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Research Article

Redesign of water-diesel emulsion fuel mixer

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ABSTRACT

Emissions and fuel consumption are essential parameters to indicate the working of a combustion engine. This paper discusses the methods to achieve lower emissions and efficient fuel consumption. One of the methods is by making emulsion fuel. The emulsion-making methods are surfactant emulsion, micro-emulsion, ultrasonic emulsion, and real-time emulsion non-surfactant (RTES). In the research, the emulsion fuel is a mixture of B30 Biodiesel and water without surfactant that is supplied in real-time after being mixed in a mixer. The ratio is 85% biodiesel and 15% water. The RTES mixer in the old model has a big size, and high-power consumption of about 150-433.5 *W*. This research aims to develop a simple design and low power consumption of the RTES Mixer. The new RTES mixer design only needs 150 *W* motor power. Its dimension is more superficial and produces tiny droplets with a main diameter range between 0.1 to 0.5 μm, visually well-mixed.

1. INTRODUCTION

Exhaust emissions and fuel consumption are essential parameters of engine performance, and therefore, various methods and technologies have been developed to improve exhaust emissions and engine fuel consumption [1]. One of these methods is mixing water into the fuel, B30 biodiesel fuel, in an emulsion. The principle of an emulsion is to combine two or more substances that do not mix naturally [2].

When water and diesel fuel are mixed, naturally, they will not be homogenous [3]. Diesel fuel floats above the water because water is heavier than any oil [4]. If the diesel fuel is biodiesel (in Indonesia, known as "bio-solar"), the white bubbles occur there, and those bubbles are the bio-oil fraction. It is made with animal or vegetable oil (biodiesel in Indonesia uses vegetable oil) [5]. Initially, biodiesel was easy to clot, and some conditions that cause clotting are cold temperature and long-time storage. Therefore, the water and biodiesel mixture needs methods to make it useable as an alternative fuel [6].

Emulsion fuel must be stable for a long period. Stability is about keeping two immiscible liquids homogenous, not separate [7]. Some methods can make a stable emulsion, such as surfactant addition, micro-emulsion, ultrasonic, and real-time mixing [8]. Those methods can be combined or only one option chosen [9].

A mixing unit is an emulsion maker that works on stirring the mixture with a specific rotation speed [10]. The stirring power source is an electric motor connected to the transmission system or direct shaft connection. Unfortunately, the current mixer technology still uses a large mixer type, requiring a large placement space and consuming large amounts of power. Therefore, it is necessary to develop a mixer design that is more compact and consumes less power [11].

Although previous mixer design studies found a reduction in NOx and fuel consumption, they still faced several problems [12,13]. Research conducted by Yahya et al. [12] showed that droplet size increases to 56 *μm* by using ultrasonic transducer temperature at 44°C. The power required for the ultrasonic transducer is 120 *W* [12]. Sartomo used a real-time emulsion non-surfactant (RTES) mixer using 3000 *rpm* until 7000 *rpm* mixing speed. It needs 150 – 433,5 *W* power and uses a big motor (1 phase AC motor) [13].

Therefore, this research introduces a new method of making water-diesel emulsion fuel. Development aspects are designing a simple RTES mixer with a compact size, low energy consumption, and stable emulsion. This research has no surfactant usage, with a water-diesel ratio of 15% water and 85% biodiesel [14]. The absence of surfactants will reduce costs due to high prices [15].

2. MATERIAL AND METHODS

The redesign of the mixer began with knowing the specific fuel flow requirements of the engine. First, the need for fuel discharge was measured by calculating the fuel volume difference. Next, the fuel was filled in the measuring cup and channelled to the diesel engine injection pump. When the diesel engine operated at a certain speed, the difference in fuel volume was calculated within 1 minute, and then the results were converted into units per second [16]. From the measurement results, the fuel flow rate was 15 *ml*/second at 2,600 *rpm*.

In the latest design, the RTES mixer was made with smaller dimensions. Dimensions were made as small as possible for more practical placement. DC motors were used because it's available in small sizes and can produce high rotations of up to 11,500 *rpm* [17]. The selection of motor power was adjusted to the stirring rotation. Research by Sartomo [13] showed that it took 150 *W* of power to operate the RTES mixer at 3000 *rpm*. Based on these references, a motor with a power of 150 *W* is selected, a DC motor type.

