Journal of Heat and Mass Transfer Research 8 (2021) 283- 299

Journal of Heat and Mass Transfer Research

Journal homepage: http://jhmtr.semnan.ac.ir

Semnan University

Hydro-Thermal Performance Evaluation of Nanofluids Flow in Double Pipe Heat Exchanger: Effects of Inner Pipe Cross Section, Circular or Cam-Shaped

Aso Rezaei [a], Zahra Baniamerian [*,b]

[a] MSc Student, Department of Mechanical Engineering, Tafresh University, Tafresh, Iran.
[b] Associate Professor, Department of Mechanical Engineering, Tafresh University, Tafresh, Iran.

PAPER INFO

Paper history:
Received: 2021-01-19
Revised: 2021-06-25
Accepted: 2021-06-28

Keywords:
Double-pipe heat exchanger;
Cam-shape cross-section;
Nanofluid;
Heat transfer coefficient;
Efficiency of heat exchanger;
Pressure drop;
Energy ratio (PEC and PR).

ABSTRACT

This study investigates numerically the hydro-thermal behavior of nanofluids in double-pipe heat exchangers with two different cross-sections using four different nanofluids. Two types of different circular and cam-shaped cross-sections, four types of different nanofluid of various concentrations are assessed. The results show that cam-shaped cross-section has reduced the heat transfer rate and the pressure drop compared to the circular cross-section. The heat transfer rate has been increased in both types of heat exchanger by increasing the concentration of nanoparticles, but the pressure drop and friction coefficient has been increased compared to pure water. The results of investigating energy ratio show that the highest performance evaluation criterion (PEC) is related to the silver nanoparticles and the energy ratio (PR) increases by increasing the percentage of nanoparticle concentration. But the energy ratio has been decreased for other nanoparticles by increasing the volume percentage of nanoparticles. The results of thermal and hydraulic studies show that the highest PR value is related to water/TiO2 nanofluid and cam pipes have a higher energy loss. Maximum heat transfer improvement for circular pipes is 26.74% related to Ag nanoparticles while this value is 21.15% for cam-shaped pipes.

DOI: 10.22075/JHMTR.2021.22159.1327

1. Introduction

The capability of heat transfer of conventional fluids is low due to its poor thermal properties compared to many solids such as non-metals, polymers and especially metals. Minimizing heat transfer systems on the one hand, and increasing the need for high heat flux in equipment on the other hand, necessitates the need for heat transfer in short time and high intensity. Therefore, various techniques have been used to increase heat transfer according to the need of industry, among them; it can refer to increasing thermal surfaces (fins), vibration of thermal surfaces, injection or fluid suction.

These methods can hardly cope with the high demand for heat transfer in processes including electronic chips, laser systems and high-energy equipment. Therefore there is an urgent need for new and novel concepts to increase the intensity of heat transfer. Fluid cooling or heating plays an important role in many industrial applications including heat sources, manufacturing materials and products, transportation an electronics, and the heat transfer coefficient of these fluids plays an important role in the development of high-efficiency heat transfer equipment. Improving the thermal properties of heat transfer fluids can be a better method for heat transfer. Research on increasing heat transfer has a great importance and in recent years, it has been considered by many researchers so that some have tried to introduce a new type of fluid with improved thermal properties. Suspending very small solid particles in conventional fluids is one of the new methods to improve the thermal efficiency of the fluid. In the initial study, although the addition of solid particles in millimeter and micrometer sizes and dimensions leads to abnormal increase of fluid thermal properties such as the coefficient of thermal conductivity, but it causes problems

[*]Corresponding Author: Zahra Baniamerian ,Associate Professor, Department of Mechanical Engineering, Tafresh University, Tafresh, Iran.
Email: amerian@tafreshu.ac.ir

such as poor stability, erosion of equipment and transfer lines, closure of pipelines, and extremely high pressure drop.

Therefore, although the presence of solid particles with such dimensions increases the heat transfer, but their application in practical cases is not possible due to the deposition in pipelines and equipment. Over two decades ago, nanometer-sized particles (between 1 and 100 nm) were manufactured by the rapid development of nanotechnology, and used in various fluids instead of micrometer-sized particles. By decreasing the size of the solid particles in the fluid, the coefficient of higher thermal conductivity, better stability and lower pressure drop were observed compared to fluids containing particles in the millimeter and micrometer dimensions [1-4].

Many researchers believe that adding nanoparticles to the base fluid enhances the heat transfer properties.

However, the following theories have been generally agreed by most researchers [5].

- The increase in the coefficient of heat transfer increases by increasing volume concentration of nanoparticles.
- The coefficient of heat transfer increases by increasing Reynolds number.

In the following studies, the use of nanofluids in heat exchangers has been discussed.

One of the ways to increase the heat transfer of conventional fluids is to add metallic or non-metallic particles to the base fluid that have higher heat conductivity compared to the base fluid, the idea first proposed by Maxwell. By advancing science and production of nanoparticles, a new type of fluids was introduced that could overcome the problems of using large particles. This was first performed by Choi in 1995, [6] that the concept of nanofluids was presented by Choi for the first time. Many researchers have investigated the effects of adding nanoparticles on heat transfer of basic fluids in various heat exchangers experimentally or numerically [7-16].

Bayat et al. [17] have experimentally investigated the thermal-hydraulic performance of the cam-shape tubes in a cross-section layout. According to their results, both the drag coefficient and the Nusselt number depend on the position of the pipes and the Reynolds number. The results show that the drag coefficients and friction coefficients of the cam-shape tubes are 64% and 93-92% are lower than the circular tubes, respectively. Also, the thermal-hydraulic performance of the cam-shape tubes is 5-6 times higher than the circular tube. And the heat transfer from a single- cam-shape tube about 11-5 percent less than a single-circular tube with equivalent diameter.

Borujerdi & Lavasani [18] experimentally investigated the characteristics of heat transfer and flow behavior from a constant-temperature cam-shape tube in a transverse flow of air at a wide range of angles of attack. Their results show that the highest value of heat transfer coefficient in the whole Reynolds range is at $\alpha = 90°$ and the lowest value is at $\alpha = 30°$. Lavasani & Bayat [19] have numerically studied the heat transfer from two cam-shape cylinders in transverse flow arranged side by side. Their results showed that the Nusselt number can increase by up to 36%. Lavasani & Bayat [20] also studied numerically the heat transfer from two cam-shape cylinders in transverse flow, one after the other. Their results showed that the Nusselt number can be 5 to 33 times larger.

Borujerdi & Lavasani [21] investigated the pressure drop and heat transfer of a cam-shape cylinder at different angles. For $L/D_{eq} = 0.4$ in a wide range of different Reynolds number, the pressure drag has a minimum value $C_D = 0.4$ at attack angles $\alpha = 330°$, $180°$, $30°$ and a maximum value $C_D = 0.9$ at $\alpha = 90°$, $270°$. Also, the mean Nusselt number of the cam-shape tube relative to the circular tube at angles $\alpha = 90°$, $270°$, the maximum value is $1.05 < \frac{Nu_{cam}}{Nu_{cir}} < 1.08$ and at angles $\alpha = 30°$, $180°$, the minimum value is $0.87 < \frac{Nu_{cam}}{Nu_{cir}} < 0.92$. Lavasani & Bayat [22] have investigated the numerical study of pressure drop and heat transfer of nanofluid from cam-shape tube and circular tube. The results show that by adding nanoparticles to the base fluid, the coefficient of friction has been increased in both types of tubes. The coefficient of friction for the circular tube in linear and cross arrangements has been increased 17% and 19%, respectively, and it has been increased 17.2% and 17.1%, respectively for the cam-shape tube with linear and cross arrangements. The heat transfer of water nanofluid/ Al_2O_3 in circular and cam-shape tubes is about 14% and 12% higher than water, respectively

Arya et al. [23] investigated the heat transfer properties and pressure drop of ethylene glycol / Mgo nanofluid in a double-pipe heat exchanger. The results show that heat transfer coefficient in heat exchanger has been increased by 27% for wt = 0.3% in comparison with pure ethylene glycol. It has also been observed that the use of Mgo nanoparticles has increased the pressure drop by 35%. Mund et al. [24] studied numerically and experimentally heat transfer of two water/Al_2O_3 and water/TiO_2 nanofluids in a heat exchanger. Experimental and numerical results show that the efficiency of water hybrid nanofluid/TiO_2 is higher than Al_2O_3. As a result, this nanofluid can be considered as a cooling fluid.

Bahmani et al. [25] investigated the turbulent flow of water/alumina nanofluids in a double-pipe heat exchanger with a co-current and counter-current flow. It is observed from the results that the addition of nanoparticles at higher Reynolds has more effect on heat transfer coefficient and Nusselt number. Also, the maximum increase in thermal efficiency and Nusselt number has been occurred in the counter-current flow, which is 30% and 32.7%, respectively. In all cases, the changes in the outlet temperature of the nanofluid and the wall temperature are greater than the base fluid by increasing the concentration of nanoparticles. The maximum increase in efficiency of heat exchanger is at 5% concentration, which increases the concentration of nanoparticles reduces the efficiency of the heat exchanger.

Akhtari et al. [5] investigated numerically and experimentally the effects of water nanofluid/aluminum oxide in a double-tube and shell-tube heat exchanger. The results show that the performance of both heat exchangers.

has been increased by increasing concentration of nanoparticles as well as increasing hot and cold fluid flow. The rate of heat transfer in double-tube and shell-tube heat exchanger has been increased 13.2% and 21.3% compared to pure water, respectively, and the performance of shell and tube heat exchanger increased 26.2% when using nanofluids. This study has been used as reference.

