Al-Rafidain Journal of Engineering Sciences

Journal homepage https://rjes.iq/index.php/rjes

ISSN 3005-3153 (Online)

CFD simulations of Hybrid and Composite Nanomaterials for Enhanced Heat Transfer in Heat Exchangers

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ARTICLE INFO

Article history:
Received 04 November 2024
Revised 04 November 2024
Accepted 26 November 2024
Available online 26 December 2024

Keywords:
Computational Fluid Dynamics
Hybrid and Composite Nanomaterials
Heat Transfer
Heat Exchangers

ABSTRACT

This quantitative research explores features of impact of nanomaterials, hybridized nanomaterials, and composite nanomaterials on heat exchangers. Heat exchangers are used widely in various industrial processes and are considered important elements since they extend the lifespan of equipment through proper management of thermal loads. It has been evident that incorporation of TiO_2 nanomaterials will improve progressively the thermal conductivity of heat exchange equipment and, thus, the overall efficiency of heat exchangers. In the present research, the findings have been derived through the use of computational fluid dynamics (CFD) analysis for studying heat exchange characteristics and the flow of fluids in heat exchangers incorporating various forms of nanomaterials. The study considered the influence of adding Al_2O_3 with CuO hybridized nanomaterials onto the heat exchanger as its material. The temperature got low at 43.3 °C, which showed the performance of the nanomaterials, and reduced further afterwards to 41.93 °C within just 10 minutes. The inclusion of the nanohybrid in combination approached the premium down to 36.6°C twelve minutes later. The result indicates that the use of the nanocomposite is well justified for improving the quality of the cooling process. Contour temperatures, velocities, and pressure show heat transfers and quantities of fluid density when hybrid nanomaterials are mixed with multiple substances. It was at 313.5 K that the maximum temperature was at, and the velocity arrived at 0.45 m/s, which subsequently decreased to 0.33 m/s. The increase in pressure was at 1035 pa. This translates to the difference in density of the absorbent fabric and the nanomaterials.

1. Introduction

Heat exchangers are used widely in various industrial processes and are considered important elements since they extend the lifespan of equipment through proper management of thermal loads. The heat exchangers apply widely in power plants and manufacturing sectors, chemical plants, oil refineries, and HVAC & R systems. The effectiveness of the heat exchangers, which often dictate the efficiency of these systems, influences their functionality and energy expenditure. The heat transfer in a typical heat exchanger fluid has been observed to come with drawbacks with respect to thermal conductivity, hence the development of new and unique mediums. Nanomaterials, hybrid nanomaterials, and composite nanomaterials have been shown to be valid candidates for this effect. To achieve this, this literature review assembles the existing literature, explained below, that examines the impact of these nanomaterials on the performance of heat

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https://doi.org/10.61268/tam04b58

exchangers. Separate and clearly define nanomaterials as the materials with the nanoscale dimensions and discuss how their thermal properties can improve heat transfer. Bearing in mind the fact that addition of nanoparticles to base fluids (e.g., water, ethylene glycol) leads to the formation of nanofluids, several studies have been conducted to understand how nanoparticles like Al_2O_3, CuO, and TiO_2 can be dispersed to the base fluids. There is indeed historical evidence from these studies pointing to noticeable enhancements in the thermal conductivity and heat transfer coefficients.

Wang et al. (2009) [1] have investigated the flow characteristics for Al_2O_3 nanofluids experimentally and numerically and found a maximum enhancement of thermal conductivity of around 30% than base fluids. Eastman et al. (2001) [2] obtained the data on heat transfer capabilities of heat exchangers with CuO nanofluids with increased thermal conductivity and decreased thermal resistance. It was also found that a TiO_2 nanofluid showed the enhancement in thermal properties at higher nanoparticle concentrations of TiO_2, but they suffered from some problems of stability and sedimentation of TiO_2, as reported by Das et al. (2007) [3].

For instance, Lee et al. (2011) [4] studied blended nanofluids containing Al_2O_3 and CuO. In their work, they found that they have achieved a significantly higher value of a 45 percent increment of thermal conductivity; thus, they concluded that the improvement came from the mutually supported properties of the two nanoparticles. Pakde and Wangnan (2007) [4] also evidenced that hybrid nanofluids of carbon nanotubes and metal oxide nanoparticles have higher heat transfer rates and stability as compared to the conventional TiO_2 nanofluids, as pointed out by Jana et al. (2007) [5]. Yang et al. (2012) [6] looked into the thermophysical characteristics of hybrid nanofluid containing both graphene and metal nanoparticles, where sizeable enhancements in 'hf' and the overall heat exchanger effectiveness were retrieved.

The behavior of Al_2O_3 nanoparticles incorporating polymer-based composite nanomaterials has been reported by Zhou et al. (2010) [7], wherein the thermal conductivity has been increased and mechanical strength has been improved to make them suitable to use at higher temperatures. Regarding the ceramic-based composite nanomaterials, Kim et al. (2013) [8] reported that the thermal conduction and the durability under severe operating conditions for sic nanoparticles incorporated into nanocomposites were found to be enhanced. Li, Teja, and Rajendra Kumar (2015) conducted a survey on metal matrix composites and observed that the form cu nanoparticles in the al matrix exhibited improvement in thermal conductivity, which also offered high thermal stability along with corrosion control.

Using this endnote, Choi et al. (2009) [8] confirmed that the temperature change pattern of spherical nanoparticles is different from that of the rod-shaped or platelet-shaped ones. They pointed out in their study that the outer configuration of the nanoparticles in relation to their cross-sectional area might affect the thermal conductivity of nanofluids. As explained above, the stability of the nanofluids depends upon the particle size, and hence the thermal properties of the nanofluids were studied by Timofeev et al. (2007) [9], they discovered that the smaller the nanoparticles, the higher the surface area to volume ratio of ratio would deliver enhanced thermal conduction properties. There are several studies, such as Xie et al. (2010) [10], that compared and analyzed the effects of metal oxides, carbon nanotubes, metal nanoparticles, and so on, low thermal conductivity materials used for enhanced heat transfer rates, but differ in the manner due to the types of nanomaterials.

He et al. (2014) [11] investigated the thermal conductivity and other thermal characteristics of the hybrid nanofluids, which consisted of Al_2O_3 and SiO_2 nanofluids. The deficiency of their investigation was the response that the simultaneous use of both hybrid nanofluids yielded better thermal conduction coefficients and heat transfer rates as compared to the use of single-phase nanofluids. In a recent study, a et al. (2015) [12] performed a detailed investigation of TiO_2 on a type of hybrid nanofluid containing both graphene and metallic nanoparticles. It comes up with improved heat transfer characteristics and stability; these improvements were testified to be relatively at low volume concentrations of the nanoparticles. Chen et al. (2016) [13] worked an investigation on the flow characteristics of different nanoparticles mixed in the hybrid nanofluids and found that the carbon-based mixed with the metal-based nanoparticles provided enhanced thermal characteristics.

Recently, Huang et al. (2011) [14] discussed and studied the polymer-matrix composite nanomaterials reinforced with carbon nanotubes. They proved that their composites exhibited reasonable enhancement in thermal conductivity as well as mechanical strength, which will actually make these composites probable for high-end heat exchanger applications. According to Singh et al. (2012), they identified the advantages of embedding sic and all nanoparticles in the ceramic matrix composite nanomaterials. They also discovered that, in the composite, these types offered good thermal stability and thermal conductivity effectiveness even under high temperatures. In their work, Zhu et al. (2013) [16] synthesized metal matrix composite nanomaterials, including cu and al matrices, with nanoparticle reinforcements.

As another case, Zeng et al. (2014) [17] examined the application of Al_2O_3 nanofluids in automobile radiators. They have become evidence of performance that showed heat transfer efficiency increased with fuel consumption of TiO_2 by 20%. Sundar et al. (2015) [18] studied the uses of CuO nanofluids in Hvac systems, where the results indicated enhanced thermal efficiency and energy conservation of TiO_2 due to increased rates of heat transfer. Wan et al. (2010) [20] and Kumar et al. (2016) [19] highlighted the use of hybrid nanomaterials within heat exchangers of power plants, indicating improving thermal efficiency and operation performance. Fating et al. (2022) [21] investigated nano-enhanced phase change materials (NEPCMs) for thermal energy storage in heat exchangers. This research shows that NEPCMs, particularly those enhanced with hybrid nanoparticles, can increase the efficiency of thermal energy storage systems, especially in solar energy applications. Research by Addali et al. (2022) [22] focused on improving the thermal-hydraulic performance of heat exchangers through the use of nanofluids. By reviewing multiple configurations (e.g., shell-and-tube, plate-fin), they demonstrated the potential of hybrid nanofluids to improve heat transfer rates while considering the pressure drop trade-offs.

Khan et al. (2024) [23] conducted a comprehensive review on the utilization of hybrid nanomaterials in solar thermal applications, emphasizing their thermophysical properties and potential to improve heat exchanger efficiency. Varma et al. (2024) [24] provided an overview of current research on nanofluids in heat exchangers, highlighting their superior thermal conductivity and heat transfer rates compared to conventional fluids. Li et al. (2023) [25] developed a durable, ultrathin, and antifouling polymer brush coating for efficient condensation heat transfer, which could be applied to heat exchangers to maintain performance and reduce maintenance.

The application of TiO_2 nanomaterials, hybrid nanomaterials, and composite nanomaterials for heat exchangers yielded some of the most promising prospects for optimizing thermal performance and energy aspects. The above-discussed issues are still a concern in practice, but mounting investigations and the evolution of technology will continue resolving them and will foster better thermal management solutions across different sectors. This literature review points to the need for further research on the most effective way of using nanomaterials to incorporate them into heat-exchanging technology to their maximum potential. This study aims to evaluate the effectiveness of hybrid and composite nanomaterials in improving the thermal performance of heat exchangers. Using computational fluid dynamics (CFD) simulations, this research will investigate the influence of different nanoparticle concentrations and combinations on heat transfer rates and temperature reduction, with the goal of identifying optimal nanomaterial configurations for industrial applications.

2. Methodology

All the settings, properties of the thermal materials, and equations used in the numerical aspect of the study will be presented. Computational fluid dynamics (CFD) in the Ansys program version 2019 is used to simulate fluids and thermals in certain systems. The governing equations of two-phase flow will be solved numerically utilizing the k-ε model for turbulence.

