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Modelling for HT Enhancements Using Nano Fluids for Cooling of Electronic Components

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Abstract

The increasing demand for high-performance electronic devices, such as processors and graphics cards, has escalated the challenges associated with heat dissipation. Traditional cooling methods, including air and water cooling, are becoming insufficient as devices generate higher amounts of heat. To address these challenges, the use of nanofluids—suspensions of nanoparticles in base fluids—has emerged as a promising solution for enhancing thermal management. Nanofluids, particularly those containing aluminum oxide (Al_2O_3) and multi-walled carbon nanotubes (MWCNT), have shown superior heat transfer properties compared to conventional fluids due to their high thermal conductivity and enhanced heat transfer performance. This study investigates the impact of nanoparticle concentration, tube diameter, and flow rate on the heat transfer efficiency of Al_2O_3 and MWCNT nanofluids in electronic cooling systems. Using computational fluid dynamics (CFD) simulations and experimental testing, the research aims to provide a comprehensive understanding of how nanofluid properties affect heat dissipation. The findings suggest that increasing nanoparticle concentration significantly enhances heat transfer, with MWCNT-based nanofluids outperforming Al_2O_3 nanofluids in terms of thermal conductivity. The study demonstrates that nanofluids can serve as highly effective coolants for next-generation electronics, offering compact and efficient cooling solutions.

Keywords: Nanofluids, Heat Transfer, MWCNT, Al_2O_3, Cooling Systems, CFD Analysis.

1. Introduction

The advancement of processors, graphics cards, smartphones, and other electronic devices has come with the increase of more compact and powerful devices that generate more heat and require better cooling systems to allow devices to maintain performance and run longer. Traditional cooling systems are insufficient for the new generations of highly compact and powerful devices and therefore new cooling systems are needed(Sohel Murshed & Nieto De Castro, 2017). For example, newer devices are traditionally cooled with air or watercooling systems while the new generations of devices require more advanced and more efficient systems. One advanced solution is the use of nanofluids which are suspensions of nanoparticles and fluids that are better for heat transfer and thermal conductivity.

Nanofluids are made by inserting nanoparticles (usually between 1 and 100 nm) into standard fluids like water or ethylene glycol(Chamsa-ard et al., 2017). Nanofluids have shown to significantly improve thermal properties in comparison to their baseline fluids. Strong and low viscosity fluids have improved heat transfer and are great for heat transfer applications. Nanofluids are great for electronic cooling application. For example, the use of Al_2O_3 (aluminum oxide) and MWCNT (multi-walled carbon nanotubes) nanoparticles have shown to improve the cooling efficiency to a greater extent than standard fluids in cooling applications. This research focuses on improving the thermal conductivity of nanofluids, namely Al_2O_3 and MWCNT, used as coolants in electronic systems(Devarajan et al., 2018). The primary aims of the proposed study are to examine the effects of nanofluid volume concentration, tube diameter, and flow rate on heat transfer efficiency. The work seeks to elucidate the impact of nanofluid parameters, including concentration and particle type, on the total heat dissipation in cooling systems using computational fluid dynamics (CFD) models and experimental testing. The results of this study may facilitate the development of more efficient and compact cooling methods for future high-performance devices.

2. Literature Review

2.1 Nanofluids

Nanofluids are a mixture of nanoparticles (suspended solids) mixed in liquids, and are great for thermal management because of great properties like thermal conductivity (the ability to conduct a heat flow) and heat transfer. An example is a study done by **Nandy Putra et al, (2011)** where the Nanofluids of alumina-water and titania-water proved to cool better than the classic refrigerants used in CPU cooling systems. In the study, a heat exchanger system was used where heat was transferred from a CPU to a coolant. It was found that the nanoparticles in the coolant lowered the thermal load (reduced the effect of heat) on the CPU and the thermal performance was better at different temperatures (25°, 30°, and 35°). This proved that Nanofluids are effective in high-performance electronic devices(Putra et al., 2011). In 2007, **Cong Tam Nguyen and others** studied how adding nanoparticles to base fluids (including water) can help improve thermal mass and heat transfer performance. They found that nanoparticles improve heat transfer coefficient and dielectric loss of the coolant, and that a 6.8% volume concentration of nanoparticles resulted in a 40% higher heat transfer compared to pure water. Also, in their study, nanofluids containing 36 nm particles were found to have superior heat transfer performance compared to those containing 47 nm particles(Nguyen et al., 2007).
M. Rafati et al. (2012) looked at how different nanofluids, like alumina, silica, and titania, impact the cooling performance of liquid cooling applications. They found that when cooling processors, the use of all nanofluids, especially those based on alumina, reduced thermal resistance and performed better than standard cooling fluids such as water and ethylene glycol(Rafati et al., 2012). Additionally, **Y.H. Diao et al. (2017)** analyzed MWCNT-water nanofluids in MHEs. Their results showed that MWCNT nanofluids improved heat transfer and had greater friction and Nusselt numbers than those of pure water. Also, in comparison to smooth tubes, nanofluids improved heat transfer in micro-fins(Diao et al., 2017). Considering turbulence, **W.H. Azmi et al. (2016)** analyzed the friction factors and thermal conductivities of TiO_2 and Al_2O_3 nanofluids. Their research concluded that the thermal conductivity of Al_2O_3 nanofluids was higher than that of TiO_2 nanofluids, and although the friction factors increased with the increase of the nanoparticle concentration, the heat transfer performance was enhanced to a greater degree with the increase of the nanoparticle concentration(Azmi et al., 2016).
G. Hetsroni et al. (2002) did experimentation on an absorber plate for electronic cooling with the use of dielectric liquids while trying to keep the temperature between 323K and 333K. The experiment proved the channel's ability regarding the efficient heat dissipation of the dielectric nanofluid and resulting in the further proof of the suitability of nanofluids for the thermal management of electronic cooling(Hetsroni et al., 2002). **D.A. Nield et al. (2013)** investigated how viscous dissipation and diffusion impact parallel plate channels with nanofluids. It was noted in the research that the concentration of the nanoparticles, along with the temperature, had a considerable impact on the amount of heat that was absorbed(Nield et al., 2007).

2.2 Experimental Models

Experimental research on nanofluids has shown great promise for enhancing heat transfer in several applications. **Fotukian Alali (2023)** conducted convective heating experiments with Al_2O_3/H_2O nanofluids in circular tubes and found that these nanofluids had a greater heat transfer coefficient than plain water. Their study showed that Al_2O_3 nanofluids were more thermally efficient than the other nanofluids studied(Alali et al., 2023).
In the same way, **Eastman et al. (2001)** studied how copper nanoparticles in ethylene glycol affected the thermal conductivity of the nanofluid, and therefore, the ability of the nanofluid to improve heat dissipation(Eastman et al., 2001). In the automotive field, **Ollivier et al. (2006)** studied the use of nanofluids as engine coolants. They found that more heat was absorbed by the engine and the cooling system of the engine became more efficient as more nanoparticles were added. This study demonstrated the usefulness of nanofluids in the thermal management of automotive engines(Ollivier et al., 2006). Additionally, **Arani and Amani (2012)** explored the effects of TiO_2/H_2O nanofluids on heat transfer and pressure drop and found that with the increase of Reynolds number, Nusselt number also increased, signifying enhanced heat transfer efficiency. This work continued to support the positive effects of nanofluids in heat transfer improvements through different flow conditions(Abbasian Arani & Amani, 2012).
Suleiman Akilu and Others (2019) studied how beta-modified silicon carbide nanofluids in ethylene and propylene glycol affect, electrical and thermal conductivity and viscosity. It was found that with increasing temperature and

concentration of nanofluids, electrical and thermal conductivities of nanofluids increased and the viscosity of nanofluids decreased. Thus the nanofluids started transferring heat more efficiently. The above studies show how promising nanofluids are in thermal management of systems, particularly in electronic cooling and automotive applications. The additional heat transfer that nanoparticles offer in the base fluids, justifies the need to conduct more research to enhance cooling methods for high-performance systems(Akilu et al., 2019).