All the mentioned studies show that the use of nanofluids increases heat transfer coefficient and heat transfer rate. The thermal performance of the heat exchangers is improved by using nanofluids. Nanofluids can also reduce cost and reduce the volume of heat exchanger.

In this study, the hydro-thermal behavior of nanofluids in double-pipe heat exchangers with two different cross-sections using four different nanofluids is numerically assessed. Circular and cam-shaped cross-sections are individually simulated and compared. Effects of using nanoparticles on increasing heat transfer and increasing flow pressure drop is assessed by the PEC factor. Also, by introducing the parameter of energy ratio PR, the performance of the two cam-shaped and circular tube heat exchangers are compared. In fact, by applying nanofluids instead of pure water, pressure drop is increased along with the heat transfer which is not desirable. Therefore for evaluating the advantage of using nanoparticles both factors one as useful and the other as the adverse factor should be simultaneously concerned. PEC and PR factors help to simultaneously concern both factors. Both Aspen EDR and FLUENT software are used to simulate these two heat exchangers.

2. Heat Exchanger Geometery

As it is shown in Figures (1 and 2), in this project, two double-pipe heat exchangers, one with a circular tube and the other with a cam-shaped tube, were evaluated and compared. And. The geometrical properties of the heat exchangers investigated are presented in Table (1). The pipes of heat exchanger are made of stainless steel. And in order to reduce the heat loss along the axial direction, an external insulated tube has been considered. In order to better evaluate the cam-shape on the heat exchanger performance, the cam-shaped tube is designed in a way that the hydraulic diameter to be equal to the inner diameter of the circular-tube heat exchanger. The other dimensions in both geometries are completely identical.

Al_2O_3, TiO_2, CuO and Ag nanoparticles were mixed with pure water by volume percentages of 0.5 %, 1 %, 2 %, 3 %, 4 % and 5 %. Four different nanofluids were created. The direction of flow of hot and cold fluids in different heat exchangers is co-current. The hot fluid temperature is 323 K and the cold fluid temperature is 296 K. The hot fluid is the nanofluid and the cold fluid is pure water, which nanofluid flows inside the shell and the pure water flows inside the tube. In order to provide the conditions for comparison and validation of the results, all dimensions and conditions of the flow have been selected similar to the article [5].

The heat transferred (Qh) from the hot fluid and the heat absorbed by the cold fluid (Qc) are calculated by Equations (1 and 2) [3]:

$$Q = Q_h = (\dot{m}\,Cp)_h\,\Delta T_h \tag{1}$$

$$Q = Q_c = (\dot{m}\,Cp)_c\,\Delta T_c \tag{2}$$

The efficiency of heat exchanger which represents the ratio of actual heat transfer to the highest thermo dynamical heat transfer in the heat exchanger [3]:

$$Q\varepsilon = \frac{Q}{Q_{max}} = \frac{C_h(T_{h1} - T_{h2})}{C_{min}(T_{h1} - T_{c1})} \tag{3}$$

The Nusselt dimensionless number is defined as follows to evaluate the heat transfer in the converter [3]:

$$Nu = \frac{h\,.D_{eq}}{k} \tag{4}$$

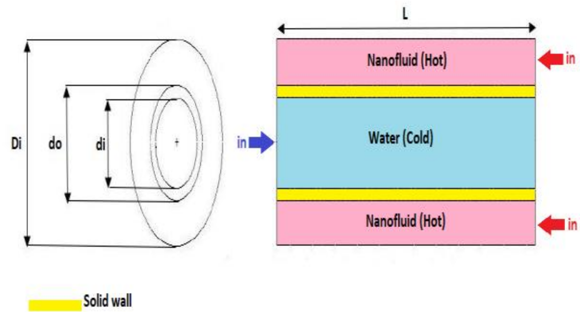

Figure 1. Geometry of double-pipe heat exchanger of circular tube

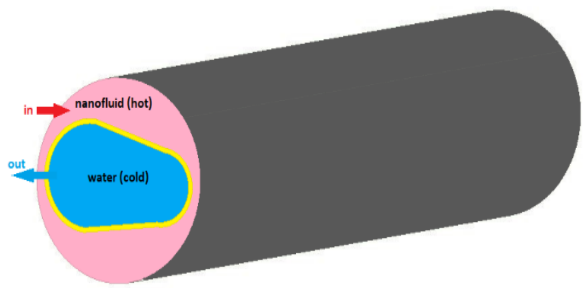

Figure 2. Geometry of double-pipe heat exchanger of cam-shaped tube

Table 1. Geometric characteristics of the heat exchanger

Length	1.575 m
Inlet diameter (inner tube)	0.037 m
Outlet diameter (inner tube)	0.04 m
Inlet diameter (outer tube)	0.62

3. Numerical Simulation

In the present simulation, the flow of nanofluids with constant physical properties is assumed to be incompressible and the viscous dissipation is considered in the energy equation. FLUENT software and finite volume approach have been used to solve the governing equations including mass, momentum, energy and turbulence equations, and the SIMPLE algorithm has been used for pressure and velocity coupling. In such a case, the equations governing the phenomenon in the vector state are as follows [5]:

Continuity equation:

$$div\left(\rho\vec{V}\right)=0 \tag{5}$$

Momentum equation:

$$div\left(\rho\vec{V}\,\vec{V}\right)=-grad+\nabla.\left(\mu\nabla\vec{V}\right)+S_m \tag{6}$$

Energy equation:

$$div\left(\rho\vec{V}\,C_pT\right)=div\left(k\;gradT\right)+S_e \tag{7}$$

In the present study, in the FLUENT software, laminar model has been used in the slow flow state and k-ε model has been used in the turbulent flow state and standard performance near the wall in the standard regime of the problem has been simulated.

3.1. Thermophysical Properties of Nanofluids

The simulation of nanofluids in this study as a pure fluid is equivalent with thermophysical properties. Accordingly, the thermophysical properties of nanofluids are calculated using the most famous equations in history and are defined as new fluid properties. To calculate the nanofluid viscosity, we use equation (8) [5]:

$$\mu_{nf}=\mu_{bf}(1+2.5\emptyset) \tag{8}$$

The density and thermal capacity of nanofluids are calculated based on the ratio of nanoparticles used in nanofluids using equations (9) and (10) [5]:

$$\rho_{nf}=(1-\emptyset)\rho_{bf}+\emptyset\rho_p \tag{9}$$

$$Cp_{nf}=(\emptyset\,Cp_p+(1-\emptyset)\rho\,Cp_{bf})/\rho_{nf} \tag{10}$$

There are various equations for calculating the nanofluid conductivity, the simplest and most commonly used has been used in the present study [26]:

$$\frac{K_{nf}}{K_{bf}}=(1+3.5\emptyset+2.5\emptyset^2) \tag{11}$$

Since the heat transfer coefficient of nanofluid is higher than the base fluid due to reasons such as Brownian motion, increasing conduction coefficient, changing thermophysical properties, etc., so it is not appropriate to use the common equations of heat transfer coefficient of convection for these fluids. Aspen software is not able to calculate heat transfer coefficient of convection and for the software performs the thermal calculations correctly, it is required to give the value of heat transfer coefficient of convection to the software as an input. Accordingly, the equation (12) is used to calculate the convective heat transfer coefficient of nanofluids [27]:

$$h_{nf}=\frac{K_{n.f}}{D_{eq}}\;1.7\left(Re_{nf}^{0.4}\right) \tag{12}$$

Geometry meshing is performed using Gambit. For the investigated geometries, organized and non-structured meshes and Pave meshing methods with Tet / hybrid elements were applied. Figures (3 and 4) show the number of meshes used in mesh independent conditions. The analysis and simulation were performed using both FLUENT and Aspen EDR software.

In the FLUENT software, in order to reduce the computational costs the double-pipe heat exchanger of circular tube is modeled, axisymmetric, but the double-pipe heat exchanger of cam-shaped tube is analyzed in 3D. In order to provide suitable conditions for comparing the performance of these two heat exchangers, dimensions and shell sizes for both heat exchangers are selected similar and in cam-shaped heat exchanger, dimensions of cam cross-section are selected such that its hydraulic diameter is equal to the pipe diameter of heat exchanger.

3.2. Boundary conditions

The input of heat exchanger is simulated using the velocity-inlet condition and the pressure-outlet condition is set for the output boundaries. For the inner tube wall because of wetting by two fluids, Coupled condition is used while the outer tube wall is considered insulated.

3.3. Investigating the mesh independency

A number of different meshes have been tested to perform mesh independency to obtain results independent from number of meshes (Figure 5). Finally, 196,000 organized-type cells were used for the double-pipe heat exchanger of circular tube, and the cam tube heat exchanger was meshed using 1100,000 unorganized cells.

