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Research Article

Experimental Study on the Effect of Addition Micro Additives Zinc Oxide and Graphite Powder at Biodiesel to Decrease the Pressure Drop of Microchannels

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Abstract: Biodiesel is a trend in diesel engines for changing fossil fuels. The diesel engine's important factor is the injector's spray quality. The rise of air-fuel mixing results in a better combustion process. Biodiesel existed as an alternative fuel to change the role of fossil fuels. Palm oil biodiesel is used to experiment with blend B30. The addition of micro additives to biodiesel showed an increase in performance and spray quality. However, the presence of the micro additive may affect the flow characteristics, including pressure drop inside the fuel and injector channel. The current research studied the effect of micro additive materials on biodiesel toward the pressure drop inside the microchannel by replicating the shape and size of the fuel and injector channel. The microchannel is made from a glass tube with an inner diameter of 2.771 mm and 3.614 mm for straight microchannels and a diameter of 2.757 mm, and a 90-degree bend for the bend microchannel. The result showed that adding an additive of graphite powder (GP) and zinc oxide (ZnO) to biodiesel can decrease pressure drop per unit length by up to 59% and 49%, respectively. The data showed a linear relationship between the pressure drop and the Reynolds number. The result affirmed that the friction factor has the same trend as the conventional theory.

Keywords: Biodiesel; Micro additive; Microchannel; Pressure drop

1. Introduction

Energy is one of the essential things necessary for economic growth, as well as for increasing industrialization and transportation in a country (Tamilvanan et al., 2018). Fossil fuels are the

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primary source of energy for power generation and transportation worldwide. The diesel engine, which utilizes fossil fuels as a combustion system, is widely employed in transportation, heavy machinery, and power generation due to its high durability and efficiency (Prahmana et al., 2024). One major obstacle to using diesel engines is gas emissions from the combustion of fossil fuels. The transportation sector produces almost 30% of the world's greenhouse gas emissions that lead to global warming (Geng et al., 2017). Moreover, energy demand is going away from the limit, and its availability is getting scarcer over time due to rising prices of petroleum products and limited resources. The alternative solution to prevent fossil extinction is to use renewable energy to reduce gas emissions.

Biodiesel is an alternative fuel from renewable energy materials derived from the transesterification process of vegetable oils and animal fats, including corn and sugar beet, seeds, wheat, and tallow (Prahmana et al., 2024: Sahoo, et al. 2007). Biodiesel fuels provide renewable and clean energy, promising sustainability, and eco-friendly fuels (Haryono et al., 2024; Kusrini et al., 2024). Fossil fuels will be replaced by biodiesel in diesel engines and motor vehicles without changing the engine. Biodiesel has included a biodegradable and non-toxic substance to reach clean energy. Also, biodiesel can reduce greenhouse gas emissions by up to 90% to achieve net zero emissions. (Morgan, 2005; Theil, 2005). The research was conducted on the production of biodiesel from crude rice bran oil using ultrasound-assisted transesterification and Response Surface Methodology (RSM). The RSM model was used to optimize the process parameters, including the methanol-to-oil ratio, reaction time, and catalyst concentration. The results showed that the optimal conditions for the transesterification process were a methanol-to-oil ratio of 6:1, a reaction time of 48 minutes, and a catalyst concentration of 0.51 wt.%, resulting in a methyl ester yield of 94.12%. Additionally, the properties of the rice bran biodiesel met the standards of ASTM D6751 and EN 14214 (Said et al., 2018; Ibrahim et al., 2020). The biodiesel production of a mixture of different oils derived from palm oil, soybean oil, used cooking oil, canola oil, and sunflower oil was experimented with utilizing a transesterification process and mole ratio variations of oil. The total vol. of the mixture was the amount of 300 mL for each oil used with the transesterification at the temperature of 60°C for 1 hour. Mole ratios of oil were arranged to 1:3, 1:6, 1:9, 1:12, and 1:15. The results showed that all experiment parameters of methyl ester content, density, acid value, and total glycerol in the multi-feedstock biodiesel were appropriate for the quality standards of ASTM D 6751, EN 14214, and SNI 7182-2015. Biodiesel at mole ratios of 1:3 and 1:6 should be considered to reduce the use of methanol for biodiesel production in the industry. The mole ratio of 1:6 was the highest yield of 92.99% with a methyl ester content of 99.58% mass (Wahyono et al., 2022). Research on the production of Biodiesel from Free Fatty Acids (FFA) was carried out using a ZrO_2/Bagasse Fly Ash (BFA) as catalyst support for biodiesel production from Palm Fatty Acid Distillate (PFAD). The BFA catalyst was characterized using Nitrogen adsorption-desorption, X-ray diffraction (XRD), and X-ray fluorescent (XRF). The BFA catalyst performance was investigated by varying the reaction temperatures, molar ratios of methanol to PFAD, and catalyst loading. The model showed a splendid fit for the result which indicated that Eley-Rideal is a valid model to describe that reaction with the surface reaction step as the rate-determining step (Rahma & Hidayat, 2023).

