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RESEARCH ARTICLE

THE EFFECT OF DENSITY AND VISCOSITY ON THE VELOCITY PROFILE IN LAMINAR FLUID FLOW IN A HORIZONTAL PIPE

S. KIRANMAIYE[1], Dr.K.JONAH PHILLIPH[2]

[1]Lecturer in Mathematics, Govt. Degree College, Naidupet

[2]Lecturer in Mathematics, T.R.R. Govt. Degree College, Kandukur

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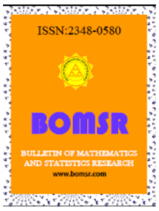

ABSTRACT

The fluid flow in pipes is a crucial aspect of the industrial sector, necessitating a well-designed process to ensure system safety and efficiency. Computational fluid dynamics (CFD) is the most comprehensive and effective methodology for simulating fluid flow. The research findings were acquired by manipulating the density and viscosity variables in order to observe their impact on the velocity of the fluid. As the density of the fluid increases, the distance required for the fluid to reach a fully developed condition also increases. Empirical evidence demonstrates that even when the density reaches 3 kg/m^3, the fluid has not yet achieved a state of complete development at a specific location of 5.64 m. At this position, the fluid is moving at a speed of 1.79 m/s, with a maximum fluid velocity of 1.9 m/s. Higher density and viscosity result in reduced average fluid velocity, preventing full development conditions from being reached within a 10-meter distance. The given conditions state that the density of the fluid is 10 kg/m^3 and the viscosity is 2×10^{-3} kg/m/s. Under these circumstances, the average speed of the fluid is determined to be 1.4 m/s. At a density and viscosity of 30 kg/m^3 and 4×10^{-3} kg/m/s, respectively, the average fluid velocity reaches 1.32 m/s. As viscosity increases and density decreases, full development conditions are achieved more quickly within a 10 m distance. At a viscosity value of 4×10^{-3} kg/m/s and a density of 0.5 kg/m3, a constant speed of 1.96 is attained at a position of 4.73 m. The viscosity value is 6×10^{3}

kg/m/s and the density is 0.25 kg/m3. At a position of 1.45 m, a constant speed of 1.96 m/s is achieved.
Keywords: density, viscosity, CFD, speed.

INTRODUCTION

Fluid flow is used in manufacturing industries such as food, polymer, pharmaceutical, oil, construction, water treatment and power generation industries (Eesa, 2009). The process of fluid flow in pipes is fundamental in the industrial world so that a fluid flow design process in pipes is needed to achieve system safety and efficiency. The fluid flow design process in a piping system is a very broad aspect so that this study only discusses one aspect of the design, namely the effect of density and viscosity on the speed of the fluid flowing in the pipe.

The development of a methodology to predict fluid flow in detail and efficiently is currently needed. The existing methodology for solving fluid flow problems is computational fluid dynamics (CFD). CFD is an analysis method for systems involving fluid flow, heat transfer, and things related to both (Rusche, 2002).

In this study, a two-dimensional horizontal pipe model is used to simulate laminar fluid flow. The fluid used in this study does not have a specific viscosity and density in a substance such as water or oil. This is because when using fluids that have certain viscosity and density, the effect of both on fluid velocity cannot be investigated in depth.

When the effect of density and viscosity on fluid velocity is known. Then the process of designing a fluid flow system in a pipe can be adjusted to the type of fluid and the power input required to channel the fluid to reach the desired position or condition (Munkejord, 2005).

The formulation of the problem in this study is how density and viscosity affect the velocity profile in laminar fluid flow in a horizontal pipe. The process of answering the problem formulation will be given in the research methodology section. The research methodology is globally divided into two parts, namely the creation of a horizontal pipe model and computational fluid dynamic (CFD) simulation.

