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Performance Analysis of Double Pipe Heat Exchanger Using Nano Fluids

C. P. Ajey[1], Kanchiraya Shivalingaiah[2], Gireesha R. Chalageri[3], Shivakumar K. Malladad[4], K. Gagan Shetty[4], G. Vikas[4], R. B. Ashok[1]*

[1]*Faculty of Mechanical Engineering, PESITM, (Visvesvaraya Technological University, Belagavi), Shivamogga - 577204, Karnataka, India; ashokrbanagar@gmail.com*

[2]*Faculty ofMechanical Engineering, Government Engineering College, Visvesvaraya Technological University, Belagavi - 573201, Karnataka, India*

[3]*School of Mechanical Engineering, KLE Technological University, Hubballi - 580031, Karnataka, India*

[4]*Faculty of Mechanical Engineering, Sahyadri College of Engineering and Management, (An Autonomous Institution), Adyar, Mangaluru - 575 007, Karnataka, India*

Choosing an appropriate heat transfer fluid is a crucial factor in the design of a heat exchange system. A nanofluid is a colloidal mixture composed of a base fluid and nanoparticles. It is a promising heat transfer fluid in various applications due to its improved thermal conductivity and heat transfer rate. The increasing demand and acceptance for nano-fluids as heat transfer fluids in various applications have led to an increase in research investigations on this topic. Nanofluid technology has recently expanded to include the impregnation of multiple nanoparticles in base fluids, known as hybrid or nanocomposites. For this study, we have chosen three distinct nanoparticles and two base fluids to examine their thermo-physical characteristics and heat transmission rate. Nanofluid is prepared via the sonication method. The experiment is used to determine the thermos-physical characteristics of various nano-fluids. The double-pipe heat exchanger is employed to measure the heat transfer rate and efficiency of nano-fluids. Among six samples prepared in the present work, the ZnO2+CNT+TiO2+EG sample had shown reduced kinematic and dynamic viscosities for all the temperature ranges. However, an average value of heat transfer rate was recorded for ZnO2+CNT+TiO2+EG at 675.87 (J/s) for parallel flow and 630.79 (J/s) for counter flow. And the least effectiveness was recorded for distilled water. The hybrid nanofluid demonstrates a superior heat transfer rate and effectiveness in both parallel flow and counter flow applications. Therefore, it may be efficiently utilised in many heat transfer applications.

Keywords: *Double Pipe, Heat Exchanger, Nano-Fluids, Nanoparticles, Performance*

1.0 Introduction

Heat exchangers are widely used in several technological domains such as the chemical sector, power generation, food processing, environmental engineering, waste heat recovery, automobile radiators, and refrigeration. Efforts were undertaken to enhance the heat transfer rate in heat exchangers to reduce the time required for heat transfer and improve energy efficiency. The efficiency of various methods to enhance heat transmission is generally limited by the comparatively poor thermal conductivities of the heat transfer fluids. This constraint hinders the advancement of efficiency and size reduction in heat exchangers. Given the growing demands of modern technology, it is imperative to develop new heat transfer fluids that have greater heat transfer capacity.

**Author for correspondence*

A nano-fluid is a colloidal mixture consisting of a base fluid and nanoparticles. It is a cutting-edge heat transfer fluid that shows great promise in heat transfer applications due to its significantly improved thermal conductivity. Nano-fluids are a novel category of fluids created by spreading components that are only a few nanometers in size (such as nanoparticles, nanofibres, nanotubes, nanowires, nanorods, nanosheets, or droplets) in base fluids. Typically, the dimensions of these nanoparticles range from 1 to 100 nanometers. The selection of the nanoparticle is directly contingent upon the augmentation of a desired characteristic of the underlying fluid.

1.1 Nanoparticles

The term nanoparticle is derived from the Latin prefix "nano". It is utilised to represent the fraction of a unit that is equal to one billionth. In this context, nanoparticles are often defined as particles that have a size within the range of a few nanometers. Nanoparticles typically have a size ranging from 100 to 2500 nm. Particles of a size lower than 100 nm are referred to as ultrafine. These things are being thoroughly investigated because of their potential applications in the domains of medicine, optics, and electronics. Below is a list of many types of nanoparticles. Below mentioned nanoparticles were adopted in the present work due to their high thermal conductivity, which significantly enhances the overall thermal conductivity of nano-fluids when they are used as additives[1].

1.1.1 Carbon Nanotube (CNT)

Carbon nanotubes are a remarkable material that finds applications in several disciplines such as the study of materials, automotive, optical, electrical, aerospace, and energy conversion. They exhibit exceptional properties in terms of electrical conductivity, thermal conductivity, mechanical strength, chemical reactivity, and optical characteristics. Carbon nanotubes can efficiently carry both electricity and heat and can exhibit properties like those of metals or semiconductors. Carbon nanotubes possess remarkable properties that make them highly versatile in various applications. Graphene can be employed in several applications, including lithium-ion batteries, polymer-based composites, nano-electronics as diodes and transistors, and super-capacitors such as electromechanical actuators and sensors[1]. Carbon nanotubes are utilised in the realm of advanced membrane technology for water desalination. Carbon nanotubes have become a new type of nanomaterial due to their distinctive structure, large surface area compared to volume, and strong chemical stability. These nanotubes possess the capabilities of their separate components and exhibit a synergistic effect when combined with other materials. Therefore, researching carbon nanotubes is now crucial to expedite the development of cutting-edge technology in several domains.

Carbon nanotubes exhibit a tubular morphology, consisting of cylindrical sheets of carbon that are rolled into a tube-like structure resembling a latticework fence. Carbon nanotubes can be classified into three types: single-walled, double-walled, and multi-walled. A single-walled carbon nanotube is composed of a single cylindrical sheet of graphite, while a multi-walled carbon nanotube is made up of many layers of zinc oxide sheets. Empirical and theoretical investigations have shown that cylindrical structured nanoparticles have superior thermal conductivity in comparison to spherical nanoparticles.