Table 2. Thermophysical properties of based fluid and nanoparticles [28] [29]

Nanoparticle	ρ $(kg\,m^{-3})$	K $(w\,m^{-1}k^{-1})$	Cp $(Jkg^{-1}k^{-1})$
AL_2O_3	3970	40	765
TiO_2	4250	8.9	686.2
CuO	6320	76	531.8
Ag	10500	429	235

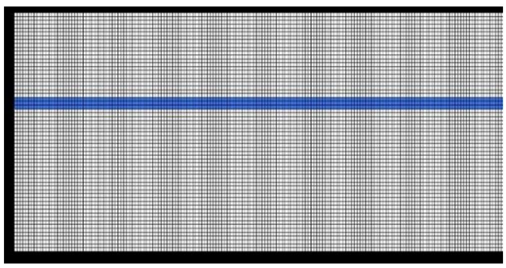

Figure 3. Mesh topology (double-pipe heat exchanger of circular tube)

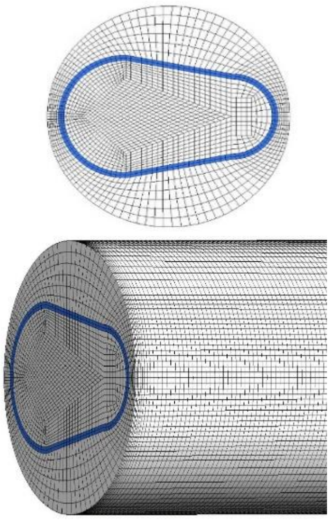

Figure 4. Mesh topology (double pipe heat exchanger of cam-shaped tube)

3.4. Mesh independency

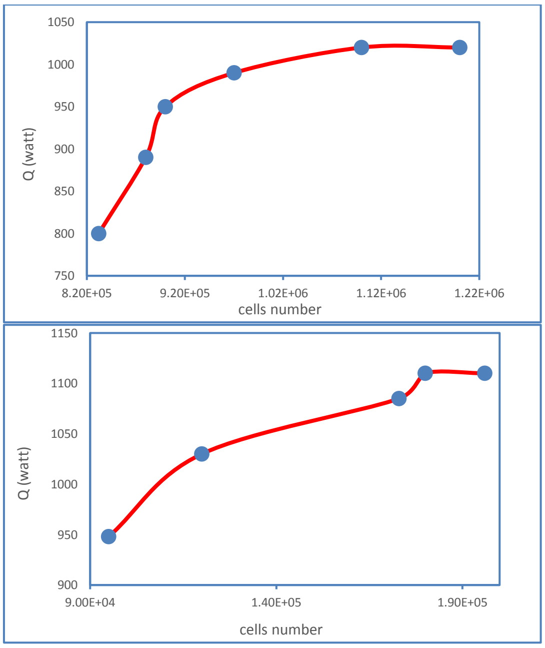

Figure 5. Mesh independency validation. Left side: cam-shaped tube, right side: circular tube

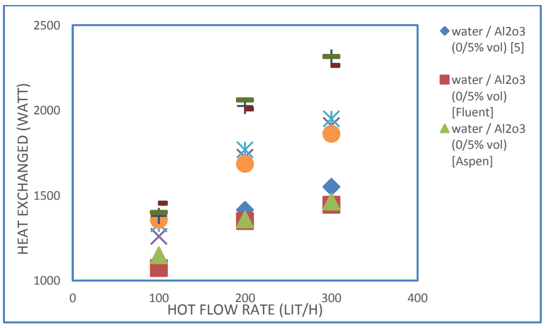

Figure 6. Validation of FLUENT and Aspen EDR results with reference [5]

3.5. Validation

Akhtari results [5] have been used for validation. They investigated water/aluminum oxide nanofluids in two tube and shell and tube heat exchangers with two percent volumes of 0.2 and 0.5 percent nanoparticles. The use of nanofluids over pure water has increased the heat transfer rate in both types of heat exchanger. For this purpose, the results of the water/aluminum oxide nanofluid at 0.5% concentration were investigated. Validation was done with software Aspen EDR and FLUENT.

As it can be seen in Fig. 6, the results are very close together, and the results for the three cold fluid flows 90, 180 and 270 liters per hour is about 1 to 7%. The maximum error for FLUENT and Aspen are 6.5% and 7.2%, respectively, and the average FLUENT error is 3.43% and the mean Spin error is 3.4%, respectively.

4. Results and Discussion

Water/Al_2O_3, water/TiO_2, water/CuO, and water/Ag nanofluids were investigated at 0.5, 1, 2, 3, 4, and 5 vol% at temperature 323 K. Heat transfer rate is tabulated for circular and cam-shaped heat exchanger in Table 3. According to the Table, it is observed that the rate of heat transfer of nanofluids is higher than water and the heat transfer rate increases by increasing volume fraction of nanoparticles. Similar trend is observed in both types of heat exchangers. The rate of heat transfer was increased from 2 to 27% compared to pure water by increasing concentration of Al_2O_3, TiO_2, CuO and Ag nanoparticles from 0.5 to 5%, in double-pipe heat exchanger of circular tube. In heat transfer processes of conductivity and convection, one of the effective properties of fluid is its thermal conductivity. The increase of this property indicates the high heat transfer coefficient. The results show that for all nanofluids with different concentrations, the heat transfer rate is linearly increased, which the heat transfer rate increases by increasing fluid flow and volume fraction of the nanoparticles. The results show that the nanofluid containing Ag nanoparticles has the highest heat transfer rate compared to other nanoparticles, which has the highest thermal conductivity compared to other nanoparticles. Also, heat transfer rate has increased compared to the base fluid by increasing mass flow rate of both hot and cold fluids. This increase in heat transfer rate was observed in results obtained from both softwares, which in a constant flow by increasing the volume fraction of the nanoparticles, the heat transfer rate increases. Also at a constant concentration, by increasing flow, heat transfer rate has been increased.

The heat transfer rate in the cam-shaped tube heat exchanger has been decreased about 9-57 % compared to circular tube heat exchanger. However, in lower mass flow rates and low volume concentrations, the difference in heat transfer rate is lower between two heat exchangers, and the heat transfer difference between the two heat exchangers has been increased by increasing mass flow and concentration of the nanoparticles.

Table 3. Comparison of heat transfer rate of different nanofluids compared to pure water (circular and cam-shaped heat exchanger)

Hot flow rate (lit/h)	Cold flow rate (lit/h)	nanoparticles	$\emptyset = 0.5\%$	$\emptyset = 1\%$	$\emptyset = 2\%$	$\emptyset = 3\%$	$\emptyset = 4\%$	$\emptyset = 5\%$
100	90	Al_2O_3 (circular pipe)	+3.67	+5.12	+6.28	+7.43	+7.72	+8.4
		Al_2O_3 (Cam-shape pipe)	+3.45	+4.21	+5.93	+7.56	+9.28	+10.9
		TiO_2 (circular pipe)	+3.67	+5.7	+7.53	+8.01	+8.11	8.98
		TiO_2 (Cam-shape pipe)	+3.56	+4.31	+6.15	+7.88	+9.61	+11.33
		CuO (circular pipe)	+3.67	+5.75	+7.55	+9.66	+10.43	+11.11
		CuO (Cam-shape pipe)	+3.77	+4.85	+7.12	+9.39	+11.55	+13.71
		Ag (circular pipe)	+5.12	+6.28	+9.85	+11.88	+14.68	+16.9
		Ag (Cam-shape pipe)	+4.21	+5.57	+8.85	+11.77	+14.57	+17.27
200	90	Al_2O_3 (circular pipe)	+2.27	+3.25	+3.63	+4.54	+5.07	+5.68
		Al_2O_3 (Cam-shape pipe)	3.96	4.52	+6.03	+7.45	+8.86	+10.37
		TiO_2 (circular pipe)	+3.03	+3.86	+4.31	5	+5.37	+6.21
		TiO_2 (Cam-shape pipe)	+3.99	+4.71	+6.22	+7.73	+9.15	+10.56
		CuO (circular pipe)	+3.18	+3.87	+5.07	+5.9	+6.66	+7.5
		CuO (Cam-shape pipe)	+4.15	+5	+6.88	+8.58	+10.37	+11.98
		Ag (circular pipe)	+3.63	+4.62	+6.21	+7.57	+9.09	+10.07
		Ag (Cam-shape pipe)	+4.43	+5.56	+7.92	+10.1	+12.07	+13.96
300	90	Al_2O_3 (circular pipe)	+5.16	+5.57	+6.1	+7.63	+7.78	+8.07
		Al_2O_3 (Cam-shape pipe)	+3	+3.53	+4.86	+6.28	+7.43	+8.67
		TiO_2 (circular pipe)	+5.89	6.03	+6.76	7.92	+8.21	+8.36
		TiO_2 (Cam-shape pipe)	+3	+3.62	+5.04	+6.37	+7.61	+8.9
		CuO (circular pipe)	+6.03	+6.4	+7.2	+8.14	+8.8	+8.92
		CuO (Cam-shape pipe)	+3.09	+3.89	+5.48	+7	+8.49	+8.91
		Ag (circular pipe)	+6.25	+7.05	+8.21	+9.38	+10.18	+11.27
		Ag (Cam-shape pipe)	+3.36	+4.33	+6.23	+8.05	+9.82	+11.23
100	180	Al_2O_3 (circular pipe)	+3.57	+5.43	+7.61	+9.4	+9.71	+10.33
		Al_2O_3 (Cam-shape pipe)	+3.46	+4.43	6.26+	+8.28	+10.21	+12.13
		TiO_2 (circular pipe)	+3.65	+6.29	+9.16	+9.79	+10.1	+11.42
		TiO_2 (Cam-shape pipe)	+3.56	+4.52	+6.55	+8.57	+10.59	+12.62
		CuO (circular pipe)	+3.69	+6.44	+9.2	+12.04	+13.44	+14.52
		CuO (Cam-shape pipe)	+3.85	+5.2	+7.89	+10.5	13.1+	+15.6
		Ag (circular pipe)	+5.59	+7.38	+14.84	+15.46	+19.58	+23.38