Palm oil biodiesel is a type of biodiesel made from vegetable oil. The obstacle to using palm oil biodiesel has a high-pressure drop and viscosity. Those cause a significant loss coefficient in the fuel line and decrease the diesel engine performance. In order to reduce the viscosity of palm oil biodiesel, three methods could be carried out; heating, transesterification, and mixing with a lighter oil (Murayama et al., 2000). Heating was the best method to utilize vegetable oils as fuel. Also, preheat of the vegetable oil decreased the viscosity and eased the problem of the injection process (Prasad et al., 2000). Many studies have been conducted to improve the performance and reduce gas emissions of diesel engines. The effect of additives on diesel engines using aluminum oxide (Al_2O_3), cerium oxide (CeO_2), and graphite oxide (GO) with a single droplet combustion experiment improved the combustion efficiency and reduced emissions in diesel engines significantly (Ooi et al., 2016). Engine tests using preheated palm oil biodiesel blends (PO20, PO30, PO40) and pure biodiesel were carried out to investigate the engine performance and emission of Carbon Monoxide (CO). The result stated that palm oil biodiesel blends PO20 was better in performance and lowest for CO emission (Prabu et al., 2018; Suryantoro et al., 2016). The Euglena Sanguinea (ES) biodiesel and their blend (ES20D80, ES40D60, ES60D40, ES80D20) were conducted by experimental test and adding graphite oxide (GO) in Homogeneous Charge Compression Ignition (HCCI). The Euglena Sanguinea microalgae-based biodiesel with GO nanoparticles showed a similar performance to the compression ignition engine. Compared to diesel fuel, the experiment showed a slight gain in performance and a significant reduction in HC, CO, smoke, and NOx emissions (Murugesan et al., 2022).

The pressure drop was one of the prominent indicators due to the performance of diesel engines. The Reynolds number increased along with the increase of pressure drop and the decrease of the bend loss coefficient. In addition, the pressure drop increased along with the bend angle increase, and the cross-sectional diameter decreased at the same Reynolds number (Junianto and Hendrarsakti, 2021). The pressure drop per unit length was almost the same as the conventional theory for a larger diameter channel in the straight microchannel (Hendrarsakti et al., 2021). Adhesion was intermolecular forces of attraction between biodiesel and the wall in the microchannel. Adhesion forces generated the capillary action in the microchannel. Capillary action was the adhesive and cohesive force of the fluid to flow molecules into the microchannel against external forces. When the diameter of the tube got smaller, the combination of cohesive and adhesive forces between the liquid and microchannel would lift the liquid (Oh et al., 2014).

