Heat Transfer Analysis of Al_20_3 Nanoparticles

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Heat Transfer Analysis of Al_2O_3 Nanoparticles

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Abstract: *The capability of temperature variation is essential for cooling industrial operations like transportation such as car and heavy vehicle radiators, electronics devices, petroleum industrial systems, etc. Different methods and fluids are used in the cooling process in industrial systems. The basic fluids are based on temperature, thermal stability, and the effectiveness of heat transmission. Thermal characteristics improve when nanoparticles are added to the basic fluid. Using Al_2O_3 nanofluid the heat transfer and variation in the temperature at the entrance side and outlet side of the micro-channel pipe were studied. Through ANSYS Fluent, a well-defined method for utilizing Al_2O_3 nanofluids to investigate the impact of various performance optimization factors of nanofluids was performed. The temperature of the nanofluids at the inlet and outlet is found 300 K and 313.7 K, respectively during the simulation. The pressure drops from the inlet side to the outlet side as well a result that raising the temperature, heat coefficient, thermal conductivity, and viscosity of the base fluids when Al_2O_3 nanoparticles are added.*

Keywords: Nanoparticles; Stability; Thermal conductivity; Temperature; Viscosity.

1. INTRODUCTION

The heat transfer function is very important for cooling industrial processes [1]. When molecules in fluids like liquids and gases move, heat transmission happens. The flow of fluid from the surface of the object can transfer heat from one fluid to another object is called convection. Fig. 1 illustrates the convection heat transfer [2]. On the other hand, fluid movement causes bulk heat transfer during fluid movement. Gases and liquids don't transmit heat well under typical conditions. But they may transport heat very quickly. This method transmits heat by an increase in flow, dispersion, or both. Because solid particles are immobile, convection does not happen between them.

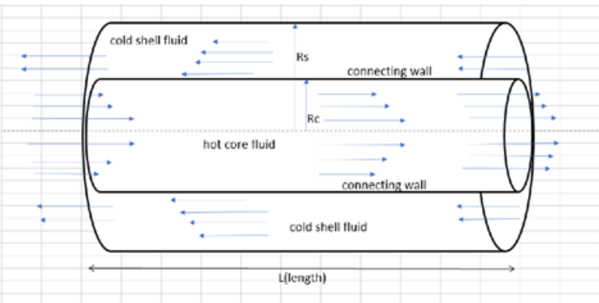

Fig. 1. Systematic diagram of convention. Reproduced from ref. [2]. Copyright 2022 MDPI.

The base fluids (convectional heat transfer fluid) are fluids that are based on their properties such as temperature, thermal stability, and heat transfer efficiency [3]. The fluids that are used for the cooling process in the industrial system and different technologies are water, ethylene glycol, and ionic liquids. Due to their poor thermal performance, these convectional heat transfer fluids have not shown sufficient for cooling applications [4]. The past years have witnessed rapid developments in nanotechnology, bringing up a broad range of opportunities for researchers and engineers to explore. One of the most remarkable consequences of this development is nanofluid. Due to their excellent thermal conductivity, nanofluids offer a lot of potential as high-energy carriers. Nanofluids are large applications because of their enhanced thermal conductivity. But when related to nanotechnology, nanoparticles are significant. The different types of nanoparticles are metals, semiconductors, ceramics, etc. One of the most important metal oxides, alumina nanoparticles (Al_2O_3) have a variety of uses and specific physio-chemical characteristics. Nanofluids of Al_2O_3 have been used in a wide variety of industries, including the petroleum sector, lubrication, surface coating, and biological applications. Nanofluids have been employed in several biomedical and nanomedicine applications, including nano-drug delivery, cancer therapies, sensing, and imaging, and nano-cryosurgery, according to the literature. For instance, there are several uses for magnetic nanofluids, along with the enhancement of contrast in magnetic resonance imaging, magnetic cell separation, and hyperthermia. There are several published reports on the use of nanofluids in non-renewable energy areas, such as the petroleum industry.
Most significantly, it has been discovered that alumina possesses superior thermal conductivity and a high coefficient of convective heat transfer. To include Al_2O_3 deposition in water, this investigation is thus being performed. The heat transfer ratio of conventional heat transfer fluid (base fluid) is enhanced by adding some Al_2O_3 particles (nanoparticles) because the thermal performance has increased [5]. The thermal conductivity of Al_2O_3 nanoparticles is very large as compared to the base fluids. So that if we increased the Al_2O_3 nanoparticles, then increase the thermal properties of nanofluids. Nanofluids are made by mixing conventional heat transfer fluids, such as oils, ethylene glycol, and water, with nanoparticles (Al_2O_3) having typical sizes