1.1.2 Titanium Oxide

Titanium dioxide, commonly referred to as titanium (IV) oxide, is an inorganic substance that has the chemical formula TiO_2. When employed as a colouring agent, it is referred to as titanium white, Pigment White 6 (PW6), or CI 77891. The substance is a white solid that cannot dissolve in water, however mineral formations may have a black appearance. As a pigment, it possesses a broad spectrum of uses, encompassing paint, sunscreen, and food colouring. When employed as a substance for colouring food, it is assigned the E number E171. In 2014, global production surpassed 9 million tonnes. Titanium dioxide is utilised in around 66% of all pigments, and pigments derived from this oxide have been assessed to be worth $13.2 billion.

1.1.3.Zinc Oxide

Zinc oxide is a chemical substance that is not derived from living organisms and has the chemical formula ZnO. The substance is a white powder that cannot dissolve in water. Zinc oxide (ZnO) is utilised as an additive in a wide range of materials and products, such as cosmetics, nutritional supplements, rubbers, plastics, glass, ceramics, cement, lubricants, paints, sunscreen products, creams, lotions glues, sealing compounds, colouring agents, foods, batteries, ferrites, fireproofing materials, semiconductors, and first-aid tapes. While zinc oxide can be found spontaneously as mineral zincite, most of it is manufactured artificially.

1.2 Base Fluid

The main fundamental/base fluids used in the formulation of nano-fluids include water, ethylene glycol, water/ethylene glycol blends, and other types of oils. Fundamental fluids generally have lower thermal conductivity ratings than metals. Given that most solids exhibit higher thermal conductivity than base fluids, a practical approach to improve the thermal conductivity of fluids is by incorporating small quantities of solid particles into the base fluids. Ethylene glycol, which exhibits superior heat transfer enhancement compared to water, is frequently employed as the primary fluid for creating nano-fluids.

1.3 Preparation Methods for Nano-Fluids

The initial and crucial step in experimental research involving nano-fluids is the preparation of the nano-fluids. Nano-fluids are created through the dispersion of solid particles at the nanoscale size into basic liquids like water, ethylene glycol, oils, and so on. When preparing nano-fluids, it is important to ensure that the nanoparticles are evenly distributed in the liquid and that a suitable method is used to maintain the consistency of the suspension and prevent settling. The manufacture of nano-fluids primarily involves two methods: the one-step approach and the two-step method.

The one-step process, seen in Figure 1, involves the simultaneous production and dispersion of granules in the fluid. This technology eliminates the procedures of drying, storing, transporting, and distributing nanoparticles, resulting in reduced aggregation of nanoparticles and increased stability of fluids. The single-step procedures can produce nanoparticles that are uniformly disseminated and can be securely suspended in the base fluid. The produced nanoparticles display morphological shapes such as needles, polygons, squares, and circles.

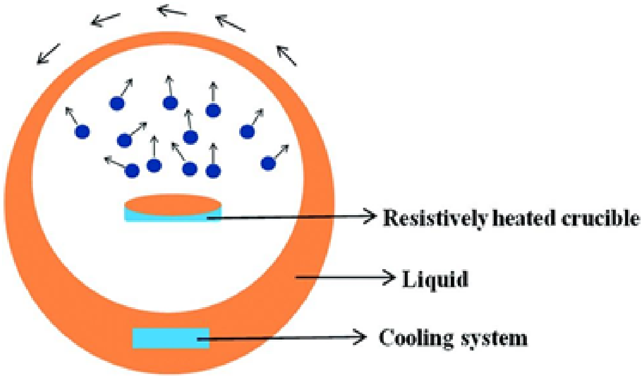


Figure 1. Diagram depicting a one-step method for synthesising nano-fluids.

The synthesis of nano-fluids on a wide scale using a single physical process is not feasible and is also expensive. Therefore, there is a growing trend towards the development of a one-step chemical method. Nevertheless, there are certain drawbacks associated with the one-step approach. One crucial factor is the presence of leftover reactants in the nano-fluids, which occur because of incomplete reaction or stabilisation. Elucidating the nanoparticle effect is challenging without eliminating the impurity effect.

The two-step process is the predominant technique employed for the preparation of nano-fluids. The approach involves the initial production of dry powders of nanoparticles, nanofibres, nanotubes, or other nanomaterials using chemical or physical means. Next, the nano-powder will be evenly distributed in a liquid during the second stage of processing using intense magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenization, and ball milling. The two-step procedure is the most cost-effective approach for producing nano-fluids on a wide scale, as the techniques for synthesising nanopowders have already been successfully implemented in industrial production. Nanoparticles tend to agglomerate because of their high surface area and surface activity. Surfactants are a crucial strategy for improving the stability of nanoparticles in fluids.

1.4 Heat Exchanger

Heat exchangers are apparatuses that enable the transfer of thermal energy between two fluids with differing temperatures while preventing any intermingling between them. Heat exchangers are widely utilised in various applications, including domestic heating and air-conditioning systems, as well as chemical processing and power generation in big industrial facilities. Heat exchangers and mixing chambers have a key distinction: heat exchangers prevent the two fluids from blending. In a car radiator, heat is carried through conduction from the hot water circulating inside the radiator tubes to the air passing through the closely positioned thin plates that are connected to the tubes. The process of heat transfer in a heat exchanger typically includes the movement of heat through convection in each fluid and conduction through the wall that separates the two fluids[2].

When examining heat exchangers, it proves beneficial to employ an overall heat transfer coefficient (U) that encompasses the collective influence of these factors on heat transfer. The rate of heat transfer between the two fluids in a heat exchanger is dictated by the temperature gradient at a specific location, which varies along the exchanger's length. In the analysis of heat exchangers, it is often more convenient to utilize the Logarithmic Mean Temperature Difference (LMTD). This value signifies the average temperature difference between the two fluids across the entirety of the heat exchanger.

