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Development of an Automatic Biodiesel Production Plant with a Cooling System for Reducing Purification Time

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***Abstract* - There are three stages for processing biodiesel-based used cooking oil: the esterification process, cooling and purifying FAME, and filtration of crude biodiesel. Usually, the time required for purifying FAME is very long because it has to follow the sedimentation process several times. Therefore, this research developed a biodiesel purification machine equipped with a cooling system. The cooling system aims to make the sedimentation process faster. The cooling system uses a thermoelectric module attached to a pipeline from the esterification tank to a purification tank. This machine is also equipped with a control system and valve driven by motor to perform the process automatically. The design of the biodiesel purification machine has been successfully developed and has followed a series of tests. The test results on the accuracy of flowmeters show that they work correctly. The application of a cooling system is proven faster the sedimentation process, which in turn shortens the time of the biodiesel purification process. In addition, the control system allows the machine to operate automatically, thereby reducing the operator's need significantly.**

***Index Terms* - biodiesel, purification, cooling system, flowmeter, FAME.**

INTRODUCTION

Indonesia is one of the countries that have vast natural resources, including petroleum. The overuse petroleum is worried giving an impact on the availability of the resources because it cannot be renewable. Based on data from the Indonesian downstream oil and gas regulatory authority, consumption of Fuel Oil in 2016 increased by 2.76% to 73.56 million kiloliters from the previous. Therefore, one way to reduce the use of fossil fuels is by switching diesel to biodiesel. Biodiesel is an alternative fuel because it comes from plants. However, although biodiesel is auspicious, the biggest challenge is the higher production costs compared to oil prices [1-3].

Many methods and processes for making biodiesel have been carried out, one of which is the manufacture of biodiesel through the zeolite adsorption process [4-6].

Despite all these researchers using zeolite for the adsorption process, they made several modifications and used different main ingredients, such as waste cooking oil and soybeans. Another method of making biodiesel is using NaOH as a catalyst [7-11]. Similar to the case of the zeolite method, even though they used the same catalyst material, the composition and mechanism of the process are different.

Many studies have been performed to develop the technology for producing palm oil [12-14]. Other developments have been also carried out in producing biodiesel from waste cooking oil [15]. The development of biodiesel made from waste cooking oil has a double benefit for environmental protection; the first is reducing the amount of carbon gas due to biodiesel coming from plants. The second is reducing waste, where waste cooking oil is hazardous to the environment. In addition, biodiesel is biodegradable and contains almost no sulfur. Another advantage of biodiesel from waste cooking oil mentioned by Rachmadona et al. [16] is that it could reduce production costs. Most biodiesel-based waste cooking oil research has focused on developing appropriate catalyst composition at the stage of the esterification process [17, 18].

The drawback of making biodiesel from waste cooking oil is the long production time. The long production time is mainly caused by the time required for purification the fatty acid methyl ester (FAME). The FAME is the output resulting from the esterification process. The purifying process takes a long time because the sedimentation process to separate the biodiesel phase, the glycerol phase, and the dirty water phase needs a long time. In addition, the biodiesel purifying process must be carried out repeatedly to get good results. The development of biodiesel processing equipment has been widely studied. In 2013, Jaryadi et al. [19] developed a biodiesel processing machine where the separation process already uses an automatic valve opening system. The use of the control system is still limited to valve opening and closing.

Khan et al. [20] also developed a simple machine using used materials with an almost similar mechanism as developed by Jaryadi et al. [19]. Both developed machines were not equipped with a cooling system; hence, the purification process took a very long time.

Another biodiesel processing machine was developed by Zhang et al., [21]. The esterification process was performed using an ultrasonic reactor. The reactor-based ultrasonic wave was also developed by [22-24]. Test results on reactor-based ultrasonics waves show that this method increases the mass transfer rate, which is higher than 60oC [23]. Higher temperatures cause the cooling and purifying process longer. In addition, most of the reactor-based ultrasonic wave is generally without a cooling system and separating the glycerol and biodiesel phases is performed manually. To overcome the problem of long processing time, Abbaszaadeh et al., [24] apply an electrostatic method that uses high-voltage electricity and weak currents. However, the time required only for the sedimentation process is high, within 40 – 70 minutes.

