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Computational analysis of magnetohydrodynamic effects on biodiesel flow rate

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Abstract

The purpose of this research is to determine the velocity characteristics of fluid (fuel) flow in a pipe surrounded by minimal magnetic (electromagnetic) field strength by using computational fluid dynamics simulations. For a more detailed discussion, Magnetohydrodynamics (MHD) theory is used, which is a branch of science that studies fluid flow that can conduct electric current due to the influence of a magnetic (electromagnet) field. The fuel used is B0, B10, B20 and B30. The magnitude of the electromagnetic field used is 0.15 Tesla. the result is that the flow rate of B0 fuel has decreased by 0.623%. B10 fell to 0.41%. The B20 was down 0.618% and the B30 was down 0.648%. Thus the magnetic field strength of 0.15 Tesla is able to change the speed of the fuel flow even if only slightly. This information is needed as a basis for the development that the magnetic field is able to change the value of the flow velocity; this will provide information related to improving the quality of combustion and fuel savings in the future.

Keywords:
Magnetohydrodynamics (MHD), Computational Fluid Dynamics (CFD), flow velocity, fuel.

1 Introduction

Human daily activities are very dependent on fuel. Humans continue to rely on fossil fuels, such as coal, oil and natural gas to meet their needs. Because fossil fuels are non-renewable, their recovery takes a very long time. As a result of this situation, fuel prices rose. One solution for the problem is to flow fuel through a magnetic field.. The purpose of using a magnetic field in this situation is to slow down the speed of the fluid and break up the agglomerated fuel molecules so that they react more easily with the air molecules and the resulting combustion is more thorough. The concept theory and Computational Fluid Dynamics (CFD) simulation are used in this study.

Research related to *magnetohydrodynamics* in fluid flow has been carried out by Engin *et al*, in 2012. In this study, a magnetic field was used ranging from 0.5 – 1.5 Tesla or around 5000-15000 Gauss and there was a decrease in the velocity of the fluid flow around 80-95% [1]. In 2015 Anggriani developed research on *magnetohydrodynamics* in micropolar fluids that were given a magnet of 1-10 Tesla. Micropolar fluid flows through the porous sphere This study observed the influence of magnetic parameters and permeability parameters on the fluid velocity and micro rotation rate. The results showed that the greater the magnetic parameters given, the lower the micro rotational speed in concentrated flow, while it increased in slightly concentrated flow. Charisma, in 2016 reported the results of his research related to *magnetohydrodynamics* in fluid flow in a cylinder, the magnitude of the magnetic field provided is 1.3-2.3 Tesla. The result is that the greater the magnetic parameters, the lower the fluid velocity. This happens due to the influence of the large Lorentz force on the magnetic ball which causes the fluid passing through the magnetic ball to receive a Lorentz force which can change the flow profile [2]. Rahayu *et al* in 2018, reported the results of their research that the flow of micropolar fluids decreased due to the *magnetohydrodynamic* effect with a given magnetic field of 1.3-1.9 Tesla[3].

Based on the description above, research related to *magnetohydrodynamics* has been carried out by many people, it's just that all use large magnetic field strengths, namely above 0.5 Tesla or 5000 Gauss and no one explains what the minimum magnetic field can affect fluid flow. Therefore this study will be analyzed the characteristics of fluid flow to *magnetohydrodynamics* for a magnetic field of 1500 Gauss or 1.5 Tesla. The choice of 1500 Gauss is related to its smaller dimensions so that when it is placed on a two-wheeled vehicle it is comfortable. Knowing the characteristics of fluid flow can give a more correct picture of about magnetism and complete combustion[4].

A particular type of *Magnetohydrodynamic* (MHD) flow that has been studied extensively is the flow in a channel between two parallel plates, known as Hartmann flow [5][6]. The problem analyzed is shown in Fig. 1. The parallel plates are separated by a distance of 2y0. A magnetic field is applied in the upward y direction. Differential pressure between the inlet and outlet plates is applied so that a flow profile that varies in the y direction develops. The pressure gradient in the z direction is chosen as zero so that flow occurs only in the x direction. The magnetic field creates an electromotive force on the liquid as it moves between the plates [7].