Based on research before, research about the effect of adding micro additives on the pressure drop along the microchannel flow can be conducted. Research on adding micro additives by comparing straight and bend microchannels in biodiesel has never been completed. The micro additive is added to biodiesel to investigate the change in pressure drop on the microchannel, which is measured using the pressure transducer. However, the study on the micro additive addition for biodiesel has yet to develop fully. Things that still need to be researched are the most effective micro additives to get the highest efficiency, as seen from changes in pressure drop and Reynolds number on microchannels. A palm oil biodiesel blend of B30 was selected for the experiment. The research uses graphite powder (GP) and zinc oxide (ZnO) as micro additives. Researchers want to compare the use of carbon (GP) and metal (ZnO) based materials on the pressure drop of the microchannel flow. The use of metal-based additives can negatively impact the environment because metal-based additives do not burn out in the combustion chamber resulting in a high Particulate matter (PM) (Schmidt and Corradini, 1997; Desantes et al., 2003; Payri et al., 2004). The prominent factor in a diesel engine is the quality of the spray at the nozzle. Improving the air-fuel mixing results in a better combustion process and performance. The spray characteristics are influenced significantly by the flow property in the nozzle orifice. Internal flow depends on the cavitation phenomena and pressure drop in the fuel line (Kegl et al., 2020; Orihuela et al., 2018). Therefore, this study can determine the effect of different fuels on pressure drop. This research has the benefit of seeing the cavitation phenomena in the fuel line that affects the spray quality of the nozzle.

2. Methods

2.1. Experimental Setup

In the preparation, the equipment needed is a syringe pump, microchannels, pressure transducers, Nipple, Arduino, personal computer, test fluid (V-Power Diesel), micro additives, seals, and fluid resistance compounds. A syringe pump adjusts fluid injection according to the required design. The pressure transducer measures the pressure in the fluid and the pressure drop at the straight and bends microchannel. A Nipple connects the injection with the microchannel and the place to put pressure transducers. Arduino is to acquire data by receiving and processing data from the pressure transducer. The personal computer receives and displays pressure measurement data from Arduino. Micro additives, namely graphite powder and zinc oxide, are added to the test fluid. Seals and fluid resistance compounds are used to prevent any leakage during the testing process.

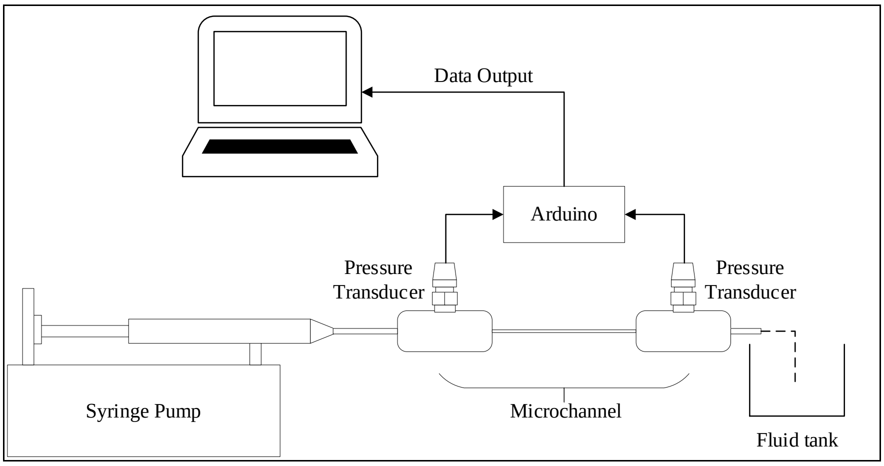


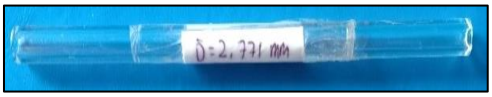
Figure 1 The schematic diagram of the experimental setup

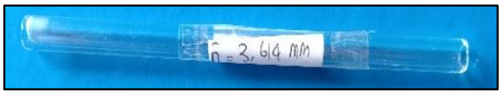
2.2. Straight and Bend Microchannels

The experiment will be performed with the scheme shown in Figure 1. The measurement results from pressure transducers are transferred to a computer to get the data on pressure changes that occur in the microchannel flow. Microchannels must be cleaned using alcohol and aquadest/distilled water to prevent contamination from the previous samples that result in incorrect measurements. The research is conducted on the straight and bend microchannels. The diameter and length of microchannels were measured using the INSIZE calipers with an accuracy of 0.02 mm, with dimensions shown in Table 1. Microchannels used in the experiment are shown in Figure 2.

Table 1 Variation of microchannel dimension

Diameter (mm)	Length (mm)	Angle (degree)
2.771	103	180
3.614	103	180
2.757	56	90


(a.)