The purpose of the study is to determine the effect of density and viscosity on the velocity profile in laminar fluid flow in a horizontal pipe. Changes in density and viscosity variables will be carried out in the study to see their effect on the velocity variable. Fluid velocity consists of two parts, namely the initial velocity of the fluid entering the horizontal pipe model and the velocity at full expansion. The influence of density and viscosity will be seen in the two parts of the velocity.

METHODOLOGY

The study entitled the influence of density and viscosity on the velocity profile in laminar fluid flow in a horizontal pipe has a research method as shown in Figure 1. The study began by determining the description of the horizontal pipe model system. Determination of the system description is carried out to limit the system to be studied and determine the initial values that will be used to see the effect of density and viscosity on the velocity profile. The description of the system used in this study is given in Table 1.

Table 1. Description of the Two-Dimensional Horizontal Pipe Model System

No	Description Model Value	Mark
1	Spacing *mesh*	110 x 7 *mesh*
2	Element *mesh*	Quad
3	Viscous *model*	Laminar
4	Model size 2D	10 x 0.2 meter unit
5	Initial fluid velocity	1 m/s
6	Operating pressure	1 atm
7	Fluid viscosity	2×10^{-3} kg/m.s
8	Fluid density	1 kg/m^3

The mesh spacing is selected at 110 x 7 mesh so that the fluid flow in the horizontal pipe section can be simulated well*. The mesh element is selected as quad* because the rectangular element (quad) has the same geometry as the horizontal pipe model (Patil, 2023). The viscosity model is selected as laminar so that the analysis process is simpler. The initial fluid velocity and operating pressure are selected at small values so that the research process on the effects of density and viscosity can be carried out without being affected by the effects of initial velocity and operating pressure.

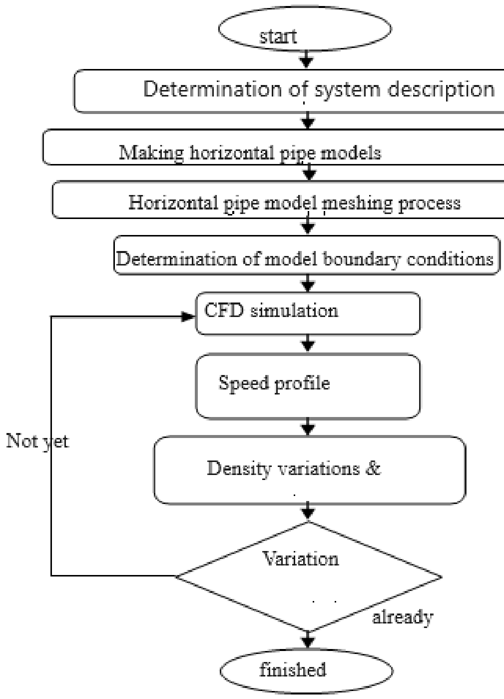

Figure 1. Flow chart on Research Methodology

The viscosity value of 2×10^{-3} kg/m.s and density of 1 kg/m^3 were selected as the initial values for this study. Based on research conducted by Rajesh Bhaskaran in 2002, when the viscosity value is 2×10^{-3} kg/m.s and density of 1 kg/m3, the velocity profile reaches two desired conditions, namely the velocity when the fluid enters the horizontal pipe model and the velocity when the fluid has reached a fully developed condition. When the process of describing the two-dimensional horizontal pipe model system has been carried out, the next step is to create a horizontal pipe model. The model is created using Gambit 2.2.30 software. The process of creating a horizontal pipe model is the same as drawing an object using computer aided design (CAD). The size of the model used is a length of 10 meters and a width of 0.2 meters. The results of creating a horizontal pipe model can be seen in Figure 2.