less than 100 nm. Based on their size, shape, physical, chemical, manufactured or natural, and synthetically generated or byproduct characteristics, nanoparticles may be categorized into a variety of categories [6]. Lipid-based nanoparticles, carbon nanoparticles, metal nanoparticles, ceramic nanoparticles, semiconductor nanoparticles, and polymeric nanoparticles are only a handful of these. Fig. 2 provides the categorization of the nanoparticles diagram. The thermal properties of Al_2O_3 nanoparticles depend on the size of the particles. When the size of Al_2O_3 nanoparticles are small, then the volume fraction increase and vice versa. Thus, the thermal properties of Al_2O_3/H_2O nanofluids are usually enhanced. A basic fluid's thermal expansion is smaller than that of a nanofluid. The basic fluid's thermal conductivity improves when Al_2O_3 particles of nanometer size are included.

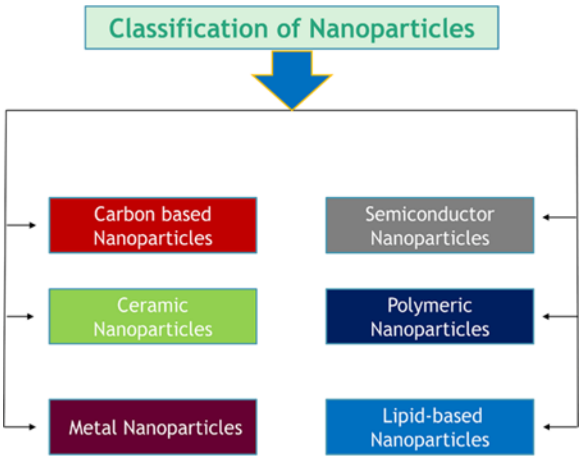

Fig. 2. Schematic Diagram of Classification of the Nanoparticles.

In general, one-step and two-step manufacturing techniques generate stable and highly conductivity nanofluids. The one-step process simultaneously develops the Al_2O_3 nanoparticles and dissolves the fluid [7]. The one-step technique has certain benefits, including avoiding the Al_2O_3 nanoparticle agglomeration. This is because the procedures of drying, storing, dispersing, and transporting particles into the base fluid are merged, which reduces nanoparticle agglomeration. The one-step physical process is exceedingly costly and cannot create nanofluids on a large scale, hence it is changing quickly [8]. Unfortunately, one-step techniques also have certain shortcomings. The most important one is that the nanofluids still contain reactants from incomplete reactions or stabilization. It is difficult to comprehend the nanoparticle impact without eliminating this impurity effect. The one-step method is defined in Fig. 3 [9].

On the contrary, the two-step method is extensively used for producing nanostructured materials like Al_2O_3 nanoparticles. [10]. The dry powder that is produced after using the physical and chemical processes is then dissolved in the base fluid (water). Due to the effectiveness of earlier industrial procedures, this technique is a convenient option for the mass manufacturing of nanofluids (Al_2O_3/H_2O). Aggregation of nanoparticles throughout the two-step procedure is inevitable due to the high surface activity of the particles. The characteristics of the nanostructured materials may be impacted by this technique. As a result, scientists have begun to create the nanofluid using a more traditional technique rather than the two-step procedure. Numerous reduction approaches, including the one-step method, have been developed since it is challenging to produce sustainable nanofluids using the two-step process [11]. The two-step method is illustrated in Fig. 4 [9].

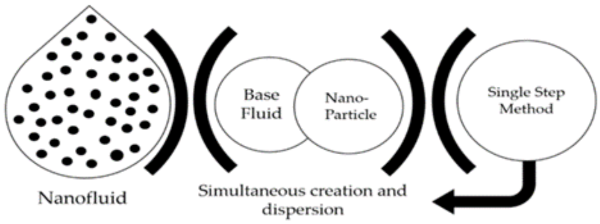

Fig. 3. One step method. Reproduced from ref. [9]. Copyright 2018 MDPI.