Some studies have highlighted pulsating pumps and a few of them are discussed as, Pulsating Heat Pipes (PHPs or OHPs) are innovative two-phase heat transfer devices utilizing oscillating liquid slug and vapour plug flows in compact, bent tubes. Unlike conventional heat pipes, PHPs lack a wick structure, eliminating countercurrent liquid-vapor flow. Recent work has focused on experimental flow visualization and heat transfer characterization, alongside theoretical modeling of oscillating two-phase flow dynamics. A tabulated summary captures key aspects of this research, highlighting advancements in flow visualization, heat transfer behaviours, and theoretical modelling, while also addressing unresolved operational, modelling, and application questions for PHPs[3]. The selection of appropriate polymeric materials is critical for designing and producing flexible fluidic systems and heat transfer devices like pulsating heat pipes. To make informed choices among numerous materials, a comparative hybrid Multi-Criteria Decision-Making (MCDM) model was developed, evaluating fourteen criteria and twelve materials. Through three hybrid MCDM methods (AHP-GRA, AHP-CoCoSo, and AHP-VIKOR), PTFE, PE, and PP emerged as top contenders, with PTFE ranking highest overall. This approach aids industry professionals and researchers in efficiently selecting polymeric materials for various applications[4]. Some researchers have made studies on thermal performance in flat polypropylene PHPs, considering factors like channel turns, gravity orientation, and heat transfer fluids. Understanding polymeric PHPs' design impact is crucial for improving thermal management in electronics and satellites. Prototypes with varying channel turns were created using laser welding on polypropylene sheets, allowing for a thorough thermal performance assessment[5].

Some specifications of the heat exchanger are as depicted below:

Specimen material: Copper tube
Size of the specimen: 12.5 mm x 1500 mm long
Outer shell material: Galvanized iron
Size of the outer shell: 40 mm
Geyser capacity: 1 liter, 3 kW
Rotameter to adjust the flow rate of cold and hot liquid[6]

2.0 Summary of Past Work

Numerous industrial operations entail the exchange of thermal energy. In any industrial facility, the addition, removal, or transfer of heat across different process streams has become a crucial requirement. Several studies have been conducted to comprehend the heat transfer efficiency for its practical use in enhancing heat transmission. Nano-fluid, a novel type of heat transfer medium, has been explored for its potential use as enhanced heat transfer fluids. Multiple studies are conducted to enhance the thermal conductivity of the base fluid by utilising nano-fluids.

In their study, Marquis and Chibante[7] examined the performance of carbon nanotubes, specifically single-walled and multi-walled nanotubes, when mixed with base fluids. They found that this blending resulted in a significant enhancement of thermal conductivity in various heat transfer fluids, including mineral and synthetic oils, water, water/ethylene glycol mixtures, and commercially available heat transfer fluids like antifreeze. The thermal conductivity values exhibited significant variation depending on the specific carbon nanotube utilised, the applied load, and the chosen processing method. The initial assessment of the viscosity of heat transfer nano-fluids and other dynamic properties indicates that these fluids have the potential to be utilised in various applications, such as engine cooling systems, oil coolers, and heat pumps, to greatly enhance their thermal and lubricating efficiency.

The 2019 publication by Sivashanmugam *et al.*,[8] provided an elaborate account of the utilization of nano-fluids in heat transfer applications across several heat exchanger configurations. Studies have shown that the use of nano-fluids significantly enhances convective heat transfer, with the improvement increasing exponentially. The research demonstrated that incorporating nanoparticles into the base fluids resulted in a significant increase in the heat transfer coefficient, which directly correlated with higher particle concentrations. The researchers reported that the rise in the effective thermal conductivity and the significant turbulent motion of nanoparticles as the particle concentration increases are the primary factors contributing to the improvement in heat transfer.

In their 2018 publication, Yu and Xie[9] specified a comprehensive review of the latest advancements in nano-fluid research. This included an examination of the methods used to prepare nano-fluids, the techniques for evaluating their stability, strategies for improving their stability, the underlying mechanisms of stability, and their potential applications in various fields such as heat transfer intensification, mass transfer enhancement, energy, mechanics, and biomedicine. The researchers noted that the characteristics of nano-fluids are significantly influenced by the shape and properties of the additive. Their research revealed that the thermal conductivity improvement was modified by using ball milling and cutting to transform the treated Carbon Nanotubes (CNTs) into generally straight CNTs with a suitable distribution of lengths. These modified CNTs were then suspended in the nano-fluids.

In their 2016 work, Albadr *et al.*,[10] experimented to investigate the forced convective heat transfer and flow properties of a nano-fluid composed of water and varying volume concentrations of Al_2O_3 nano-fluid. The researchers determined that dispersing the nanoparticles in distilled water enhances the thermal conductivity and viscosity of the nano-fluid. This enhancement becomes more pronounced as the quantity of particles increases. Another result was that the friction factor correlates positively with the increase in particle volume concentration. This is due to the augmented viscosity of the nano-fluid, resulting in minimal impact on pressure drop.

Salmaan *et al.*,[11] performed an experimental investigation on the use of nano-fluids as a coolant in the cooling system of a vehicle engine. The rate of heat transmission and its effectiveness are enhanced as the volume concentration of nanoparticles increases, ranging from 0 to 0.5. The addition of zinc oxide particles resulted in a heat transfer boost of around 61% and increased efficacy. This was observed at a constant mass flow rate of 0.345Kg/s and Reynolds number. The use of nano-fluids + water coolant with a 50-volume concentration enhances the thermal performance of a radiator, particularly when the air Reynolds Number is increased. The thermal conductivity rose by 61.05% as the volume concentration of zinc oxide particles in the base fluid increased.