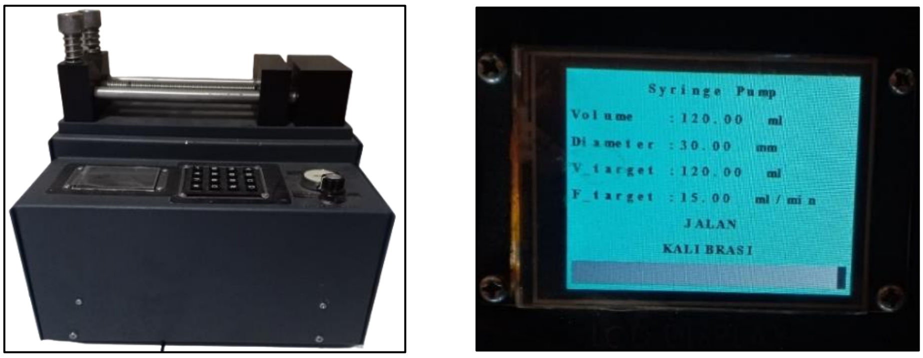

(b.)


(c.)

Figure 2 Microchannels with a diameter of 2 mm (a) 3 mm (b) and a 90-degree bend (c)

2.3. Syringe Pump

A syringe pump is an equipment for injecting or pushing fluids by injection to the microchannel. The injections use the product of Terumo Syringe with a vol. capacity of 60 mL. The syringe pump is designed in the thermal laboratory of ITB for research purposes, as shown in Figure 3 (a). The electronic device used in a syringe pump is a motor stepper NEMA 23 with a 2.3 inches square plate and 1.8° step angle (200 steps/revolution). The syringe pump sets the amount of biodiesel injected into the microchannel with parameters of vol., diameter, vol. target, and flow target, as shown in Figure 3 (b).



(a) (b)

Figure 3 Syringe pump equipment (a) and monitor display (b)

2.4. Arduino

Arduino is configured as shown in Figure 4. The measurement results of Arduino are displayed on a serial monitor to check the pressure on pressure transducers. Arduino acquires the pressure data from pressure transducers and then displays the data on the personal computer. Arduino AT Mega 2560 is used for the experiment.