3. RESEARCH METHODOLOGY

3.1 Selection of Material

- **Copper Tubes**: Copper has a lot of great uses, but for this specific scenario, the great use of copper being great is the great use for the great utilization of the system that uses copper for great uses of great things in great systems is targeted for the proper purposes for the individualized heating problems that systems have for heating purposes. Great systems have great uses for transferring the systems, and the systems that have great purposes for great uses of systems that utilize the system for heating purposes.

- **Nanofluids**: Nanofluids are a combination of base fluids (such as water) and nanoparticles (solid particles of Nano-size). These fluids are engineered to enhance heat transfer properties beyond those of conventional fluids. The nanoparticles, often metal oxides or carbon-based materials like MWCNT (multi-walled carbon nanotubes) and Al_2O_3 (aluminum oxide), are added to improve thermal conductivity and enhance the overall efficiency of heat management systems.

Material	**Property**	**Value/Description**
Copper Tubes	Thermal Conductivity	~401 W/m·K
	Density	~8.96 g/cm³
	Melting Point	~1085°C
	Tensile Strength	~210 MPa
	Corrosion Resistance	High (with potential for patina formation over time)
Nanofluids	**Base Fluid**	Water, Ethylene Glycol, or Oil (commonly used)
MWCNT	Thermal Conductivity	~3000-6000 W/m·K (varies with quality and purity)
	Aspect Ratio	High (typically >1000)
	Density	~1.3-2.1 g/cm³
Al_2O_3 Nanoparticles	Thermal Conductivity	~30 W/m·K
	Particle Size	~10-100 nm (varies by application)
	Density	~3.95 g/cm³
	Specific Heat Capacity	~0.9 J/g·K

Heat dissipation from microprocessors is growing continually. Demand for microprocessors with strong computational capabilities has grown owing to expansionin information technology. Heat dissipation from high end CPU is 110-140 W. To remove this much heat, standard air-cooling methods are not adequate. So for many applications this technology will have to be replaced by some modern heat managementstrategies Advancement in nanofabrication and techniques permitted to make solid particles of nanoparticle size. These particles are combined with base fluids such as water. The combination thus generated is called as nanofluids. Different experimental inquiry have been done employing different nanofluids for heat transfer improvement.Although there are many different types of nanofluids available, choosing the proper one will provide the best results for increasing heat.

Nanofluids
↓
Electronic Chemical balance for weight
↓
Mixed with water
↓
Magnetic stirrer

Fig 1. A schematic diagram of the preparation of nanofluids

Fig 2. A Multivalved Carbon Nanofluid with Technical Specifications

4. CFD MODELLING

4.1 Modelling

In Computational Fluid Dynamics (CFD) analysis, modeling plays a crucial role in simulating and predicting fluid flow behavior within a given system. The modeling process involves creating a virtual representation of the physical system under study, which includes defining the geometry, boundary conditions, and material properties.

Start
↓
Define Objectives
↓
Geometry Creation
↓
Boundary Condition
↓
Material Properties
↓
Meshing
↓
Turbulence Model Selection
↓
Solver Configuration
↓
Conclusion
↓
End

Fig 3. CFD Analysis Flowchart

By properly constructing the system and accurately incorporating the correct boundary conditions, material properties, and turbulence models, CFD analysis aids engineering system design and optimization by providing useful information pertaining to fluid flow behavior.

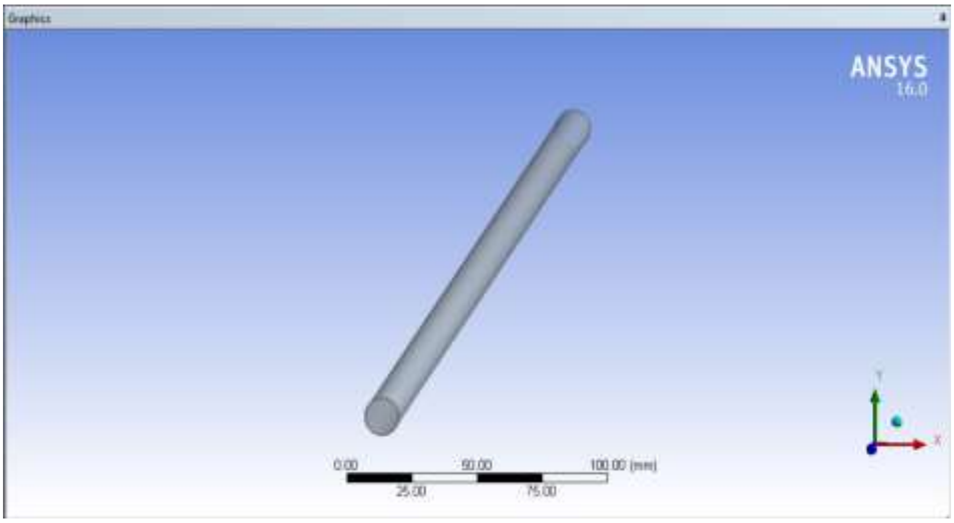

Fig 4. 3D Model of tube for 13.5 mm diameter and 800 length

The illustration shows a 3D model of a metal pipe which has been dimensioned 800 mm long and 13.5 mm in diameter and which has been marked with axial markers to indicate scale. Tube covers with dimension marked are to enhance precision of the model. The word “σπιτά” is most likely out of place and possibly points to a formula. This model can be used in a wide variety of fields including engineering, manufacturing, and educational and scientific research, and can be used to analyze components, build models for prototyping, analyze data and teach concepts.

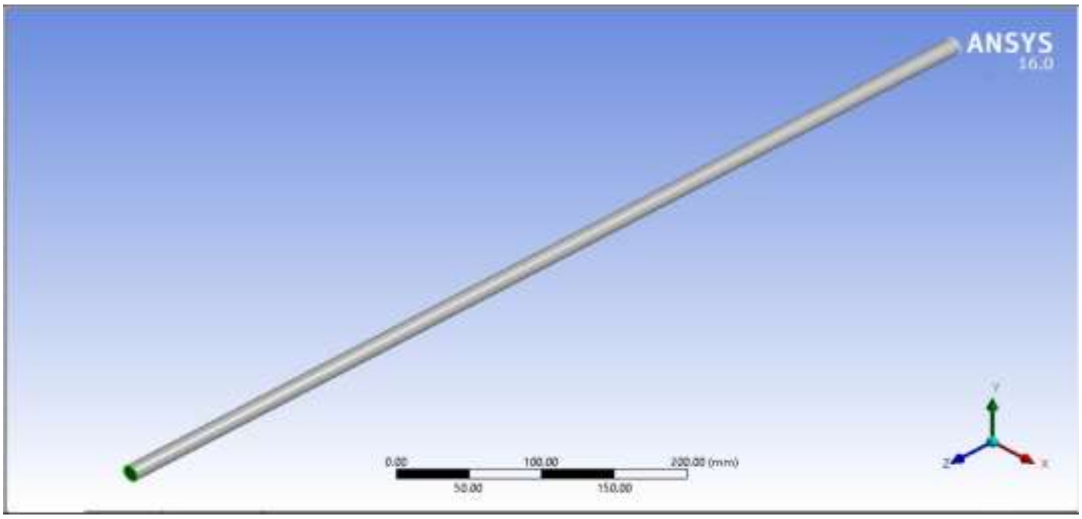

Fig. 5. selection to assign boundary conditions and to measure temperature at different locations

The 3D model shows some kind of tunnel with defined measurement points and structures for calculations or experiments, probably for heat transfer or fluid movement research. Some of the labels, such as, Surface 400, Inlet, and DOutlet, as well as the coordinates 0.00 150.00 300.00 (mm) define specific region, boundary condition, and position of the model. In relation to things, the labels show the tunnel and the important points for the inlet and outlet of the fluid movement. All this detail of the model helps to conduct the necessary research to analyze the behavior of the fluid or the heat in the model.