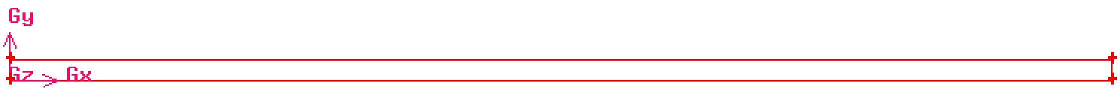

Figure 2. Two-Dimensional Horizontal Pipe Model

The next process is meshing on the two-dimensional horizontal pipe model. The two-dimensional horizontal pipe model is divided into finite elements to calculate the fluid flow phenomenon in each element. The mesh division on the horizontal pipe is 110 meshes for the horizontal part and 7 meshes for the vertical part. The results of the mesh process on the horizontal pipe model are given in Figure 3.

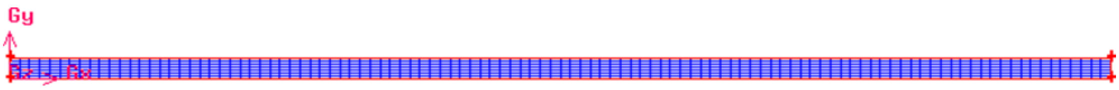

Figure 3. Mesh Results on Horizontal Pipe Model

The determination of boundary conditions on each part of the horizontal pipe is carried out after the meshing process is complete. In the horizontal pipe system model, there are four types of boundary conditions, namely velocity inlet, wall, axis and pressure outlet. The velocity inlet boundary condition is the boundary condition of the incoming fluid, the wall boundary condition is the horizontal pipe wall, the axis boundary condition is the midpoint of the fluid flow and the pressure outlet boundary condition is the fluid flow out of the horizontal pipe model. The boundary conditions on the two-dimensional horizontal pipe model can be seen in Figure 4.

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Table 2. CFD Simulation Conditions for Viscosity and Density Variables

No	Simulation	Viscosity	Density
1	First	Fixed (2 x 10 $^{-3}$ kg/m.s)	Increased value (Range 10-50 kg/m^3)
2	Second	Increased value (*Range* 2 x 10 $^{-3}$– 8 x 10 $^{-3}$ kg /m.s)	Constant (1 kg/m^3)
3	Third	Increased value (*Range* 10 x 10 $^{-3}$– 50 x 10 $^{-3}$ kg /m.s)	Increased value (Range 2-6 kg/m^3)
4	Fourth	Decreased value (*Range* 0.25 x 10 $^{-3}$ – 1 x 10 $^{-3}$ kg /m.s)	Increased value (Range 1-7 kg/m^3)
5	Fifth	Increased value (*Range* 2 x 10 $^{-3}$ -8 x 10 $^{-3}$ kg /ms)	Decreased value (0.125 -1 kg/m^3)

RESULTS AND DISCUSSION

The results of the study are in the form of a graph between fluid velocity and position in the horizontal pipe model. The division of the results and discussion sub-chapters is adjusted to the division of the simulation process as explained in table 2.

Increased Density and Constant Viscosity

The first condition is when the density increases and the viscosity is constant. The effect of increased density and constant viscosity on the velocity profile can be seen in Figure 5. The viscosity value is 2 x 10^{-3} kg/ms.