Transmission in a timing belt pulley was used to get a rotation close to 3000 *rpm*. The function of the timing belt pulley was to reduce the rotation of the electric motor so that the rotation was close to the target, which was 3000 *rpm* [18]. By adjusting the housing dimensions, the pulley diameter was 36 *mm*, and 12 *mm* was selected. The pulley ratio used is 3:1, so it lowers rotation become 3,833.33 *rpm*. The rotation value was close to 3000 *rpm* and could be adjusted by reducing the DC motor voltage through the power supply setting [19].

Research conducted by Prasetya [20] found that the minimum diameter of the blade shaft is 2 *mm*. However, this research design used a diameter of 8 *mm*, so it is still safe. While the diameter of the drive shaft is 5 *mm*, adjusting the diameter of the motor shaft. The shafts are safe because those diameters are more significant than the requirement [20]. Figure 1 shows the form of the new RTES mixer system, and its specification is shown in Table 1.

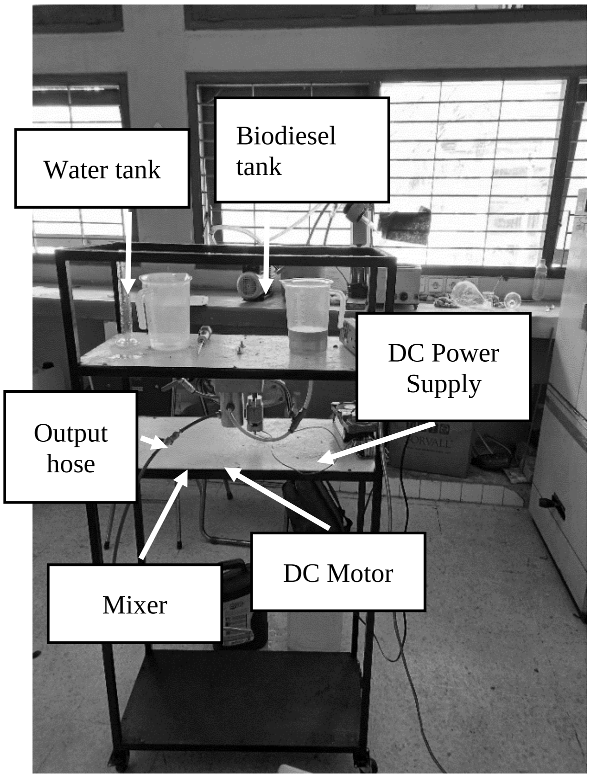


Figure 1. RTES mixer new system.

After being assembled, the new RTES mixer was also being tested. The tests were visual tests and droplets' diameter measurements using a microscope. A Microscope, OptiLab camera, and laptop were used as the support devices. The distribution of droplet diameters can be shown in a statistical graphic and diagram [21]. Figure 2 displays the microscope, camera, and laptop system for recording and measuring the droplet distribution and size.

Table 1. RTES mixer specification.

Description	Specification
Material	Aluminium (tank, blade), stainless steel (shaft)
Mixer dimension *(mm)*	40 *mm* (diameter), 91 *mm* (height), 1 *mm* (thickness)
Biodiesel capacity	500 *ml*
Water capacity	500 *ml*
Mixing capacity	70 *ml*
Electric motor	DC775 12*V*
Motor power	150 *W*
Max motor rev	11.500 *rpm* @12*V* DC
Transmission system	pulley with a timing belt (3:1)
Shaft diameter	5 *mm* (motor), 8 *mm* (*mixer*)
Power source	DC Power Supply

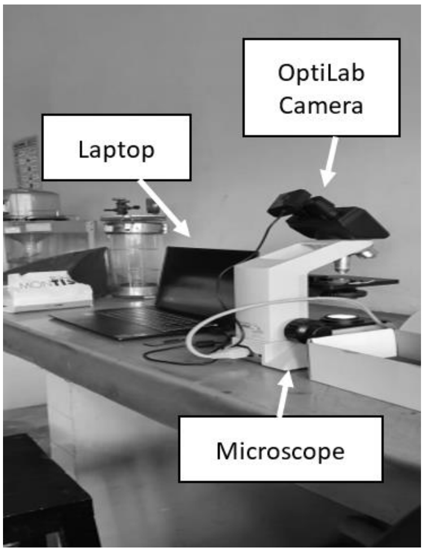


Figure 2. Microscope, camera, and laptop system.