4.2 Meshing

Meshing means cutting up the space in which the simulation will occur into sections (or cells) so that the equations that govern fluid movement can be solved computationally (as opposed to analytically). The space needs to be cut into many sections due to the complex movement of fluids in the space. Without good cutting (or meshing), the simulation will not be trustworthy. This is why meshing must be done correctly. This is what meshing in CFD analysis means:

- **Mesh Generation:** Meshing involves creating a mesh, which is a collection of small geometric elements that discretize the domain. Elements can be either structured (as in hexahedral cells) or unstructured (as in tetrahedral or polyhedral cells). The mesh should represent the geometric and flow detail accurately to replicate the physical system accurately.

- **Mesh Quality:** The precision of a simulation result is influenced by the characteristics of its mesh. A high-end mesh has elements that are well formed, does not have significant distortion, and properly resolves flow gradients. Mesh detailing average the qualities of elements skewness, element aspect ratio, and element orthogonalities in relation to the simulation's numerical stability and convergence.

- **Mesh Density:** The term mesh density signifies the total number of elements employed in discretizing a particular domain. Thus, a finer mesh comprising smaller elements is capable of detecting small-scale flow phenomena and accurately addressing boundary layer effects. However, increased mesh density leads to increased computational costs. Therefore, one must find a compromise between accuracy and computational efficiency.

- **Boundary Layer Meshing:** Some regions close to solid boundaries experience significant viscous effects. To capture the velocity gradients here, boundary layer meshing is used. This means making a finer mesh layer next to the walls to capture boundary layer flow and, therefore, provide good wall shear stress and heat transfer prediction.

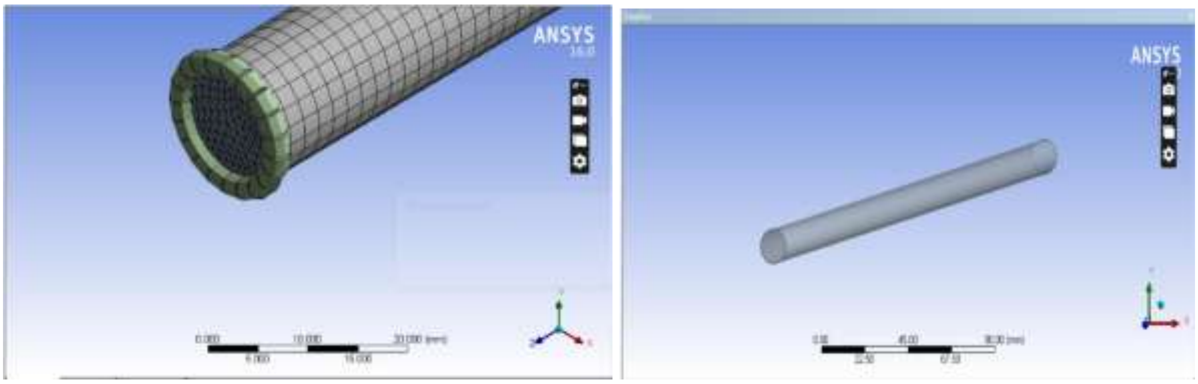

Fig 6. 3D meshed model for 13.5 mm diameter and 800 length

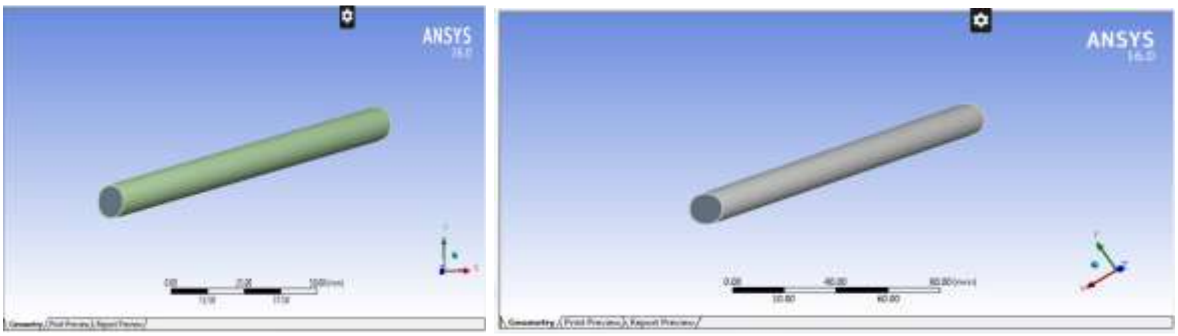

Fig 7. 3D meshed model for 9 mm and 4 mm diameter and 800 length Al_2O_3

The image shows a 3D CAD model of a simple black metal pipe that has been prepared for some Finite Element Analysis (FEA) simulations. This model is highly meshed in order to create appropriate representations of the physical model,

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as accurate representations enable the simulation of complete engineering analyses. These analyses include the model's response to applied external forces (which inform the design of the model's structural integrity), the model's design for optimal heat transfer (which is simulated to inform the model's thermally efficient design), and the model's design for optimal plumbing (which is simulated to inform the model's design for accurate prediction of pressure and flow rate). Given the refined meshing, one can infer that a lot of engineering thought has gone into analyzing and designing the different functions of the pipe.

