

ANSYS Simulation of Enhanced Heat Transfer in Compact Pipes Using Al₂O₃-Water Nanofluids"

Muhammad Sufian¹, Basit Ali¹

¹Department of Physics, Government Islamia Graduate College Civil Lines, Lahore, Pakistan

Correspondance : *sanisaith@gmail.com, basit_nano@yahoo.com

Abstract: Al₂O₃-Water nanofluids have become popular for their significantly higher heat transfer rates, which are related to their increased thermal conductivity. These fluids are particularly useful in tiny pipelines, especially in situations where effective thermal control is required. Because of this, they are particularly beneficial to sectors like aerospace and automotive, where the need for lightweight and compact heat exchanger designs is crucial. This research investigates several input factors, such as temperature and velocity, using ANSYS Fluent. The investigation's initial temperature was 290 K, and the pipe's entry velocity was 3.78×10^{-1} m/s. At 2.98×10^2 K, the exit temperature stabilized. However, a clear inverse link between the temperature at the pipe's output side and the velocity at its entrance side was found. This unique development served as the main focus of our investigation on how to optimize heat flow and thermal conductivity inside the pipe. We used a two-phase approach, incorporating the nanofluid phases phi-0 and phi-4, to increase our comprehension. This methodological decision departs from traditional research, which frequently uses simulations in a single phase. Our new method was inspired by the necessity for a more thorough investigation. The results of this study demonstrate the effectiveness of the two-phase method, showing a significant rise in heat flow and thermal conductivity when compared to traditional one-phase simulations used in earlier research. This emphasizes how our approach was original and significant, bringing fresh perspectives to the field of nanofluid heat transfer research.

Keywords: ANSYS Fluent; Al₂O₃ Nanofluids; Compact pipe; Fluid Dynamics; Heat Transfer Enhancement.

1. INTRODUCTION

A rising number of industrial applications, particularly small pipe systems, have shown an interest in improving heat transfer efficiency in recent years. This interest is driven by the requirement to enhance the functionality of thermal management systems, heat exchangers, and energy-efficient processes. Utilizing nanofluids, which are created suspensions of nanoparticles in base fluids, is one possible strategy [1]. The use of aluminium oxide (Al₂O₃) nanoparticles distributed in water, also known as Al₂O₃-Water nanofluids, is the main focus of this study's numerical analysis of heat transfer increase within compact pipes. The investigation of the complex interaction of heat transmission processes inside these systems using ANSYS simulation software, especially when different Al₂O₃ nanoparticle volume percentages are present [2]. To clarify any possible benefits of using Al₂O₃-Water nanofluids in small-diameter pipe designs through this work. To shed light on the potential of these nanofluids to promote heat transmission by modelling single-phase flow and using biased edge scaling for meshing. This study contributes to continuing efforts to improve thermal performance in small pipe systems, with implications for a variety of sectors, including advanced manufacturing and energy generation.

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According to ANSYS simulations, the use of Al_2O_3 -Water nanofluids has enormous potential in a variety of industrial fields. Improved heat transfer characteristics in small pipes have wide-ranging effects, especially when it comes to thermal management and energy efficiency. These nanofluids are used in the sector of power generation to enhance the performance of heat exchangers and condensers, which will ultimately result in more effectively producing electricity and using less energy. Compact pipes transporting Al_2O_3 -Water nanofluids can be included in cooling systems in the automobile sector, improving engine performance and fuel economy [3]. These nanofluids also preserve the thermal stability of essential systems like aeroplane engines in aerospace applications. Precision in manufacturing processes is improved by heat dissipation with Al_2O_3 -Water nanofluid-cooled pipes. Stability issues in Al_2O_3 -Water nanofluids by using regulation of the dispersion of nanoparticles, hence avoiding aggregation. Extensive stability is ensured by meticulous testing and analysis, which increases the durability and reliability of our conclusions. Additionally, the usage of these nanofluids in medical equipment and apparatus that need precise temperature control might be advantageous for the medical industry. In conclusion, Al_2O_3 -Water nanofluids in compact pipes have a variety of industrial applications that are examined using ANSYS simulations. These applications promise improved thermal performance, energy savings, and better efficiency in different thermal management systems.