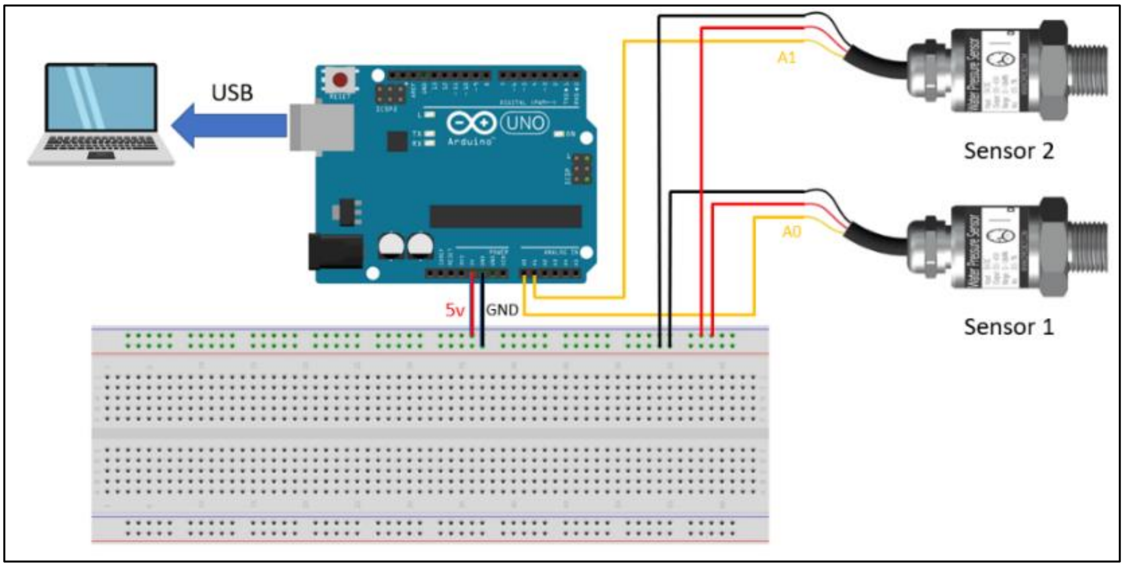


Figure 4 The schematic diagram of Arduino using two pressure transducers

2.5. Pressure Transducers

A pressure transducer is an instrument to measure fluid pressure. The pressure transducer is used to determine the pressure conditions on the microchannel for monitoring and controlling flow, speed, and vol.. Pressure transducers are installed between both sides of the microchannel with nepple as shown in Figure 1. Nepple is a component to connect the injection and pressure transducers with the microchannel. Pressure transducers can measure the fluid pressure at the inlet and outlet of the microchannel. The pressure transducer specification can be seen in Table 2.

Table 2 The data specification of the pressure transducer

Item	Specification
Name	WPT-83G Ceramic Sensor Pressure Transmitter
Code	WPT-83G-EZG4
Measuring Range	0 - 10 kPa
Accuracy	± 0,5% FS
Output Signal	0.5 - 4.5 V
Supply Voltage	DC 5 V
Operating Temperature	(-20 °C) - 85 °C
Sensor Type	Al_2O_3 96% Ceramic Sensor
Over Load Capacity	150% of Full Scale
Burst Capacity	200% of Full Scale
Response Time	≤ 3 ms

2.6. *Characterization of Biodiesel*

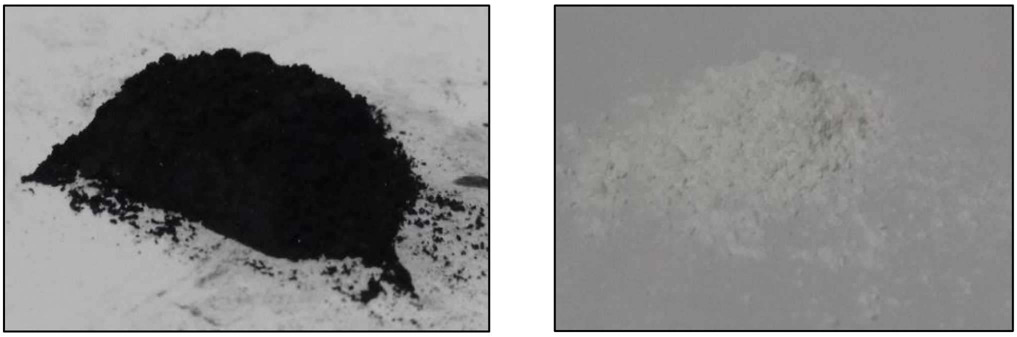
The test fluid used in this study was V-Power Diesel which Shell Indonesia produced. The test fluid would be added with micro additives GP and ZnO. Using the Particle Size Analyzer (PSA) of Horiba SZ-100 at the Electron Microscopy Laboratory of ITB, the average diameters of ZnO and GP were found to be 1.3104 µm and 1.8998 µm, respectively, as shown in Figure 5. Using the Ultrasonic Bath, the biodiesel blend (V-Power Diesel) with micro additives was conducted at the Metal Laboratory of ITB. The proportion of biodiesel blend used was B30+GP and B30+ZnO (Fayad et al. 2022; Soudagar et al., 2020; Ooi et al., 2018; Khalife et al., 2017a, 2017b). The amount of biodiesel blend is shown in Table 3. Surfactants also were used during blending to prevent agglomeration. The blending results were then measured in density and viscosity through the Fisher Analysis Method at the Physical Chemistry Laboratory of ITB, as shown in Table 4. Data acquisition was carried out based on the results of tests using Arduino. Furthermore, the data would be analyzed to see the trending of the pressure drop, Reynolds number, friction factor, and loss coefficient.

Table 3 The proportion of biodiesel blends

Biofuel Blends	Biodiesel	Dosage of Additive	Dosage of Surfactant
D (70%) + BD (30%)	Fatty acids, C16-18 and C18-unsatd., Me esters (FAME, Biodiesel)	-	-
D (70%) + BD (30%) + Nanoparticle	Fatty acids, C16-18 and C18-unsatd., Me esters (FAME, Biodiesel)	Zinc Oxide (ZnO) 30 ppm	CATB 10 mg
D (70%) + BD (30%) + Nanoparticle	Fatty acids, C16-18 and C18-unsatd., Me esters (FAME, Biodiesel)	Graphite Oxide (GP) 25 ppm	Sorbitan Oleate 2% wt.