In their study, Saravanakumar *et al.*,[12] examined different methods of improving the rate of heat transmission in a radiator by employing various types of nanofluids. They determined that the utilisation of nano-fluids results in a higher rate of heat transfer in comparison to water and ethylene glycol. The researchers noted that the utilization of nano-fluids led to an increase in both the overall heat transfer coefficient and heat transfer rate in the cooling system.

In their study, Yerrennagoudaru *et al.*,[13] provided a concise overview of the latest advancements in nano-fluid research. They conducted computational fluid dynamic analysis on four distinct nano-fluids and subsequently assessed the results. To conduct experiments and observe an increase in heat conductivity, the sizes of nanoparticles are altered within the range of 70 to 230 nm for the preparation of nano-fluids. The nanofluids utilised for computational fluid dynamic analysis include magnesium oxide water, copper oxide water, titanium oxide water, and iron oxide water. Two fluids were chosen for the experimental study, and the findings of the experiments were compared with the results obtained from computational fluid dynamics to conclude.

The literature review suggests that the performance of a heat exchanger can be enhanced by including nanoparticles in the base fluid. The addition of nanoparticles to the base fluid leads to a significant enhancement in the heat transfer coefficient. The thermal conductivity of the nano-fluid increases according to an increase in the volume concentration of nanoparticles in the base fluid. Various nano-fluids have undergone testing for heat transfer applications, and the findings indicate superior heat transfer capabilities in comparison to the base fluid.

2.1 Problem Formulation: Problem Statement

Many sectors have a critical requirement for ultra-high-performance cooling. Nevertheless, the main constraint in the development of energy-efficient heat transfer fluids for cooling applications is the low thermal conductivity. The conventional coolants now in use, such as water, oil, and ethylene glycol, have drawbacks in terms of their relatively low heat conductivity. The research demonstrates that the addition of nanoparticles to the base fluid can augment its thermal conductivity. However, the study of nano-fluids' behaviour in heat transfer is nevertheless in its nascent phase and so remains incompletely explored. Research is required to further the field of nanotechnology and ascertain the potential applications of nanoparticles and nano-fluids in heat transfer.

3.0 Materials and Methodology

3.1 Materials

The materials utilised in the formulation of nano-fluids are as follows: a nano-fluid is created by combining two primary fluids, namely distilled water, and ethylene glycol. The nanoparticles utilised in the study include multi-walled carbon nanotubes, zinc oxide, and titanium oxide. Based on the availability and the scope, the nanoparticles are selected for the preparation of the samples and tests.

3.2 Methodology

The present work is executed using the following approaches. The procedures are presented in a flow chart, depicted in Figure 2.

3.3 Nanoparticle and Base Fluid Selection

The selection of nanoparticles is based on their heat transmission capability, and they are then mixed with the base fluid to create the nano-fluid. Distilled water and ethylene glycol are the predominant base fluids utilised in

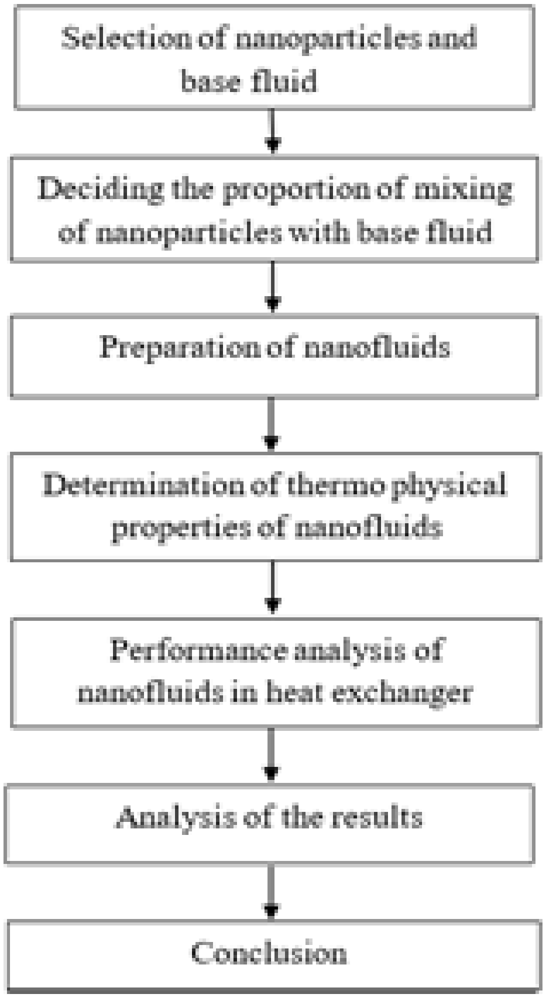


Figure 2. Flowchart depicting the current work.

heat exchangers. The nanoparticles chosen for this study include zinc oxide, titanium oxide, and carbon nanotube. A nano-fluid is created by combining zinc oxide, titanium oxide, and carbon nanotubes, which possess excellent thermal conductivity, with a base fluid. This nano-fluid is then utilised for heat transfer applications.

3.4 Preparation of Nano-fluids

The fabrication of nano-fluids is a crucial step that requires a methodical and cautious approach. The current study utilises ethylene glycol and distilled water as the primary fluids for creating nano-fluids. In this procedure, nanoparticles are introduced into the base fluid and agitated consistently for a few hours. The nanoparticles exhibit long-term suspension without sedimentation at the container's bottom.

Agglomeration of nanoparticles typically occurs when the nanoparticles are suspended in the base fluid. The test samples of zinc oxide, titanium oxide, and carbon nanotube-based nano-fluids were subjected to a magnetic stirring method for approximately 72 hours to estimate their properties. After preparing the nano-fluid samples, they are inspected, and no particle settlement is detected at the bottom of the flask after a few hours. The nano-fluid suspension, which is created using magnetic stirring, is highly effective for determining thermal physical characteristics[14-17].