Hot flow rate (lit/h)	**Cold flow rate (lit/h)**	**nanoparticles**	$\emptyset = \mathbf{0.5}\%$	$\emptyset = \mathbf{1}\%$	$\emptyset = \mathbf{2}\%$	$\emptyset = \mathbf{3}\%$	$\emptyset = \mathbf{4}\%$	$\emptyset = \mathbf{5}\%$
100	180	Ag (Cam-shape pipe)	+4.43	+6.26	+10.01	+13.58	+16.85	+20.03
200	180	Al_2O_3 (circular pipe)	+2.01	+2.53	+3.46	+5.59	+6.17	+6.9
		Al_2O_3 (Cam-shape pipe)	+3.46	+4.43	6.26+	+8.28	+10.21	+12.13
		TiO_2 (circular pipe)	+2.42	+3.51	+4.27	+5.65	+6.34	+7.6
		TiO_2 (Cam-shape pipe)	+3.56	+4.52	+6.55	+8.57	+10.59	+12.62
		CuO (circular pipe)	+2.53	+3.63	+5.48	+7.15	+8.59	+9.98
		CuO (Cam-shape pipe)	+3.85	+5.2	+7.89	+10.5	13.1+	+15.6
		Ag (circular pipe)	+3.05	+4.67	+7.38	+9.75	+12.29	+14.07
		Ag (Cam-shape pipe)	+4.43	+6.26	+10.01	+13.58	+16.85	+20.03
300	180	Al_2O_3 (circular pipe)	+1.5	+2.18	+3.07	+5.05	+5.46	+6.35
		Al_2O_3 (Cam-shape pipe)	+3.65	+4.39	+6.17	+7.88	+9.59	+11.38
		TiO_2 (circular pipe)	+2.08	+2.91	+3.74	+5.57	+5.98	+6.82
		TiO_2 (Cam-shape pipe)	+3.65	+4.55	+6.34	+8.13	+9.91	+11.62
		CuO (circular pipe)	+2.23	+2.96	+4.58	+6.03	+7.18	+8.53
		CuO (Cam-shape pipe)	+3.9	+4.95	+7.15	+9.26	+11.32	+13.41
		Ag (circular pipe)	+2.39	+3.69	+5.72	+7.75	+9.52	+10.98
		Ag (Cam-shape pipe)	+4.3	+5.69	+8.45	+11.13	+13.65	+16.1
100	270	Al_2O_3 (circular pipe)	+3.78	+5.84	+8.27	+9.34	+10.41	+11.62
		Al_2O_3 (Cam-shape pipe)	+3.01	+3.77	+5.35	+6.94	+8.52	+10.11
		TiO_2 (circular pipe)	+3.78	+6.84	10.05+	+10.84	+10.98	+12.48
		TiO_2 (Cam-shape pipe)	+3.01	+3.84	+5.51	+7.17	+8.75	+10.33
		CuO (circular pipe)	+3.79	+7	+10.1	+13.55	+14.97	+16.19
		CuO (Cam-shape pipe)	+3.24	+4.22	+6.11	+8.07	+9.88	+11.69
		Ag (circular pipe)	+6	+8.05	+13.9	+17.33	+22.18	+26.74
		Ag (Cam-shape pipe)	+3.47	+4.75	+7.16	+11.54	+13.2	+13.66
200	270	Al_2O_3 (circular pipe)	+1.77	+2.53	+3.7	+5.62	+6.7	+7.9
		Al_2O_3 (Cam-shape pipe)	3.41	+4.24	+6.37	+8.4	+10.52	+12.55
		TiO_2 (circular pipe)	+2.28	+3.49	+4.71	+6.28	+7.24	+8.82
		TiO_2 (Cam-shape pipe)	+3.5	+4.43	+6.64	+8.77	+10.89	+13.01
		CuO (circular pipe)	+2.38	+3.85	+5.98	+8	+9.98	+11.75
		CuO (Cam-shape pipe)	+3.87	+5.17	+8.03	+10.8	+13.57	+16.25

Hot flow rate (lit/h)	Cold flow rate (lit/h)	nanoparticles	$\emptyset = 0.5\%$	$\emptyset = 1\%$	$\emptyset = 2\%$	$\emptyset = 3\%$	$\emptyset = 4\%$	$\emptyset = 5\%$
200	270	Ag (circular pipe)	+3.19	+5.17	+8.21	+11.09	+14.24	+16.62
		Ag (Cam-shape pipe)	+4.43	+6.46	+10.43	+14.12	+18	+21.14
300	270	Al_2O_3 (circular pipe)	+1.47	+2.33	+3.22	+5.02	+6.1	+7
		Al_2O_3 (Cam-shape pipe)	+2.82	+3.66	+5.5	+7.41	+9.24	+11
		TiO_2 (circular pipe)	+2.15	+3.04	+4.21	+6.14	+6.72	+7.8
		TiO_2 (Cam-shape pipe)	+2.9	+3.81	+5.72	+7.63	+9.47	+11.38
		CuO (circular pipe)	+2.46	+3.22	+5.38	+6.81	+8.25	+9.95
		CuO (Cam-shape pipe)	+3.13	+4.27	+6.64	+8.93	+11.15	+13.29
		Ag (circular pipe)	+2.82	+4.21	+6.86	+9.14	+11.92	+13.49
		Ag (Cam-shape pipe)	+3.51	+5.11	+8.1	+10.92	+13.67	+16.2

The highest increase in heat transfer rate of double-pipe heat exchanger of circular tube in water/Ag nanofluid at 5% concentration is about 26.74%. Also, the maximum increase in heat transfer rate at 5% concentration for water/CuO, water/TiO_2 and water/Al_2O_3 nanofluids is 16.2%, 12.48% and 11.62%, respectively.

Investigating the increase of heat transfer rate in double-pipe heat exchanger of cam-shaped tube is that the maximum increase in heat transfer rate of water /Ag nanofluid is about 21.15% at 5% concentration compared to pure water. For other water/CuO, water/TiO_2 and water /Al_2O_3 nanofluids, it is 16.25%, 13% and 12.55%, respectively.

It can be seen in Figure 7 and 8, the heat transfer rate has been increased by increasing concentration of nanoparticles and increasing hot fluid flow.

As it can be seen in Figure 9, the use of a cam-shaped tube in the double pipe heat exchanger reduces the heat transfer rate compared to the double-pipe heat exchanger of circular tube. When using a cam-shaped tube, the heat transfer rate has been decreased about 9-57 % compared to the circular tube heat exchanger.

The effect of, type and concentration of nanofluids of nanoparticle on pressure drop has been shown in Table 4 individually for cam-shaped and circular cross-section heat exchanger. As it can be seen when using nanofluids, the pressure drop has been increased compared to pure water. The highest pressure drop is related to water/Ag nanofluids and the lowest pressure drop is related to water/Al_2O_3, water/TiO_2 and water/CuO nanofluids. The results show that adding nanoparticles to the base fluid increases the pressure drop. In fact, the presence of nanoparticles increases the viscosity of the nanofluid relative to the base fluid, which increases the pressure drop, the more the particle concentration is, the higher the pressure drop will be. It can also be seen that by increasing the mass flow rate of the hot fluid (nanofluid), the pressure drop has been increased compared to pure water. According to the results, increasing the pressure drop in the water /Ag nanofluid reaches about 68%.

It is also evident from the results of Table 4 that the increase in pressure drop in the cam tube heat exchanger has been reduced compared to the circular tube heat exchanger. In this heat exchanger, using different anofluids, pressure drop has the maximum increase of 39% compared to pure water. The pressure drop for cam-shaped exchangers has been reduced compared to the circular tube heat exchanger.

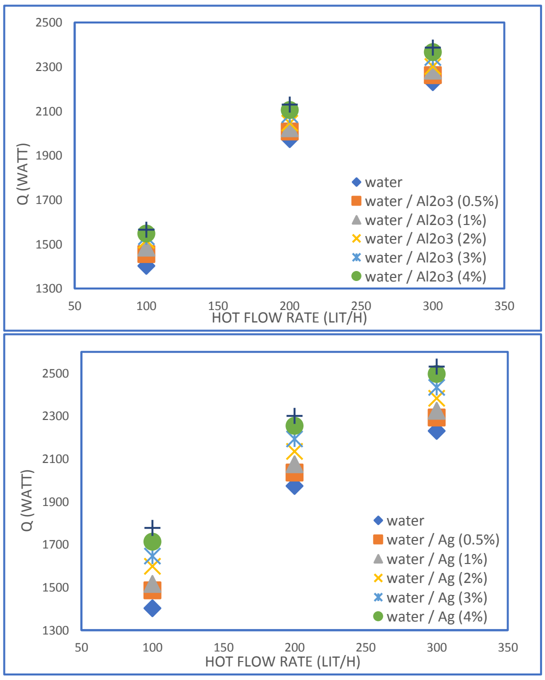

Figure 7. Increasing heat transfer rate of (a:water/Al_2O_3) and (b:water/Ag) nanofluids ($\dot{Q}_c = 270$ lit/h) (double-pipe heat exchanger of circular tube)