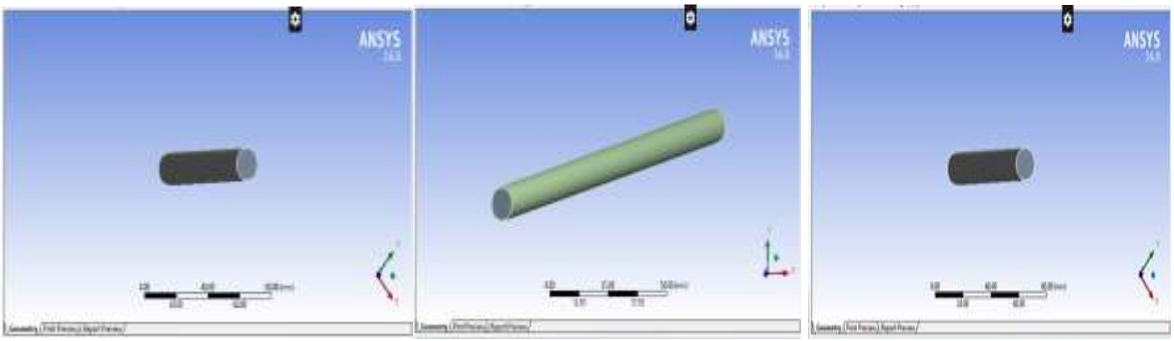


Fig 8. 3D meshed model for 13.5 mm, 9 mm and 4 mm diameter and 800 length MWCNT

Fig 9. A Schematic Diagram of 13.5 mm Copper Tube

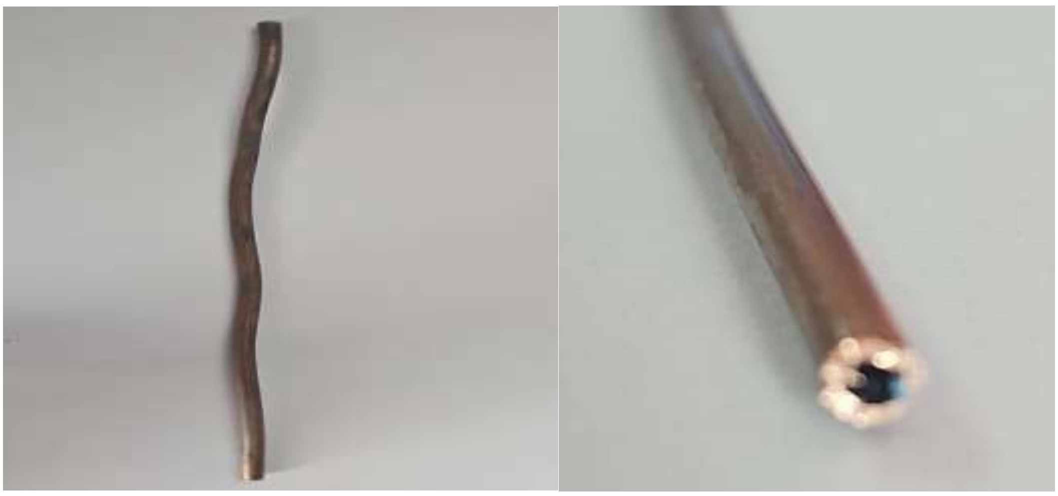


Fig 10. A Schematic Diagram of 4 mm Copper Tube

4.3 Procedure of Experiment to be performed

In order to conduct the experiment, the experimental apparatus is comprised of three test sections of copper tubes with inner diameters of 4 mm, 9 mm, along with 13.5 mm.

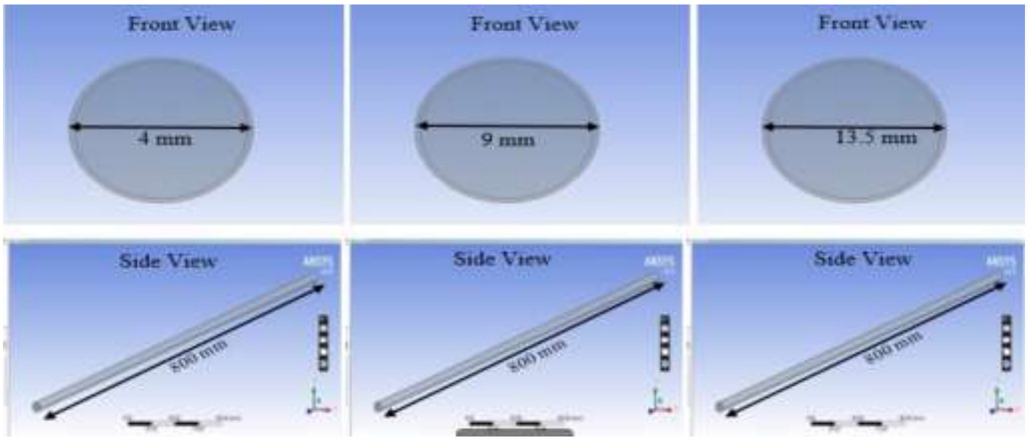


Fig 11. A Schematic CFD Diagram of 4 mm, 9mm, 13.5mm Copper Tube

4.3.1 For Water

Heat dissipation from microprocessors is growing continually. Demand for microprocessors with strong computational capabilities has grown owing to expansionin information technology. Heat dissipation from high end CPU is 110-140 W. To remove this much heat, standard air-cooling methods are not adequate. So for many applications this technology will have to be replaced by some modern heat managementstrategies. Advancement in nanofabrication and techniques permitted to make solid particles of nanoparticle size. These particles are combined with base fluids such as water (Menni et al., 2020). The combination thus generated is called as nanofluids. Different experimental inquiry have been done employing different nanofluids for heat transfer improvement. Although there are many different types of nanofluids available, choosing the proper one will provide the best results for increasing heat. Many studies employ oxide varieties of nanopowders, such as Ti oxide, MWCNT, and Al2O3. Within the context of this experiment, Al2O3 and MWCNT nanoparticles are used, with water serving asthe base fluid (Moreira-Santos et al., 2008).

4.3.2 For Al2O3/water

Nanofluids containing Al2O3 and water are used, with vapour concentrations of 0.1%, 0.3%, 0.5%, and 0.7%. The first test portion has an inner diameter of 13.5 mm and is initially filled with an Al2O3/water nanofluid with a volume concentration of 0.1%. All of the valves are closed except for the one in the first test area, which is left open. After reaching a steady state condition, record all values for different flow rates. Now, different test sections and concentrations are subjected to the same procedures (Stephenson et al., 2000).

4.3.3 For MWCNT/water

A nanofluid comprising MWCNTs and water is used, with a volume concentration of 0.1%, 0.3%, 0.5%, and 0.7%. The first test segment has an inner diameter of 13.5 mmand is used to pass a nanofluid comprising MWCNTs and water with a volume concentration of 0.1%. The first component of the test has its valves open while the others are closed.

5. RESULTS & DISCUSSIONS

Numerous graphs display the calculated findings of the Nusselt number vs Reynolds number and the heat transfer coefficient versus Reynolds number. Reynolds number, Nusselt number Vs Reynolds number.

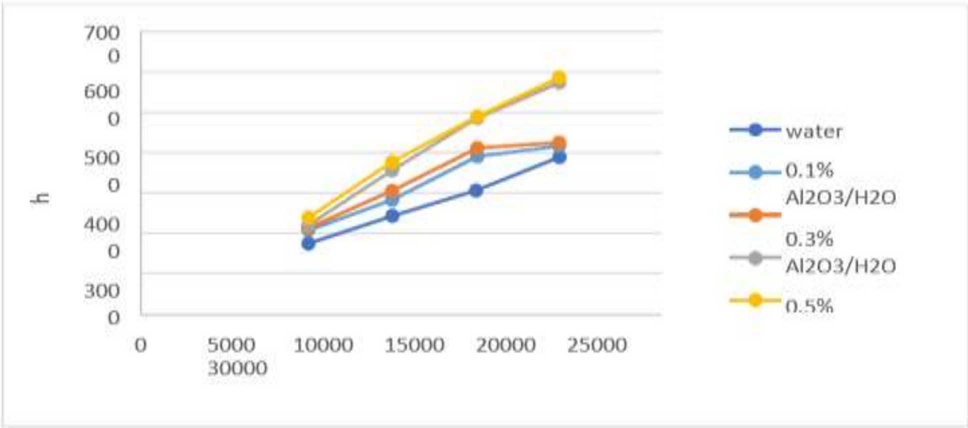


Fig 12. Heat transfer coefficient Vs Reynolds no. for water and Al2O3/water for allconcentrations

The graph above shows how, in tandem with a rise in Reynolds number, the total amount of the Al2O3/water nano fluid increases as the coefficient of heat transfer increases. Also, the heat transfer coefficient of the Al2O3/water nanofluid is higher than that of water.