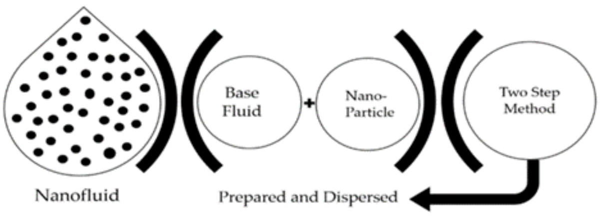

Fig. 4. Two-step method. Reproduced from ref. [9]. Copyright 2018 MDPI.

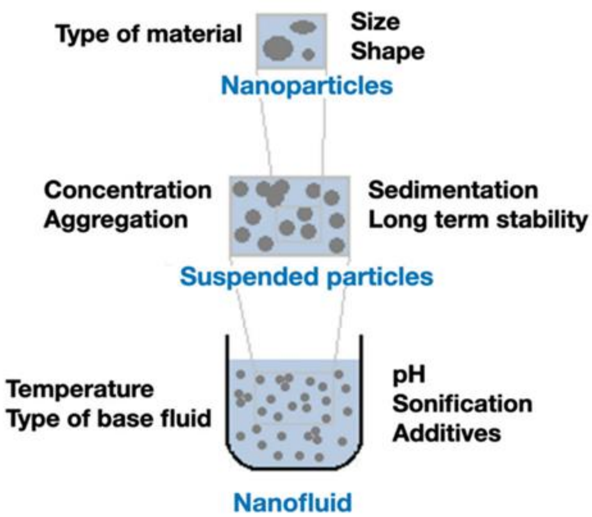

Fig. 5. Schematic diagram of stability factors. Reproduced from ref. [13]. Copyright 2021 MDPI.

Agglomeration of nanoparticles is a significant problem in all nanopowder technologies and impacts both methods for creating mixtures of nanoparticles. Stability is one of the most important aspects of any nanofluid system in any usage, especially in heat transmission [12]. It remained a technological procedure to create similar nanofluids with high stability, although numerous kinds of research on the stability of dispersion containing solid particles. In a conclusion, the study of nanofluid stability includes the main components that affect stability as well as the technique that may be used to evaluate nanofluid stability. The stability of Al_2O_3 nanofluids depends on different factors which are surface modifications, pH regulation, nanofluid preparation method, homogenization, and nanoparticle addiction. Fig. 5 defines how the factors affect the stability of nanofluids [13]. The nanofluid is based on thermo-physical parameters like viscosity, conductivity, and heat transfer coefficient [14]. The key feature of nanofluid is conductivity. One of the very important thermodynamic parameters of nanofluids that needs to be examined to show that these new improved suspensions can be used in heat transfer applications is their thermal conductivity. There are several ways for determining the thermal conductivity of nanofluids, including optical approaches, the transient hot wire method, the temperature oscillation approach, the transient plane source method, and numerous others [15]. Higher thermal conductivity is preferred in applications where heat transmission is involved. Despite being intricate suspensions, nanofluid system's thermo-physical characteristics, such as thermal conductivity, can be influenced by several circumstances. The Maxwell correlation was developed to calculate the thermal conductivity of suspensions containing solid particles Equation (1) gives an approximation value of thermal conductivity [16].

$$\frac{k_{nf}}{k_{bl}} = 1 + [\frac{3(\alpha-1)\emptyset}{(\alpha+2)-(\alpha-1)\emptyset}] \quad (1)$$

Where α is K_p/K_{bl} and K_{bl}, K_p, and K_{nf} are the thermal conductivity of the conventional fluid, the nanoparticle, and the nanofluid respective, and ∅ is the volume fraction of the particles in nanofluids. The viscosity must also be evaluated to choose the effective nanofluid with the best properties for cooling applications. Viscosity, which is determined by a fluid's internal resistance to flowing, is significant in all thermal applications involving flowing fluids. Additionally, fluid viscosity has an impact on Reynolds and Prandtl numbers, and the heat transfer coefficient (HTC) is a function of these numbers. As a result, viscosity is just as crucial to all fluid flow engineering systems as thermal conductivity. For calculating the viscosity of suspensions containing solid particles, Einstein's equation provided formula (2), from which most of these correlations have been obtained [17].