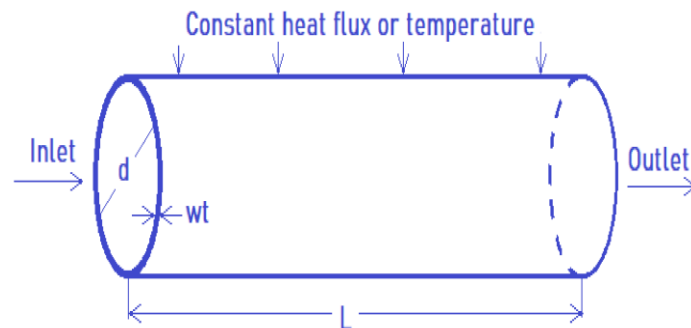


Fig.1 Heat transfer analysis through pipe diagram [4]
<https://doi.org/10.3390/nano12030299>.

Al_2O_3 -Water nanofluids are used in small pipes because they have a number of advantageous properties, such as greatly higher heat transfer rates due to increased thermal conductivity, which makes them very appealing for applications needing effective thermal management. More compact and lightweight heat exchanger designs are made possible by these nanofluids, which are particularly advantageous for the aerospace and automobile sectors [5]. The long-term stability of the nanofluid can be impacted by concomitant difficulties, such as possible problems with nanoparticle aggregation and settling. Additionally, it might be expensive to make high-quality nanofluids with evenly dispersed nanoparticles. Additionally, depending on variables like nanoparticle concentration, temperature, and system design, the specified advantages might not always result from the higher thermal conductivity. Nevertheless, especially in critical applications where effective thermal management is crucial, the benefits of improved heat transmission frequently exceed the disadvantages. It is

necessary to tackle issues such as nanoparticle aggregation. If allowed to develop, these problems might damage the Al_2O_3 -Water nanofluids' long-term stability and effectiveness, which would limit their use in a variety of sectors.

Al_2O_3 nanofluids, composed of aluminium oxide (Al_2O_3) nanoparticles distributed in a base fluid like water or oil, display substantial improvements in thermal conductivity. As an illustration, a frequently used Al_2O_3 -water nanofluid with a tiny volume fraction (ϕ) of just 0.01 can show a notable improvement in thermal conductivity [6]. The thermal conductivity of the resultant nanofluid (k_{nf}) can reach around 1.206 W/(mK) if the thermal conductivity of pure water (k_{base}) is roughly 0.606 W/(mK) and the thermal conductivity of Al_2O_3 nanoparticles (k_{np}) is around 35 W/(mK). Al_2O_3 nanofluids are appealing for a variety of heat transfer and cooling applications due to their improved thermal conductivity, which also increases their efficiency and efficiency. The flow behaviour of nanofluids is significantly influenced by viscosity (μ_{nf}). Think about an Al_2O_3 -ethylene glycol nanofluid, for instance, with a volume fraction (μ) of 0.05. The nanofluid's predicted viscosity using the Einstein equation is around 0.0236 Pa's if the viscosity of pure ethylene glycol (μ_{base}) is 0.0211 Pa's. This outcome shows that viscosity increases somewhat when Al_2O_3 nanoparticles are added relative to the base fluid [7]. Although the viscosity of nanofluids typically remains low at low volume fractions, it is crucial to monitor and comprehend these changes because they can have an impact on the system's overall performance and efficiency, particularly in applications where flow resistance and pump power consumption are crucial factors.