3.5 Determination of Thermal Properties of Nano-fluids

The crucial parameters required for estimating nano-fluids are their density, kinematic viscosity, dynamic viscosity, and specific heat. The thermal characteristics of nano-fluids are determined through experimental estimation using various combinations. The resulting data are then graphically compared with different samples of nano-fluids. Figure 3 depicts the redwood viscometer, a device utilised for measuring the kinematic viscosity of various nano-fluids. The density of the nano-fluid can be readily estimated by obtaining the weight and volume of the sample. Experiments are conducted on nano-fluids at various temperatures to determine the duration required to gather a specific volume. The kinematic and dynamic viscosity can be calculated by applying appropriate formulas.

3.5.1 Nano-fluid Sample 1 (Zinc Oxide and Ethylene Glycol)

The densities of zinc oxide nano-fluid are determined at various temperatures using an appropriate formula, while the kinematic viscosity at various temperatures is evaluated using a suitable correlation. Dynamic viscosity can be established by establishing the relationship between density and kinematic viscosity. Table 1 depicts the thermo-physical characteristics of zinc oxide and ethylene glycol-based nano-fluids were investigated at various temperatures.

Figure 3. Redwood viscometer apparatus.

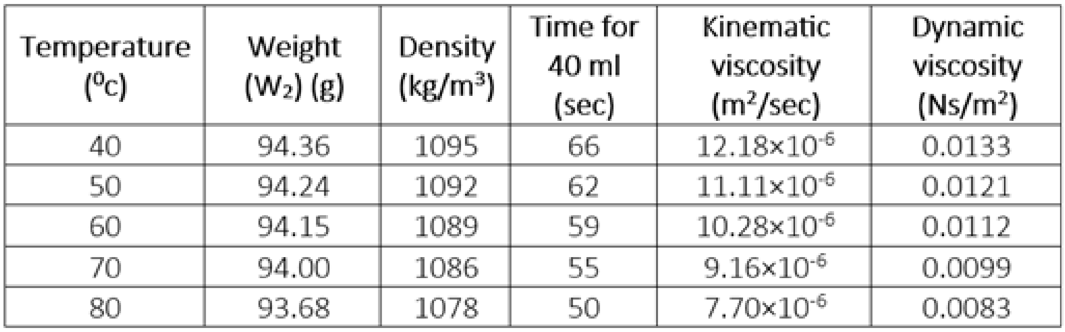
3.5.2 Nano-fluid Sample 2 (Carbon Nanotube and Ethylene Glycol)

Like nano-fluid 1 (zinc oxide and ethylene glycol) characteristics (as depicted in Table 1), sample 2 characteristics were also tabulated in Table 2. From Table 2 it is observed that, as the temperature of the sample increases then relevant weight, density, kinematic and dynamic viscosities were observed to be falling with fall in time for 40 ml.

3.5.3 Nano-fluid Sample 3 (Titanium Oxide and Ethylene Glycol)

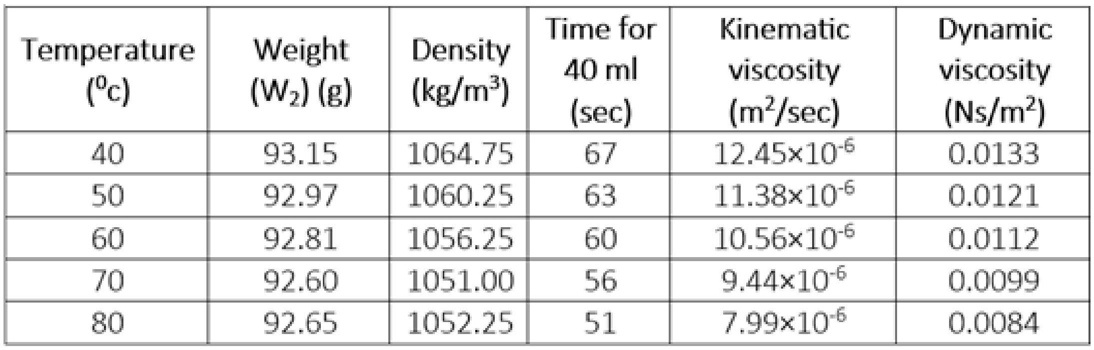
Like nano-fluid sample 1 and 2 characteristics, sample 3 characteristics were also tabulated in Table 2. From Table 2 it is observed that, as the temperature of the sample increases then relevant weight, density, kinematic and dynamic viscosities were recorded for negligible reduction in their values.

Table 1. The thermo-physical characteristics of zinc oxide and ethylene glycol-based nano-fluids were investigated at various temperatures



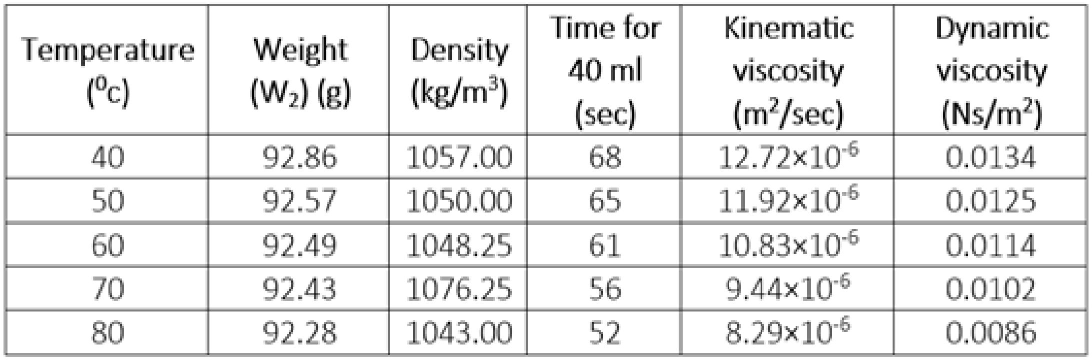
Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	94.36	1095	66	12.18×10^{-6}	0.0133
50	94.24	1092	62	11.11×10^{-6}	0.0121
60	94.15	1089	59	10.28×10^{-6}	0.0112
70	94.00	1086	55	9.16×10^{-6}	0.0099
80	93.68	1078	50	7.70×10^{-6}	0.0083