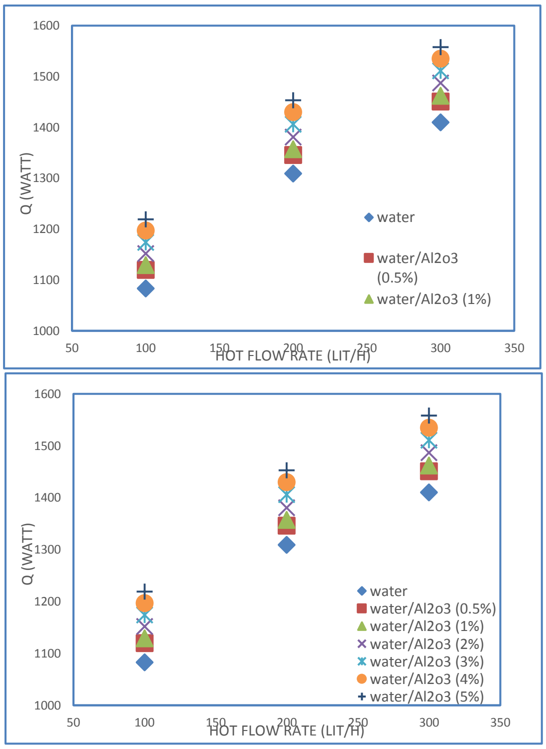

Figure 8. Increasing heat transfer rate of (a:water/Al_2O_3) and (b:water/Ag) nanofluids ($\dot{Q}_c$ = 270 lit/h) (double-pipe heat exchanger of cam-shaped tube)

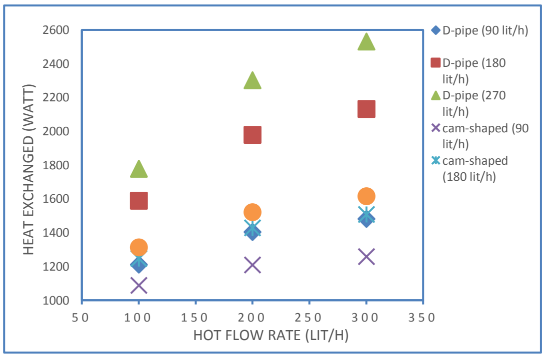

Figure 9. Comparison of the results of the heat transfer rate of water/Ag nanofluids (5%) (Both types of heat exchanger).

Figures (10 and 11) shows that by increasing the concentration of nanoparticles, the pressure drop in both types of heat exchanger increases. But the increase in pressure drop in the cam-shaped heat exchanger is less than the circular tube.

Changes related to the thermal efficiency of the heat exchanger caused by the cross-section change, the change of volume fraction of the nanoparticles, and the different hot and cold fluids can be observed in Tables (5) as well as Figure (12-14). According to the results, at minimum cold fluid, the efficiency of heat exchanger increases by increasing volume fraction of nanoparticles and increasing hot fluid. But increasing the cold flow reduces the efficiency of the heat exchanger. The best thermal performance is related to Ag nanoparticles at 5% volume concentration, which the performance of heat exchanger has been improved 15.5% compared to the base fluid. Also, the thermal performance of the heat exchanger has been improved about 23.3% compared to pure water using water/Ag nanofluid for the cam-shaped heat exchanger in the best conditions.

Changes related to the thermal efficiency of the heat exchanger caused by the cross-section change, the change of volume fraction of the nanoparticles, and the different hot and cold fluids can be observed in Tables (5) as well as Figure (12-14). According to the results, at minimum cold fluid, the efficiency of heat exchanger increases by increasing volume fraction of nanoparticles and increasing hot fluid. But increasing the cold flow reduces the efficiency of the heat exchanger. The best thermal performance is related to Ag nanoparticles at 5% volume concentration, which the performance of heat exchanger has been improved 15.5% compared to the base fluid. Also, the thermal performance of the heat exchanger has been improved about 23.3% compared to pure water using water/Ag nanofluid for the cam-shaped heat exchanger in the best conditions

By examining the thermal performance of both heat exchangers, the results show that the thermal performance of the cam tube heat exchanger is less than the heat performance of the double-pipe heat exchanger.

4.1. Performance Evaluation Criteria (PEC)

As it can be seen from the above results, the cam-shaped heat exchanger reduces the heat transfer rate of the heat exchanger along with decreasing the pressure drop and accordingly the pumping power. Accordingly, in order to better evaluate the performance of these two heat exchangers, a parameter is defined called energy ratio [30]. The performance of both heat exchangers is comparable to each other (using PR performance factor) and to the conditions of nanofluid as refrigerant (using PEC factor).

$$PEC = \frac{\frac{Nu_{n.f}}{Nu_w}}{(\frac{f_{n.f}}{f_w})^{1/3}} \tag{13}$$

$$PR = \frac{\frac{Nu_{cam}}{Nu_{D.P}}}{(\frac{f_{cam}}{f_{D.P}})^{1/3}} \tag{14}$$

Figures (15 and 16) show the results of the PEC in hot mass flow rate of 200 Lit/h and cold flow rate of 270 Lit/h. These results show the thermal-hydraulic performance of nanofluids relative to the base fluid in both types of exchangers. As it can be seen, the maximum PEC was obtained when using silver nanoparticles and the amount of PEC has been decreased by increasing the volume fraction of the nanoparticles. This indicates that increasing the concentration of silver nanoparticles has a better effect on the heat transfer process than the coefficient of friction. But for the other Al_2O_3, CuO and TiO_2 nanoparticles, the PEC has been decreased by increasing concentration of nanoparticles, indicating that in this type of nanoparticles, the pressure drop has a more dominant effect on heat transfer by increasing volume fraction.

Table 4. Comparison of pressure drop of different nanofluid compared to pure water (%)
(Circular and cam-shaped tube heat exchanger)

Hot flow rate (lit/h)	Cold flow rate (lit/h)	nanoparticles	$\emptyset = 0.5\%$	$\emptyset = 1\%$	$\emptyset = 2\%$	$\emptyset = 3\%$	$\emptyset = 4\%$	$\emptyset = 5\%$
100	90	Al_2O_3 (circular pipe)	1.58+	+11.11	+22.22	+35.23	+46.03	+58.73
		Al_2O_3 (Cam-shape pipe)	+2.1	+3.5	+9.82	+16.84	+24.91	+33.68
		TiO_2 (circular pipe)	2.53+	+11.74	+27.61	+36.82	+46.03	+60.63
		TiO_2 (Cam-shape pipe)	+2.1	+3.5	+9.82	+17.19	+24.91	+34.03
		CuO (circular pipe)	3.17+	+12.06	+30.15	+38.09	+47.61	+61.58
		CuO (Cam-shape pipe)	+2.1	+3.85	+10.52	+17.89	+26.31	+35.43
		Ag (circular pipe)	4.76+	+12.38	+31.74	+38.73	+53.33	+66.98
		Ag (Cam-shape pipe)	+2.22	+4.21	+11.22	+19.29	+27.71	+38.59
200	180	Al_2O_3 (circular pipe)	3.59+	+7.18	+17.6	+29.22	+38.8	+53.05
		Al_2O_3 (Cam-shape pipe)	+2.17	+4.03	+10.54	+17.36	+25.42	+34.41
200	180	TiO_2 (Cam-shape pipe)	+2.01	+4.03	+10.69	+17.51	+25.58	+34.88
		CuO (circular pipe)	4.91+	+9.94	+20.59	+32.21	+45.02	+59.52
		CuO (Cam-shape pipe)	+2.32	+4.34	+11.16	+18.44	+26.82	+36.43
		Ag (circular pipe)	5.5+	+10.53	+22.75	+35.56	+48.74	+68.5
		Ag (Cam-shape pipe)	+2.63	+4.96	+12.24	+20	+26.82	+38.13
300	270	Al_2O_3 (circular pipe)	2.54+	+7.08	+17.4	+28.74	+39.13	+50.82
		Al_2O_3 (Cam-shape pipe)	+2.3	+4.13	+10.57	+17.5	+25.48	+34.61
		TiO_2 (circular pipe)	3.3+	+8.59	+18.63	+29.98	+41.67	+52.88
		TiO_2 (Cam-shape pipe)	+2.3	+4.23	+10.67	+17.69	+25.76	+34.9
		CuO (circular pipe)	+3.92	+9.83	+21.25	+31.77	+43.39	+57.35
		CuO (Cam-shape pipe)	+2.4	+4.42	+11.25	+18.55	+26.92	+36.53
		Ag (circular pipe)	+4.95	+10.45	+23.45	+33.42	+51.58	+61.62
		Ag (Cam-shape pipe)	+2.59	+5.09	+12.34	+20.19	+28.07	+39.42