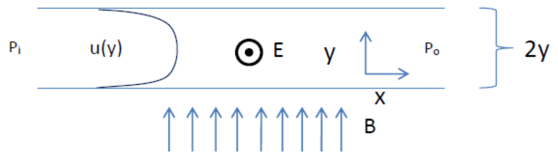

Fig. 1. Electric and Magnetic Fields Applied to a Pressure Driven Parallel Plate Flow

The basic formula used in the Computational analysis of magnetohydrodynamic (MHD), is the Maxwell equation, Navier-Stokes, Force Equation and Energy Conservation (scalar). Maxwell's equations are used to describe the behavior of electromagnetic fields that interact with fluids. and the Navier-Stokes Equation describes fluid motion and is used to calculate fluid velocity, pressure, and density. The combination of these two equations, Eq. 1 Maxwell's-Navier Stokes describes the effect of electromagnetic fields on fluids that can significantly change the behavior of fluid flow. For example, magnetic fields can induce eddies, suppress turbulence, or even completely change flow patterns.

The Maxwell and Navier-Stokes equations used in MHD are:[8]

$$\left(\frac{\partial p}{\partial t}\right) + \nabla \bullet \left(\rho \bar{v}\right) = 0 \tag{1}$$

The Force Eq. 2, also known as the momentum equation, is used to describe Newton's law of motion in fluid flow. This equation states that the force applied to the fluid is equal to the change in momentum of the fluid over time. In MHD, this equation is modified to account for the effects of magnetic fields on the fluid flow.

Force Equation (vector)

$$\rho \frac{\partial \bar{v}}{\partial t} = -\nabla p + J \times B \tag{2}$$

The Energy Conservation Eq. 3, also known as the Bernoulli equation, is used to describe the conservation of energy in fluid flow. This equation states that the total energy in the fluid flow, consisting of kinetic energy and potential energy, must remain constant during fluid flow. In MHD, the energy conservation equation is modified to account for the effects of magnetic fields on the fluid flow.

Energy Conservation (scalar)

$$\rho \frac{\partial}{\partial t}\left(e+\frac{v^{2}}{2}\right) = -\nabla \bullet \left(p\bar{v}\right) + \nabla \bullet \left(k\nabla T\right) + J \bullet \bar{E} \qquad (3)$$

Where: (ρ) is represents density, (v) is velocity, (P) is pressure, (e) is internal energy, (k) is thermal conductivity and (σ) is electrical conductivity of the gas, (E) is electric field, (J) is current density, (B) is magnetic induction, (μ) is permeability and (R) is universal gas constant.

2 Materials and Methods

This experiment uses 5 types of biodiesel that are commonly used, namely B0 (100% diesel), B10 (10% biodiesel + 90% diesel), B20 (20% biodiesel + 80% diesel) and B30 (30% biodiesel + 70% diesel). The biodiesel in the storage tank is forced to flow by an electric pump to the pipe. The pipe is wound which, when given an electric current, will produce a magnetic field of 0.15 Tesla or 1500 Gauss. This experiment observes changes in the dynamics of biodiesel flow along the pipe when it is not subjected to a magnetic field and is subjected to a magnetic field. Experimental diagrams and biodiesel properties can be seen in Fig. 2.