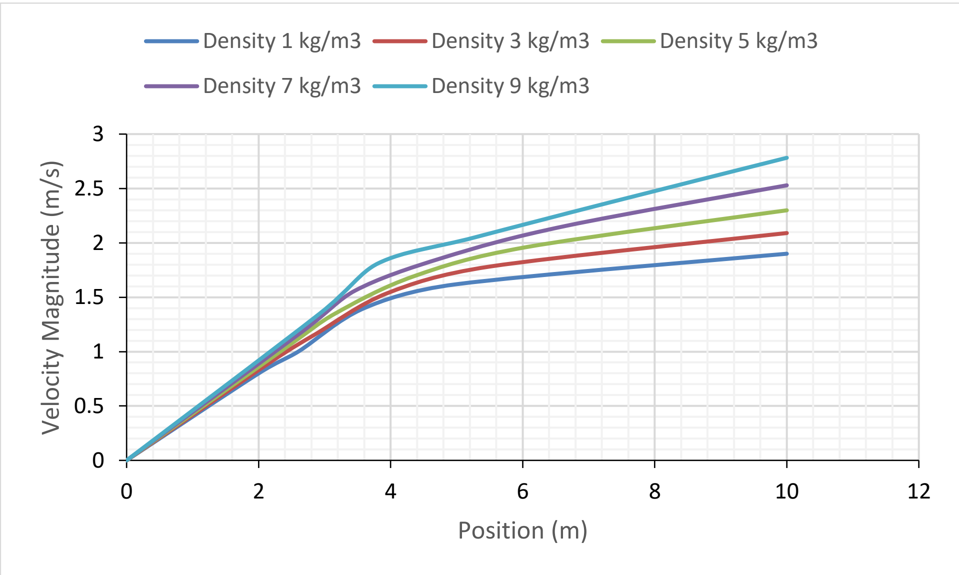

Figure 5. Effect of Increasing Density and Constant Viscosity on Velocity Profile (Density Range 1 – 9kg/m3).

When the density increases and the viscosity is constant, a phenomenon will occur as shown in Figure 5. The greater the density of the fluid, the further the fluid position is to reach a fully developed condition (stable speed). At a density of 1 kg/m^3, the fluid has reached a fully developed condition at position 5.64 meters. The fluid velocity at position 5.64 meters is 1.95 m/s. The maximum fluid velocity at position 10 meters is 1.96 m/s. When the density increases to 3 kg/m^3, the fluid has not reached a fully developed condition at position 5.64 meters. The fluid velocity at position 5.64 meters is 1.79 m/s. The maximum fluid velocity at position 10 meters is 1.9 m/s.

Increased Viscosity and Constant Density

The second condition is when the viscosity increases and the density is constant. The effect of increasing viscosity and constant density on the velocity profile can be seen in Figure 6. The density value is 1 kg/m3. When the viscosity increases and the density is constant, all simulation conditions (3 conditions) reach a fully developed condition (constant speed). This can be seen in Figure 6, when the green, red and black graphs reach a constant speed. The difference between the three graphs is the initial condition before reaching a fully developed condition.

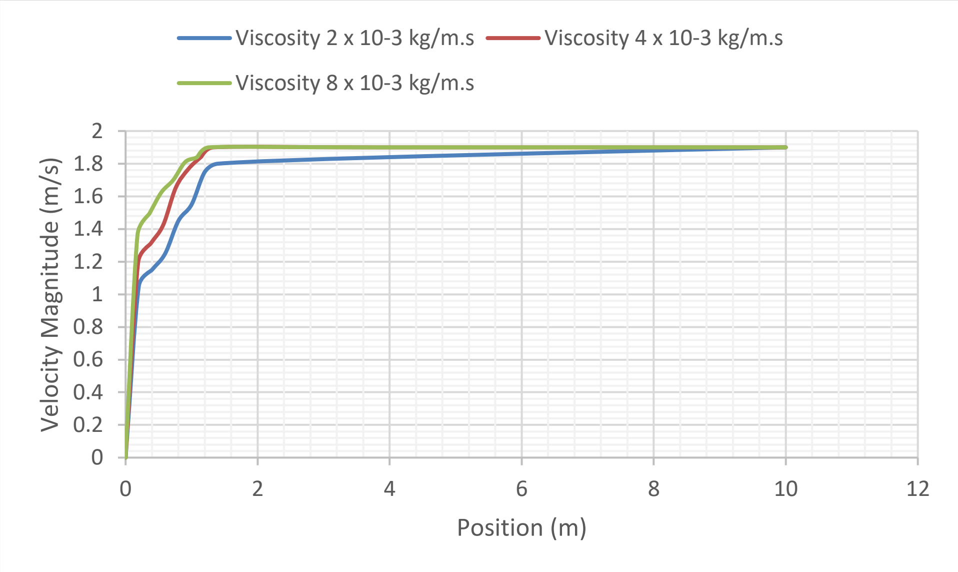

Figure 6. Effect of Increasing Viscosity and Constant Density on Velocity Profile (Viscosity Range 2 x 10^{-3} – 8 x 10^{-3} kg/m.s).