Moreover, the emulsion is made according to the type of variation in the speed and determined stirring cycle. The emulsion sample was dropped onto the microscope slide table simultaneously with the start of the image recording. Image recording is performed for up to 132 seconds. Photos at any second can be taken by capturing the screen [22]. Observational photos are reprocessed by re-entering the ImageRaster to display the size scale. To facilitate particle measurement, image scaling is pre-activated in ImageRaster, so that the scale appears automatically and fits the microscope [23]. The image that has been scaled is then measured with the circle tool in the Excel table ImageRaster software. Emulsion grains were measured by taking samples from the smallest to the largest size of 100 [24]. Samples of items that have been measured with the tools in ImageRaster can be collected for sorting or sorting in Microsoft Office Excel. The data that has been processed in Excel is then transferred to OriginPro so that it can be converted directly into various forms of statistical presentations, such as histograms and box plots [25].

3. RESULTS AND DISCUSSION

The tool's compact design requires a type of motor that is small in dimensions but still fits the needs. The mixing power is calculated using non-dimensional analysis (power number) to determine the type and power of the motor [26]. The power number is a Reynolds number (*Re*) function, which is constant when the *Re* value is above 10,000 [27]. The Reynolds number shows the flow conditions of fluid in the mixer, < 10 laminar conditions, 10 < *Re* <10,000 transitional conditions, > 10,000 turbulent conditions. The equations (1) and (2) are used to calculate the Power number and Reynold number [28].

$$Np = \frac{P}{\rho . N^3 . d^5} \quad (1)$$

$$Re = \frac{d^2 . N . \rho}{\mu} \quad (2)$$

Power number (Equation (3)) is calculated by knowing in advance the Reynolds number [28].

$$P_m = P_n . d^5 . N^3 . \rho \quad (3)$$

The viscosity of the emulsion of 85% biodiesel and 15% water is 0.0547 *Pa.s* with a density of 858.8 kg/m^3 [29]. The results of the calculation of the driving power requirements are shown in Table 2.

Table 2. Mixer's Design Parameter.

Parameter	**Value**
Blade diameter	0.029 *m*
Density	858.8 kg/m^3
Viscosity	0.0547 *Pa.s*
Mixing speed	3000 *rpm* / 50 *rps*
Reynold number	660.19
Power number	3
Impeller power	6.6 *W*

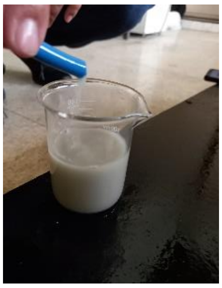
Visual stability observation time starts at 0 seconds when the mixer is stopped until 2 minutes. Changes in the physical appearance of the emulsion over time visually indicate emulsion stability. For example, mixing water and biodiesel into an emulsion is indicated by forming a milky brown liquid. After a particular time, a white precipitate will form a yellow liquid that floats [22]. The white precipitate is water mixed with vegetable fat in biodiesel, while the yellow colour is the content of pure diesel oil (in Indonesia, it is known by the market name "bio solar") from petroleum refining. Table 3 shows the visual test results of water-diesel emulsion fuel.

Overall, the emulsion mixed for 1 minute looked light green in the top layer and watery in the bottom layer at 0 seconds. The emulsion form shows that water and biodiesel are not mixed. The stirring time only lasted a short time, so the two liquids did not have time to reach the evenly mixed phase. If the emulsion is used as fuel, it can cause the engine to stop suddenly and experience a water hammer, which is water compression by the pressure of the combustion chamber. A water hammer can cause the piston head to break, resulting in fatal engine damage [30].

At 3 minutes of mixing time, various colours were obtained based on variations in mixing speed. The colour difference that occurs is the appearance of a bright yellow emulsion at 1000 *rpm* and milk chocolate at 2000 *rpm* and 3000 *rpm*. Overall, no sediment and biodiesel were seen floating on the water at 0 seconds, indicating that the emulsion was evenly mixed.