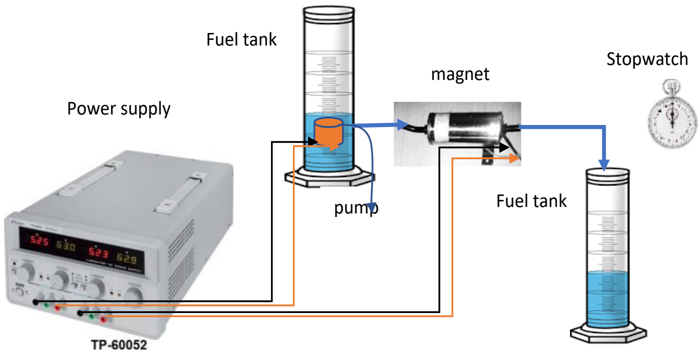

Fig. 2. Experimental Schematic Diagram

Table 1. Property of Biodiesel [9]

Biodiesel	ρ(kg/m^3)	μx10^{-6} (Pa.s)
B0	830	2257
B10	800	2314
B20	830	2483
B30	840	2665
B100	870	3967

The measurement of the volume rate per unit time was carried out by observing the change in the height of the biodiesel in the storage for 30 seconds. The volume rate data was taken for 20 repetitions with the same experimental parameters.

2.1 Simulation

The simulation domain is a pipe with a length of 80 mm and an inner diameter of 4.64 mm which is represented by a 2-dimensional approach. The domain and mesh are shown Fig. 3:

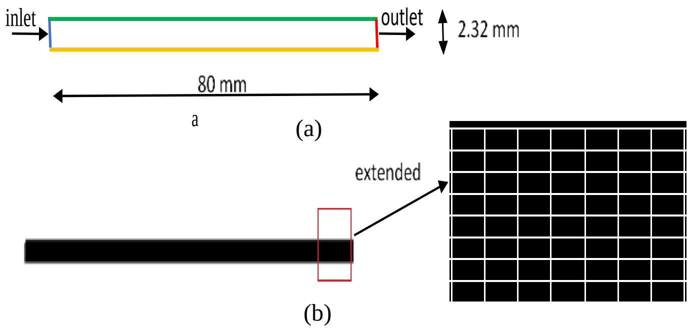

Fig. 3. (a) Domain, and (b) Grid

Domain boundaries consist of wall (green), symmetry (yellow), inlet (blue), and outlet (red). Some of the regulation equations that are activated include turbulence and magnetic fields. The simulation parameters are shown in the following table:

Table 2. Simulation parameter

Description	Value and unit	Notification
Inlet velocity	0.461 m/s	B0, B10, B20, B30
Turbulence approach		k-epsilon
Density	kg/m^3	As describe in Table 1
Viscosity	Pa.s	As describe in Table 1
Magnetic Force	0,15 Tesla	F= BIL= 52.452 N

3 Results and Discussion

The grid dependency test has been carried out using three grid densities namely 1000 x 50, 1650 x 50 and 2000 x 50. The simulation resulted from the three grid densities are as follows: more significant after using a minimum grid of 1650 x 50, because the network density is used in more height. Validation of the simulation results in the experimental data was carried out at the beginning of the analysis before the fluid was affected by a magnetic field on flow dynamics such as velocity (Fig. 4) and validation with fluids affected by a magnetic field (Fig. 5). Furthermore, Fig. 6 presents the flow rate error between the experiment and the simulation obtained.