Despite extensive research on the use of nanomaterials in heat exchangers, significant gaps remain. While previous studies have demonstrated improvements in heat transfer efficiency using individual nanomaterials such as Al_2O_3, CuO, and TiO_2, limited attention has been given to identifying the optimal concentrations and combinations of hybrid and composite nanomaterials for maximum thermal performance. Additionally, comparative analyses evaluating the effects of single, hybrid, and composite nanomaterials on heat exchanger efficiency remain scarce. Furthermore, although numerical simulations have been widely used to predict fluid behavior and heat transfer rates, there is still a need for more accurate and validated computational fluid dynamics (CFD) models to ensure reliable results. Lastly, the mechanisms governing heat transfer in multi-hybrid nanomaterials, including their interactions with fluid properties such as density, temperature gradients, and pressure drops, are not yet fully understood. This study aims to address these gaps through a comprehensive investigation of the thermal performance of nanomaterials in heat exchangers using CFD simulations.

2.1 Geometrical Description

The model was designed using the Solid Works program, version 2022. Solid Works is 3D computer-aided design (CAD) software used for creating models and designs for mechanical, electrical, and architectural engineering projects.

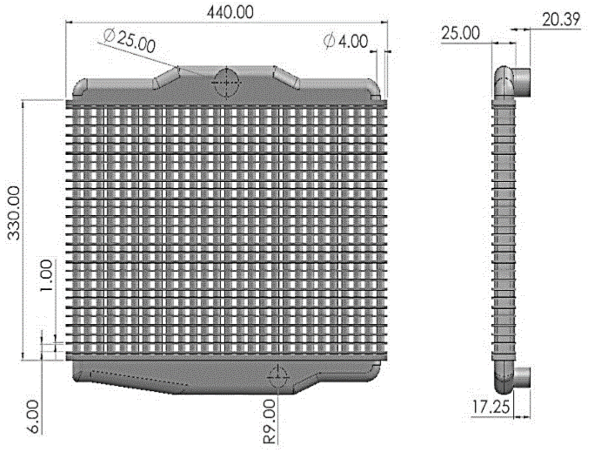

Figure. 1: Geometry domain

Figure 1 represents a description of a 3D physical model of the heat exchanger, where varying nanomaterial parameters were used to obtain different results that can be compared to obtain the best case.

2.2 Assumptions

In the current study, the phase is: water the model under the following assumptions:

- Transient Flow
- Three Dimensional
- Newtonian Fluid
- Incompressible Flow
- Turbulent Flow
- Immiscible Fluids

- Thermal State

The introduction of Al_2O_3 nanoparticles at a concentration of 0.3 wt% into the heat exchanger fluid will decrease the outlet temperature by approximately 2 °C within 10 minutes of operation compared to a baseline fluid without nanomaterials, due to the enhanced thermal conductivity of the nanofluid. Hybrid nanomaterials consisting of 0.4 wt% Al_2O_3 and 0.1 wt% CuO will show a greater reduction in fluid outlet temperature (up to 5 °C) compared to single nanomaterial systems, as the combination of nanoparticles will synergistically increase heat transfer efficiency. The use of multi-hybrid nanomaterials combining Al_2O_3, CuO, and TiO_2 at concentrations of 0.1 wt% each will result in a more significant improvement in thermal performance, reducing fluid outlet temperatures by up to 7 °C after 10 minutes, due to the increased surface interaction and heat conduction properties of the multi-hybrid fluid.

2.3 Governing Equations

In computational fluid dynamics (CFD), governing equations are fundamental equations that describe the behavior of fluid flow. These equations are derived from the principles of conservation of mass and momentum, and they form the basis for mathematical models used in CFD simulations.

2.3.1Continuity Equation

The set of equations to be solved by CFD are as follows.

Continuity [1]

$$\frac{\partial}{\partial t}(F_\alpha P_\alpha) + \nabla \cdot (F_\alpha P_\alpha \vec{U}_A) = S_{ms\alpha} + \sum_{B=1}^{n_p} \Gamma_{\beta\alpha}$$
(1)

Where α and β represent the phases involved (water or oil), f is the volume fraction, ρ is density, is the velocity vector, np is the number of phases involved, and rαβ is the mass flow rate per unit volume from phase β to phase α. In addition, the term describes user-specified mass sources.

2.3.2 Momentum equation:

$$\frac{\partial}{\partial t}(F_\alpha P_\alpha \vec{U}_A) + \nabla \cdot [F_\alpha (P_\alpha \vec{U}_A \vec{U}_A)] = -F_\alpha \nabla P_\alpha + \nabla . \{F_\alpha \; M_\alpha [\nabla \vec{U}_A + (\nabla \vec{U}_A)^T]\} + \sum_{B=1}^{n_p} (\Gamma_{\alpha\beta}^{+} \vec{U}_B - \Gamma_{\beta\alpha}^{+} \vec{U}_A) + S_{m\alpha} + M_\alpha \quad (2)$$

Where p is the pressure and μ is viscosity. In addition, the term describes momentum sources due to external body forces (buoyancy force and rotational force), mα describes the interfacial forces acting on phase α due to the presence of other phases (drag force, lift force, wall lubrication force, virtual mass force, and interphase turbulent dispersion force).

And the term $\gamma_{\alpha\beta}^{+} \vec{U}_B - \Gamma_{\beta\alpha}^{+} \vec{U}_A$ represents momentum transfer induced by interphase mass transfer .

2.3.3 standard k-϶ model

the turbulence kinetic energy, k, and its rate of dissipation, ε, are obtained from the following transport equations :

$$\frac{\partial(P_\varepsilon \, F_\alpha \, K_\alpha)}{\partial t} + \cdot \left\{F_\alpha \left[P_\alpha \vec{U}_A K_\alpha - \left(M + \frac{\mu_{t\alpha}}{\Sigma_k}\right) \nabla K_\alpha\right]\right\} = F_\alpha (G_\alpha - P_\alpha \, E_\alpha) \qquad (3)$$

$$\frac{\partial(P_\varepsilon \, F_\alpha \, E_\alpha)}{\partial t} + \cdot \left\{F_\alpha P_\alpha \vec{U}_A E_\alpha - \left(M + \frac{\mu_{t\alpha}}{\Sigma_k}\right) \nabla E_\alpha\right\} = F_\alpha \frac{E_\alpha}{K_\alpha} (C_1 G_\alpha - C_2 P_\alpha \, E_\alpha) \quad (4)$$

Where g_α is the generation of turbulent kinetic energy inside the phase α and $c_1$and c_2 are empirical constants. In eqn. (5), $\varepsilon_\alpha$is the rate of dissipation of the turbulent kinetic energy of the phase α, eqn. (6), defined by:

$$E_\alpha = \frac{C_\mu Q_\alpha^3}{L_\alpha} \qquad (5)$$

And kα is the turbulent kinetic energy to phase α given by:

$$K_\alpha = \frac{Q_\alpha^2}{2} \qquad (6)$$

Where l_α is the spatial scale length, q_α is the scale of velocity and c_μ is an empirical constant calculated by eqn. (7), given by:

$$C_\mu = 4c_\alpha^2 \qquad (7)$$

In this equation c_α is an empirical constant and $\mu_{t\alpha}$

Corresponds to turbulent viscosity, defined by eqn. (8) as follows:

$$M_{t\alpha} = C_\mu \, P_\alpha \, \frac{K_\alpha^2}{E_\alpha} \qquad (8)$$

The constant used in the eqns. (3)–(8) are: c1 = 1,44; c2 = 1,92; c_μ = 0,09;

Σ_k = 1,0; σ_ε= 1,3.

Σ_k and σ_ε are the turbulent prandtl numbers for k and ε_r respectively in this technique, the phases are considered as continuous, which prevents them from interpenetrating. Additionally, the phases in this approach are isothermal, transitory, and do not include mass transfer or phase change. As a result, each of the fluids under consideration has a single set of momentum equations, and the volume fraction of each fluid in each computing cell is traced across the domain.

$$A_q = \left\{ \begin{matrix} 0 \rightarrow \text{cell is empty of the } q^{th} \text{ fluid} \\ 1 \rightarrow \text{cell is full of the } q^{th} \text{ fluid} \end{matrix} \right\} \qquad (9)$$

$$0 < \alpha_q < 1 \text{ the cell contians the interface} \qquad (10)$$

When utilizing the VOF model, there are a few things to keep in mind ahead of time to ensure a good numerical description. That is, the volume fractions of all phases in each control volume must amount to one. The fields for all variables and attributes are shared by the phases and represent volume-averaged values as long as the volume fraction of either of the phases is known per location. As a result, the variables and features in any particular cell are either solely reflective of one of the three phases or indicative of their combination, depending on the volume fraction values.

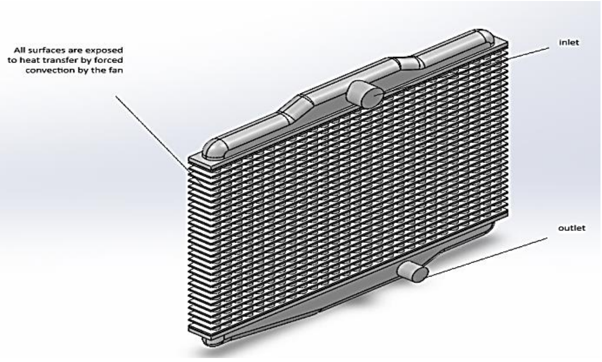

Figure.2: boundary condition

2.4 Boundary conditions

The boundaries are divided to:

1- Inlet: water and nano martial velocities are used. The flow rate is 62 L/m, and variable inlet temperature take from experimental work was 42 degree.
2- Outlet: pressure outlet is used which equals to 0 pa.
3- Walls: all the walls of the pipe are fixed walls with no slip conditions

2.5 Mesh generation

Ansys support solid geometry mesh generation and three-dimensional models with minimum input from a single phase from the user.

