ	Volume Fractions (%)
μ_{eff}	Effective viscosity (Ns/m^2)
α	Strip Angle (^0C)
S	Pitch between two louvered strips.

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