Table 2. Thermo-physical properties of carbon nanotube and ethylene glycol-based nano-fluids



Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	93.15	1064.75	67	12.45×10^{-6}	0.0133
50	92.97	1060.25	63	11.38×10^{-6}	0.0121
60	92.81	1056.25	60	10.56×10^{-6}	0.0112
70	92.60	1051.00	56	9.44×10^{-6}	0.0099
80	92.65	1052.25	51	7.99×10^{-6}	0.0084

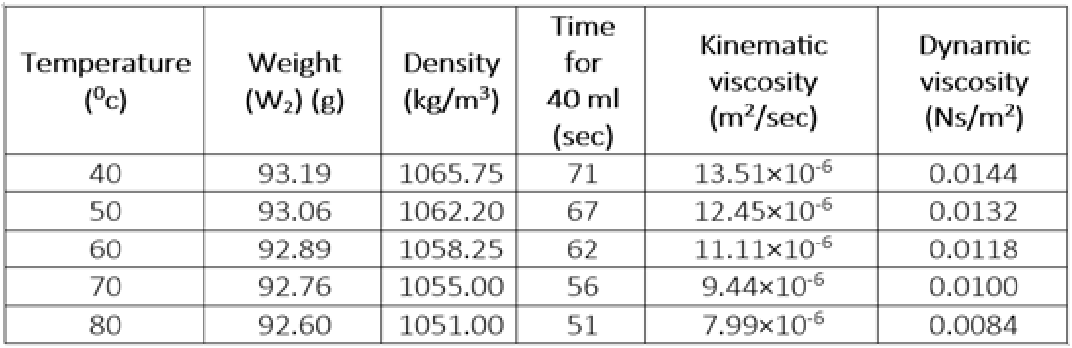
Table 3. Thermo-physical properties of titanium oxide and ethylene glycol-based nano-fluids



Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	92.86	1057.00	68	12.72×10^{-6}	0.0134
50	92.57	1050.00	65	11.92×10^{-6}	0.0125
60	92.49	1048.25	61	10.83×10^{-6}	0.0114
70	92.43	1076.25	56	9.44×10^{-6}	0.0102
80	92.28	1043.00	52	8.29×10^{-6}	0.0086

3.5.4 Nano-fluid Sample 4 (Titanium Oxide + Carbon Nanotube and Ethylene Glycol)

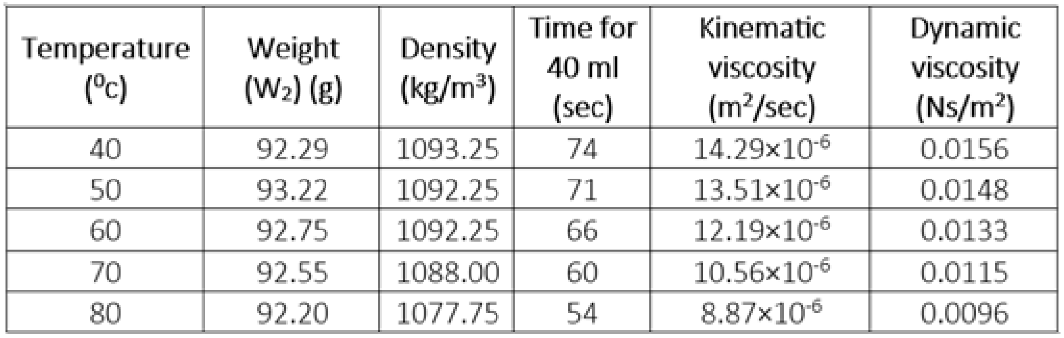
Table 4. Thermo-physical properties of titanium oxide + carbon nanotube and ethylene glycol-based nano-fluids



Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	93.19	1065.75	71	13.51×10^{-6}	0.0144
50	93.06	1062.20	67	12.45×10^{-6}	0.0132
60	92.89	1058.25	62	11.11×10^{-6}	0.0118
70	92.76	1055.00	56	9.44×10^{-6}	0.0100
80	92.60	1051.00	51	7.99×10^{-6}	0.0084

3.5.5 Nano-fluid Sample 5 (Zinc oxide+ Carbon Nanotube and Ethylene Glycol)

Table 5. Thermo-physical properties of zinc oxide + carbon nanotube and ethylene glycol-based nano-fluids



Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	92.29	1093.25	74	14.29×10^{-6}	0.0156
50	93.22	1092.25	71	13.51×10^{-6}	0.0148
60	92.75	1092.25	66	12.19×10^{-6}	0.0133
70	92.55	1088.00	60	10.56×10^{-6}	0.0115
80	92.20	1077.75	54	8.87×10^{-6}	0.0096

3.5.6 Nano-fluid Sample 6 (Zinc Oxide+ Carbon Nanotube+ Titanium Oxide and Ethylene Glycol)

Similarly, Tables 4, 5 and 6 depict the weight, density, kinematic and dynamic viscosities of sample 4 (titanium oxide + carbon nanotube and ethylene glycol), sample 5 (zinc oxide + carbon nanotube and ethylene glycol) and sample 6 (zinc oxide+ carbon nanotube+ titanium oxide and ethylene glycol) respectively.

4.0 Results and Discussion

The heat transfer property is a crucial factor that influences the choice of fluid. In this study, the nanoparticle is combined with two distinct base fluids to create a nano-fluid. The thermos-physical properties of the nano-fluid are then assessed by several tests. The performance analysis of a heat exchanger is conducted for two distinct configurations: parallel flow and counter flow. An analysis is conducted to determine the heat transfer rate and

Table 6. Thermo-physical properties of zinc oxide + carbon nanotube + titanium oxide and ethylene glycol-based nano-fluids

Temperature (^{0}c)	Weight (W_2) (g)	Density (kg/m^3)	Time for 40 ml (sec)	Kinematic viscosity (m^2/sec)	Dynamic viscosity (Ns/m^2)
40	93.81	1081.25	66	12.19×10^{-6}	0.0132
50	93.41	1071.225	60	10.56×10^{-6}	0.0113
60	93.32	1069.00	55	9.16×10^{-6}	0.0098
70	93.26	1067.50	52	8.29×10^{-6}	0.0089
80	93.03	1061.75	48	7.09×10^{-6}	0.0075

effectiveness of various nano-fluids under different flow conditions.