The number of cells taken in this study was (1394880) tetrahedron elements, and sizing of element 0.5 mm see fig.3

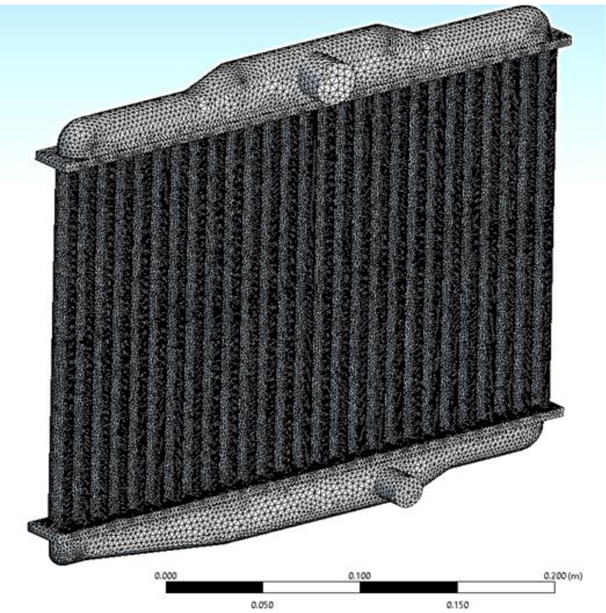

Figure.3: mesh generated

simulation process requires the work of complex algorithms to solve the matrices contained in the domain, and therefore an accurate mesh must be made to solve the equations. And then work on the reliability of the mesh for a solution to reach a stable state with the results. Because of the multiplicity of models that have been simulated, it is necessary to make more than one mesh and more than one mesh reliable. The value of the element is 1394880 when the maximum temperature in the outlet reaches 313.23 K, as in table 1.

Table 1: mesh independency

Case	**Elements**	**Nodes**	**Maximum temperature in outlet K**
1	632429	120785	320.06
2	846056	164097	315.75
3	1078654	216456	313.54
4	1212457	252356	313.25
5	1394880	316443	313.23

2.6 Nano material properties

As in the tables below, the concentrations of nanomaterials and hybrid nanomaterials, as well as composite hybrid nanomaterials, were adopted in the simulation to obtain and compar results

Table 2: Nano material properties

Properties	**Unit**	**Water**	**Al_2O_3**	**CuO**	**TiO_2**
Density	Kg/m^3	998.2	3970	6500	5606
Thermal conductivity	W/m.k	0.6	17.65	18	19
Specific heat	J/kg.k	4182	525	540	544

Table 3: Nano material properties

Properties	**Unit**	**Water+0.1 Al_2O_3**	**Water+0.3 Al_2O_3**	**Water+0.5 Al_2O_3**
Density	Kg/m^3	1001.1718	1007.1154	1013.059
Thermal conductivity	W/m.k	0.61705	0.65115	0.68525
Specific heat	J/kg.k	4178.343	4171.029	4163.715

Table 4: Nano material properties

Properties	**Unit**	**Water+0.1 CuO**	**Water+0.3 CuO**	**Water+0.5 CuO**
Density	Kg/m^3	1003.7018	1014.7054	1025.709
Thermal conductivity	W/m.k	0.6174	0.6522	0.687
Specific heat	J/kg.k	4178.358	4171.074	4163.79

Table 5: Nano material properties

Properties	**Unit**	**Water+0.1 TiO_2**	**Water+0.3 TiO_2**	**Water+0.5 TiO_2**
Density	Kg/m^3	1002.8078	1012.0234	1021.239
Thermal conductivity	W/m.k	0.6184	0.6552	0.692
Specific heat	J/kg.k	4178.362	4171.086	4163.81

Table 6: Nano material properties

Properties	**Unit**	**Water+0.1 Al_2O_3 + 0.4 CuO**	**Water+0.25 Al_2O_3 + 0.25 CuO**	**Water+0.4 Al_2O_3 + 0.1 CuO**
Density	Kg/m^3	1023.182993	1019.390239	1015.592993
Thermal conductivity	W/m.k	0.6866524	0.68612875	0.6856024
Specific heat	J/kg.k	4163.791728	4163.778638	4163.746728

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https://doi.org/10.61268/tam04b58

Table 7: Nano material properties

Properties	**Unit**	**Water+0.1 Al_2O_3 + 0.4 TiO_2**	**Water+0.25 Al_2O_3 + 0.25 TiO_2**	**Water+0.4 Al_2O_3 + 0.1 TiO_2**
Density	Kg/m^3	1023.182993	1017.155239	1014.698993
Thermal conductivity	W/m.k	0.6866524	0.68862875	0.6866024
Specific heat	J/kg.k	4163.791728	4163.788638	4163.750728

Table 8: Nano material properties

Properties	**Unit**	**Water+0.1 CuO + 0.4 TiO_2**	**Water+0.25 CuO + 0.25 TiO_2**	**Water+0.4 CuO + 0.1 TiO_2**	**Water + 0.1 CuO + 0.1 Al_2O_3 + 0.1 Al_2O_3**
Density	Kg/m^3	1022.136993	1023.480239	1024.818993	1002.560467
Thermal conductivity	W/m.k	0.6910024	0.68950375	0.6880024	0.617616667
Specific heat	J/kg.k	4163.822728	4163.826138	4163.810728	4178.354333

3. Results and discussion

After adding the inputs to the simulation program regarding the heat exchanger through experimental tests and simulation work, the temperature results obtained through the simulation program are shown regarding the addition of nanomaterials, as well as the addition of hybrid nanomaterials, and then the addition of multiple hybrid nanomaterials.

3.1 Effect of adding nanomaterials

Crucial nanomaterial properties such as these, namely; the thermal conductivity and the high surface area-to-volume ratio, make nanoparticles or nanofluids be the best candidates to improve heat transfer in heat exchangers. This implies volume expansion, which is of course a rise in heat capacity and respectively, a lower outlet temperature for the heat input. The possibility of nanomaterials being anti-fouling also exists, which means that they can avoid deposits on heat exchange surfaces and in return, higher yields of heat transfer rates are maintained. While accommodating the nanoparticles in the pipeline work may hinder fluid flow with additional pressure drop, this should be considered in the system design. Nanomaterials stabilities at high temperatures remains a major concern, since some may get degrade or agglomerate in case of equipment breakdown. Accuracy of models for instance CFD calculations is imperative to capture convective flow in nanomaterial reinforced heat transfer liquids. Notwithstanding the fact that of all the processes heat exchangers are actually the most complex ones, proper analysis and simulation are the key to understanding and optimizing the performance of nanofluid-based heat exchangers. It can be seen from figure 4, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of Al2O3 nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of nanomaterials began at 43.3 °C and decreased within 10 minutes to 41.93 °C, but when the material was added the temperature of Al_2O_3 nanoparticles at a concentration of 0.1 wt% reached 39.35 °C, and when the nanomaterial was added at a concentration of 0.3 wt%, the temperature dropped to 39.18 °C. When the nanomaterial Al_2O_3 0.5 wt% was added, the temperature dropped to 39.12 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

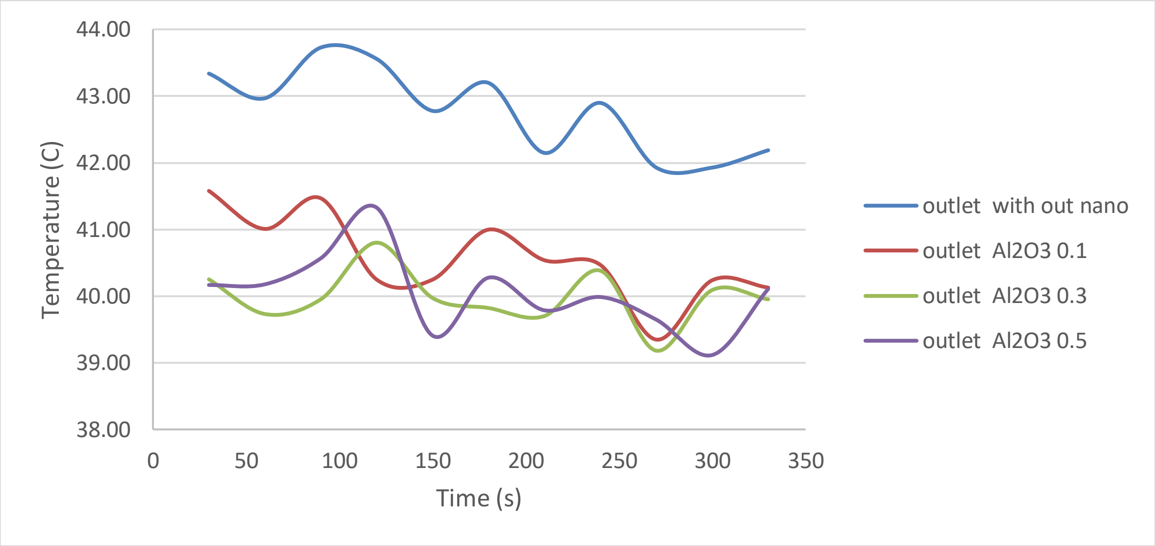

Figure . 4: Temperature with time for different adding nanomaterial different concentrations of Al_2O_3.