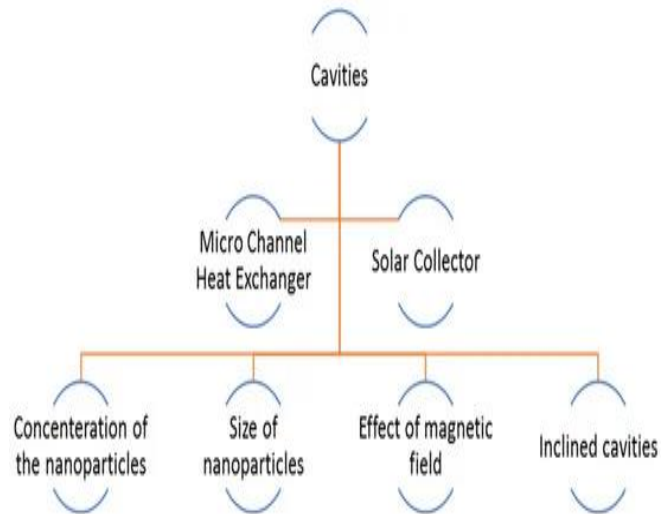


Fig.2 Flowchart diagram of Al_2O_3 Nano-fluids [8]

<https://doi.org/10.3390/nano13061131>.

A. M. Elfaghi et al. (2022) investigated that researchers have recently been more interested in the improved heat transfer properties that advanced nanofluids offer over traditional heat transfer fluids. This work uses Al_2O_3 nanofluids inside a circular pipe subject to a continuous heat flow to examine forced convection heat transfer using

numerical computational fluid dynamics (CFD) simulations. The analysis explores the fluctuations of important parameters such as the friction factor, Nusselt number, and convective heat-transfer coefficient with varying Reynolds numbers and particle volume fractions. Al_2O_3 nanoparticle volume fractions of 0.5%, 1.0%, and 2.0% are taken into account in the study, covering a Reynolds number range of 6000 to 12000. The computational results conclusively show that nanofluids perform better at convective heat transfer than their base fluids. The study further emphasizes that this heat transfer increase intensifies with larger volume concentrations of nanoparticles and Reynolds numbers, confirming the capability of nanofluids to dramatically improve heat transfer in a variety of applications [9].

A. M. Elfaghi et al. (2022) investigated that numerous industrial heating and cooling applications depend heavily on convective heat transfer. The insertion of water containing uniformly scattered metal nanoparticles is one passive technique to improve heat convection. Increased heat transmission efficiency within the system is a result of the base liquid being suspended with tiny solid metal particles or metal oxide nanoparticles. Water-based nanofluids are modelled using the commercial CFD programme FLUENT, which treats them as single-phase fluids. The study examines the effects of numerous variables on both Reynolds number and particle volume fraction, including the Nusselt number and friction factor. The study involves volume fractions of 0.5%, 1.0%, and 2.0% of Al_2O_3 nanoparticles with Reynolds numbers between 6,000 and 12,000. The computational results demonstrate that nanofluids outperform their base fluids in terms of convective heat transfer efficiency, with thermal efficiency further increasing as Reynolds numbers and nanoparticle volume concentrations rise [10].

A. Azman et al. (2021) investigated that there has been an increase in interest in nanofluids for channel-based heat transfer applications due to the increased desire for improved heat transfer capabilities in smaller and more compact devices. In order to investigate this, we ran simulations using the Ansys Fluent programme and added hybrid nanofluids to a straight pipe. The simulation was set up using the following parameters: an input temperature of 297 K, a uniform temperature maintained at 313 K along the length of the pipe, a continuum flow, Reynolds numbers ranging from 5000 to 30000, and a hydraulic diameter of 10 mm. We concentrated on studying the thermal enhancement and friction factor properties of $\text{Al}_2\text{O}_3 + \text{Cu}$ /water hybrid nanofluids in a straight pipe. Then, we contrasted the numerical outcomes between monoparticle and hybrid nanofluids. It was shown that monoparticle nanofluids at concentrations of 1% and 4% showed significant increases in Nusselt numbers, at 17% and 24%, respectively, whilst hybrid nanofluids had gains of between 2% and 5.6% in comparison to the base fluid. It's interesting to note that the friction coefficient was largely constant across all nanofluids. But the performance evaluation criterion (PEC) showed that hybrid nanofluids performed better overall than monoparticle nanofluids [11].