When the viscosity has a value of 2 x 10^{-3} kg/m.s, the fluid will reach a speed of 1.95 m/s at position 5.64 m. However, when the viscosity has a value of 4 x 10^{-3} kg/m.s, the fluid reaches a speed of 1.95 m/s at position 2.82 m. The fluid reaches a fully expanded condition faster when the viscosity increases to 8 x 10^{-3} kg/ms. The fluid reaches a speed of 1.95 m/s at position 1.45 m. The maximum fluid velocity value for all viscosity conditions increases by 1.96 m/s. The greater the viscosity value, the faster the fluid experiences a fully expanded condition.

Viscosity Increases and Density Increases

The third condition is when the viscosity increases and the density increases. The effect of increasing viscosity and increasing density on the velocity profile can be seen in Figure 7. The viscosity range is from 2 x 10^{-3} kg/m.s to 6 x 10^{-3} kg/m.s and the density range is from 10 kg/m3 to 50 kg/m3.

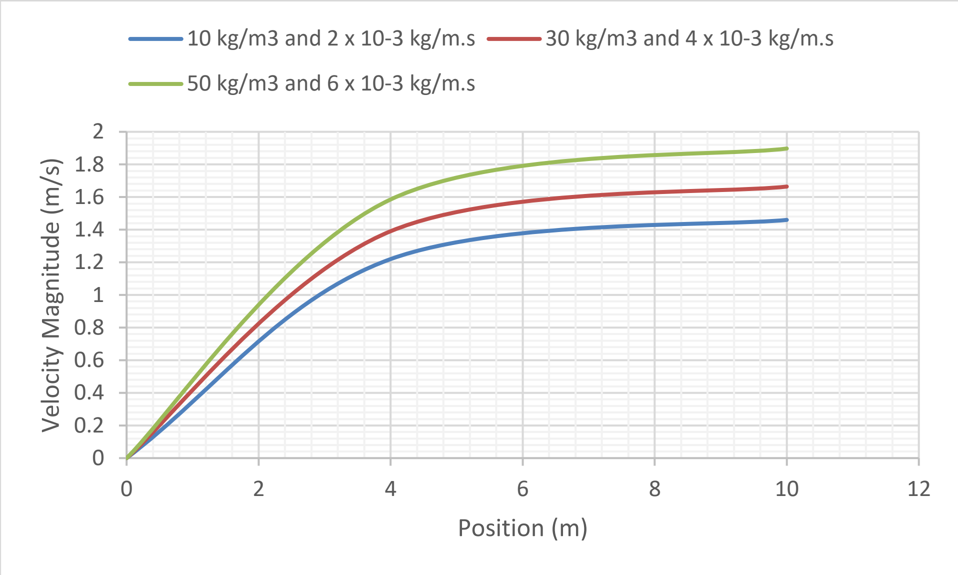

Figure 7. Effect of Increasing Viscosity and Density on Velocity Profile (Viscosity Range 2 x 10^{-3} – 6 x 10^{-3} kg/m.s and Density 10-50 kg/m3).

When viscosity increases and density increases, the velocity profile against position has characteristics as in Figure 7. The greater the density and viscosity, the lower the average fluid velocity. This is evidenced by a density of 10 kg/m3 and a viscosity of 2 x 10^{-3} kg/m.s which has an average fluid velocity of 1.4 m/s.

When density and viscosity increase to 30 kg/m3 and 4 x 10^{-3} kg/m.s, the average fluid velocity becomes 1.32 m/s. The same thing also happens when the density and viscosity increase to 50 kg/m3 and 6 x 10^{-3} kg/m.s. The average fluid velocity becomes 1.3 m/s.

The fully developed condition is never achieved when the density and viscosity increase. This is evident in Figure 7, all three graphs never reach constant speed. The gradient of the three graphs is never 0, the gradient value on the red graph is 0.045. The gradient value on the green graph is 0.04 and the black graph is 0.039.