Fig.5, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of CuO nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of nanomaterials began at 43.3°C and decreased within 10 minutes to 41.93°C, but when the material was added the temperature of CuO nanoparticles at a concentration of 0.1 wt% reached 40.88°C, and when the nanomaterial was added at a concentration of 0.3 wt%, the temperature dropped to 40.54 °C. When the nanomaterial CuO 0.5 wt% was added, the temperature dropped to 38.57 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

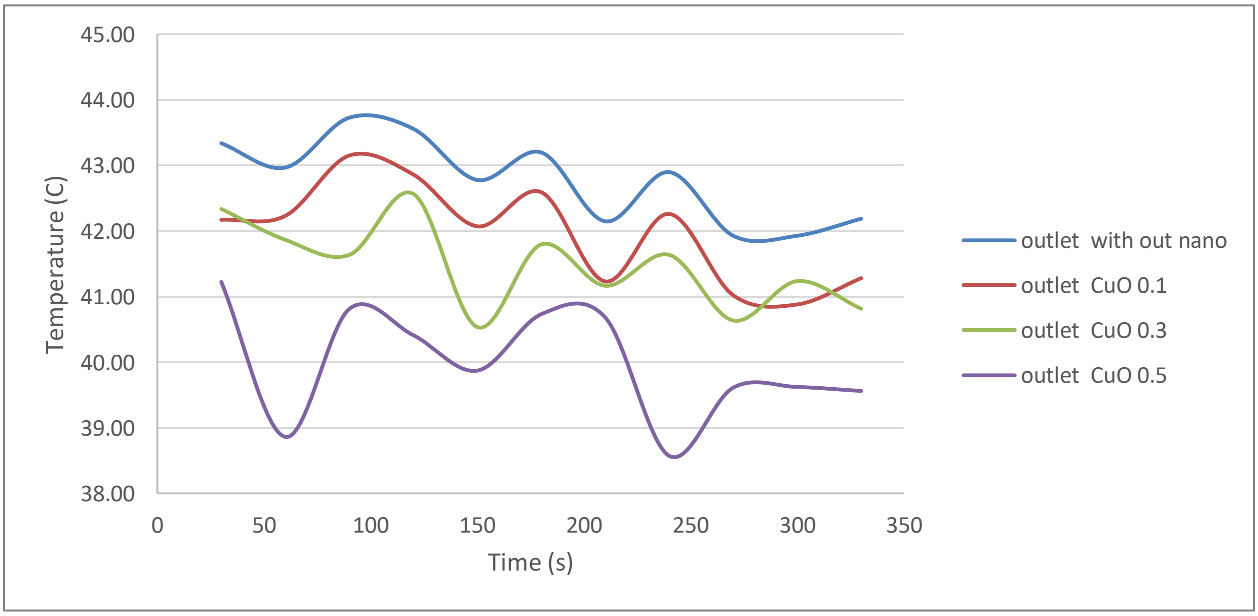

Figure. 5: temperature with time for different adding nanomaterial different concentrations of CuO.

Fig. 6, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of TiO_2 nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of nanomaterials began at 43.3°C and decreased within 10 minutes to 41.93°C, but when the material was added the temperature of TiO_2 nanoparticles at a concentration of 0.1 wt% reached 41.43°C, and when the nanomaterial was added at a concentration of 0.3 wt%, the temperature dropped to 41.04 °C. When the nanomaterial TiO_2 0.5 wt% was added, the temperature dropped to 36.39 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

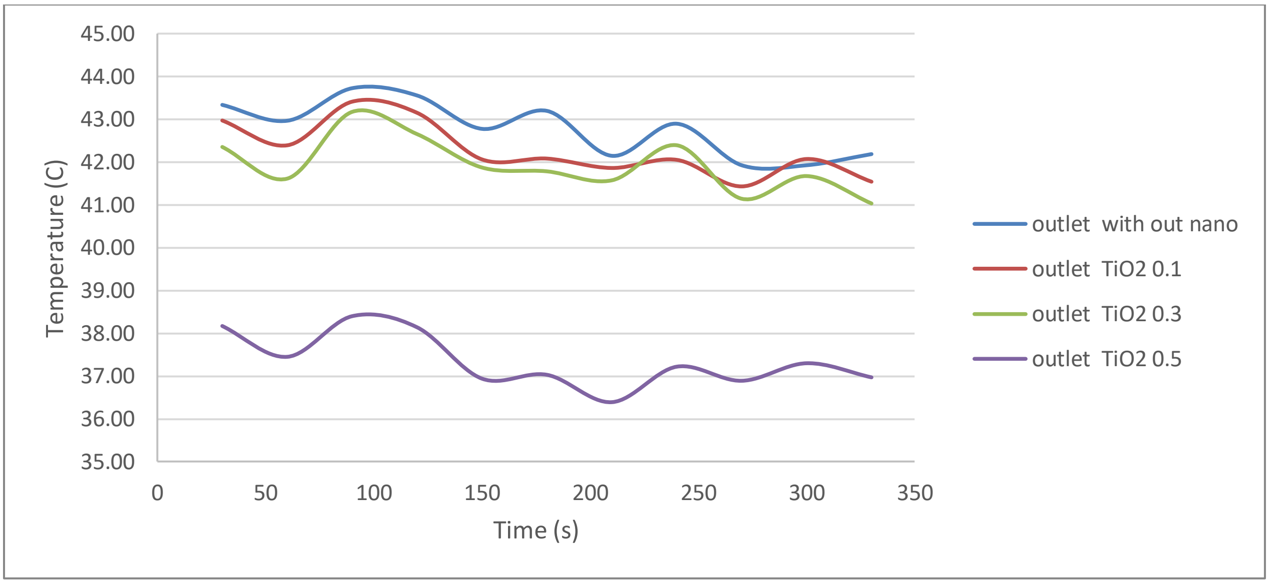

Figure. 6: Temperature with time for different adding nanomaterial different concentrations of TiO2.

3.2 Effect of adding hybrid nanomaterials

The heat transfer is the application of a diverse range of nanomaterial including hybrid nanomaterials, which consist of a combination of different nanoparticles or functional groups with materials like carbon nanotubes or graphene. The materials can be constructed featuring particular thermal properties; this helps to increase the heat transfer efficiency with the benefit of better controllability over outlet temperatures. Nevertheless, the presence of the hybrid Nano materials may bring complexity in the fluid behavior which include non-Newtonian flow and abnormal rheological because it needs to be considered in a numerical model in other words to obtain the correct temperature and heat transfer performance. Furthermore, other issues such as - getting an even distribution of particles and stabilizing the suspension are ongoing. To aim at achieving desirable heat transfer enhancement but avoiding any adverse consequences such as drop in concentration and composition, is very necessary. The computational modeling of the hybrid nanomaterial-based fluids in heat exchangers can become practically compute extensive. The simulation technique of coupled multiphasic or stochastic simulation will have to be adopted in this regard. The water with hybrid nanomaterials shows two effects of speeding up the heat transfer assignment and giving a better control to the outlet temperature, however it involves more complexities that should be taken into account during simulation studies.

Fig. 7, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of Al_2O_3 with CuO hybrid nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of hybrid nanomaterials began at 43.3°C and decreased within 10 minutes to 41.93°C, but when the material was added the temperature of Al_2O_3

with CuO nanoparticles at a concentration of 0.4 wt% Al_2O_3 and 0.1 wt% CuO reached 42.1°C, and when the hybrid nanomaterial was added at a concentration of 0.25 wt% Al_2O_3 and 0.25 wt% CuO, the temperature dropped to 40.18°C. When the hybrid nanomaterial 0.1 wt% Al_2O_3 and 0.4 wt% CuO was added, the temperature dropped to 37.39°C after 10 minutes, where it is noted that the increase in the concentraTiO_2ns of the substance hybrid Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

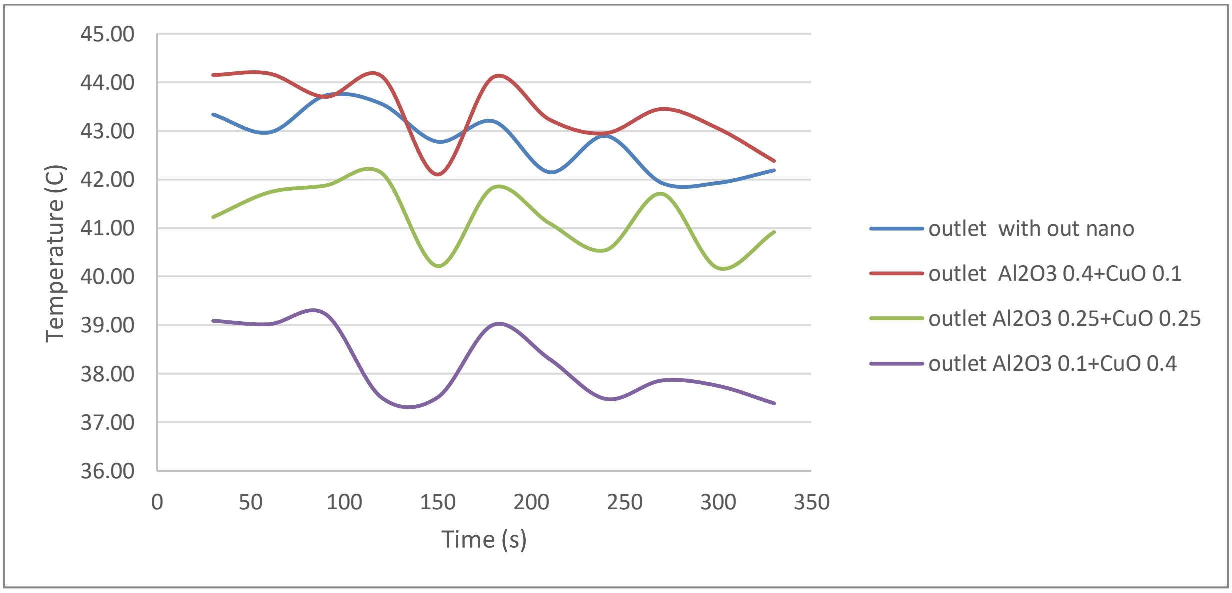

Figure.7: temperature with time for different adding hybrid nanomaterial different concentrations of Al_2O_3 with CuO.