Therefore, in this paper, a machine for producing biodiesel-based waste cooking oil was developed. This machine was designed to carry out three stages of biodiesel processes: the esterification process, the purification and cooling process, and the filtration process. The machine for the esterification stage has been developed by Rahmawaty et al. [25]. The discussion in this article focuses on developing a biodiesel purification system equipped with a cooling system. This machine uses a specially designed thermoelectric module as a cooling system for oil received from the heating tank (esterification process). At the same time, the purifying system uses a motorized valve conditioned by a flow sensor so that the opening of the valve adjusts to the input volume of oil that is put into the processing tank.

This machine was developed to reduce the time of purification process during producing biodiesel from used cooking oil. The fast-cooling process is expected to speed up the precipitate process to produce the glycerol phase. The automatic system applied to this machine, apart from speeding up the biodiesel processing process, also aims to make the biodiesel purification process sustainable and can significantly reduce operator involvement.

MATERIALS AND METHODS

This study aims to design and construct a biodiesel purification machine equipped with a cooling system. Therefore, in the beginning, the machine should be designed, including the design of mechanical construction, the design of electronic systems, and the design of control systems. The design was then used to develop the construction of the machine. Several tests were performed to ensure the developed machine met the objectives of this research. The engine testing process is carried out to determine machine performance and capacity.

In addition, tests are also conducted to determine the variables used in programming the control system, such as the time required for the sedimentation process or the fluid flow rate.

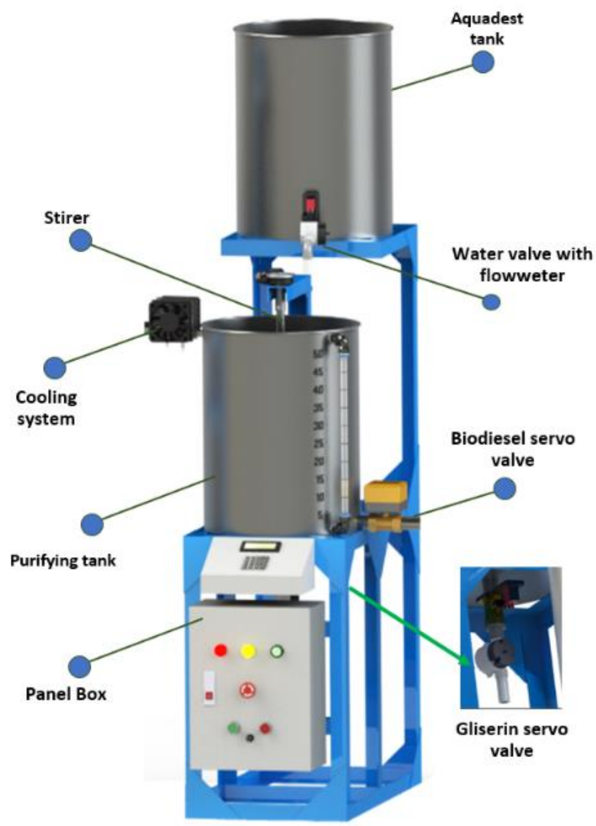

FIGURE 1 THE DESIGN OF PURIFICATION MACHINE FOR BIODIESEL BASED USED COOKING

The aquadest tank has a valve driven by a servo motor and a flowmeter to define the water output volume. In the purification tank, there is an indicator of the volume. Before the FAME enters the purification tank, it will be cooled using a Peltier module. The purification tank also has a valve driven by a servo motor and a flowmeter to regulate glycerol disposal. A motor is used for stirring the mixture. There is a control panel and interface to display the temperature and input the volume of the material being processed.

The design of the machine is presented in Figure 1. The aquadest tank on the top is equipped with a flowmeter to clculate the amount of aquadest enter to the purification tank. The amount of aquadest released was requlated by opening the servo-valve during the purification process. The block diagram of the flowmeter working system can be seen in Figure 2a. The working process of the servo-valve is controlled by Arduino based on the volume set in the beginning. When the servo valve is opened, the liquid flows through the flowmeter. Then the flowmeter calculates the volume of liquid released. When the volume has reached a given setpoint, the servo-valve closes again.