$$\mu_{nf} = \mu_{bl}(1 + 2.5\emptyset) \quad (2)$$

Where the symbol ∅ is the volume percentage of solid particles dispersed in the conventional liquid, μ_{bl} is the viscosity of the base liquid, and μ_{nf} is the viscosity of the suspension. The following equation (3) can be used to correlate the experimental data or the computational fluid dynamics (CFD) simulation results acquired in convection-forced heat transfer investigations in lengthy ducts and pipes.

$$Nu = \Phi(Re)\,\Theta(Pr) \quad (3)$$

Where the symbols Φ stand for the Reynolds number and ϴ Prandtl number is the corresponding function. They have many applications in technology and the field of science. Nanofluids are thought to provide significant benefits over traditional heat transfer fluids. The thermal characteristics of host fluids can be considerably enhanced by a very small amount of guest nanoparticles when they are evenly dispersed and suspended in base fluids [18]. Several researchers have suggested different physical ideas, and procedures, and created new models for enhancing the transport features in an attempt to understand unexpected discoveries and so get beyond the constraints of classical models. In the current work, a discussion of the broad-ranging fundamental evolution of nanofluids has been made by laying out a massive picture of the small nanofluid biosphere through a brief review of some historically significant turning points, including the concepts of nanofluids, the preparations and performances of nanofluids, the conductivity, and viscosity, of nanofluids, and potential applications and advantages of nanofluids.

Many researchers and engineers' study nanofluids for heat transfer. We have investigated the transfer and temperature through the straight pipe using ANSYS software. P. C. Mukesh Kumar et al. (2015) investigated the Al_2O_3/water nanofluid CFD analysis of heat transmission and pressure decrease in helically coiled heat exchangers. High-pressure drop (red color) and high-temperature area (green hue) near the coil exit. The temperature of the coiled fluid is 309 K at the entrance and 317 K at the outflow [19]. Sudhanshu Pathak and H. S. Sahu (2018) concluded that heat transfer through nanofluids (Al_2O_3) in a heat exchanger depends on temperature [20] and flow rate inside the pipe and also shows that the inlet temperature is 303 K and outlet temperature 365 K. A. Azman et al. (2021) investigated that the Al_2O_3+Cu/water nanofluids flow in a straight Pipe enhanced the heat transfer coefficient and temperature [21] at inlet and outlet are 297 K, 313 K respectively. W Ajeel et al. (2022) investigated the AL_2O_3 nanofluid's Heat Transfer performance in laminar flow in mini-tube. It was found that the heat transfer was significantly improved [22], particularly in the entry area, by up to 17.8%, and that the pressure drop, friction factor, and needed pumping power of the nanofluids all increased in combination. H Xie et al. (2020) investigated the heat transfer coefficients of Al_2O_3, MgO, and ZnO nanofluids were all significantly improved [23], with MgO nanofluids showing the largest improvement of up to 25.2% at a Reynolds number of 1000. Y Raja Sekher et al (2013) investigated the heat transfer enhancement for solar thermal applications using Al_2O_3 nanofluids. According to their findings, at 1.8 % volume concentration, convective heat transfer was enhanced by 32 % and increased with the Prandtl number of the flow [24]. E Esmaeilzadeh et al. (2013) investigated a horizontal tube used in an experiment to study hydrodynamics and heat transfer properties of Al_2O_3/water under laminar flow. Results showed that as compared to distilled water, the average heat transfer coefficient rose by 6.8% with a volume concentration of 0.5 percent and by 19.1% with a volume concentration of 1 percent [25]. We study the heat transmission through Al_2O_3 nanofluids using ANSYS Fluent in a straight channel micro pipe. The input and output temperatures of the nanofluids in this work are 300 K and 313.7 K, respectively. Different scientists and researchers investigated heat transmission using nanofluids and utilized them in many engineering and technological domains [26–32].