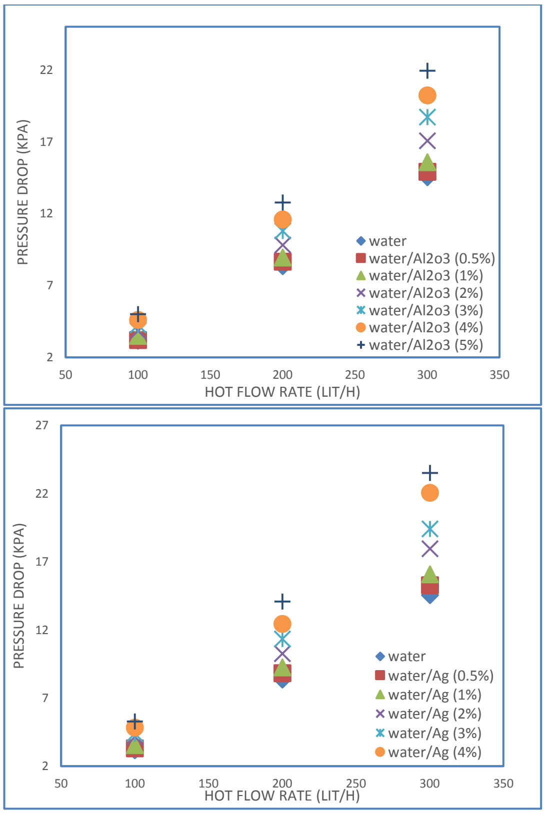

Figure 10. Changes in pressure drop of (a:water/Al_2O_3) and (b:water/Ag) nanofluid compared to base fluid (circular tube heat exchanger)

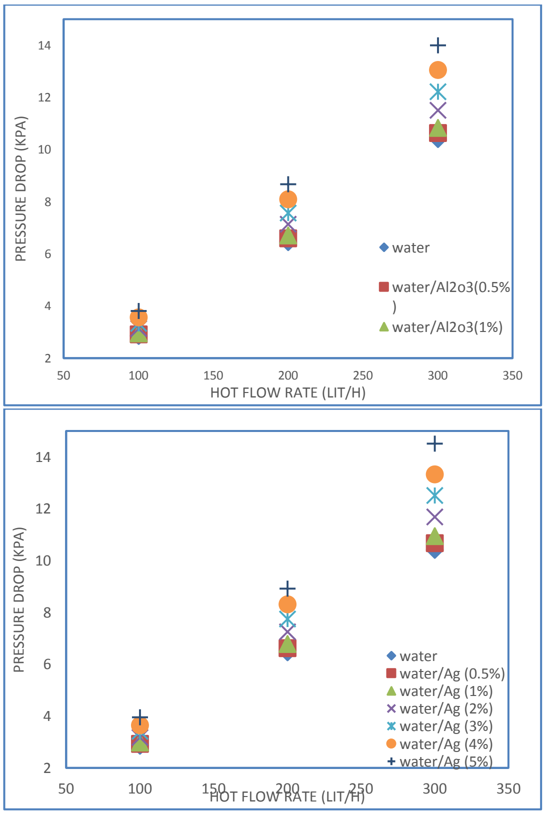

Figure 11. Changes in pressure drop of (a:water/Al_2O_3) and (b:water/Ag) nanofluid compared to base fluid (Cam-shaped tube heat exchanger)

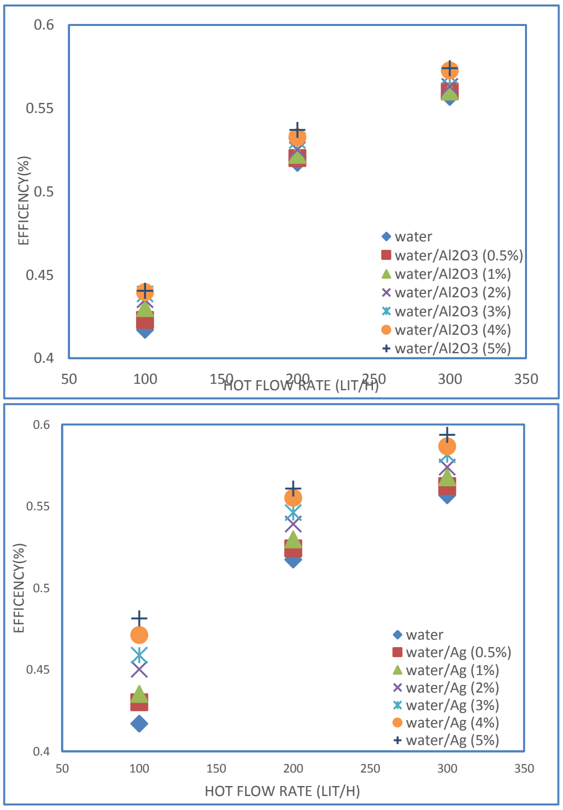

Figure 12. Comparison of thermal efficiency of (a:water/ Al_2O_3) and (b:water/Ag) nanofluids ($\dot{Q}_c$ = 90 lit/h) (circular tube heat exchanger)

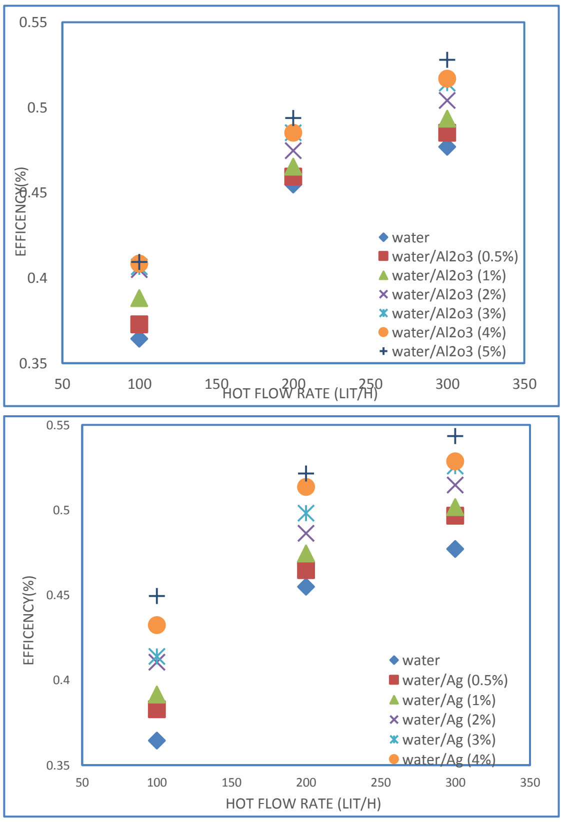

Figure 13. Comparison of thermal performance of (a:water/Al_2O_3) and (b:water/Ag) nanofluids ($\dot{Q}_c$ = 90 lit/h) (cam-shaped tube heat exchanger)

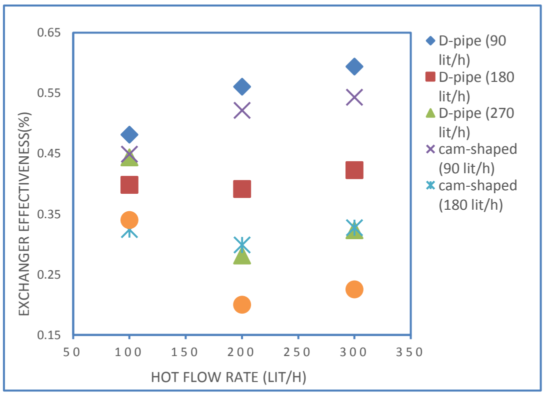

Figure 14. Comparison of thermal efficiency results of water/Ag nanofluids (5%) (Both types of heat exchanger)

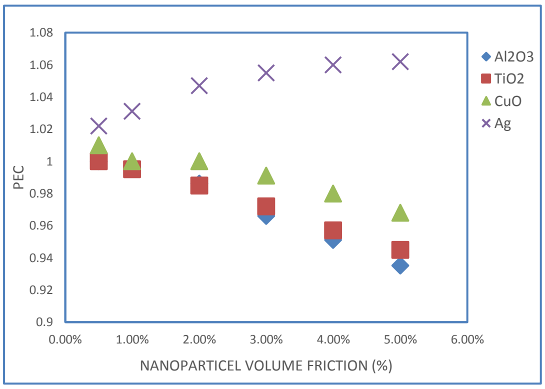

Figure 15. PEC of different nanofluids (cam-shaped tube heat exchanger)

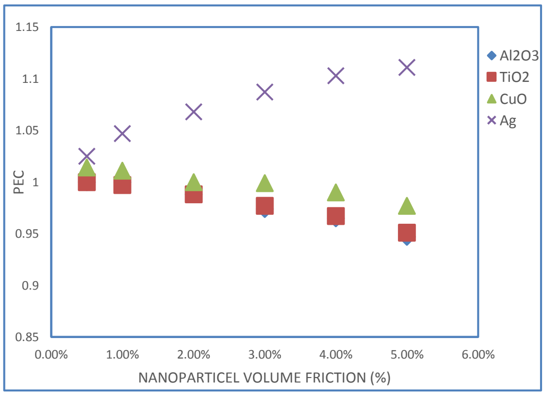

Figure 16. PEC of different nanofluids (circular tube heat exchanger)

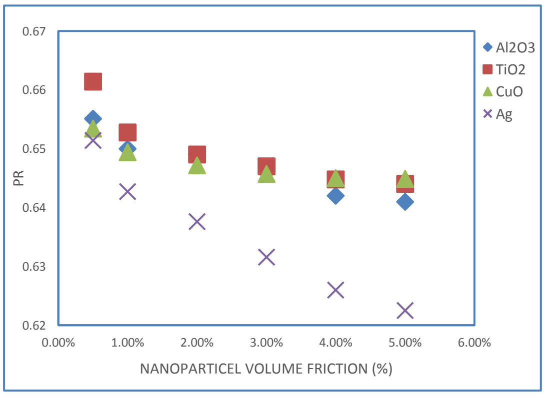

Figure 17. PR of different nanofluids (Comparison between two heat exchanger)

This increase of PEC in silver nanofluid is due to the high thermal conductivity of silver compared to other particles. Figure (17) shows the performance results of the two heat exchangers relative to each other. As it can be seen, because the heat transfer in the cam-shaped tube heat exchanger is much less than the circular tube, the PR value is lower than one, and the PR value decreases by increasing concentration of nanoparticles. The maximum PR is related to the water/TiO_2 nanofluid. As it can be seen from the previous results, this nanofluid does not have the highest heat transfer (Nusselt number) and the lowest pressure drop, but considering the relationship (14), the Nusselt number values and the coefficient of friction for this nanofluid are such which has the best performance evaluation criteria. It is also evident that at higher volume fraction, as the Nusselt number increases, the pressure drop is so high that the use of high concentration nanofluids is not economical and also the use of a cam-shaped tube in double-pipe heat exchanger reduces the Nusselt number, as a result, it is not economical in terms of thermal-hydraulic properties and increases energy losses.