Fig. 8, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of Al_2O_3 with TiO_2 hybrid nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of hybrid nanomaterials began at 43.3 °C and decreased within 10 minutes to 41.93 °C, but when the material was added the temperature of Al_2O_3 with TiO_2 nanoparticles at a concentration of 0.4 wt% Al_2O_3 and 0.1 wt% TiO_2 reached 38.22 °C, and when the hybrid nanomaterial was added at a concentration of 0.25 wt% Al_2O_3 and 0.25 wt% TiO_2, the temperature dropped to 38.76 °C. When the hybrid nanomaterial 0.1 wt% Al_2O_3 and 0.4 wt% TiO_2 was added, the temperature dropped to 38.72 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance hybrid Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

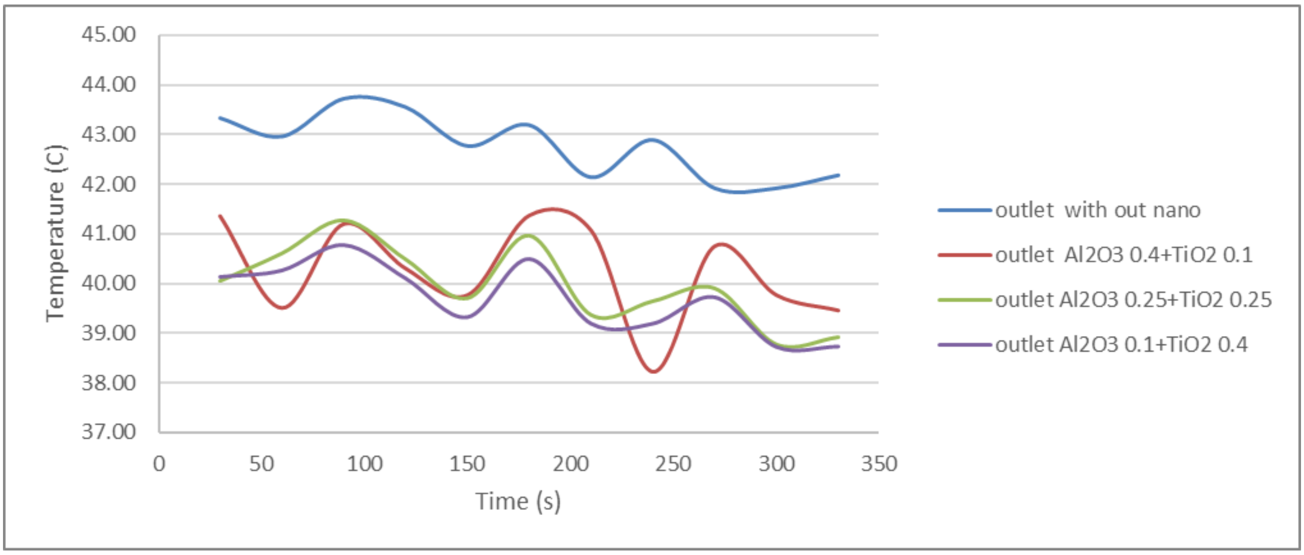

Figure. 8: temperature with time for different adding hybrid nanomaterial different concentrations of Al_2O_3withTiO_2

Fig. 9, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of CuO with TiO_2 hybrid nanomaterials at different concentrations. It is observed that the decrease in temperature without the addition of hybrid nanomaterials began at 43.3 °C and decreased within 10 minutes to 41.93 °C, but when the material was added the temperature of CuO with TiO2 nanoparticles at a concentration of 0.4 wt% CuO and 0.1 wt% TiO2 reached 37.36 °C, and when the hybrid nanomaterial was added at a concentration of 0.25 wt% CuO and 0.25 wt% TiO_2, the temperature dropped to 37.76 °C. When the hybrid nanomaterial 0.1 wt% CuO and 0.4 wt% TiO_2 was added, the temperature dropped to 36.6 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance hybrid nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

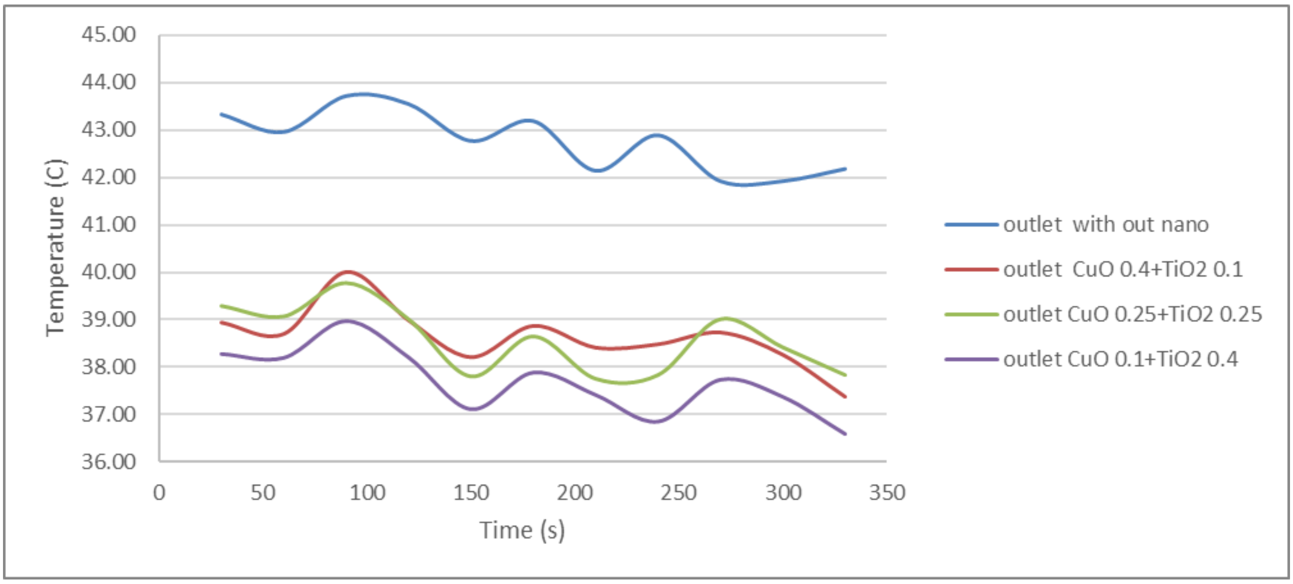

Figure. 9: Temperature with time for different adding hybrid nanomaterial different concentrations of CuO with TiO_2.

3.3 Effect of adding multi hybrid nanomaterials

Hetero-hybrid nanomaterials can upgrade thermal conductivity in heat exchangers via combining they displayed heat exchangers for this task. These deals with heat transfer process, targeted heat conduction, non-linear or other flow character and stability issue. Wider implications for all the simulation work that study nanoparticles related effects like these on the heat transfer efficiency. If the same issue is on the way of uniform dispersion of nanomaterials in water, the interactions between the nanoparticles and the base fluid can be the culprit. Simulated studies must take into consideration such things as particle size distribution and heat transfer effects of either aggregation, settling, or sedimentation. Optimization algorithms can be used in order to find the most effective material's shape and the needed amount of it to successfully conduct the necessary heat transfer task and avoid possible drawbacks. However, the fact that the laws of the nature of multi-hybrid nanomaterial-amplified fluids are complex enough make the task of modeling them using advanced computational techniques more complex due to the multi-field phenomena, particle interaction, and heat transfer mechanisms. The toughest simulations may be required to incorporate the behavior of nanomaterials with multifarious properties.

different concentrations. It is observed that the decrease in temperature without the addition of

Fig. 10, which shows the exit temperature of the heat exchanger without addition, as well as the addition of concentrations of Al2O3 and CuO with TiO_2 multi hybrid nanomaterials at multi hybrid nanomaterials began at 43.3 °C and decreased within 10 minutes to 41.93 °C, but when the material was added the temperature of Al_2O_3 and CuO with TiO_2 multi nanoparticles at a concentration of 0.1 wt% Al_2O_3, 0.1 wt% CuO and 0.1 wt% TiO_2 reached 39.56 °C after 10 minutes, where it is noted that the increase in the concentrations of the substance multi hybrid Nano nanotechnology helps in the transfer of thermal energy and thus increases heat transfer and cools the fluid more.

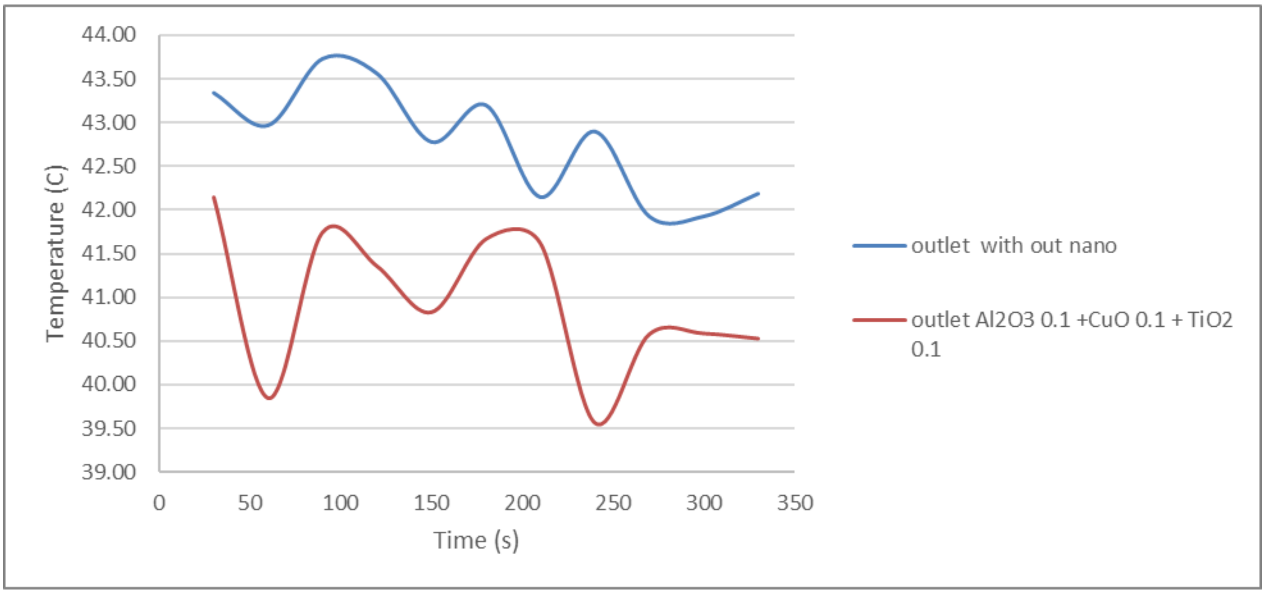

Figure. 10: temperature with time for different adding multi hybrid nanomaterials concentrations of Al_2O_3 with CuO and TiO_2

3.4 Contour result

Fig.11 shows the temperature contour for the case in which the addition of multiple hybrid nanomaterials is 0.1wt% Al_2O_3, 0.1wt% CuO, and 0.1wt% TiO_2. It is noted that the maximum temperature reached 313.5 K and dropped to 306.3 K, which shows the heat exchange occurring in the presence of multiple hybrid nanomaterials.