Table 4 Density and viscosity of fluid test

Item	Viscosity (cP)	Density ($\frac{g}{ml}$)	Temperature (°C)
B30	2.973	0.8315	25
B30 + ZnO	2.391	0.8188	25
B30 + GP	2.545	0.8216	25



(a) (b)

Figure 5 Sample of graphite powder (a) and zinc oxide (b)

The measurements usually have an error. It is necessary to ensure that the experiment is conducted correctly by evaluating and limiting the possibility of error. The deviation between the measured result and the actual result is referred to as an error. The true value of a measurement must be within the range of the measurement results. Measurement uncertainty analysis is a procedure used to measure the validity and accuracy of data. The accuracy of the measurement uncertainty is very important to ensure the validity of the test data. Analysis of the measurement uncertainty must be carried out to provide some quantitative description for the validity of the test data because the measurement result is something uncertain (Li et al., 2007). Due to the limitations of measuring instruments, measurement results will be in a range that causes an uncertain value at the range. Analysis of measurement uncertainty will affect the data obtained and a deviation from the theory.

3. Results and Discussion

The microchannel's diameter slightly affected the pressure drop and the Reynolds number. The comparison of pressure drop per unit length of the test results to the Reynolds number is shown in Figure 6. The chart stated that the pressure drop per unit length increases along with the increase of the Reynolds number. In the straight channel, the microchannel with diameters of 2.711 mm and 3.514 mm showed that the pressure drop per unit length (experimental) has a similar trend to the Poiseuille Equation (theoretical). The palm oil biodiesel decreased the pressure drop per length up to 59% for the straight microchannel with additive B30+GP, Reynolds number of 6.056, and diameter 2.771 mm. While for the bend microchannel, the palm oil biodiesel reduced pressure drop up to 49% with additive B30+ZnO, Reynolds number of 6.556, a diameter of 2.757 mm, and a 90-degree bend. The regression line was found to be non-linear due to external factors such as adhesion forces and capillary action. However, the results confirm that the conventional theory is still applicable to microchannels with a diameter of 2-3 mm. According to this theory, increasing the diameter of the microchannel can help reduce the pressure drop (Darcy-Weisbach equation).

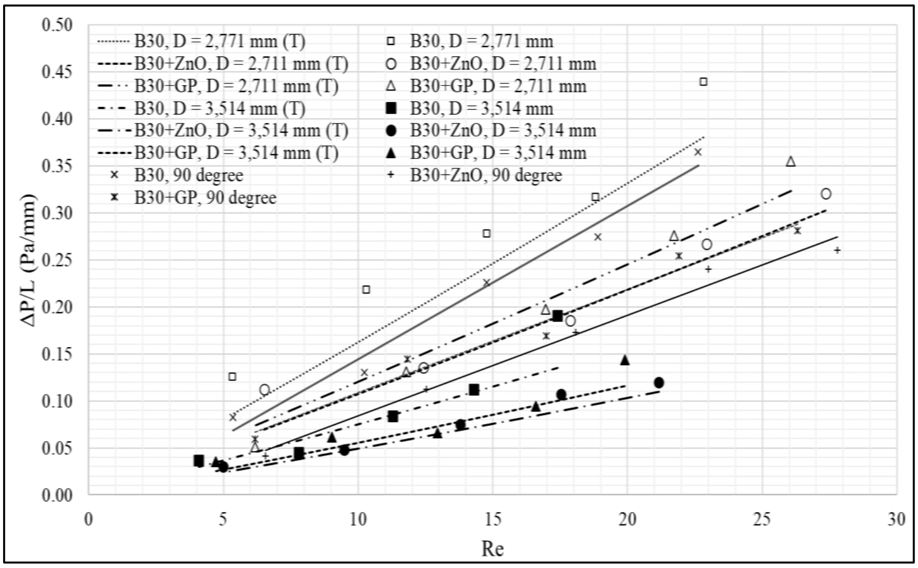


Figure 6 Comparison pressure drop per length (ΔP/L) with respect to Reynolds number (Re).