The heat transfer through conventional heat transfer fluids is poor because the thermal conductivity is less than Al_2O_3 nanoparticles. In this study, we discussed the heat transfer and pressure drop through Al_2O_3 nanofluids at the inlet side and the outlet side of the microchannel pipe with the turbulent fluid flow. To solve this problem, we have used the finite-volume-based ANSYS Fluent student version (2022) software. Fig. 6 illustrates the model geometry of the pipe [33].

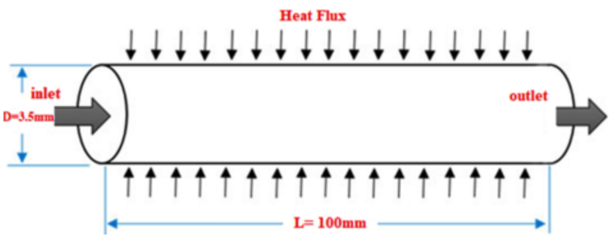

Fig. 6. Schematic diagram of model. Reproduced from ref. [33]. Copyright 2017 MDPI.

2. ANSYS SIMULATION

ANSYS is a Software used for simulation on a large scale globally. Many researchers have used ANSYS software for simulation fabrication [34–44]. ANSYS provides researchers the ability to test their ideas against a wide range of variables, breaking design and mission boundaries. Companies may develop and validate like never before with the power of ANSYS multi-physics software solutions and digital mission planning. A pipe flow, one of the most typical designs in the industry, with a thickness, of 7 mm and a length of 100 mm taken into account to make this study more clear-sighted (Fig. 7).

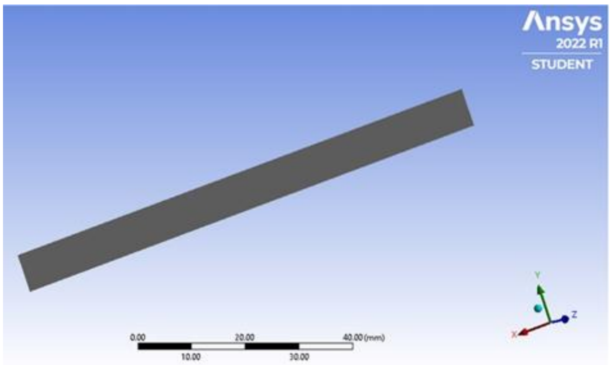

Fig. 7. Modeling of micro-channel pipe.

These simulations develop better capturing and comprehension of the nanoparticle's near-wall behavior. As a result, the near wall section or the boundary layers need a higher resolution or relatively small linear boxes for better meshing. A small computational effort, however, required that the mesh not be too fine. Fig. 8 displays the mesh that was employed in this study. The mesh geometry is consisting of 48861 nodes and 48000 elements.

After the meshing process, we have to take the solution setup. There are just three parameters available for model selection. All other options are still set to Default. The three variables are the Eulerian, Energy-on, and Standard K-E Turbulence models. Boundaries that are imposed on the model such as velocity and pressure on the inlet, outlet pressure, and interior surface body are a mixture of nanofluids, and upper and lower walls are heat fluxes. In the solution, the setup added the material for preparing the nanofluid. These materials are water liquid and aluminum oxide. Aqueous alumina (Al_2O_3+H_2O) nanofluids with a volume fraction of 0.5 are the working fluid employed in this simulation, and the thermal characteristics of the aluminum oxide and water are briefly discussed. Thermal conductivity, viscosity, specific heat, and density of aluminum oxide are 40 W/mK, 1.72 x 10^{-5} kg/ms, 786 J/kg K, and 3970 kg/m^3, respectively, while those of water are 0.6 W/mK, 1.003 x 10^{-3} kg/ms, 4182 J/kg K, and 998.1 kg/m^3, respectively. The Hybrid initialization occurs in the initialization after all the processes that run and the calculation 4000 number of iterations.

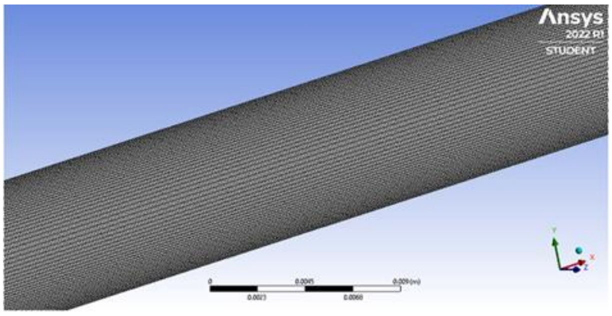

Fig. 8. Meshing of micro-channel pipe.