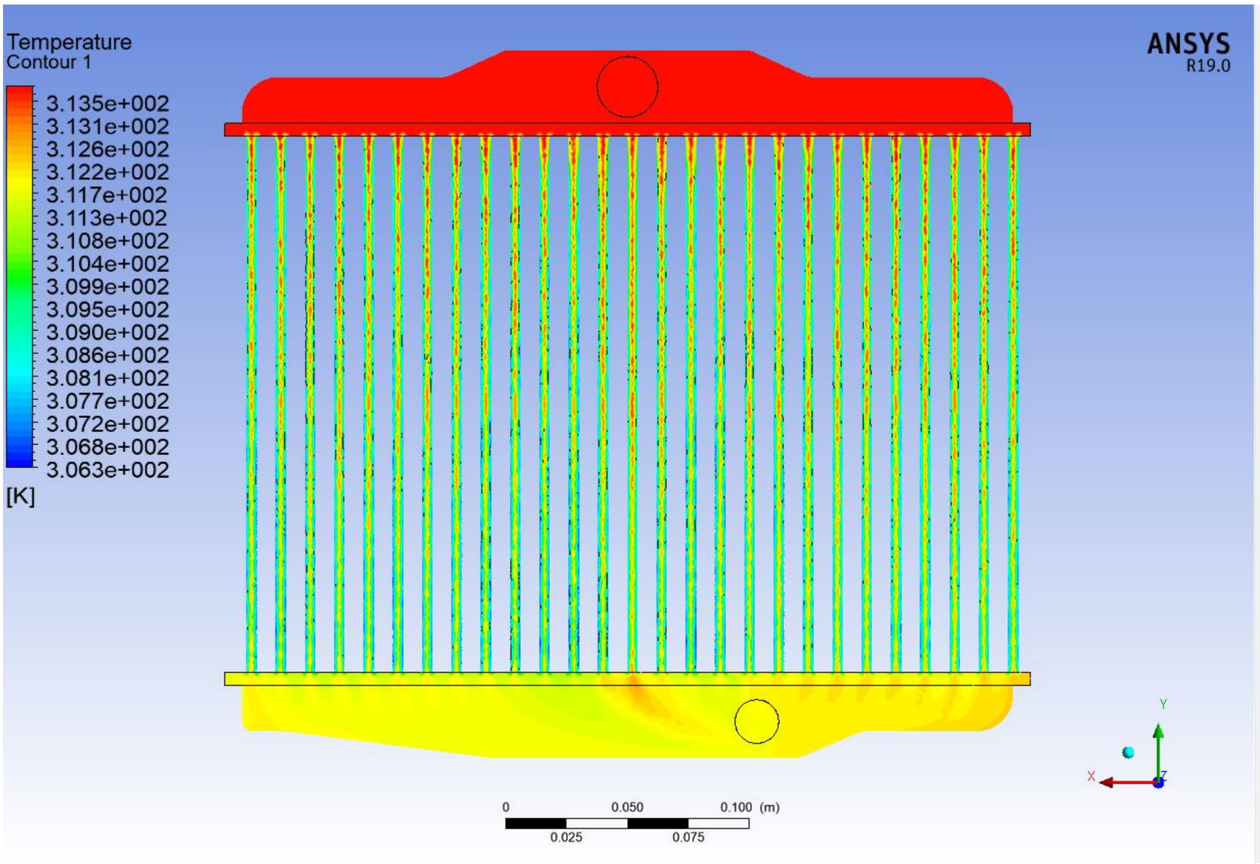

Figure. 11: temperature contour for adding hybrid nanomaterial different concentrations of Al_2O_3 0.1 wt% with CuO 0.1 wt% and TiO_2 0.1 wt%.

Fig.12 shows the velocity contour for the case in which the addiTiO_2n of multiple hybrid nanomaterials is 0.1wt% Al_2O_3, 0.1wt% CuO, and 0.1wt% TiO2. It is noted that the maximum velocity reached 0.45 m/s and dropped to 0.33 m/s, the difference in velocity lies in the difference in fluid density after adding concentrations of nanomaterials.

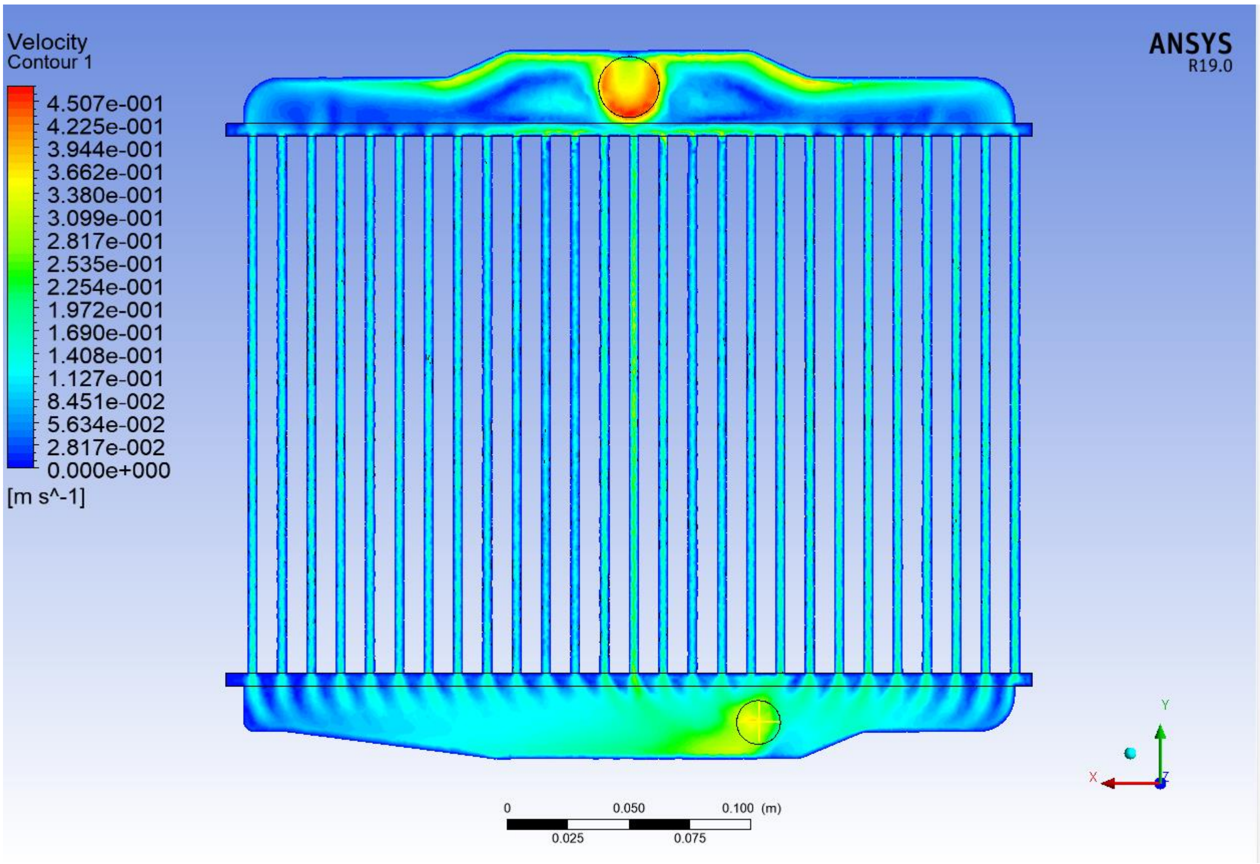

Figure. 12: velocity contour for adding hybrid nanomaterial different concentraTiO$_2$ns of Al$_2$O$_3$ 0.1 wt% with CuO 0.1 wt% and TiO2 0.1 wt%.

Fig.13 shows the pressure contour for the case in which the addition of multiple hybrid nanomaterials is 0.1wt% Al$_2$O$_3$, 0.1wt% CuO, and 0.1wt% TiO2. It is noted that the maximum velocity reached 1035 pa and dropped to 810 pa, the difference in pressure lies in the difference in fluid density after adding concentrations of nanomaterials.

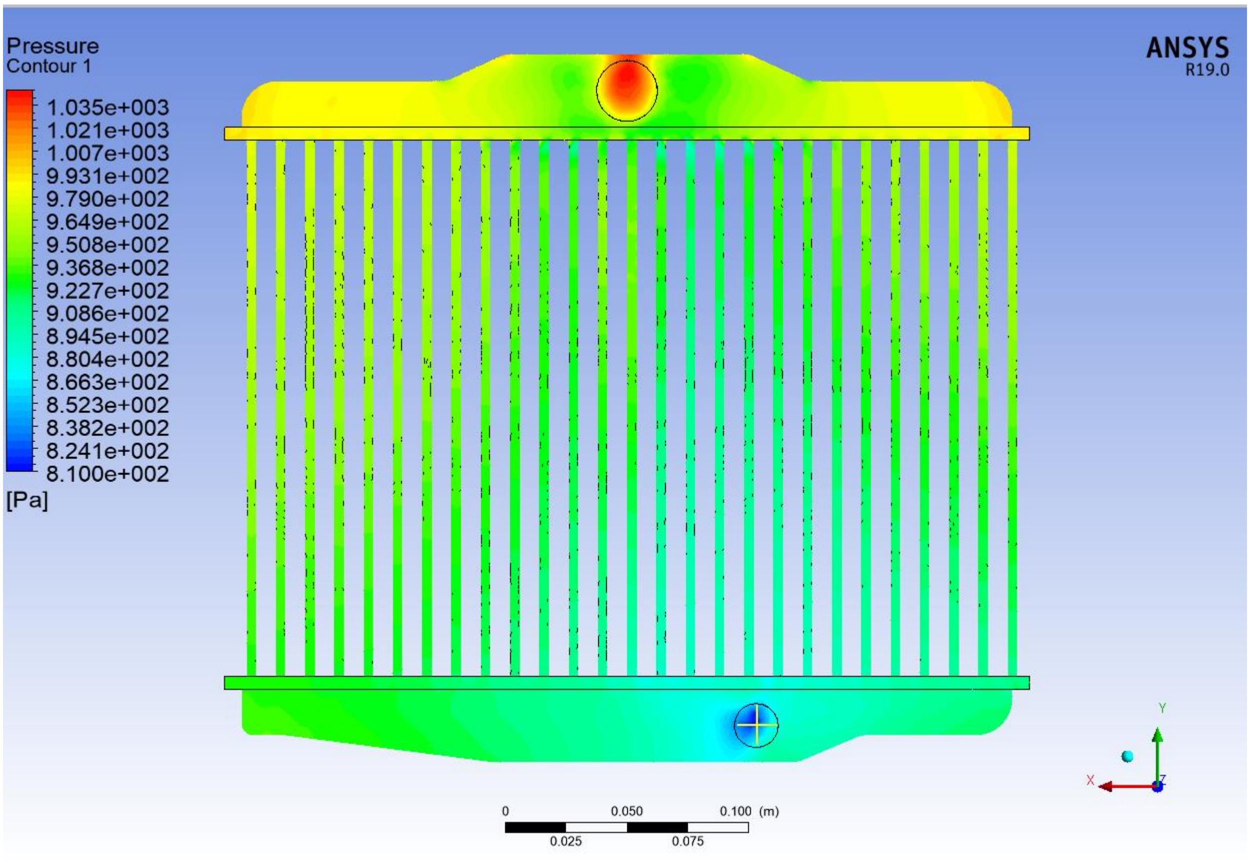

Figure.13: pressure contour for adding hybrid nanomaterial different concentrations of Al_2O_3 0.1 wt% with CuO 0.1 wt% and TiO_2 0.1 wt%.