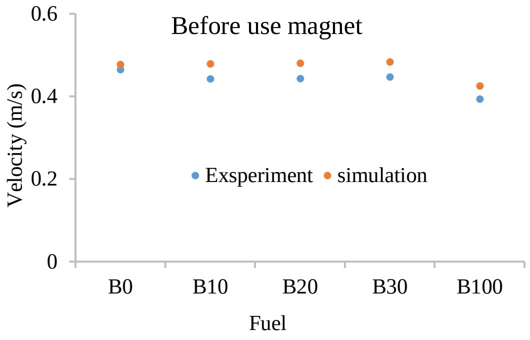

Fig. 4. Validation of outlet velocity before applying magnetic field

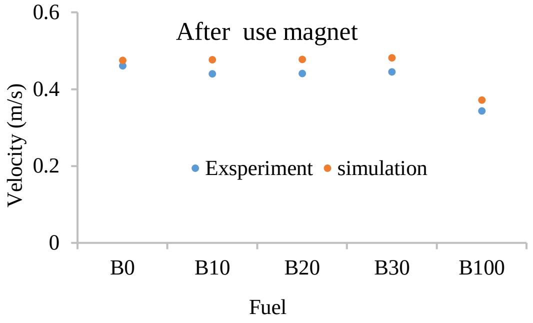

Fig. 5. Validation of outlet velocity after applying magnetic field

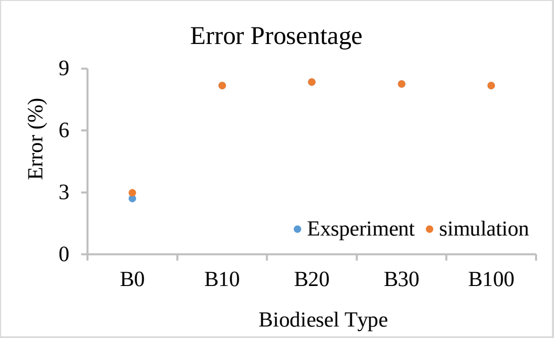

Fig. 6. Simulation error on experiment

In Fig. 4 and 5 it appears that the experimental results with the simulation have almost the same value, or the error is below 10% as shown in Fig 6, it can be said that the data obtained from the simulation is valid.

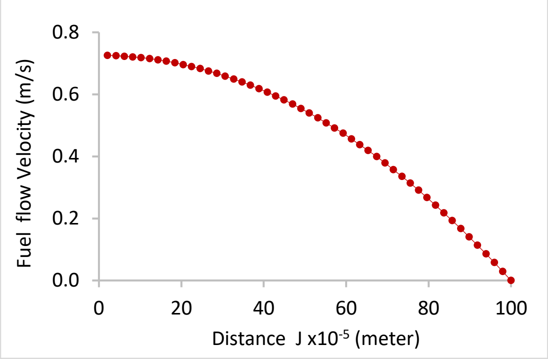

Fig. 7. Velocity before being applied to a magnetic field (MHD) at B0

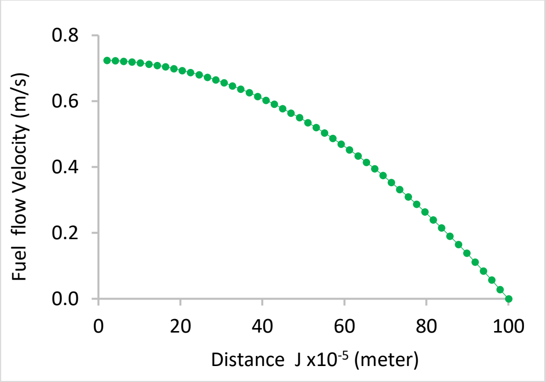

Fig. 8. Velocity after being applied to a magnetic field (MHD)at B0

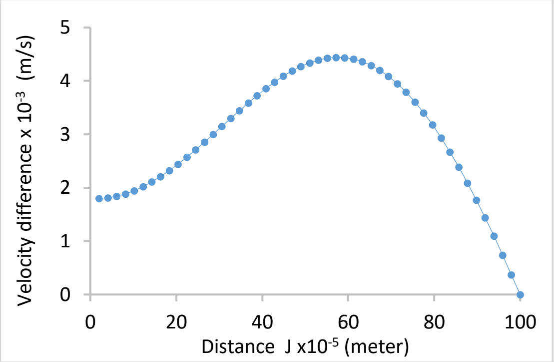

Fig. 9. Velocity differences of Non MHD & MHD at B0

Fig. 7 and 8 show the characteristics of the fuel flow rate. At first glance they look the same, but if you look closely they are different. The Characteristics of fluid flow without a magnetic field (MHD) is showed by the fluid velocity that is reduced significantly from the middle of the pipe to the pipe wall. This reduction is caused by the fluid flowing on the pipe wall experiencing friction that is large enough to inhibit the fluid flow rate.