K. Somasekhar et al. (2018) investigated that using CATIA, a multi-pass shell and tube heat exchanger with a three-tube model was created. Then, meshing was completed using the ICEM CFD programme, and simulations were finished using the CFD-FLUENT software. In a turbulent flow regime, the temperature drop and heat transfer

characteristics of an Al_2O_3 -water nanofluid were compared to those of pure water using the computational fluid dynamics programme Fluent. In this work, Al_2O_3 - H_2O was used as a nanofluid instead of distilled water as the cooling medium. Finally, results from the CFD simulation were contrasted with those from the experimental data. The Peclet number, volume percentage of suspended nanoparticles, and particle composition were all examined in relation to heat transmission capabilities. The research results demonstrated that adding nanoparticles to the base fluid (distilled water) notably enhances heat transfer characteristics [12].

J. Choi and Y. J. I. J. o. T. S. Zhang (2012) investigated that globally, several sectors have committed large resources to reducing the greenhouse gas emissions that cause global warming. A proactive strategy emphasizing enhanced energy efficiency has been implemented in industrial situations to help accomplish this aim. Enhancing heat exchangers has drawn a lot of scientific interest among the methods intended to increase energy efficiency. Another team of researchers has been investigating the use of nanofluids to improve the efficiency of heat transport within pipe systems concurrently. The idea behind nanofluids came from the discovery that fluids with suspended nanoparticles had significantly better thermal conductivity than conventional heat transfer fluids. Prior to the invention of nanoparticles, millimetre- or micrometer-sized particles were the focus of research into fluid and heat transmission issues. Sadly, these particles created a number of real-world problems, such as a lack of suspension stability, pipeline clogs, system abrasion, and more. However, these fundamental limitations are not present in fluids containing nanometer-sized particles, leading to reported thermal conductivity levels that contradict theoretical expectations [13].

2. ANSYS SIMULATION

For doing real-time simulations, ANSYS software signifies itself as an effective tool. ANSYS has been used by many researchers in their simulations conducted before real manufacture [14-31]. In this work, heat transfer analysis within a small pipe is simulated using ANSYS Fluent software, enabling us to assess both velocity and temperature. The pipe has a surface area of 1.35×10^{-3} square metres, and Figure 3 shows a basic representation of the pipe's shape.

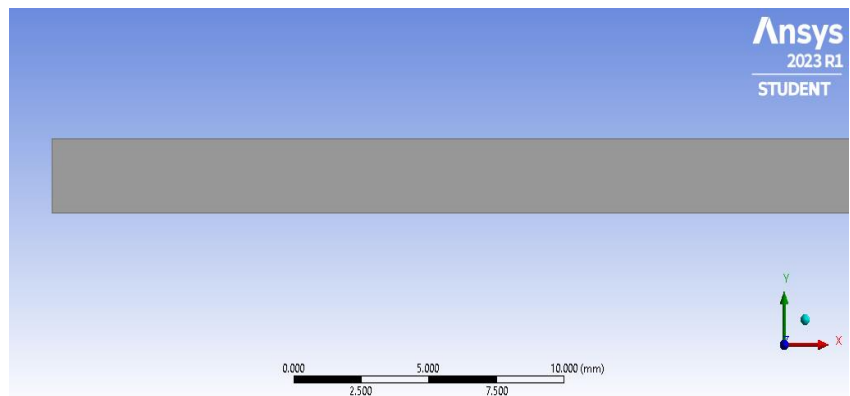


Fig.3 Geometry of the pipe.

A solid component, the pipe has one face, four edges, and four vertices. Its length is 0.6 metres, and its breadth is 2.25×10^{-3} metres. The nanofluid's starting velocity is 0.233 metres per second. ANSYS uses engineering data to specify material characteristics for real-time simulation. The length, viscosity (0.001098 kg/ms), density (1113.472 kg/m³), thermal conductivity (0.6926 W/m K), and outlet temperature of 293 K are all significant components of the pipe's material composition. The shape and element size of the pipe have been carefully optimized to ensure realistic modelling. The coarse span angle centre, medium smoothing, and coarse relevance centre parameters are part of the mesh setup. As a consequence, a mesh geometry with 19513 nodes and 18000 components is produced. Figure 4 depicts the mesh setup of the pipe.