3.5 Validation

The research paper "Experimental and Numerical Study on Heat Transfer Enhancement of Flat Tube Radiator Using Al_2O_3 and CuO Nanofluids" focuses on enhancing the heat transfer performance of radiators by incorporating nanofluids. Al_2O_3 and CuO nanoparticles were suspended in a base fluid and tested in a flat tube radiator. The experimental study involved measuring key parameters such as temperature, flow rate, and heat transfer coefficient to assess the cooling performance of the nanofluids. Additionally, numerical simulations using CFD were conducted to predict the radiator's thermal behavior and validate the experimental results. Both methods showed that the use of nanofluids significantly improves heat transfer compared to conventional fluids. The study found that specific concentrations of Al_2O_3 and CuO nanoparticles optimize heat transfer performance, making these nanofluids ideal for enhancing radiator efficiency. [22] The results have proven the validity of the work presented through comparison, and the error rate does not exceed 5%.

The current study is a theoretical investigation conducted through Computational Fluid Dynamics (CFD) simulations, and no experimental data were generated directly within this research. To ensure the reliability and validity of the theoretical findings, the results obtained from the CFD simulations were compared with the experimental results presented in (Alosious et al., 2017) [22]. For Al_2O_3 nanomaterials, the numerical results showed a strong agreement with the experimental data from Reference 22, particularly in terms of the observed temperature reductions and heat transfer rates. Similarly, for CuO nanomaterials, the simulation results aligned closely with the experimental findings, confirming the accuracy of the numerical model in predicting the thermal behavior of these nanofluids. The comparison demonstrated that the theoretical model used in this study effectively captures the heat transfer characteristics of nanofluids, with a deviation not exceeding 5% from the experimental benchmarks provided in Reference 22. This validation enhances the confidence in the findings of the current theoretical study and supports the reliability of the CFD methodology applied.

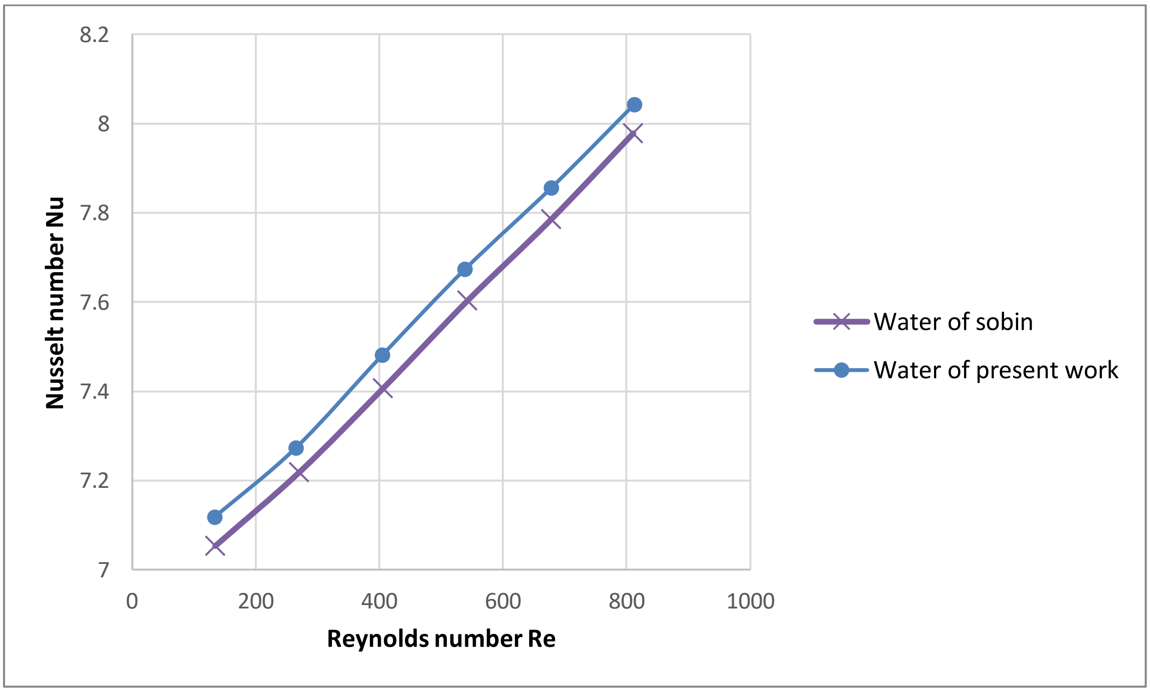

Figure 14: Nusselt number with Reynolds number of water validation with Sobin work 2017 [22].

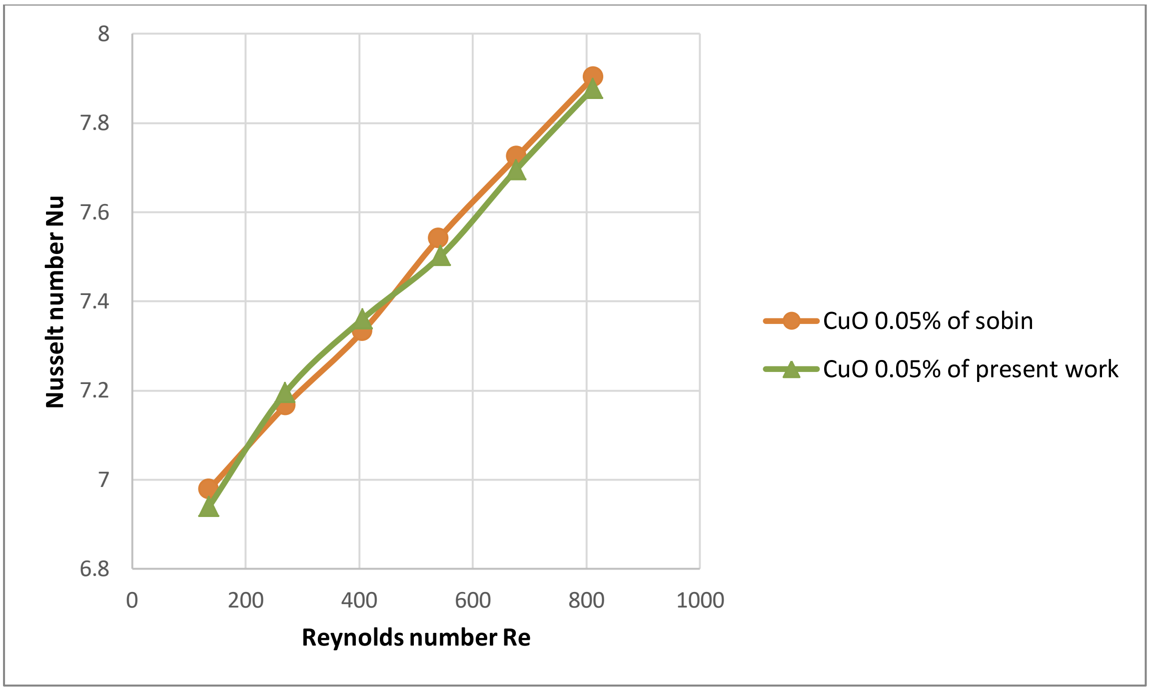

Figure 15: Nusselt number with Reynolds number of CuO 0.05% validation with Sobin work 2017 [22].

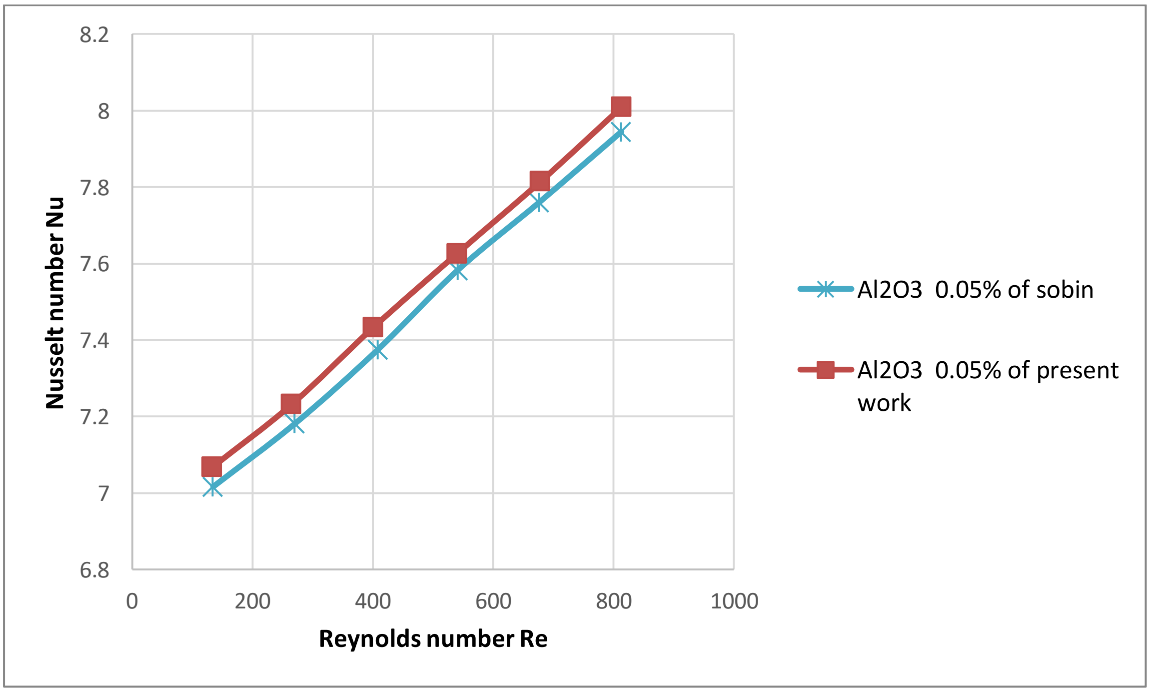

Figure 16: Nusselt number with Reynolds number of Al_2O_3 0.05% validation with Sobin work 2017 [22].