In Table 6, a comparison was performed between the results of Aspen EDR and FLUENT for water/Ag nanofluids at two volume concentration of 0.5 and 5%. As it can be seen, the results of the heat transfer rate are very close, (the difference between the results is 1-7 %), the difference of pressure drop results (8-20 %) and the difference of thermal efficiency results is (7-20%). Both software seems suitable for analyzing heat exchangers.

5. Concluding Remarks

In this study which has been numerically conducted by two softwares of FLUENT and Aspen EDR, four different nanofluids were used in double-pipe heat exchanger with two different cross-sections and the results are as follows:

1. Comparing the results of both types of heat exchanger shows that when using nanofluid in cam-shaped tube heat exchanger, thermal issue has a less growth than circular tube heat exchanger. As it can be seen, the results of heat transfer rate and thermal efficiency of the cam-shaped tube are lower than the circular tube, but investigating the results of pressure drop show that increasing the pressure drop when using cam-shaped tube is less than the circular tube and the results of cam-shaped tube show the hydraulic advantage of this type of pipe.
2. Investigating the results of the energy ratio shows that the use of the cam-shaped tube has reduced the Nusselt number compared to the circular tube, and although the increase in pressure drop in this tube is lower than the circular tube, it caused the amount of PR to be reduced. The highest PR value is related to water/TiO_2 nanofluids. The results also show that the highest energy ratio (PEC) is related to water/silver nanofluid which in this type of nanoparticles, energy ratio has been increased by increasing volume fraction of nanoparticles but it decreased for other nanoparticles. The upward trend of PEC for silver nanoparticles is due to the high thermal conductivity of this type of particle compared to other particles, which caused the thermal effect to be more dominant over hydraulic effect, as well as the downward trend of energy ratio for other nanoparticles, heat transfer rate has been increased but the pressure drop (friction coefficient) increased with more slope, which decreased the value of energy ratio index.

Table 5. Thermal efficiency of different nanofluids (circular and cam-shape tube heat exchanger)

Hot flow rate (lit/h)	Cold flow rate (lit/h)	nanoparticles	$\emptyset = \mathbf{0.5}\%$	$\emptyset = \mathbf{1}\%$	$\emptyset = \mathbf{2}\%$	$\emptyset = \mathbf{3}\%$	$\emptyset = \mathbf{4}\%$	$\emptyset = \mathbf{5}\%$
100	90	Al_2O_3 (circular pipe)	+1.43	+3.11	+4.31	+5.17	+5.44	+5.63
		Al_2O_3 (Cam-shape pipe)	+2.3	+6.53	+11.11	+11.6	+12.07	+12.35
		TiO_2 (circular pipe)	+1.58	+3.66	+5.56	+6.06	+6.71	+7.21
		TiO_2 (Cam-shape pipe)	+2.58	+6.64	+11.82	+12.51	+13.94	+16.35
		CuO (circular pipe)	+1.59	+3.71	+5.63	+7.86	+8.7	+9.4
		CuO (Cam-shape pipe)	+2.63	+6.86	+12.23	+12.81	+14.8	+17.31
		Ag (circular pipe)	+3.11	+4.34	+7.96	+10.02	+13	+15.41
		Ag (Cam-shape pipe)	+5.04	+7.43	+12.62	+13.55	+18.63	+23.29
200	180	Al_2O_3 (circular pipe)	+0.78	+1.36	+2.22	+4.02	+4.74	+5.9
		Al_2O_3 (Cam-shape pipe)	+0.95	+1.147	+2.86	+5.16	+5.58	+7.57
		TiO_2 (circular pipe)	+1.3	+2.31	+3.18	+4.6	+5.84	+6.71
		TiO_2 (Cam-shape pipe)	+2.1	+2.9	+3.67	+5.92	+7.07	+8.98
		CuO (circular pipe)	1.41+	+2.66	+4.43	+6.08	+7.55	+9.06
		CuO (Cam-shape pipe)	+2.15	+3.74	+4.62	+6.7	+8.75	+10.13
		Ag (circular pipe)	1.96+	+3.67	+6.25	+8.8	+11.41	+13.32
		Ag (Cam-shape pipe)	+2.21	+4.24	+5.7	+8.22	+12.2	+12.82
300	270	Al_2O_3 (circular pipe)	0.31+	+1.35	+2.05	+4.11	+5.12	+6.1
		Al_2O_3 (Cam-shape pipe)	+1.05	4.31	+7.51	+9.47	+10.63	+11.47
		TiO_2 (circular pipe)	+1.15	+2.05	+3.23	+5.15	+6.2	+7
		TiO_2 (Cam-shape pipe)	+2.63	+5.26	+7.89	+9.73	+11.63	+13.73
		CuO (circular pipe)	+1.35	+2.36	+4.49	+5.53	+7.31	+9.12
		CuO (Cam-shape pipe)	+5.26	+5.79	+8.94	+10.1	+12.1	+14.84
		Ag (circular pipe)	+1.81	+3.16	+5.92	+8.22	+11.07	+12.6
		Ag (Cam-shape pipe)	+5.3	+6.31	10	+13	+15.63	+18.47

Table 6. Comparison of Aspen EDR and FLUENT results for water/Al_2O_3 nanofluids at two concentrations of 0.5 and 5%

Nanoparticles (%)	Cold flow rate (Lit/h)	Hot flow rate (Lit/h)	Q(watt) FLUENT	Q(watt) Aspen	ΔP (KPa) FLUENT	ΔP (KPa) Aspen	T-outlet (K) FLUENT	T-outlet (K) Aspen	ε (%) FLUENT	ε (%) Aspen
0.5%	100	100	1073	1149	3.29	2.6	312.43	313.84	0.423	0.3773
		200	1350	1359	8.65	6.7	316.77	317.56	0.52	0.4466
		300	1446	1464	14.91	13.6	318.53	319.13	0.56	0.4811
	200	100	1333	1358	3.29	2.6	309.96	312.14	0.482	0.4073
		200	1768	1686	8.65	6.7	314.64	316.21	0.348	0.2773
		300	1950	1864	14.91	13.6	316.84	318.03	0.385	0.3066
	300	100	1455	1401	3.29	2.6	308.81	310.17	0.525	0.4809
		200	2008	2061	8.65	6.7	313.54	314.66	0.35	0.3146
		300	2263	2316	14.91	13.6	315.88	316.79	0.288	0.2541
5%	100	100	1115	1141	5	4	313.07	314.27	0.4405	0.406
		200	1395	1451	12.78	8.8	317.15	317.97	0.5369	0.4752
		300	1486	1551	21.93	17.3	318.83	319.46	0.5741	0.5078
	200	100	1409	1489	5	4	310.55	312.5	0.4611	0.3947
		200	1853	1832	12.78	8.8	315.03	316.61	0.3657	0.3
		300	2040	2009	21.93	17.3	317.14	318.37	0.4034	0.329
	300	100	1545	1571	5	4	309.41	310.47	0.5033	0.4697
		200	2129	2261	12.78	8.8	313.88	315.09	0.3377	0.2988
		300	2386	2518	21.93	17.3	316.17	317.16	0.3046	0.2749

3. Results from numerical simulations show that adding different nanoparticles to the base fluid increases the rate of heat transfer. This increase varies in different volume fractions and the coefficient of heat transfer increases by increasing volume fraction of the nanoparticles, which these results are observed in both software and both types of heat exchangers. The highest increase in heat transfer has been observed among the four nanofluids used in this water/Ag nanofluid simulation in amount of 26.74%. Also, the maximum increase in heat transfer rate at concentration 5% for water/CuO, water/TiO_2 and water/Al_2O_3 nanofluids is 16.2%, 12.48% and 11.62%, respectively. In the cam-shaped heat exchanger, the maximum increase in heat transfer rate compared to pure water that is 21.15% is related to water/Ag nanofluid, for other water/CuO, water/TiO_2 and water/Al_2O_3nanofluids, increase in heat transfer rate It is equal to 16.25%, 13% and 12.55%, respectively. Consequently, it can be said that silver nanoparticles have more effect on heat transfer coefficient compared to other nanoparticles. In the study of heat transfer rate in both types of heat exchanger, the heat transfer rate in cam-shaped tube heat exchanger has been decreased about 9-57 % compared to circular tube heat exchanger.