3. RESULTS AND DISCUSSION

For ANSYS simulation, heat transfer through nanofluids is designed with a straight pipe using an inlet, outlet, and walls of heat flux also the thickness and length of the pipe. For a crisp value of temperature, the difference is 13 K, the thickness is 7 mm, and the length is 100 mm. For real-time simulation, a geometry of nanofluids with dimensions is designed by ANSYS fluid flow fluent. The initial temperature of the pipe is 300 K. Heat is transferred with the nanofluids through the pipe. For verification of simulation results, heat transfer is also calculated using the standard formulation of the temperature of nanofluids. In this work, the nanofluid's input and output temperatures are 300 K and 313.7 K, respectively (Fig. 9).

The simulation's results are in good agreement with the standard preparation results. The results of the work concluded that the pressure of the transfer of heat through nanofluids has an inverse relation to temperature. The results of temperature at the inlet side and exit side of the microchannel pipe were discovered to be 309 K & 317 K, 303 K & 365 K, and 297 K & 313 K, accordingly, to the previous research by P.C. Mukesh Kumar et al. (2015), Sudhanshu Pathak & H.S Sahu (2017), and A. Azman et al. (2022). In this study, the results for the temperatures at the inlet and outflow of the pipe are 303 K and 313.7 K, respectively. The strong agreement between the results of this investigation and earlier studies is made abundantly clear in this essay. Rectangular heat transfer surfaces are used to increase heat transmission while reducing pressure drop, resulting in more thermal management when nanofluid is present. Numerical analysis showed the effect of the specimen on a microchannel while Al_2O_3 nanofluids are present. It has been established that channels with Al_2O_3 nanofluids produce better heat transfer performance because the energy of the molecule increase, which is complemented by a slightly higher -4.6×10^{-1} Pa pressure drop. Results showed a much-increased rate of heat transfer at the cost of a significant pressure drop. Fig. 10 also shows how pressure drops gradually from the inlet side to the outlet side are 2.845×10^{-1} and -5.241×10^{-1} respectively. P.C. Mukesh Kumar et al. (2015) studied the possibility that the friction between fluid particles and tube inner wall surfaces creates pressure reduction. The microchannel pipe's inlet and output pressure drops are 5.36×10^{3} and -4.24×10^{2}, respectively [16].

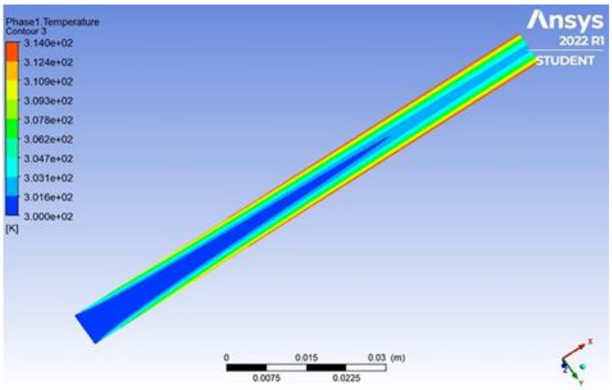

Fig. 9. Temperature contour mapping.

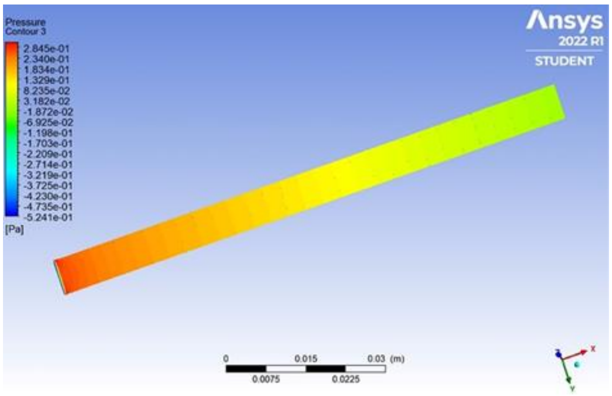

Fig. 10. Pressure contour mapping.