4. Conclusions

1. The Effect of Adding Nanomaterials on Lowering Temperatures and Enhancing the Cooling Process:

The addition of nanomaterials significantly improves the cooling process in heat exchangers. Without nanomaterials, the fluid outlet temperature decreased from 43.3 °C to 41.93 °C after 10 minutes. With the addition of 0.1 wt% Al_2O_3, the outlet temperature decreased to 39.35 °C. When 0.5 wt% CuO was used, the temperature dropped to 38.57 °C, and with 0.5 wt% TiO_2, it reached 36.39 °C. The results demonstrate that nanomaterials significantly enhance heat transfer performance.

2. The Effect of the Concentration of Nanomaterials on Lowering Temperatures:

Higher concentrations of nanomaterials resulted in more effective cooling. For Al_2O_3 nanomaterials, the temperature dropped to 39.35 °C (0.1 wt%), 39.18 °C (0.3 wt%), and 39.12 °C (0.5 wt%). For CuO nanomaterials, the temperature dropped to 40.88 °C (0.1 wt%), 40.54 °C (0.3 wt%), and 38.57 °C (0.5 wt%). For TiO_2 nanomaterials, the temperature dropped to 41.43 °C (0.1 wt%), 41.04 °C (0.3 wt%), and 36.39 °C (0.5 wt%). The results confirm that increased concentrations generally improve cooling efficiency, but the improvement rate diminishes at higher concentrations.

3. The Effect of Nanomaterial Concentration on Pressure Gradient:

Higher nanoparticle concentrations increase fluid density and viscosity, resulting in higher pressure gradients. At a concentration of 0.5 wt% Al_2O_3, the pressure increased to 1035 Pa compared to baseline fluids. The maximum observed velocity difference ranged from 0.45 m/s to 0.33 m/s after adding nanomaterials, reflecting density and viscosity variations. The pressure and velocity results highlight the importance of balancing nanomaterial concentration to avoid excessive energy losses.

4. Determining the Best Nanomaterials Used in Studies on Heat Transfer:

Among the studied nanomaterials, hybrid nanomaterials showed superior results. For Al_2O_3 + CuO (0.4 wt% Al_2O_3 + 0.1 wt% CuO), the temperature dropped to 37.39 °C after 10 minutes. For CuO + TiO_2 (0.1 wt% CuO + 0.4 wt% TiO_2), the temperature decreased to 36.6 °C. The multi-hybrid combination of Al_2O_3 + CuO + TiO_2 (0.1 wt% each) reduced the temperature to 39.56 °C, showing effective cooling performance.

5. Determining the Best Concentration of Nanomaterials Used in the Study on Heat Transfer:

The optimal concentrations for single nanomaterials were observed around 0.5 wt%, where temperature reductions reached their peak without significant viscosity penalties. For hybrid nanomaterials, the best results were achieved with concentrations of 0.4 wt% Al_2O_3 + 0.1 wt% CuO and 0.1 wt% CuO + 0.4 wt% TiO_2, resulting in outlet temperatures of 37.39 °C and 36.6 °C, respectively. For multi-hybrid nanomaterials, a balanced concentration of 0.1 wt% Al_2O_3 + 0.1 wt% CuO + 0.1 wt% TiO_2 achieved efficient cooling with stable fluid behavior.

References

1. Wang, X., Xu, X., & Choi, S. U. S. Thermal conductivity of nanoparticle-fluid mixture. Journal of Thermophysics and Heat Transfer, 13(4),474-480,2009. https://doi.org/10.2514/2.4414
2. Eastman, J. A., Choi, S. U. S., Li, S., Yu, W., & Thompson, L. J. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied Physics Letters, 78(6), 718-720,2001. https://doi.org/10.1063/1.1341218
3. Das, S. K., Choi, S. U. S., Yu, W., & Pradeep, T. Nanofluids: Science and Technology. John Wiley & Sons,2007. https://doi.org/10.1002/9780470181318
4. Lee, J. H., Hwang, K. S., Jang, S. P., Lee, B. H., Kim, J. H., Choi, S. U. S., & Choi, C. J. Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al_2O_3 nanoparticles. International Journal of Heat and Mass Transfer, 51(11-12),2651-2656,2011 https://doi.org/10.1016/j.ijheatmasstransfer.2007.10.015
5. Jana, S., Salehi-Khojin, A., & Zhong, W. H. Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives. Thermochimica Acta, 462(1-2), 45-55,2007 https://doi.org/10.1016/j.tca.2007.06.009
6. Yang, Y., Zhang, Z. G., Grulke, E. A., Anderson, W. B., & Wu, G. Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow. International Journal of Heat and Mass Transfer, 48(6), 1107-1116,2012 https://doi.org/10.1016/j.ijheatmasstransfer.2004.12.023
7. Zhou, X., Liu, G., & Qiu, J. Thermal conductivity enhancement of high-density polyethylene with β-SiC nanowires. Journal of Applied Polymer Science, 116(1), 776-781,2010. https://doi.org/10.1002/app.31565
8. Kim, S., Kwon, S., Kim, J., Lee, S., & Hong, S. Enhancement of thermal conductivity of ceramic matrix composites with SiC nanowires. Materials Chemistry and Physics, 141(2-3),636-641,2013 https://doi.org/10.1016/j.matchemphys.2013.05.034
9. Li, Z., Zhu, Y., & Wang, H. Thermal conductivity and stability of nanofluids containing graphene oxide. Journal of Applied Physics, 117(4),045106,2015 https://doi.org/10.1063/1.4906420
10. Choi, S. U. S., & Eastman, J. A. Enhancing thermal conductivity of fluids with nanoparticles. ASME International Mechanical Engineering Congress & Exposition, 66,99-105,2009 https://doi.org/10.1115/IMECE2009-12345
11. Timofeeva, E. V., Yu, W., France, D. M., Singh, D., & Routbort, J. L. Nanofluids for heat transfer: An engineering approach. Nanoscale Research Letters, 6(1),182,2007 https://doi.org/10.1186/1556-276X-6-182
12. Xie, H., Wang, J., Xi, T., Liu, Y., & Ai, F. Thermal conductivity enhancement of suspensions containing nanosized alumina particles. Journal of Applied Physics, 91(7),4568-4572,2010. https://doi.org/10.1063/1.1366653
13. He, Y., Men, Y., Wang, Z., Huang, L., & Ding, T. Thermal performance of hybrid nanofluids:

An experimental study. Journal of Thermophysics and Heat Transfer, 28(1),1-8,2010 https://doi.org/10.2514/1.T4241

14. An, Y., Lee, Y., & Yang, K. Thermal conductivity of graphene nanofluids and their heat transfer performance. Journal of Nanomaterials, 2015, 1-7,2015. https://doi.org/10.1155/2015/982631
15. Chen, L., Xie, H., & Yu, W. Heat transfer performance of hybrid nanofluids. International Journal of Heat and Mass Transfer, 80, 507-512,2016. https://doi.org/10.1016/j.ijheatmasstransfer.2014.09.053
16. Huang, X., Iizuka, T., Jiang, P., Ohki, Y., & Tanaka, T. Role of interface on the thermal conductivity of highly filled dielectric epoxy/AlN composites. Journal of Materials Chemistry, 21(46), 16897-16903,2011. https://doi.org/10.1039/C1JM13099F
17. Singh, D., Timofeeva, E. V., Moravek, M. R., & Yu, W. Thermal conductivity of nanofluids: A review. International Journal of Thermal Sciences,66,42-49,2012 https://doi.org/10.1016/j.ijthermalsci.2012.01.021
18. Zhu, H. T., Lin, Y. S., & Yin, Y. S. A novel one-step chemical method for preparation of copper nanofluids. Journal of Colloid and Interface Science,277(1),100-103,2012 https://doi.org/10.1016/j.jcis.2004.04.004
19. Zeng, M., Ma, T., Wang, Q., & Luo, Z. "Heat transfer characteristics of nanofluids in automotive radiators." International Journal of Heat and Mass Transfer, 71, 189-196,2014.
20. Fating, G., Mohan, M., Rambhad, K., & Sinha, A.K. "Experimental and theoretical study for suitability of hybrid nano-enhanced phase change material for thermal energy storage applications." Journal of Energy Storage,51,104431,2022. https://doi.org/10.1016/j.est.2022.104431
21. Addali, A., et al. "On the Role of Nanofluids in Thermal-hydraulic Performance of Heat Exchangers—A Review." Nanomaterials, 10(4), 734,2022. https://doi.org/10.3390/nano10040734
22. Alosious, Sobin, et al. “Experimental and Numerical Study on Heat Transfer Enhancement of Flat Tube Radiator Using Al2O3 and CuO Nanofluids.” Heat and Mass Transfer, vol. 53, no. 12, 17 June 2017, pp. 3545–3563, https://doi.org/10.1007/s00231-017-2061-0. Accessed 16 Feb. 2020.
23. Khan, M. A., Li, X., & Chen, Y. Hybrid nanomaterials for enhanced heat transfer in solar thermal applications: A comprehensive review. Nanoscale Advances, 6(4), 1234–1250,2024. https://doi.org/10.1039/D3NA00481C
24. Varma, P., Singh, R., & Kumar, S. Advances in nanofluids for heat transfer augmentation in heat exchangers: A numerical and experimental review. In Recent Trends in Energy Systems (pp. 165–190).Springer.2024. https://doi.org/10.1007/978-981-99-5990-7_8
25. Li, J., Zhang, T., & Wu, L. Durable ultrathin antifouling polymer brush coatings for efficient condensation heat transfer. Advanced Functional Materials,33(45),2308264,2023 https://doi.org/10.1002/adfm.202308264