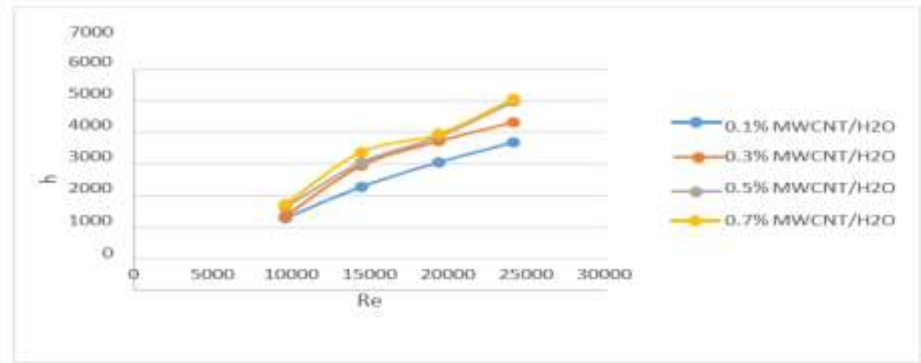


Fig 13: Heat transfer coefficient Vs Reynolds no. for water and MWCNT/water for allconcentrations

The above graph also shows how the heat transfer coefficient grows with increasing volume of the MWCNT/water nano fluid. An increase in concentration leads to a risein thermal conductivity due to the Brownian motion of the nanoparticles.

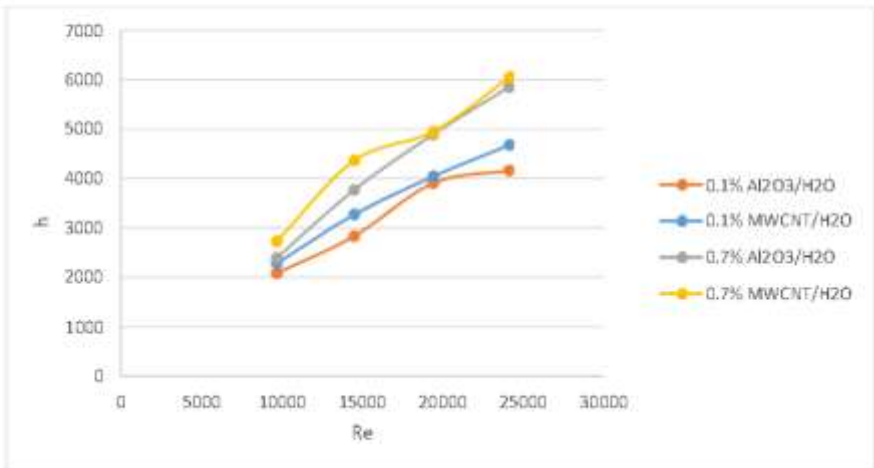


Fig 14: Heat transfer coefficient Vs Reynolds no. for Al2O3/water and MWCNT/water for 0.1% and 0.7% vol. concentration

Because MWCNT/water Nano fluid has a substantially higher thermal conductivity than Al2O3/water Nano fluid, the heat transfer coefficient for the former is greater thanthat of the latter, as seen in the above graph.

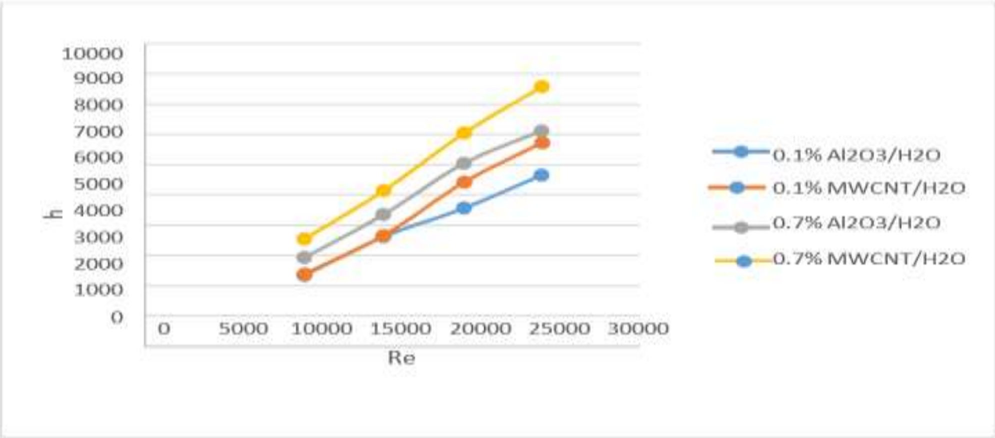


Fig 11: Heat transfer coefficient Vs Reynolds no. for Al2O3/water and MWCNT/water for0.1% and 0.7% vol. concentration

In the graph that is displayed above, the heat transfer coefficients for Al2O3/water Nano fluid and MWCNT/water Nano fluid are compared for volume concentrations of 0.1% and 0.7% respectively. The results demonstrate that the heat transfer coefficientassociated with MWCNT/water Nano fluid is greater than that associated with Al2O3/water Nano fluid.

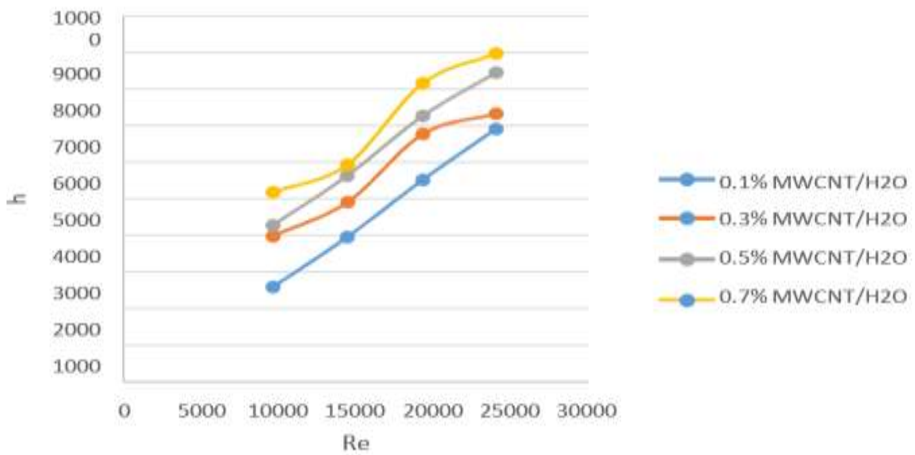


Fig 12: Heat transfer coefficient Vs Reynolds no. for MWCNT/water for all concentrations

The data shown in Figure 6.8 demonstrates that the rate of heat transfer rises in tandemwith an increase in Reynolds number when the volume of the MWCNT/water nano fluid is increased.