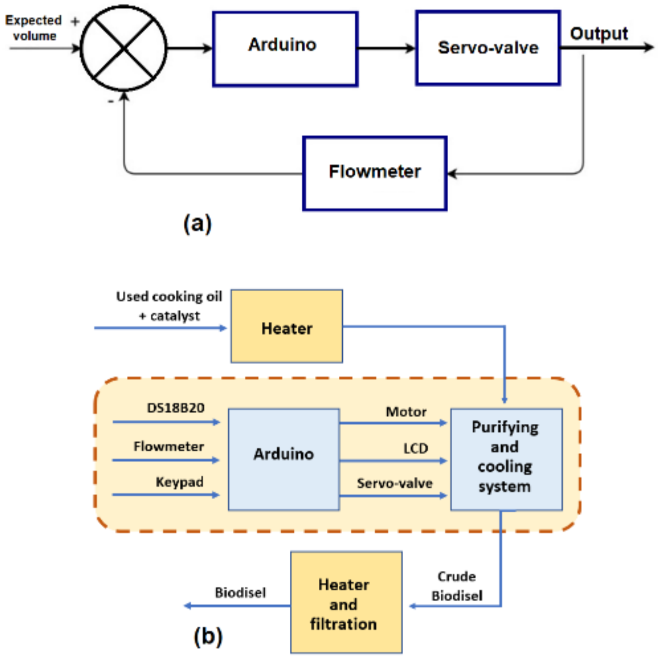

Figure 2 A) Flowmeter Diagram, And B) Block Diagram Of Biodiesel Processing Machine

Overall, the purification processes, including the cooling process, are controlled by Arduino based on several parameters such as the DS18B20, flowmeter, keypad used to control the motor, LCD, and servo-valve. The cooling and purifying process results in crude biodiesel, which is then filtered in the heating and filtration tank. The block diagram of the overall biodiesel manufacturing process is presented in Figure 2b. The section marked with the dotted line is a block diagram for the cooling and purifying processes.

A flow chart to describe the sequence of processes starting from the cooling process, purifying, to releasing biodiesel, is presented in Figure 3. The process begins with the FAME flowing from the esterification tank through a pipe connected to the cooling box. After the FAME enters the purification tank completely, the FAME is then deposited for the sedimentation process. After the sedimentation process is complete, the FAME is separated into two phases, the biodiesel phase at the top and the glycerol phase at the bottom. Servo-valve B, located at the bottom of the tank, removes the glycerol. After removing the glycerol is completed, servo-valve B closes, and servo-valve A, which is located on the aquadest tank, opens to release the aquadest into the purification tank. Then, the stririr motor is activated to mix biodiesel and aquadest. After the mixing process is completed, the mixture is deposited again for sedimentation.