The evenly mixed emulsion can be used as fuel in diesel engines. The use of emulsion as fuel needs to consider the stability of the mixture, which changes with time. After being observed for 2 minutes, the emulsion was dark green in the top layer and clear water in the bottom layer at a speed of 1000 *rpm*. The appearance of the clear water layer indicated that the emulsion had separated significantly 2 minutes after stirring. Mixing at speeds of 2000 *rpm* and 3000 *rpm* produces almost the same results in brown colour with a thin layer of clear water below. The difference lies in the clear water layer, where the layer looks clearer at 3000 *rpm* stirring but is not much different from 2000 *rpm* stirring. For use in diesel engines, emulsions stirred at speeds of 2000 *rpm* and 3000 *rpm* are recommended. The length of the line from the mixer to the injection pump of the diesel engine should be kept as close as possible so that the emulsion is still stable when it enters the injection pump.

Table 3. Visual test of emulsion.

Mixing speed (rpm)	1 minute mixing time		3-minutes mixing time	
	Observation time			
	0 second	2 seconds	0 second	2 seconds
1000				
2000				
3000				

Figures 3 to 7 show the distribution of the droplets from time to time. There are some bubbles, and a change of colour from bright yellow becomes dark grey. Bright yellow shows the diesel liquid fraction, while dark grey shows the water fraction. Blur picture with full dark grey colour proves that the two liquids are not homogenous.

Emulsions that can be measured using a microscope are only 2000 r*pm* and 3000 *rpm* mixing in 3 minutes duration. Other emulsions separate quickly, so it only shows blurred images. Overall, the emulsion mixed for 1 minute looked light green in the top layer and watery in the bottom layer at 0 seconds. The emulsion form shows that water and biodiesel are not mixed. The stirring time only lasts a short time, so the two liquids have not had time to reach the evenly mixed phase. If the emulsion is used as fuel, it can cause the engine to stop suddenly and experience a water hammer, which is water compressed by the pressure of the combustion chamber. A water hammer can cause the piston head to break, resulting in fatal engine damage.

At 3 minutes of mixing time, various colours were obtained based on variations in mixing speed. The colour difference that occurs is the appearance of a bright yellow emulsion at 1000 *rpm*, and milk chocolate at 2000 *rpm* and 3000 *rpm*. Overall, no sediment and biodiesel were seen floating on the water at 0 seconds. It indicates that the emulsion is evenly mixed. Particle size and distribution are shown in Figure 8 to Figure 19.

The use of emulsion as fuel needs to pay attention to the stability of the mixture that changes with time. After being observed for 2 minutes, the emulsion was dark green in the top layer and clear water in the bottom layer at a speed of 1000 *rpm*. The appearance of the clear water indicated that the emulsion had separated significantly 2 minutes after stirring. Mixing at speeds of 2000 *rpm* and 3000 *rpm* produces almost the same results in brown colour with a thin layer of clear water below. The difference lies in the clear water layer, where the layer looks clearer at 3000 *rpm* stirring but is not much different from 2000 *rpm* stirring. For use in diesel engines, emulsions stirred at speeds of 2000 *rpm* and 3000 *rpm* are recommended. The length of the line from the mixer to the injection pump of the diesel engine should be kept as close as possible so that the emulsion is still stable when it enters the injection pump.

In a previous study using the RTES method and ultrasonic addition, the droplet diameter was obtained between 0.3 μm to 0.7 μm. On the other hand, research using a high-speed mixing method and 0.2% surfactant resulted in most droplet diameters of 2.5 *mm* with emulsion stability lasting for one week. Thus, the emulsion in the current study is close to the results of previous studies using additional surfactants or other aids.

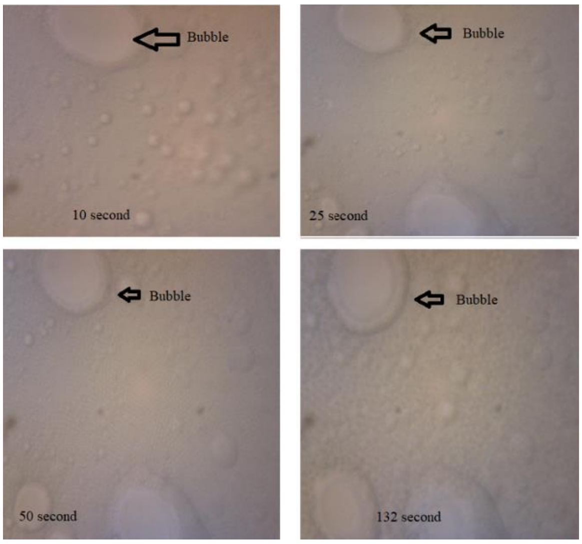


Figure 3. Droplet photos from 3 minutes 3000 *rpm* emulsion mixing.