   Ag is an expensive nanoparticle. But it should be noted that this nanofluid is supposed to be applied in a cycle and in fact it is not consumed. Therefore, due to the high improvement of heat transfer provided by Ag nanoparticles it is logical to pay an initial cost once and apply this nanofluid which widely welcomed by many industries.
4. Adding nanoparticles to the base fluid at low flows has increased the efficiency of the heat exchanger, but increasing efficiency is less at higher flows, or even reduced the efficiency of the heat exchanger. The results of thermal efficiency also show that the thermal efficiency of the cam-shaped tube is lower than the circular tube.
5. The pressure drop in the heat exchanger compared to pure water increases by increasing the volume fraction of nanoparticles. According to the results in circular tube heat exchanger, the maximum pressure drop in water/Ag nanofluid reaches about 68%. The pressure drop in the cam-shaped tube heat exchanger has also decreased compared to the double-pipe heat exchanger of circular tube, but the pressure drop has been increased 39% compared to pure water using nanofluids, but the increase in pressure drop has been decreased compared to the circular tube.
6. When using nanofluids, the outlet temperature of the heat exchanger increases. According to the results, the outlet temperature is higher when using the cam-shaped tube heat exchanger than the circular tube, which also reduces the heat transfer rate and reduces the thermal efficiency of the tube compared to the circular tube.
7. Comparing the results between the two software shows that both software have the capability to simulate the exchanges and nanofluids.

Nomenclature

D_h	Hydraulic diameter
D_{eq}	Equivalent diameter
D-pipe	Double pipe heat exchanger (circular tube)
$\dot{Q}$	Flow rate (lit/h)
$\dot{m}$	Mass flow rate, (kg/h)
Q	Heat transfer rate, (w)
Lit/h	Litter per hour
PEC	Performance Evaluation Criteria
Suffix	
c	cold
h	hot
nf	nanofluid
bf	Based fluid
Greek letters	
μ	Viscosity, kg/m.s
ρ	Density, kg/m3
$\emptyset$	Volume fraction nanoparticles
ε	Heat transfer effectiveness

References

[1] Manasrah, A.D., Al-Mubaiyedh, U.A., Laui, T., Ben-Mansour, R., Al-Marri, M.J., Almanassra, I.W., Abdala, A. and Atieh, M.A., 2016. Heat transfer enhancement of nanofluids using iron nanoparticles decorated carbon nanotubes. *Applied Thermal Engineering*, *107*, pp.1008-1018.

[2] Dondapati, R.S., Saini, V., Verma, K.N. and Usurumarti, P.R., 2017. Computational prediction of pressure drop and heat transfer with cryogen based nanofluids to be used in micro-heat exchangers. *International Journal of Mechanical Sciences*, *130*, pp.133-142.

[3] Kakac, S., Liu, H. and Pramuanjaroenkij, A., 2002. *Heat exchangers: selection, rating, and thermal design*. CRC press.

[4] Maxwell, James Clerk. A treatise on electricity and magnetism. Vol. 1. Clarendon press, 1881.

[5] Akhtari, M., Haghshenasfard, M. and Talaie, M.R., 2013. Numerical and experimental investigation of heat transfer of α-Al2O3/water nanofluid in double pipe and shell and tube heat exchangers. *Numerical Heat Transfer, Part A: Applications*, *63*(12), pp.941-958.

[6] Choi, S.U. and Eastman, J.A., 1995. *Enhancing thermal conductivity of fluids with nanoparticles* (No. ANL/MSD/CP-84938;

CONF-951135-29). Argonne National Lab., IL (United States).
[7] Choi, S.U. and Eastman, J.A., 1995. *Enhancing thermal conductivity of fluids with nanoparticles* (No. ANL/MSD/CP-84938; CONF-951135-29). Argonne National Lab., IL (United States).
[8] Wang, X., Xu, X. and Choi, S.U., 1999. Thermal conductivity of nanoparticle-fluid mixture. *Journal of thermophysics and heat transfer*, *13*(4), pp.474-480.
[9] Lee, S., Choi, S.S., Li, S.A. and Eastman, J.A., 1999. Measuring thermal conductivity of fluids containing oxide nanoparticles.
[10] Kumar, N. and Sonawane, S.S., 2016. Experimental study of Fe2O3/water and Fe2O3/ethylene glycol nanofluid heat transfer enhancement in a shell and tube heat exchanger.*International Communications in Heat and Mass Transfer*, *78*, pp.277-284.
[11] Tirandaz, N., Dehghan, M. and Valipour, M.S., 2017. Heat and fluid flow through a helical annulus enhanced by a porous material: A perturbation study. *Applied Thermal Engineering*, *112*, pp.1566-1574.
[12] Tajik Jamal-Abad, M., Dehghan, M., Saedodin, S., Valipour, M.S. and Zamzamian, A., 2014. An experimental investigation of rheological characteristics of non-Newtonian nanofluids. *Journal of Heat and Mass Transfer Research*, *1*(1), pp.17-23.
[13] Raei, B., 2020. Statistical analysis of nanofluid heat transfer in a heat exchanger using Taguchi method. *Journal of Heat and Mass Transfer Research*.
[14] Parvar, M., Saedodin, S. and Rostamian, S.H., 2020. Experimental study on the thermal conductivity and viscosity of transformer oil-based nanofluid containing ZnO nanoparticles. *Journal of Heat and Mass Transfer Research*, *7*(1), pp.77-84.
[15] Gholy Nejad, P.M., Solaimany Nazar, A.R., Rahimi Ahar, Z. and Rajati, H., 2019. Investigation on turbulent nanofluid flow in helical tube in tube heat exchangers. *Journal of Heat and Mass Transfer Research*, *6*(1), pp.31-39.
[16] YadollhiFarsani, R., Raisi, A. and Ahmadi Nadooshan, A., 2019. Experimental Investigation of the Alumina/Paraffin Thermal Conductivity Nanofluids with a New Correlated Equation on Effective Thermal Conductivity. *Journal of Heat and Mass Transfer Research*, *6*(2), pp.85-93.
[17] Bayat, H., Lavasani, A.M. and Maarefdoost, T., 2014. Experimental study of thermal–hydraulic performance of cam-shaped tube bundle with staggered arrangement. *Energy conversion and management*, *85*, pp.470-476.
[18] Nouri-Borujerdi, A. and Lavasani, A.M., 2007. Experimental study of forced convection heat transfer from a cam shaped tube in cross flows. *International Journal of Heat and Mass Transfer*, *50*(13-14), pp.2605-2611.
[19] Lavasani, A.M.A. and Bayat, H., 2012. Heat transfer from two cam shaped cylinders in side-by-side arrangement. *International Journal of Mechanical and Mechatronics Engineering*, *6*(7), pp.1298-1301.
[20] Lavasani, A.M.A. and Bayat, H., 2012. Heat transfer from two cam shaped cylinders in side-by-side arrangement. *International Journal of Mechanical and Mechatronics Engineering*, *6*(7), pp.1298-1301.
[21] Nouri-Borujerdi, A. and Lavasani, A.M., 2008. Pressure loss and heat transfer characterization of a cam-shaped cylinder at different orientations. *Journal of heat transfer*, *130*(12).
[22] Lavasani, A.M. and Bayat, H., 2016. Numerical study of pressure drop and heat transfer from circular and cam-shaped tube bank in cross-flow of nanofluid. *Energy Conversion and Management*, *129*, pp.319-328.
[23] Arya, H., Sarafraz, M.M., Pourmehran, O. and Arjomandi, M., 2019. Heat transfer and pressure drop characteristics of MgO nanofluid in a double pipe heat exchanger. *Heat and Mass Transfer*, *55*(6), pp.1769-1781.
[24] Mund, A., Pattanayak, B., Jayakumar, J.S., Parashar, K. and Parashar, S.K.S., 2019. Experimental and Numerical Study of Heat Transfer in Double-Pipe Heat Exchanger Using Al 2 O 3, and TiO 2 Water Nanofluid. In *Advances in Fluid and Thermal Engineering* (pp. 531-540). Springer, Singapore.
[25] Bahmani, M.H., Sheikhzadeh, G., Zarringhalam, M., Akbari, O.A., Alrashed, A.A., Shabani, G.A.S. and Goodarzi, M., 2018. Investigation of turbulent heat transfer and nanofluid flow in a double pipe heat exchanger. *Advanced Powder Technology*, *29*(2), pp.273-282.
[26] Esfe, M.H., Saedodin, S. and Mahmoodi, M., 2014. Experimental studies on the convective heat transfer performance and thermophysical properties of MgO–water nanofluid under turbulent flow. *Experimental thermal and fluid science*, *52*, pp.68-78.
[27] Chun, B.H., Kang, H.U. and Kim, S.H., 2008. Effect of alumina nanoparticles in the fluid on heat transfer in double-pipe heat

exchanger system. *Korean Journal of Chemical Engineering*, *25*(5), pp.966-971.
[28] Aziz, A., Jamshed, W. and Aziz, T., 2018. Mathematical model for thermal and entropy analysis of thermal solar collectors by using Maxwell nanofluids with slip conditions, thermal radiation and variable thermal conductivity. *Open Physics*, *16*(1), pp.123-136.
[29] Sobamowo, M.G., Yinusa, A.A. and Oluwo, A.A., 2018. Slip analysis of magnetohydrodynamics flow of an upper-convected Maxwell viscoelastic nanofluid in a permeable channel embedded in a porous medium. *Aeron Aero Open Access J*, *2*(5), pp.310-318.
[30] Mellal, M., Benzeguir, R., Sahel, D. and Ameur, H., 2017. Hydro-thermal shell-side performance evaluation of a shell and tube heat exchanger under different baffle arrangement and orientation. *International Journal of Thermal Sciences*, *121*, pp.138-149.