4.1 Viscosity for Different Fluids

The viscosity of various fluids is determined by conducting a test using a redwood viscometer. The nanoparticles, including zinc oxide, titanium oxide, and carbon nanotube, are combined with ethylene glycol. The resulting nano-fluids are then subjected to testing at various temperatures to evaluate the changes in flow.

Based on the graph shown (Figure 4), it can be noted that the kinematic viscosity of various fluids reduces as the temperature increases. The kinematic viscosity of zinc oxide+ carbon nanotube and ethylene glycol-based nanofluid is higher than that of any other fluids at a temperature of 400°C. The nano-fluids containing zinc oxide, carbon nanotube, titanium oxide, and ethylene glycol, as well as the nano-fluids containing zinc oxide and ethylene glycol, will both have the lowest kinematic viscosity among all other fluids at a temperature of 40°C. The nano-fluid consisting of zinc oxide and carbon nanotube in ethylene glycol has a maximum kinematic viscosity of 80°C. On the other hand, the nano-fluid containing zinc oxide, carbon nanotube, and titanium oxide in ethylene glycol has the lowest kinematic viscosity.

The determination of dynamic viscosity involves the measurement of both kinematic viscosity and density of

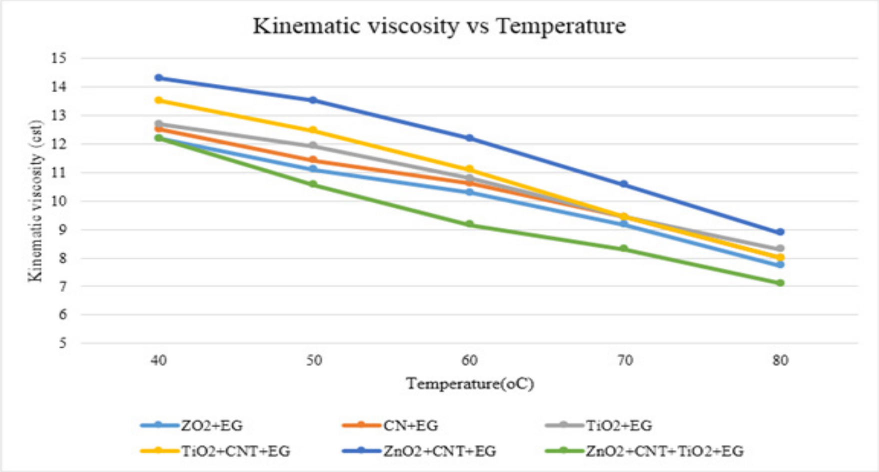


Figure 4. Comparison of kinematic viscosity for different nano-fluids.

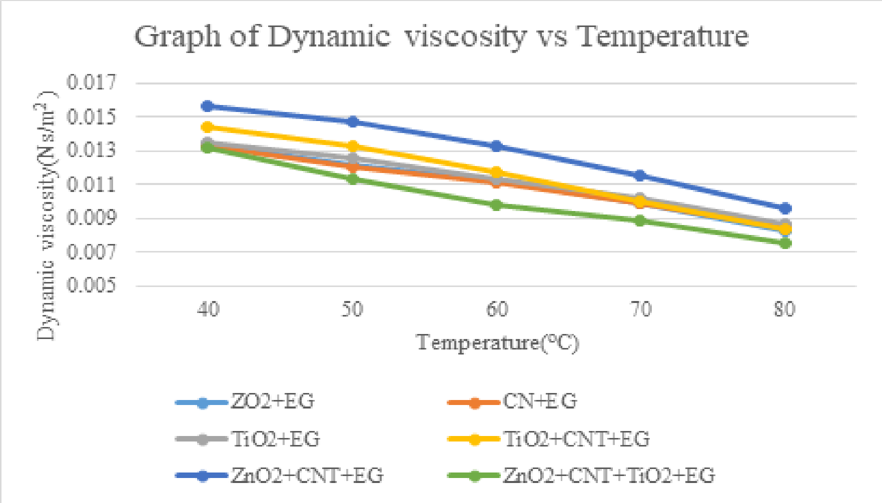


Figure 5. Comparison of dynamic viscosity for different nano-fluids.

various fluids. The measurements are plotted on a graph and analysed to determine the most appropriate fluid for the heat transfer application.

It may be inferred from the graph (Figure 5) that the dynamic viscosity of various fluids reduces as the temperature increases. The dynamic viscosity of zinc oxide+ carbon nanotube and ethylene glycol-based nanofluid is higher than that of any other fluids throughout the temperature range of 40°C to 80°C. The nano-fluids containing zinc oxide, carbon nanotube, titanium oxide, and ethylene glycol, as well as the nano-fluids containing zinc oxide and ethylene glycol, will both have the lowest kinematic viscosity among other fluids at a temperature of 40°C.

4.2 Heat Transfer Rate and Effectiveness of Different Fluids

The performance of various nano-fluids and base fluids is evaluated by conducting experiments on a twin-pipe heat exchanger. The study is conducted for two distinct combinations, namely parallel flow, and counter flow. The experiment is conducted using various flow rates of the fluid, and the outcomes of the experiment are organised in below Table 7.