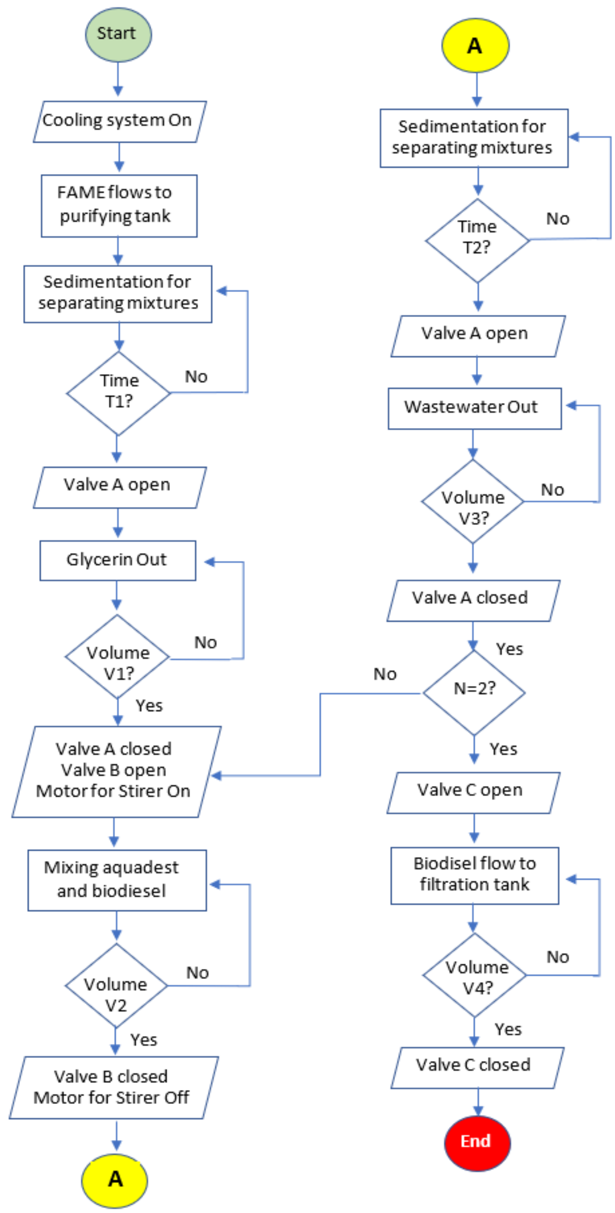

Figure 3 Flowchart Of Purifying Biodiesel Processing Equipment

Results And Discussion

The biodiesel purification machine with a cooling system has been developed, as shown in Figure 4a. Figure 4b shows a purification tank with a cooling system on top. After the esterification process, the cooling system aims to cool the FAME. The purification tank was made of stainless steel, and there is an indicator to determine the tank's volume.

Figure 4c shows the water supply valve, which is activated during the purification process. The valve is also equipped with a flowmeter. The flowmeter was used to determine the volume of aquadest entering the tank and removing from the tank. When the amount of fluid needed as typed on the keypad is reached, then the valve opens. Aquadest flow through the flowmeter and the flowmeter begins calculating the volume of incoming water. The valve is closed when the expected volume has been reached. Figure 4d shows a valve for removing glycerin after completing the sedimentation process.

A series of tests were carried out to check the machine's performance in producing biodiesel from used cooking oil. Several tests have been carried out, including the test to check the effectiveness of the cooling system. Another test was aimed to check the accuracy of the flowmeter. Furthermore, testing is also carried out to see the machine's overall performance in producing biodiesel. Details for each test result are presented in sub-chapters *A - C*.

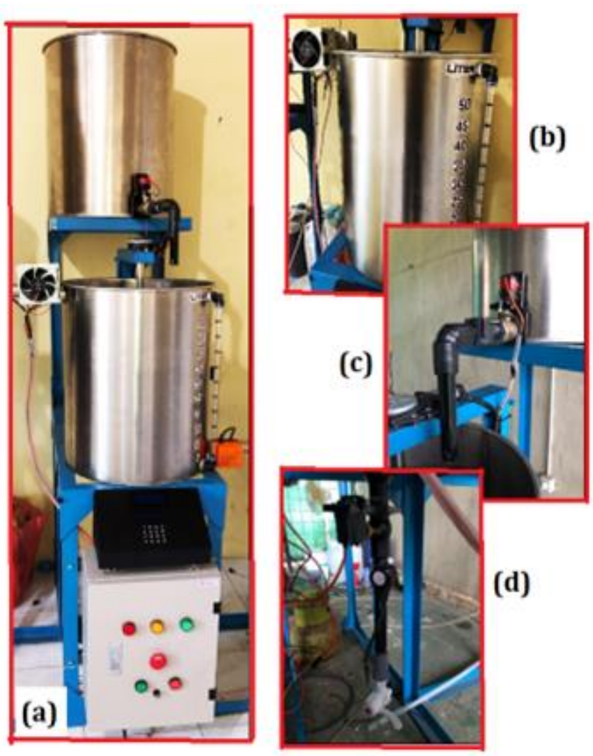

FIGURE 4 A) CONSTRUCTION OF PURIFYER MACHINE, B) PURIFICATION TANK WITH COOLING SYSTEM, C) AQUADEST VALVE, D) GLYCERIN OUTPUT VALVE

A. *Test On The Effectiveness Of The Cooling System*

The test for determining the performance of the cooling system in reducing the temperature of FAME coming out of the esterification process has been conducted. The test was carried out by heating the FAME to about 60^{o}C. Then it flows to purification tank by opening the valve of the esterification process. The FAME passes through the cooling system as shown in Figure 5a.