The friction factor and the Reynolds number were related, as shown in Figure 7. The comparison of the friction factor to the Reynolds number indicated a decrease in the microchannel diameter along with an increase in the Reynolds number. The friction factor of the experimental result showed a similar trend to the theoretical friction factor. The friction factor results in the previous research with a diameter of 0.118 mm were just a short distance from this experiment. The prior study showed that the friction factor test result has a smaller density than the result from the experiment (Hendrarsakti et al., 2021). However, the trend shown was quite identical to the result of this experiment and the same as previous research on laminar flow conditions (Sahar et al., 2016; Liu et al., 2007; Li et al., 2007; Lee et al., 2005).

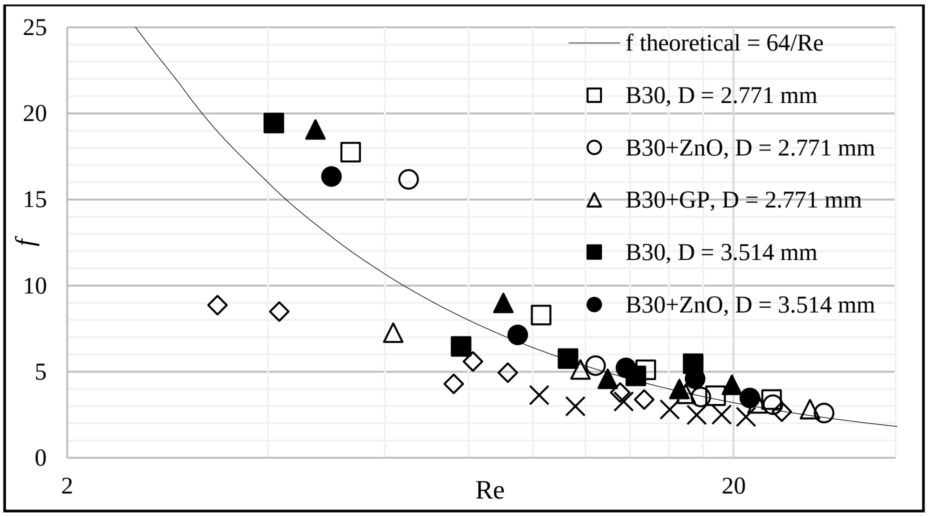


Figure 7 Comparison friction factor (f) with respect to Reynolds number (Re)

The losses occurred only in the bend microchannel. The bend loss coefficient of the microchannel with a 90-degree bend affected the Reynold numbers. The comparison of the bend loss coefficient to the Reynolds number is shown in Figure 8 along with previous research (Junianto and Hendrarsakti, 2021). The experiment produced a Reynolds number in the range of 5 - 28, which was the laminar condition. The bend loss coefficient decreased dramatically as the increasing of Reynolds number. It confirmed the same pattern in previous research (Junianto & Hendrarsakti, 2021). The loss coefficient in the laminar was more extensive than turbulent. It indicated that the bend loss coefficient was more stable along with the rise of the Reynolds number. Unfortunately, the transition condition in this research was not achieved because the Reynolds number needed to be obtained over 29. As a result, the condition was uncertain whether the condition was turbulent or laminar. Also, there was obscurity that the trend of the bend loss coefficient remained constant or volatile for the Reynold numbers of over 29.