Likewise, after the fluid passes through the magnetic field (MHD) in Fig 8, there is a decrease in the speed of the fuel flow, but it is greater than before passing through the magnetic field (MHD). The difference between fluid flow through a magnetic field and fluid flow through a non-magnetic field is shown in Fig 9. It can be seen that the largest difference occurs at a distance of $60x10^{-5}$ m.

The large flow velocity causes the kinetic energy of the fluid to be large so that the sublayer in the fluid flow area will be thicker. The thicker the sublayer in the pipe flow causes the fluid flow to be disturbed by the sublayer. So that the flow direction will be random and cause ripples.

As a result, so that the flow pressure is not normally distributed. This causes a pressure drops in highly turbulent flows. Because there is pressure left in the pipe, it is very likely that the pipe will produce heat so that there will be a decrease in the energy because other energy is left behind and generates the heat [10].

In addition, the shear stress is also a parameter that causes the thickness of the sublayer layer. Shear stress occurs due to fluid friction on the wall. In the viscous sublayer, the fluid flow is laminar and does not collide with each other, while in the middle of the pipe the fluid flow is turbulent. So because of the high turbulent velocity, it will cause eddies to form in the flow which are called Eddies.

This eddy will cause the rate of energy change (rate of dissipation) to change in the form of heat due to this friction. As a result, the fuel that passes through the magnetic field becomes slower. The heat energy that arises causes the bonding of the fuel molecules to decrease but not to be broken. This weak fuel molecule bond causes it to be easier to react with air, so that the combustion is better. This is the basis of why the magnetic field is able to save fuel[11][12].

B10, B20 and B30 fuels have the same characteristics as B0. The biggest percentage difference between fuel that does not pass through a magnetic field and through a magnetic field is B30. This is because its density is greater than the others so that the fluid frictional force is large as shown in Fig. 10. The percentage difference in flow rate between fuel that does not pass through a magnetic field and that passes the magnetic field for B0 is 0.623%. while for B10 decreased to 0.410%, and for B20 the percentage value of the difference in flow rate between fuel that does not go through a magnetic field and through a magnetic field is 0.618%. The largest, B30, is 0.648% because its density is greater than the others so that the fluid friction force is large. All these values are smaller than the results of other studies. However, this informs that a magnetic field strength of 0.15 Tesla is able to affect the fluid flow.

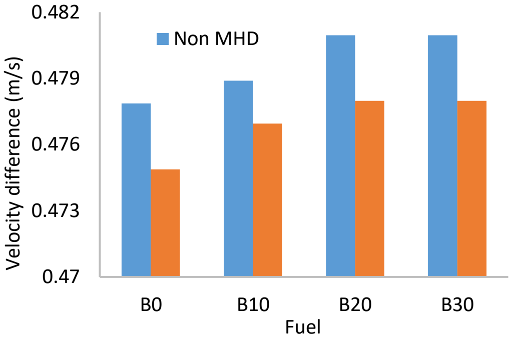

Fig. 10. Velocity differences of Non MHD & MHD

It can be concluded that the fuel flowing in a magnetic field of 0.15 tesla resulted in insignificant changes in the fuel flow rate for all fuel compositions, except in B100. However, it can also be informed that with a magnetic field of 0.15 Tesla the fuel molecules can change their flow velocity even if only slightly. The slow speed of this flow does not make the combustion process so slow. This information is needed as a basis for the development that the magnetic field is able to change the flow of velocity. This is related to fuel economy[13].

4 Conclusions

Based on the CFD simulation that has been validated with experimental results, the characteristics of the fluid, especially fuel when passed by a magnetic field will experience a decrease in flow velocity: B0 decreased by 0.623%. B10 dropped to 0.41%. B20 fell by 0.618% and B30 decreased by 0.648%. The magnetic field strength of 0.15 Tesla is able to change the speed of the fuel flow even if only slightly. This information is needed as a basis for the development that the magnetic field is able to change the value of the flow velocity. This is related to fuel economy.

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