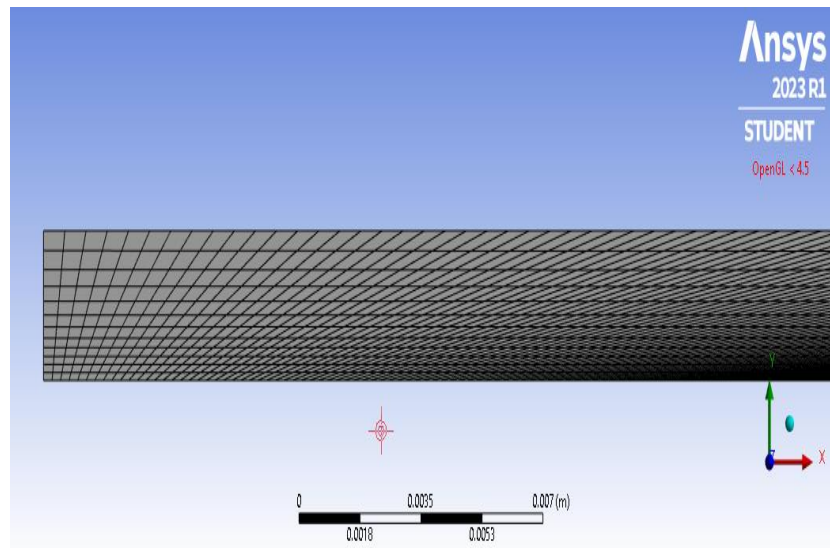


Fig.4 Mesh of the pipe.

The aim of this research is to increase the effectiveness of heat exchangers in manufacturing environments by exploring the use of nanofluids as an effective way to boost heat transmission. In order to improve total heat exchange efficiency, the study focuses on the possible advantages of enhancing thermal conductivity within a system. In addition to leaving temperatures of 293 K and 290 K, the study takes into account a variety of input velocity values, namely 0.233 m/s, 0.285 m/s, and 0.3 m/s. These thoughtfully selected circumstances are used to ensure accuracy in the outcomes and to enhance the pipe's efficiency. The study is improved by using a two-phase method with nanofluid-phases phi-0 and phi-4. This method outperforms single-phase simulation approaches by offering new insights into heat transport and thermal conductivity within the pipe.

3. RESULTS AND DISCUSSIONS

"The pipe is constructed with different inlet, outlet, and pipe wall sections in the simulation of a small pipe. Measurements from the exit part are used to calculate the velocity at the intake. Three input factors are taken into account for the simulation of heat transfer analysis utilizing Al₂O₃ nanofluids in the pipe: thickness, length, and pipe

wall design. This small-pipe simulation is focused on observing the temperature increase made possible by Al_2O_3 nanofluids. The simulation produces results that closely match the intake velocity and outlet temperature parameters, which are both stabilized at 293 K. The geometry of the pipe is built using ANSYS Fluent software, and it is developed with precise dimensions, including a thickness of 2.25 mm and a length of 600 mm. The pipe included in the real-time simulation has a cross-sectional area of $1.35 \times 10^{-3} \text{ mm}^2$. The calculations for the velocity contour mapping are shown in Figure 5.