CFD analysis results: Water

9 dia 6 lpm AL203 0.1%

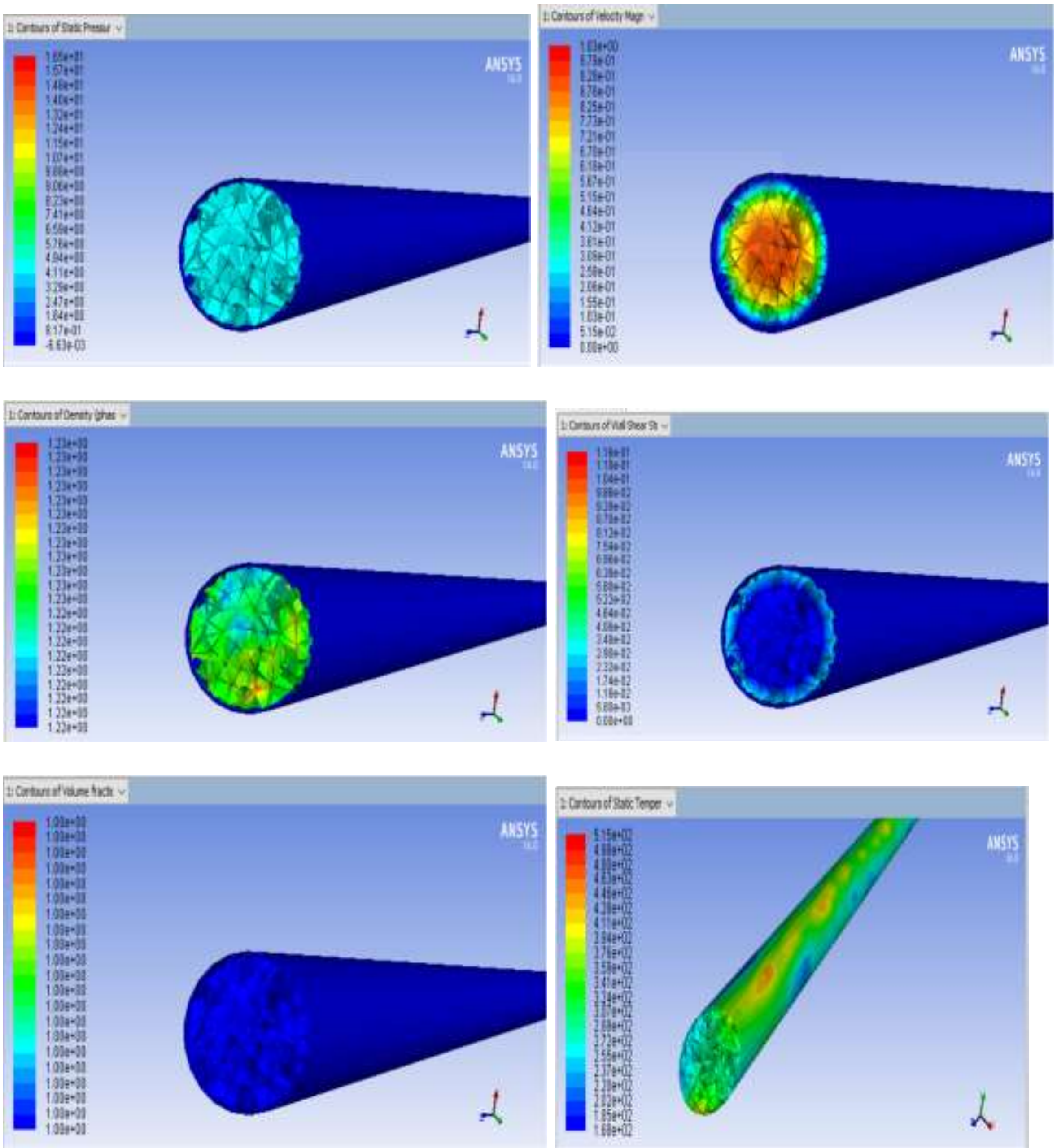


Fig 12: 9 dia 6 lpm AL203 0.1%

The figure shows various ANSYS simulation contour plots for a cylindrical pipe with a 9 mm diameter, containing a 0.1% AL_2O_3 (aluminum oxide) particle concentration. The static pressure plot indicates a pressure drop from high pressure at the walls (red) to lower pressure in the center (blue). The velocity profile displays laminar flow, with the highest velocity at the center and slower flow near the walls due to friction. The distribution of density is almost the same throughout the area, with small changes. When looking at the wall shear stress, the highest is closest to the edge of the pipe and it decreases towards the middle. Because there is a uniform volume fraction, it shows that the distribution can be simplified when it comes to alumina particles. The mixture shows temperature distribution with higher temperatures in the middle of the flow and cooler areas towards the sides of the pipe. The simulations give insight on the behavior of fluid dynamics and heat transfer within the flows of particles.

9 dia 6 lpm MWCNT 0.1%

Pressure

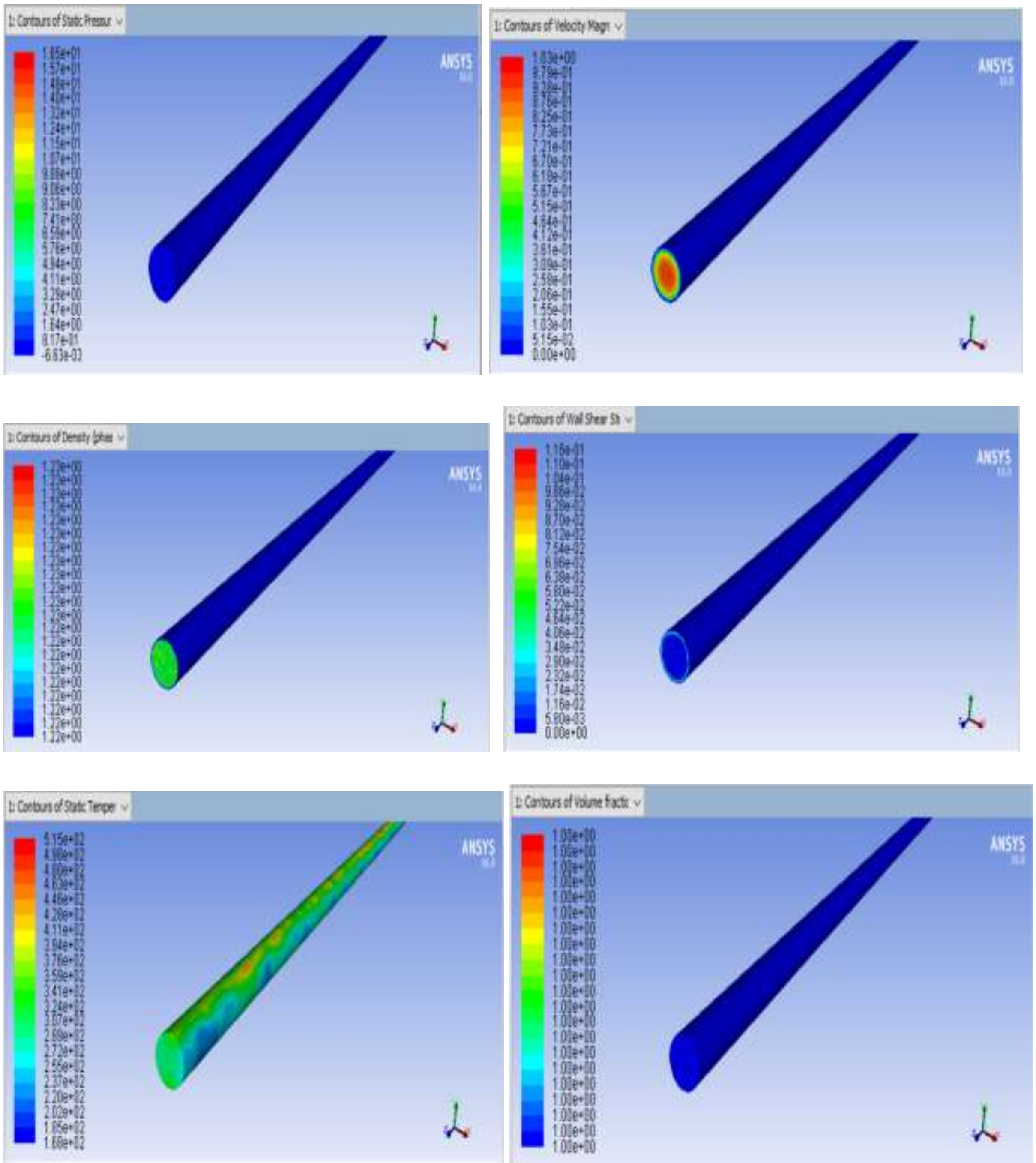


Fig 13: 9 dia 6 lpm MWCNT 0.1%

This is an ANSYS simulation of cylindrical flow with a 13.5 mm diameter and 8 LPM flow rate, 0.3% MWCNT (multi-walled carbon nanotubes) suspension. The static pressure contour shows the inlet is red and shows 7.00 x 10^2 Pa, and blue shows -1.87 x 10^2 Pa, and shows the differences in pressure through the path. The flow velocity shows red (1.11 m/s) and blue (0.00 m/s) and is important for the study of flow and turbulence. The MWCNT concentration has an effect on the density of the flow, which ranges from 1.22 kg/m³ (blue) to 1.23 kg/m³ (red). Wall shear stress from 0 to 1.13 x 10^2 Pa can be used to study erosion potential and fluid and solid material interaction. For heat analysis, the temperature distribution (blue) 242 K to (red) 361 K is important. For the study of the effect of fluid on the flow and the working of the system, a uniform volume fraction of 1.00 shows the MWCNT is completely dispersed in the fluid.