The cooling system has a thermometer for detecting the temperature of the fluid flowing through the cooling system. A thermometer is also attached to the purification tank to check the temperature of the fluid.

The cooling system was tested two times, the first to check its performance in reducing the temperature of the box without the FAME, and the second the test to check the ability to reduce the temperature of FAME. The first test is performed by activating the cooling system and detecting the temperature drop based on the temperature presented on the screen. In this test, the temperature drop in 10 seconds was measured and recorded. Time measurement using a stopwatch is shown in Figure 5b. The measurement data are presented in Figure 6a. The graph in the figure shows that the initial temperature of the cooling box is 32.3 ^{o}C, and within 10 seconds, the temperature drops to 25.69 ^{o}C. In average, the temperature drops in 10 seconds at about 6.61^{o}C.

The second test was carried out to examine the capability of the cooling system in reducing the temperature of the FAME coming out from the esterification tank as shown in Figure 5a. In this test, data collection was conducted five times. The temperature measured is the temperature of FAME when entering the cooling system (input temperature), and the temperature when FAME leaves the cooling system (output temperature). The measurement results are presented in Figure 6b. From the graph in this figure, it can be seen that the temperature of FAME that passes through the cooling system decrease. The temperature drop is the difference between the input and output temperatures. The average temperature drop from 5 times of measurement is 3.89^{o}C.

(a) (b)

FIGURE 5 A) TESTING OF THE COOLING SYSTEM, B) MEASUREMENT OF TEMPERATURE AND TIME

Although the temperature decrease was not significant, adding a cooling system could significantly accelerate the sedimentation process. The time required for the sedimentation process on the developed machine is only 20 minutes. Within 20 minutes, the formation of the glycerol phase and the biodiesel phase had occurred ideally. The sedimentation time is very fast when compared to the results of previous research on the biodiesel purification process without a cooling system. Jaryadi et al. [19] developed a biodiesel processing machine where the time required for the deposition of the biodiesel solution was 40 minutes.

Kumar et al. [14] conducted a test with the sedimentation of 60 minutes. Meanwhile Fitriani et al. [25] made biodiesel from used cooking oil manually with a settling time of one day or 24 hours. Another study conducted by Wahyuni et al., [26] with a manual process and without a cooling system resulted in a very long time of 48 hours. The results obtained from this study are still better when compared to the electrostatic method using high-voltage electricity and weak currents developed by Abbaszaadeh et al., [24]. The settling time taken ranges from 40 – 70 minutes.