Viscosity Decreases and Density Increases

The fourth condition is when the viscosity decreases and the density increases. The effect of decreasing viscosity and increasing density on the velocity profile can be seen in Figure 8. When the viscosity is 2 x 10^{-3} kg/m.s and the density is 1 kg/m3, the fully developed condition is achieved. This is evidenced by the speed at position 5.64 m of 1.95 m/s. The final speed at position 10 m is 1.96 m/s. A different phenomenon occurs when the viscosity decreases to 1 x 10^{-3} kg/m.s and the density increases to 3 kg/m^3. The fully developed condition is not achieved when the viscosity decreases and the density increases. This can be seen in the green graph, the speed at position 5.64 m is 1.6 m/s and the final speed at position 10 m is 1.76 m/s. The fluid speed achieved by the green graph is lower than the blue graph. The same thing also happens at a viscosity of 0.5 x 10^{-3} kg/m.s and a density of 5 kg/m^3. The fluid speed owned by the red graph is lower than the blue graph. Based on the phenomena that occur, it can be concluded that the lower the viscosity and the higher the density, the constant speed is never achieved within a distance of 10 m.

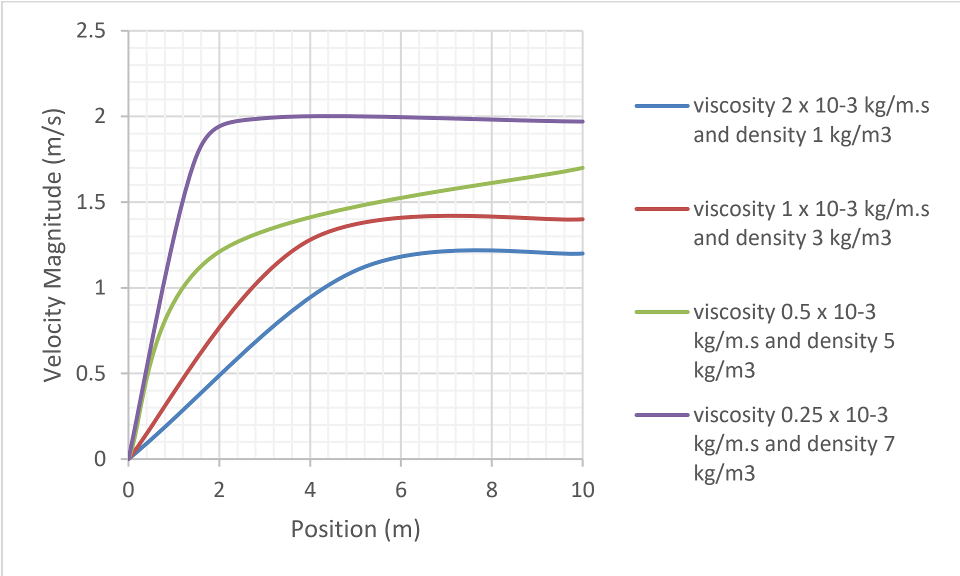

Figure 8. Effect of Decreasing Viscosity and Increasing Density on Velocity Profile (Viscosity Range 0.25 x 10^{-3} – 2 x 10^{-3} kg/m.s and Density 1-7 kg/m^3).

Viscosity Increases and Density Decreases

The fifth condition is when the viscosity increases and the density decreases. The effect of increasing viscosity and decreasing density on the velocity profile can be seen in Figure 9. The viscosity range is from 2 x 10^{-3} kg/m.s to 6 x 10^{-3} kg/m.s and the density range is from 0.25 kg/m^3 to 1 kg/m^3.