4 dia 4 lpm MWCNT 0.5%

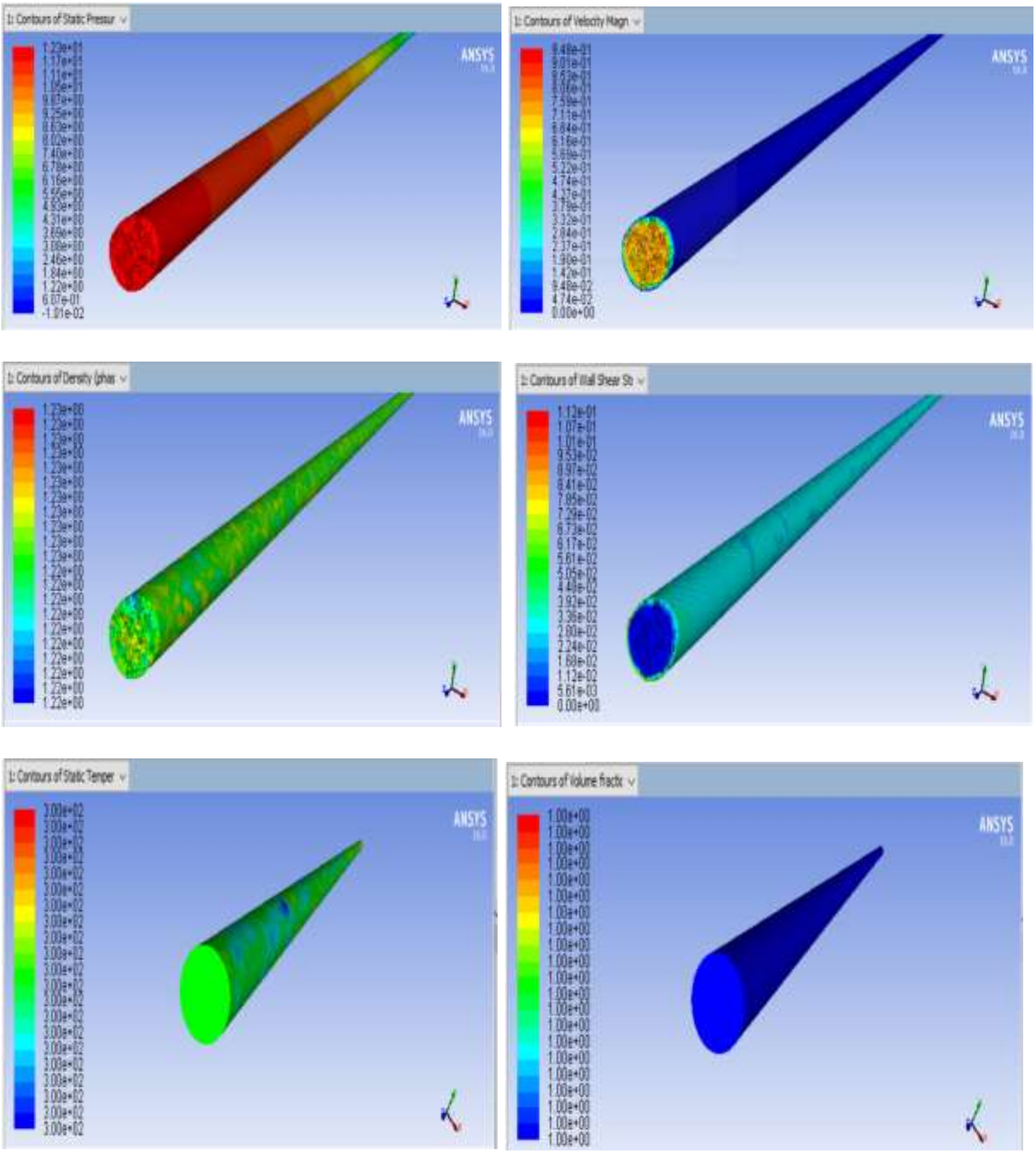
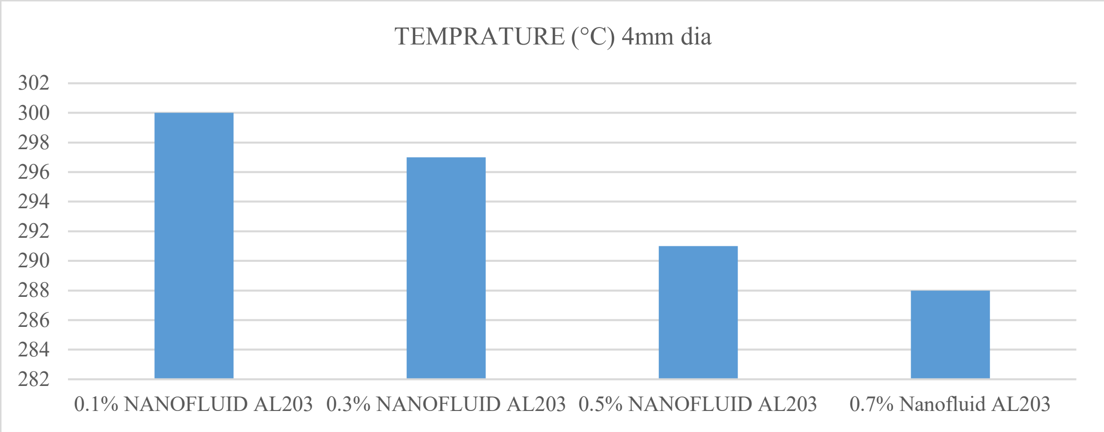