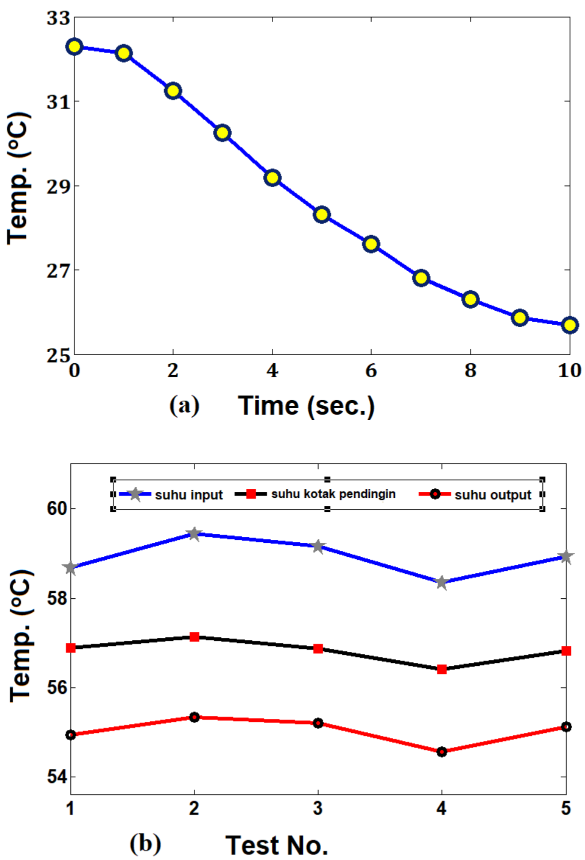

FIGURE 6 RESULTS OF TEMPERATURE MEASUREMENTS IN THE COOLER WITHOUT A SOLUTION, AND B) THE RESULTS OF MEASURING THE TEMPERATURE OF THE SOLUTION PASSING THROUGH THE COOLER

B. Test The Accuracy Of The Flowmeter

This machine has two flowmeters. The first is attached on the aquadest tank, and the second is set on the purification tank. The flowmeter on the aquadest tank is used to calculate the volume of aquadest entering the tank for purification. Meanwhile, the flowmeter on the purification tank defines the volume of dirty water removed from the purification tank after the purification process finishes.

The test in this stage is to check the accuracy of both flowmeters. Eight tests were carried out with various volumes of water. The amount of water that must be removed from the aquadest tank is set on the keypad buttons as shown in Figure 7a. Furthermore, the servo motor rotates to open the valve at an angle of 90^o.

After the valve is opened, water flows through the valve and enters the measuring cup that has been prepared, as shown in Figure 7b.

The test result on the accuracy of the flowmeter on the aquadest tank and the purification tank are presented in Figure 8. From the presented data, it can be seen that the error rate at low volume is relatively high. The highest error of the flowmeter in the aquadest tank is 37.5%, which is occurred at a volume of 250 ml. The error has decreased significantly as the volume increases. Accurate results were obtained when the volume was within 1250 ml to 2000, where the error rate is 0%. The test result also presents an almost similar trend on the flowmeter for the purification tank. The highest error of 28.57% occurred at a volume 250 ml. The error rate also decreased significantly as the volume increased. Accurate results were obtained for the volume of 1750 ml to 2000 ml, where the error rate was 0%.

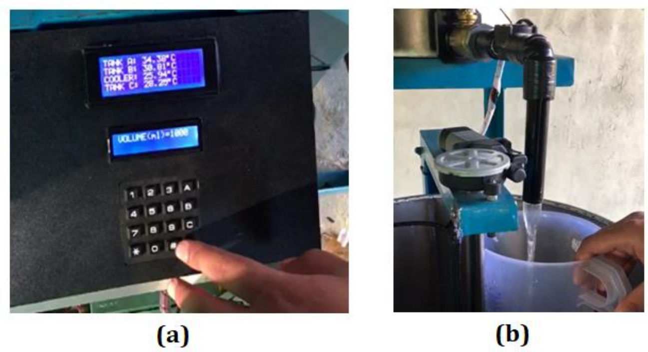

FIGURE 7 A) INPUT VOLUME ON THE KEYPAD, B) MEASURING VOLUME OF WATER OUT FROM AQUADEST TANK

The results show that the volume of aquadest entered to removed from the aquadest tank and the glycerol removed from the purification tank is not accurate at low volumes. The accuracy increases as the volume increases. From the observations, it is believed that Inaccuracy occurred due to the valve's slow motion during the opening, making the flowmeter difficult to calculate accurately. The error in opening the valve has a very significant impact on the small volumes. The impact is getting smaller as the volume increases. The results of this test indicate that the flowmeter can function appropriately for high volumes (> 1500 ml). Bearing in mind that the capacity of the purification tank is quite large, which is 30 liters. The mixing and output capacity of the purification tank is effectively above 2000 ml. The test results, as presented in Table 1, show that for a biodiesel capacity of 10.5 liters, the amount of glycerol removed is 2.5 liters. The amount of glycerol released through the purification tank increases as the amount of biodiesel processed increases. So, it can be concluded that the flowmeter is working accurately.