All graphs (green, red and black) reach full development. This can be seen in Figure 9. The difference that occurs is in the position to reach the full development condition. When the viscosity value is 2 x 10^{-3} kg/m.s and the density is 1 kg/m^3, a constant speed of 1.96 m/s is achieved at position 8.64 m. However, for a viscosity value of 4 x 10^{-3} kg/m.s and a density of 0.5 kg/m^3, a constant velocity of 1.96 m/s is achieved at position 4.73 m. The higher the viscosity and the lower the density, the faster the fully developed condition is achieved. When the value is 6 x 10^{-3} kg/m.s and the density is 0.25 kg/m^3, a constant velocity of 1.96 m/s is achieved at position 1.45 m.

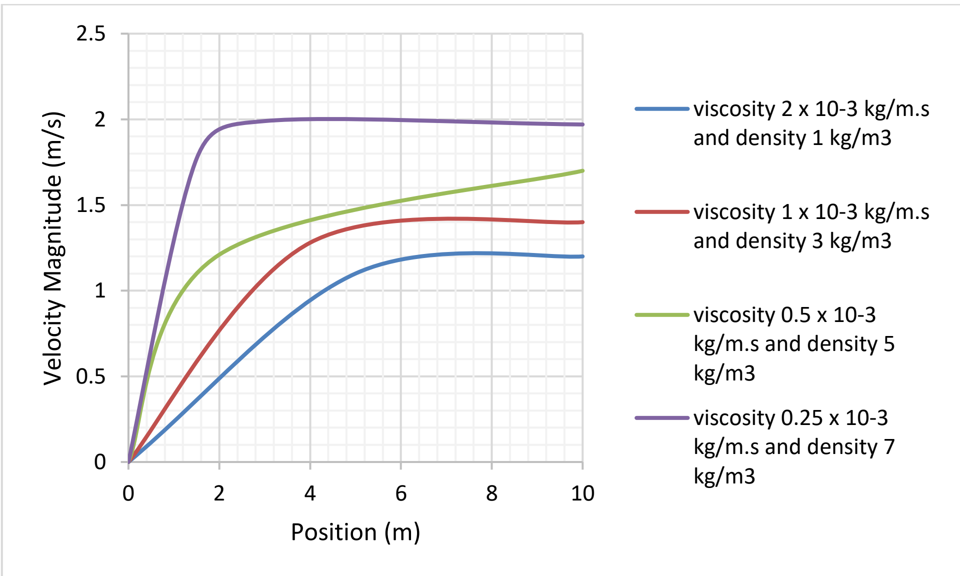

Figure 9. Effect of Increasing Viscosity and Decreasing Density on Velocity Profile (Viscosity Range 2 x 10^{-3} – 6 x 10^{-3} kg/m.s and Density 0.25-1 kg/m^3).

Conclusion

The conclusion is given as a summary of the research results that are the essence of this research. Suggestions are things that can be used as developments for research in the field of computational fluid dynamics (CFD) in the future.

The research entitled the effect of density and viscosity on the velocity profile in laminar fluid flow in a horizontal pipe has five conclusions.

The conclusions that can be given based on the research process that has been carried out are as follows:

1. The greater the fluid density, the further the fluid position is to reach a fully developed condition.
2. The greater the viscosity value, the faster the fluid experiences a fully developed condition.
3. The greater the density and viscosity, the lower the average fluid velocity and the fully developed condition is never achieved within a distance of 10 m.
4. The lower the viscosity and the higher the density, the constant velocity is never achieved within a distance of 10 m.
5. The higher the viscosity and the lower the density, the faster the fully developed condition is achieved within a distance of 10 m.

Suggestion

Computational fluid dynamics (CFD) is a field that has a very broad research aspect so that development in this field is very open in the future. Suggestions that can be given to improve understanding and uncover the mystery of CFD are as follows:

1. The model used in the study is two-dimensional so that in further research it can be developed to see the flow phenomenon with a three-dimensional model.
2. Variables that affect fluid flow such as initial velocity and system pressure need to be studied to see their effect on fluid velocity.

The viscous model in this study is laminar so that future research can be improved on the turbulent viscous model.

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