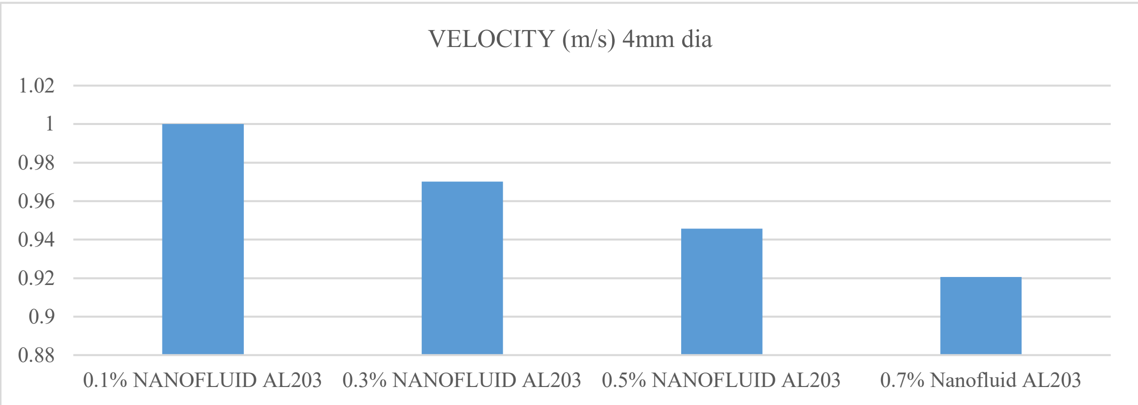
Fig 14: 4 dia 4 lpm MWCNT 0.5%

The image shows static pressure, velocity, density, wall sheer stress, temperature, and volume fraction distributions in a multi-walled carbon nanotube (MWCNT) with a 4mm diameter and 0.5% concentration at a 4 LPM distance. At the pressure varies from 1.23e+01 Pa to -1.01e-02 Pa, there are high-pressure red zones at the inlet which and pressure decreases toward green. This profile is important for the optimization of the transport of nanofluids. The velocity at the nanotube ranges from 0.00 to 0.948 m/s with center high velocities which inturn encourages efficient flow dynamics. The density ranges from 1.22 to 1.23 kg/m³ with green regions having higher density which may influence the flow and thermal properties of the fluid. The wall shear stress varies from 0.00 to 1.12e+01, showing very little frictional resistance. the temperature is around 300K and shows good thermal management. The volume fraction is 1.00, indicating total fluid saturation for stable and efficient flow within the nanotube.

CFD comparison graphs

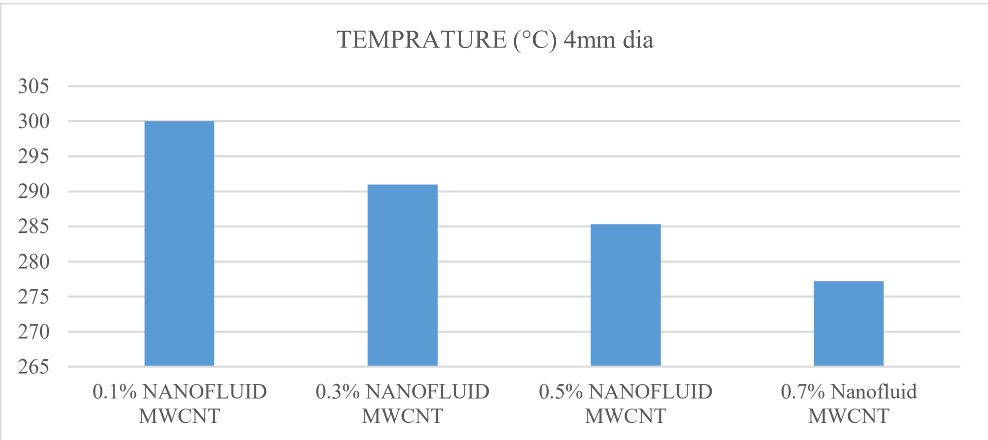


The data illustrates the impact of different levels of concentration of Al_2O_3 nanofluids on the temperature drop in a system of 4 mm in diameter. The temperature measured at 0.1% concentration is 300 degrees Celsius, but as the concentration of the nanofluids increases, the temperature is less. At 0.3% concentration, the temperature is 297 degrees Celsius, while at 0.5% concentration the temperature is 291 degrees Celsius. The largest drop in temperature is at 0.7%, which is 288 degrees Celsius. Al_2O_3 nanofluids, which have a higher concentration, improve the thermal performance as the number of nanoparticles increases the heat assisted transfer.



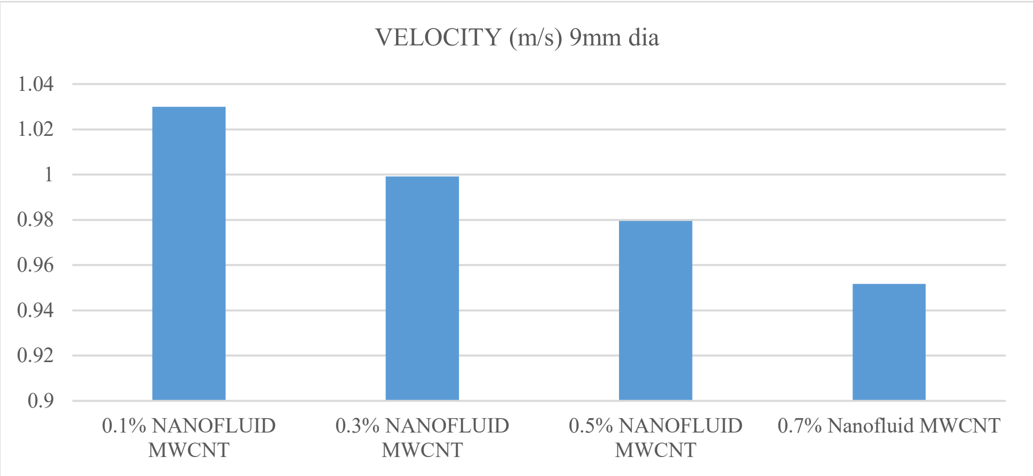
In a 4 mm diameter system, the data shows effect of different concentrations of Al2O3 nanofluids on velocity. The velocity is 1 m/s at 0.1% concentration, and then decreases as the concentration of nanofluids increases. The velocity drops to 0.9702 m/s at 0.3%, 0.94575 m/s at 0.5%, and 0.92064 m/s at 0.7%. Higher concentrations of Al2O3 Nanofluids increase the density and viscosity of the fluid, causing the flow velocity to decrease.

4 mm dia MWCNT



The results indicate changes in temperature based on the concentration of Multi-Walled Carbon Nanotube (MWCNT) nanofluid in a system with a 4 mm diameter. At a concentration of 0.1%, the temperature is 300°C but decreases with increasing MWCNT nanofluid concentration. The temperature decreases to 291°C at 0.3%, 285.3°C at 0.5%, and 277.2°C at 0.7%. Reduction in temperature means that greater amounts of MWCNT Nanofluids have a larger impact on thermal conductivity, enhancing heat dissipation and causing greater temperature drops.

9 mm dia MWCNT



The findings indicate how the different concentrations of Multi-Walled Carbon Nanotubes (MWCNT) nanofluid affect the velocity in a system with a diameter of 9 mm. For a 0.1% concentration, the velocity is 1.03 m/s, and it is seen to decline with increasing MWCNT concentration. At 0.3%, 0.97953 at 0.5%, and 0.95172 at 0.7%, the velocity drops. Increased concentration of a nanofluid creates decreased velocity which is a result of increased viscosity and density of a nanofluid and greater concentration resist to flow and causes slow movement of a fluid even though it is enhancing the heat transfer characteristics of the system.

Conclusion

This study focuses on the possibilities of using nanofluids such as Al_2O_3 and MWCNT as a coolant to transfer heat more efficiently in cooling systems of electronic devices. Through some experimental and CFD analyses, it was concluded that there was a considerable heat transfer improvement, particularly in the case of increased heat carrying nano-particle volume concentration. It has also been pointed out that MWCNT-based nanofluids provide far more improvement in heat conductivity and heat dissipation relative to Al_2O_3 nanofluids. Furthermore, the study attempted to review the role of the tube diameter and flow rate in heat transfer, in such a way that it was concluded that there were optimal flow conditions and particle concentrations for the maximum heat removal efficiency. Also, considering the importance of the study, the cooling system was designed in such a way as to give the best results while also being compact to fit a better quality electronic performance. Also, the study is a baseline for future studies focusing on the improvement of the stability, and the nanofluids environmental uncertainties in the various industrial applications. It is also possible to demonstrate, as the nanofluids technology improves, it is possible to have a better cooling system in the electronic industry.

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