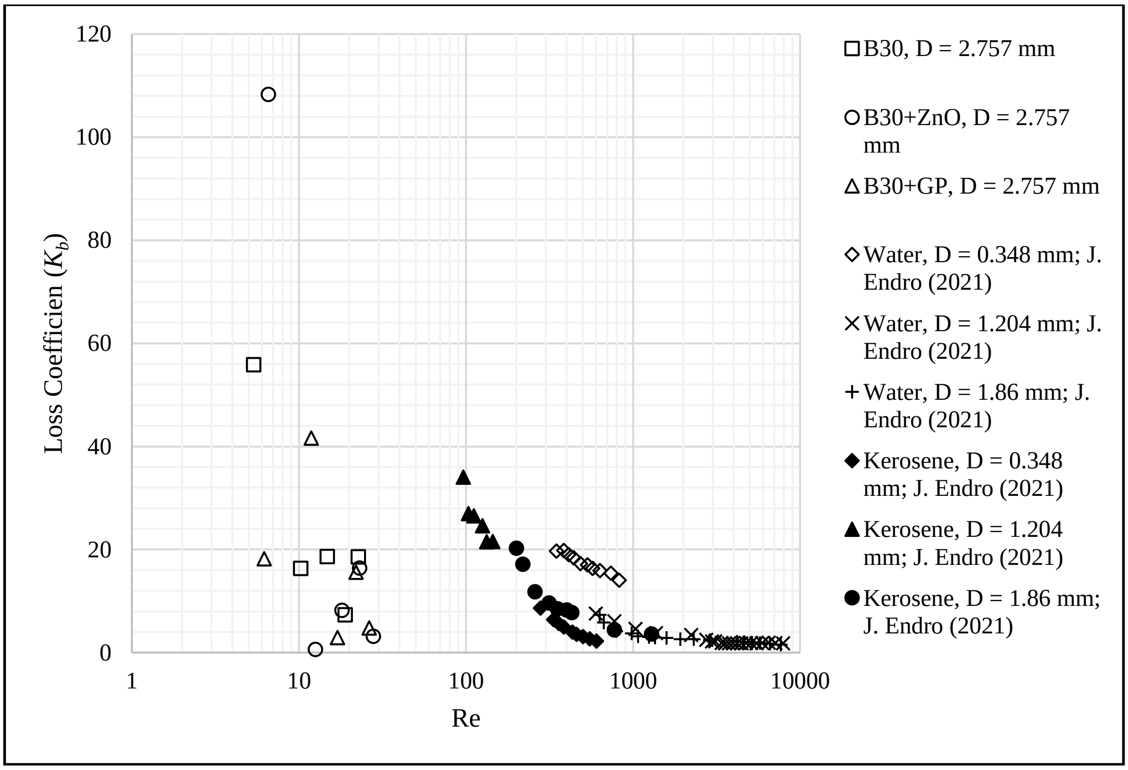


Figure 8 Comparison with loss coefficient (K_b) respect to Reynold number (Re)

4. Conclusions

An experimental study in the straight and bend microchannel using biodiesel with adding micro additive material was conducted to quantify the pressure drop in the microchannel. The Arduino microcontroller acquires the pressure data and displays the data on the personal computer. The inner diameter of the microchannel is 2.771 mm and 3.614 mm for the straight microchannel and 2.757 mm with 90 degrees for the bend microchannel. A palm oil biodiesel blend of B30 is used in the experiment. Adding micro additives to the palm oil biodiesel reduced the pressure drop per length to 59% for the straight microchannel with B30+GP and 49% for the bend microchannel with B30+ZnO. Consequently, the Reynolds number also increased. The results data stated that there was a linear relationship between the pressure drop and the Reynolds number. Also, the result of the experiment affirmed that the friction factor has the same trend as conventional theory. The traditional approach was still relevant for increasing diameter and reducing the pressure drop per length. The result of the bend coefficient loss showed the same pattern as previous research, which increased significantly along with the Reynolds number getting smaller. The current result may contribute to the development of renewable energy in internal combustion engines. The study can see if there are some improvements inside the fuel injector that would be necessary during the use of biofuel combinations with micro additives. The current study has not investigated further the nanoscale chemical and physical interactions between the B30 blend fuel and micro additives that might occur. The use of other types of micro and nano additives in future studies may help understand these interactions.

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Author Contributions

Jooned Hendrarsakti: Writing – review & editing, supervision, formal analysis, investigation. Zido Yuwazama: Writing – original draft, visualization, methodology, investigation, data curation, conceptualization. Putra Andi Kolala: Writing – original draft, investigation, formal analysis. Rico Aditia Prahmana: Writing – review & editing, formal analysis, conceptualization. Alfian Yannu Alfaridzi: Writing – review & editing. Kiki Fadillah Nurul Khotimah: Writing – review & editing. Marianus Beatriks Djala Gili: Writing – review & editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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