Table 7. Heat transfer rate and effectiveness of nanofluid

Type of fluid	Heat Transfer Rate (J/s)		Effectiveness	
	Parallel flow	Counter flow	Parallel flow	Counter flow
Zinc oxide based nanofluid	738.97	732.68	0.280	0.290
Carbon nanotube based nanofluid	540.09	631.86	0.290	0.327
Titanium oxide based nano fluid	648.25	615.14	0.280	0.290
Titanium oxide and Carbon nanotube based nano fluid	680.15	615.50	0.273	0.287
Zinc oxide and Carbon nanotube based nano fluid	694.97	632.18	0.294	0.312
Zinc oxide + Titanium oxide + Carbon nanotube based nanofluid	675.87	630.79	0.288	0.308
Distilled Water	653.14	709.63	0.220	0.250

Figure 7 shows the comparison of the heat transfer rate between the parallel and counter flow of different nano-fluid samples prepared and

Figure 7 demonstrates that the heat exchanger's efficiency is higher when the fluids are arranged in a counterflow configuration. Carbon nanotube-based nanofluid has the highest effectiveness for counter-flow arrangements. The hybrid nanofluid, consisting of zinc oxide and carbon nanotubes, demonstrates maximum efficiency in heat exchange systems with both parallel and counter flow arrangements. The effectiveness of the zinc oxide-based nanofluid is superior in both parallel and counter flow arrangements when compared to carbon nanotubes in a parallel flow arrangement. Among all the nano-fluids, distilled water has the lowest efficacy value.

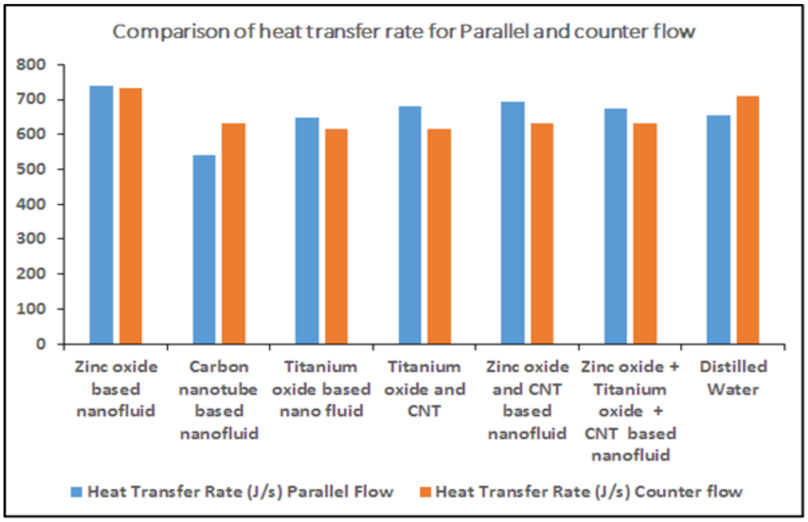


Figure 6. Comparison between heat transfer rate for parallel and counter flow.

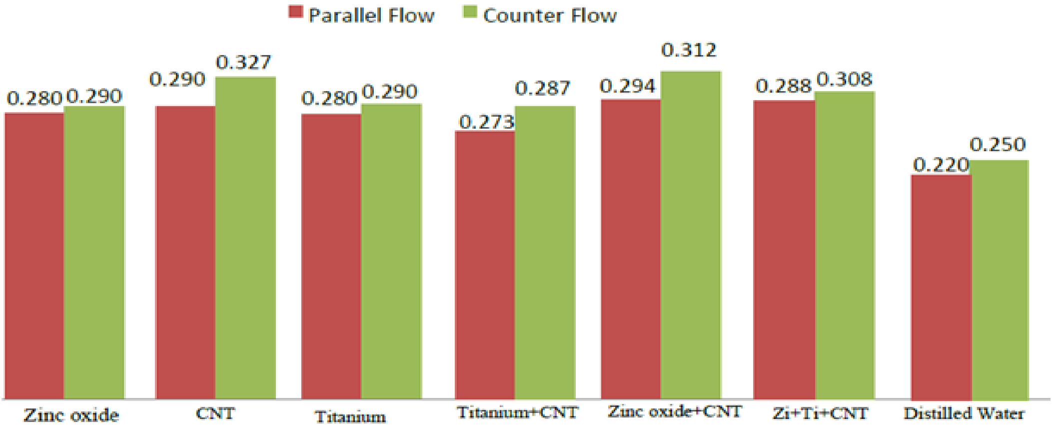


Figure 7. Comparison of effectiveness for different nanofluid samples.

5.0 Conclusion

The selection of nanoparticles and base fluids is based on their suitability for analysing viscosity, heat transfer rate, and effectiveness. Various nanofluid samples are generated and their thermal characteristics and performance parameters are analysed using a viscometer and a heat exchanger. The experiment results indicate that the kinematic viscosity of the hybrid nanofluid (zinc oxide+ carbon nanotube and ethylene glycol) is higher than that of the other nanofluid samples at all tested temperatures. The hybrid nanofluid consisting of zinc oxide, carbon nanotube, titanium oxide, and ethylene glycol will demonstrate a lower kinematic viscosity than all other samples of nano-fluids at the temperatures that were examined. The results indicate that the carbon nanotube-based nanofluid demonstrates much higher effectiveness in a counterflow configuration relative to other nano-fluids and the base fluid. The hybrid nanofluid, consisting of zinc oxide, carbon nanotube, titanium oxide, and ethylene glycol, demonstrates significantly higher efficiency in both parallel flow and counter flow configurations in comparison to zinc oxide-based nanofluid and the base fluid. The investigation reveals that incorporating nanoparticles into the base fluid will improve both the efficiency and heat transmission rate. Therefore, it may be efficiently utilised for various heat transfer applications. The future scope of performance analysis of double pipe heat exchangers using nano-fluids holds significant potential for advancements and exploration in several areas optimization of nanofluid properties, advanced nanoparticle characterization, numerical modeling and simulation, heat exchanger design innovation, long-term stability and reliability studies, energy and environmental impact analysis, industry adoption and commercialization.

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