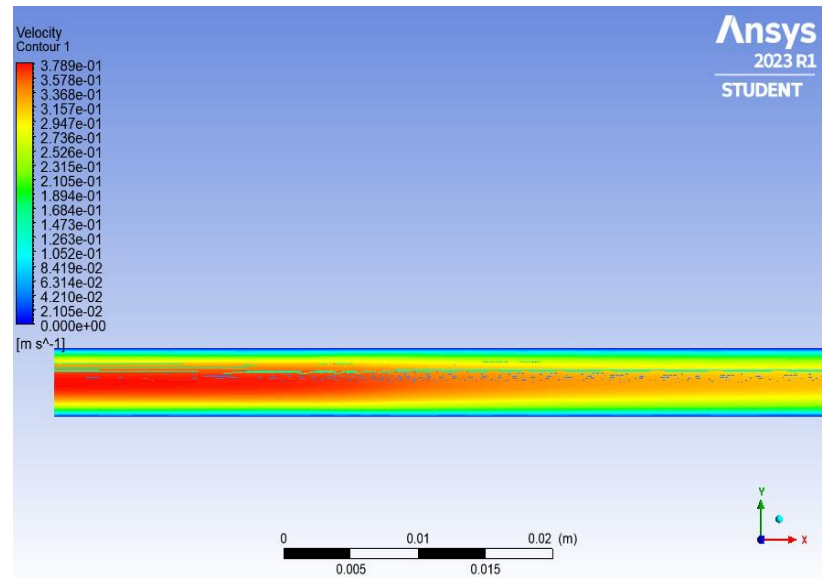


Fig.5 Velocity contour.

The pipe displays an initial velocity of 0.233 m/s at an initial temperature of 290 K. The results for the pipe are also computed using ANSYS Fluid Flow software to verify our simulation findings. We have calculated the temperature and velocity within the pipe as a result, and we have compared those numbers to information that has already been published. According to ANSYS Fluent, the pipe in this study has a temperature and velocity of $3.78 \times 10^{-1} \text{ m/s}$ and $2.98 \times 10^2 \text{ K}$, respectively. In the simulation, nanofluids are introduced into the pipe at an intake velocity, processed inside the pipe wall, and their temperatures are measured at the pipe's exit (outlet). In particular, the connection between temperature and pipe velocity is inverse. It's important to emphasize how well the simulation findings match those established calculations. Using ANSYS simulation software, the previous researchers kadhum Audaa Jehhef et al. (2019) J. Prakash Arul Jose et al. (2023), and M Ibrahim et al. (2021) discovered the temperature and velocity results of $2.8 \times 10^1 \text{ K}$ and $2.6 \times 10^{-2} \text{ m/s}$, $3.2 \times 10^{-2} \text{ K}$ and 2.38 m/s , and $3.05 \times 10^1 \text{ Pa}$ and 3.93 m/s , respectively. Results for temperature and velocity are $2.98 \times 10^2 \text{ K}$ and $3.78 \times 10^{-1} \text{ m/s}$, respectively, in this paper.

The results of this research and those from earlier studies are very matched, as this article clearly shows. Figure 6 displays the findings of the temperature contour mapping.

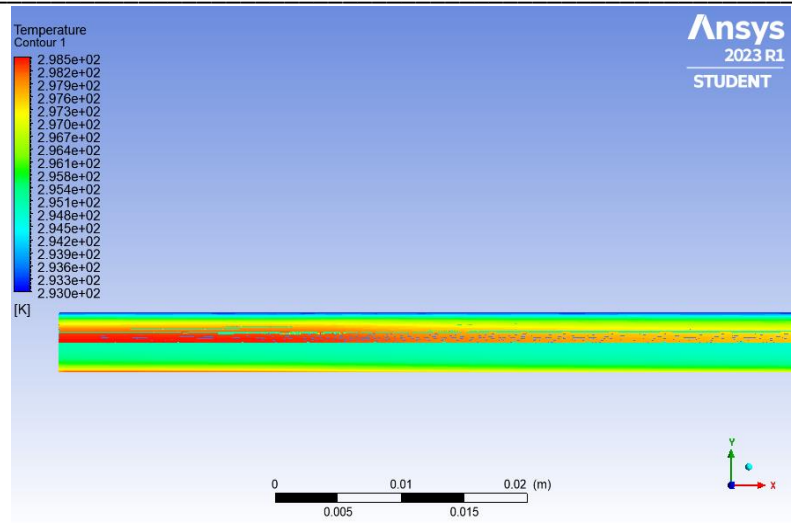


Fig.6 Temperature contour.