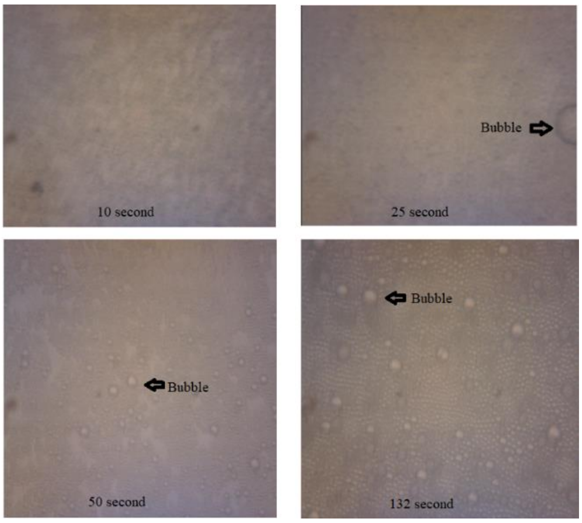


Figure 4. Droplet photos from 3 minutes 2000 *rpm* emulsion mixing.

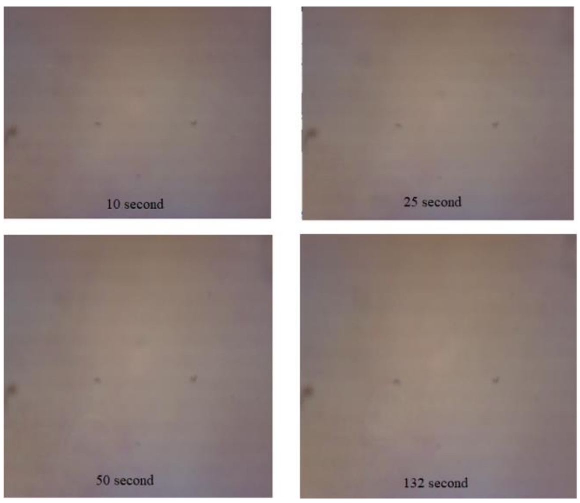


Figure 5. Droplet photos from 3 minutes 1000 *rpm* emulsion mixing.

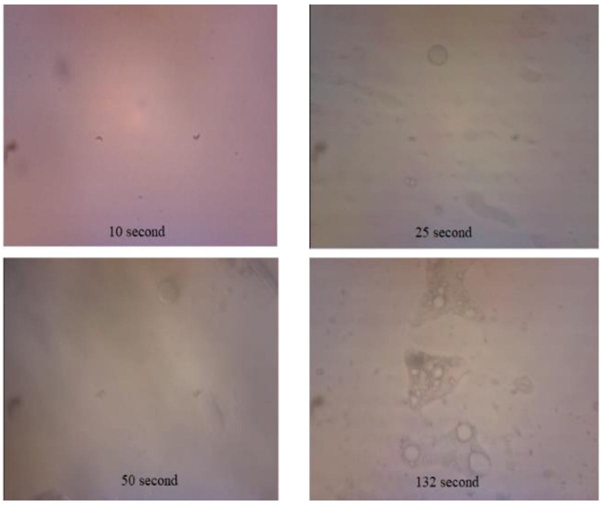


Figure 6. Droplet photos from 1 minute 3000 *rpm* emulsion mixing.

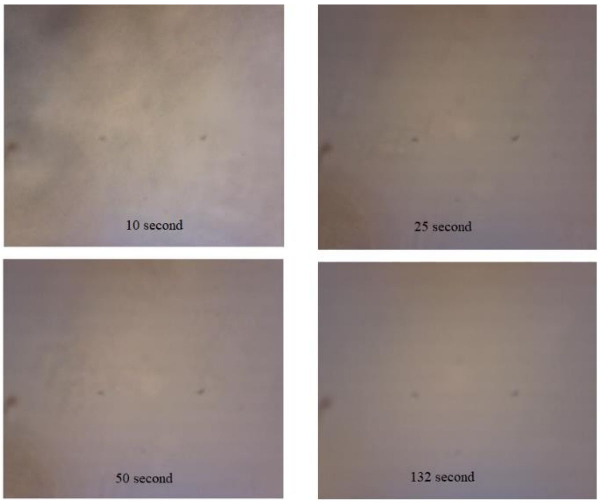


Figure 7. Droplet photos from 1 minute 2000 *rpm* emulsion mixing.