Using a flowmeter to determine the amount of volume flowing is very useful in developing this machine. The process of mixing aquadest and crude biodiesel in the purification tank, as well as the process of removing glycerol from the purification tank is carried out without the involvemen of the operator.

The application of a control system to this machine is one of the factors that speed up the biodiesel-producing process compared to several other machines that have been developed by [14, 26-28].

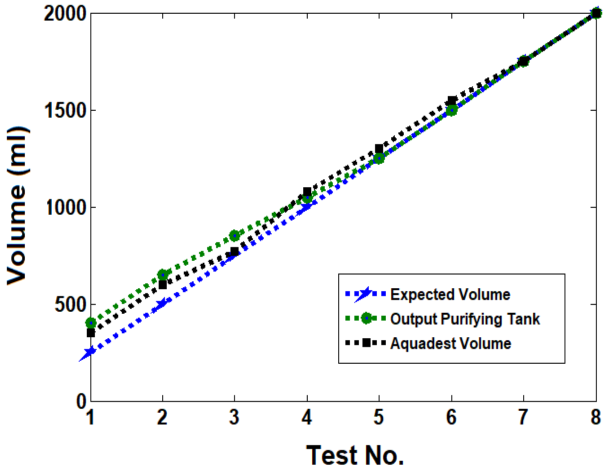

FIGURE 8 THE RESULTS OF THE FLOWMETER TEST ON THE AQUADEST TUBE AND PURIFICATION TANK

C. Measuring Efficiency Of Purification Machine In Producing Biodiesel

This test was aimed to check the efficiency of the purification machine in producing crude biodiesel before entering to the filtration process. The hot FAME enters the purification tank through the cooling system is then deposited for 20 minutes for the sedimentation process. The sedimentation was carried out to separate the glycerol and crude biodiesel phases. The glycerol phase is at the bottom, and the crude biodiesel phase is at the top. The glycerol is then removed by activating the servo motor on the purification tank to open the valve. After the glycerol is removed, the servo motor activates again to close the valve.

Furthermore, the servo motor on the aquadest tube is active to open the valve so that the aquadest enters the purification tank. At the same time, the stirrer motor is also active so that the raw biodiesel and water are mixed. After the amount of water required for purification process is reached, the servo motor on the aquadest tank is active to close the valve. Furthermore, the mixture of crude biodiesel and water is precipitated again for 20 minutes. After 20 minutes, a dirty water phase is formed at the bottom and a crude biodiesel phase at the top. Then the servo motor on the purification tank is active again to open the valve so that the dirty water phase comes out. The process of purification raw biodiesel lasts for two times so that the biodiesel becomes clean.

TABLE 1
VOLUME OF BIODIESEL OBTAINED FROM PURIFICATION PROCESS

FAME (L)	Glycerol (L)	Crude Biodiesel (L)	Crude Biodiesel %
10,5	2,5	8	76,2%
16	4	12	75%
25	6	18	72%
Average			**74,4%**

The output of the biodiesel purification process results is presented in Table 1. From the table, it can be seen that the purification process can take place well. The average crude biodiesel produced from the purification process is 74.4% of the initial volume. The initial volume is the mixture of used cooking oil and catalyst that enters the purification tank.

CONCLUSION

In this research, a biodiesel purification machine equipped with a cooling system has been developed. This machine was developed for biodiesel-based used cooking oil. Several tests were carried out to check the accuracy of the sensors used on the machine and to see the purification machine's effectiveness in producing crude biodiesel. The cooling system is proven to faster the cooling process. Even though the temperature of FAME, which is pass through the cooling system, reduces insignificantly, it could faster the sedimentation process. The test results on the accuracy of flow meters used by the machine show that they work correctly for the capacity of the machine. The application of a cooling system is proven to be able to faster the sedimentation process, which in turn shortens the time of the biodiesel purification process. In addition, the control system allows the machine to operate automatically, thereby reducing the operator's need significantly.

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