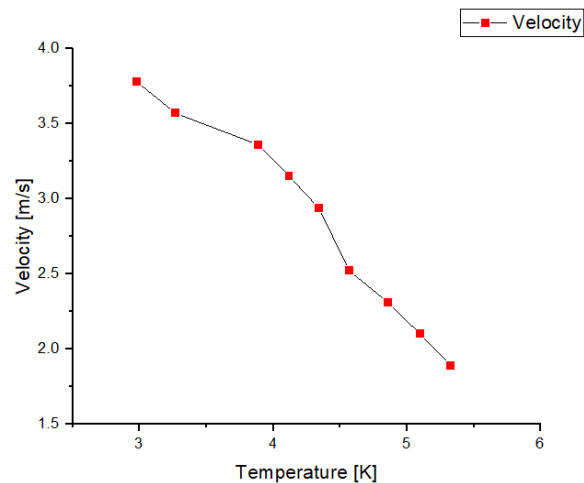


Fig.7 Graph between velocity and temperature.

The graph in Figure 7 shows the relationship between velocity and temperature keeps showing an inverse relationship. Temperature tends to drop as fluid velocity rises. Principles of fluid dynamics and energy conservation most effectively clarify. Due to the fluid's particles moving at a faster rate when the flow rate is higher, there is more kinetic energy present in the fluid. In order to maintain the rule of energy conservation, this increased kinetic energy frequently causes a decrease in internal energy, which results in a lower temperature.

"The circular figure shows percentages and vertical parts that, respectively, indicate temperature and velocity. The green part on the vertical axis of the graph depicts the maximum temperature, which is 5.33 K at the input of the pipe, and the black part has the lowest temperature, which is 2.98 K at the pipe's exit. It is therefore obvious that the temperature drops from the green section to the black part.

The circular graph shows that the black area represents the greatest velocity, which is 14.8% at the pipe's entrance, and the green area represents the minimum velocity, which is 7.4% at the pipe's outlet. This finding suggests that the pipe velocity increased gradually from the green to the black portion of the circular figure. As a result, the relation between temperature and velocity is inverse. Consult Figure 8 for a graphical representation of these temperature and velocity measurements.

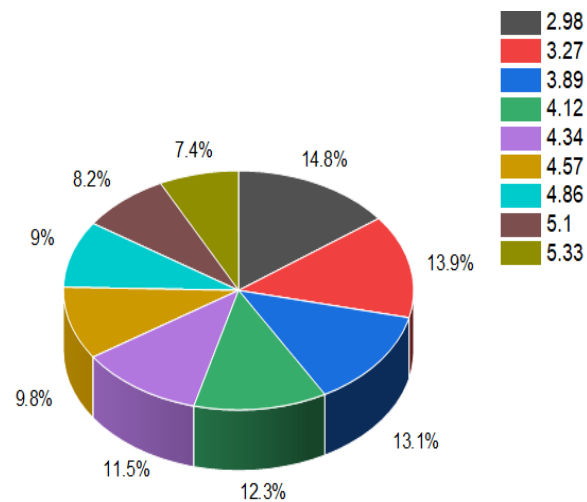


Fig.8 Circular graph plotted between temperature and velocity.

4. CONCLUSION

Utilizing ANSYS models, the study of Al_2O_3 -Water nanofluids in small pipe systems with a focus on improving heat transmission indicates promising possibilities for industrial applications. The entrance velocity is 3.78×10^{-1} m/s, and the output temperature is 2.98×10^2 K. The results of our study clearly suggest that pipe velocity and temperature are inversely related. Comparable contour mapping results have also been produced by ANSYS (Fluent) using the same input circumstances. In particular, this study uses a two-phase strategy that includes nanofluid-phases phi-0 and phi-4 to examine increased thermal conductivity and heat flow augmentation inside the pipe. This method differentiates it from earlier research, which generally makes use of a single-phase simulation. As a result, compared to equivalents employing only one phase, the modelling of this pipe greatly improves heat flow analysis and thermal conductivity. Our findings show a striking agreement with other research findings, supporting the validity of our study. Al_2O_3 -Water nanofluids showed significantly enhanced thermal conductivity, offering an achievable solution for improving thermal performance across a variety of industries.

Author's Contribution: M.S, Conceived the idea; B.A, Designed the simulated work or acquisition of data; M.S, executed simulated work, data analysis or analysis and interpretation of data and wrote the basic draft; B.A, Did the language and grammatical edits or Critical revision.

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