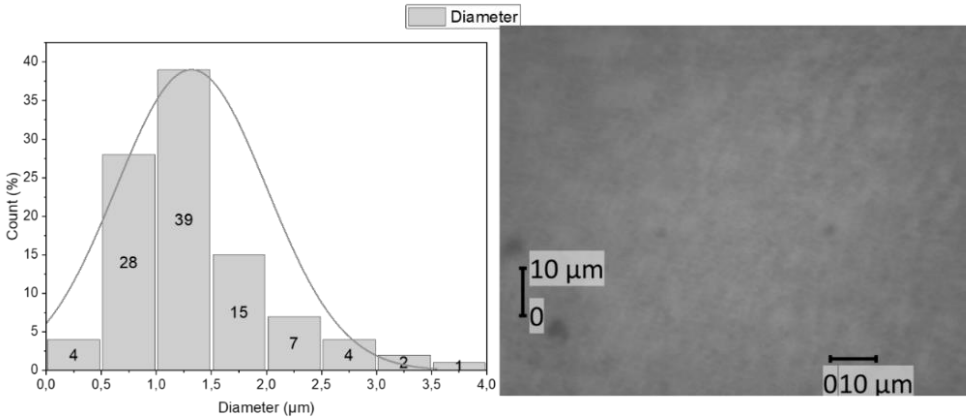


Figure 8. Emulsion particles (3 minutes mixing; 2000 *rpm*; 10 seconds).

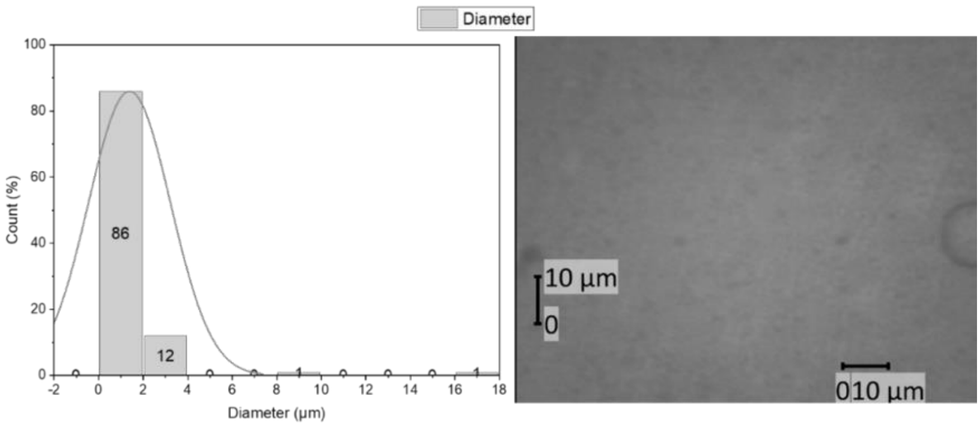


Figure 9. Emulsion particles (3 minutes mixing; 2000 *rpm*; 25 seconds).