The temperature of 300 K gradually rises through the use of the microchannel pipe entrance. And the pressure of the output nanofluids is dropping at this instant due to the increase in the energy of the molecules. As a result, the temperature of the inlet pipe and the pressure at the output are inversely related. While the nanofluid's temperature and pressure are received at the pipe's input and departure -5.241×10^{1} Pa and 300 K, respectively. The temperature is based on the outcomes of the ANSYS simulation, a graph is drawn between the microchannel pipe temperature and pressure. A basic graph diagram showing the inverse relationship between temperature and pressure from Fig.11.

The spherical graph is arranged between temperature and pressure illustrated in Fig. 12 where the pressure drops and the temperature increase gradually from the black color to the mustered color. The graph shows the many varieties of values of pressure and temperature. The black color shows the maximum value of 0.2835 Pa of pressure at the inlet side of the microchannel pipe and its percentage value is 16.2% showing the temperature. The red color shows a pressure of 0.224 Pa and its temperature value is 16.5%. The blue, green, purple, and mustered color with pressure values of 0.1834 Pa, 0.1329 Pa, 0.08235 Pa, and 0.03182 Pa respectively shows that the pressure drops gradually from the entrance side of the pipe to the existing side. The percentage values of temperature are 16.7%, 16.8%, 16.9%, and 17% of blue, green, purple, and mustered colors accordingly. The percentage value increases gradually from black color to mustered color representing that the temperature increased. Here, the temperature and pressure are inversely proportional so that the temperature at the outlet side is maximum.

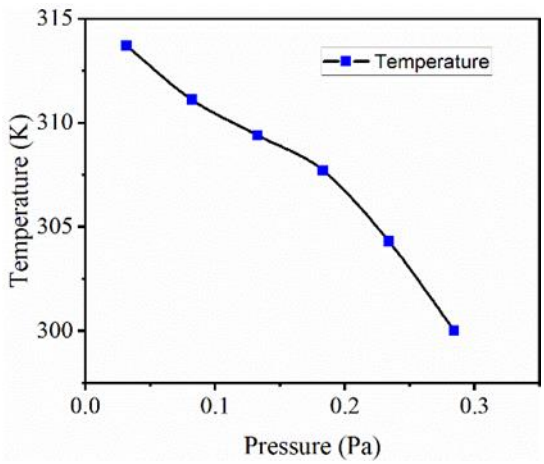

Fig. 11. Graph between temperature and pressure.

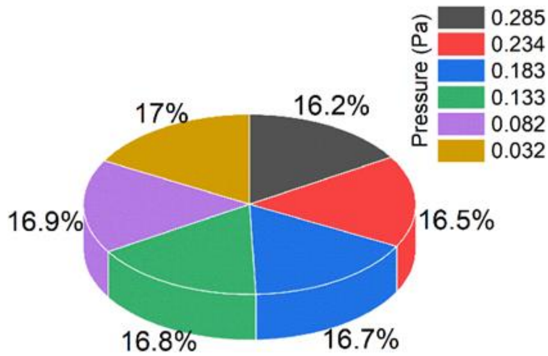

Fig. 12. Spherical graph plotted between temperature and pressure.

4. CONCLUSION

This study reflects a well-defined method for utilizing ANSYS Fluent to investigate the impact of various performance optimization factors (temperature, pressure, heat transfer coefficient, and heat transfer rate) on nanofluids of Al_2O_3 nanoparticles. The temperature of the nanofluids at the inlet and outlet is found 300 K and 313.7 K, respectively. It has been found that due to the increment of 2.46 W/mK thermal conductivity and 1.34 Kg/ms viscosity of the nanofluid while the temperature of 313.7 K and heat transfer coefficient increased although pressure drops -4.6×10^{-1} Pa. Reynolds number and Prandtl number increase with temperature. The results of our work concluded that the pressure of the transfer of heat through nanofluids has an inverse relation to temperature. The standard formulation of the temperature of nanofluids is frequently used to compute heat transfer to validate simulation findings. Our results show excellent agreement with the previous researchers.

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