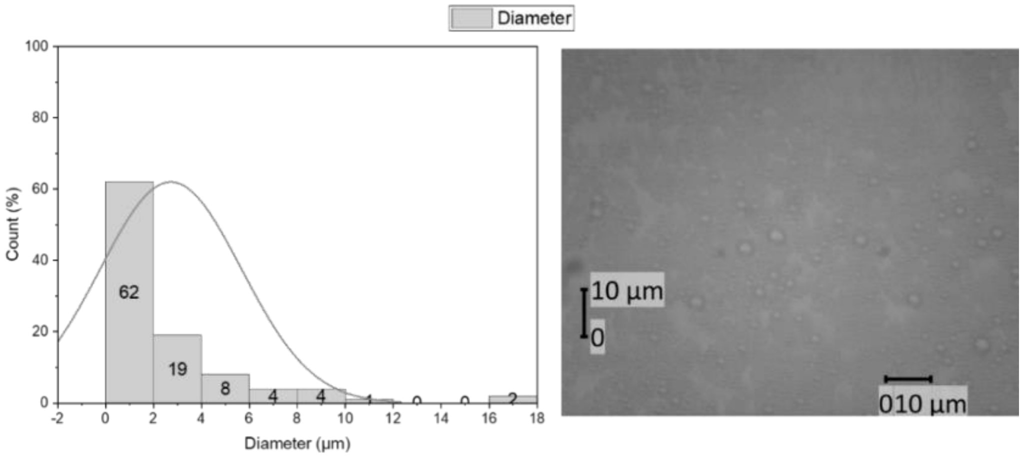


Figure 10. Emulsion particles (3 minutes mixing; 2000 *rpm*; 50 seconds).

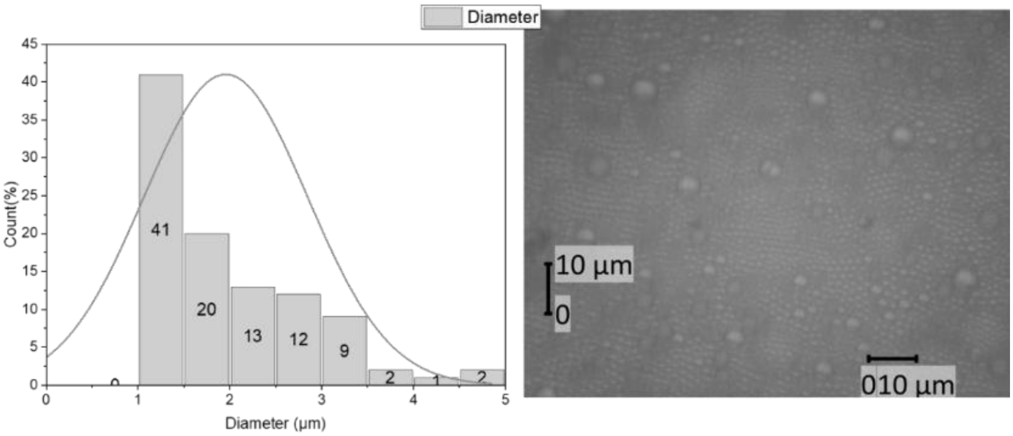


Figure 11. Emulsion particles (3 minutes mixing; 2000 *rpm*; 132 seconds).

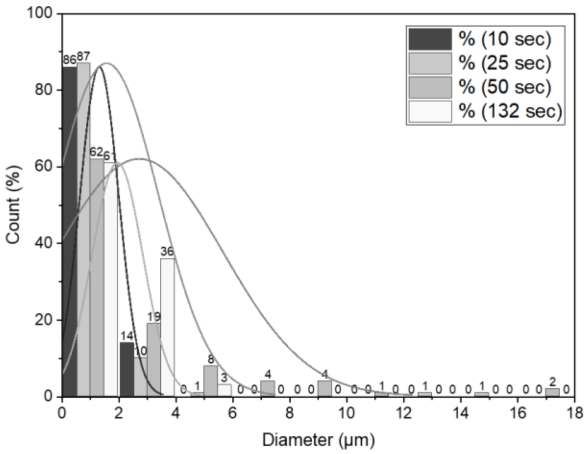


Figure 12. Droplet diameter distribution (2000 *rpm* mixing).

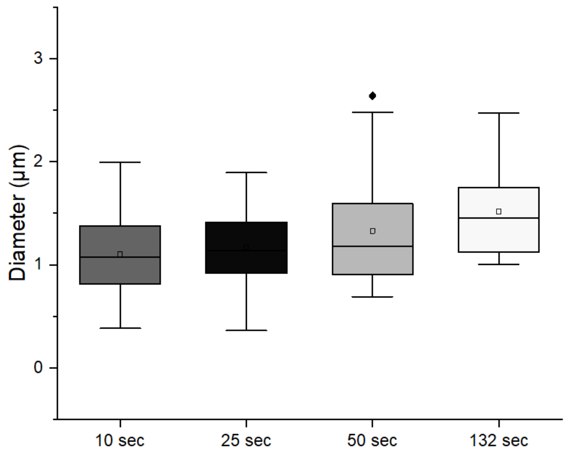


Figure 13. Droplet diameter at a certain time (mixing 3000 *rpm*).

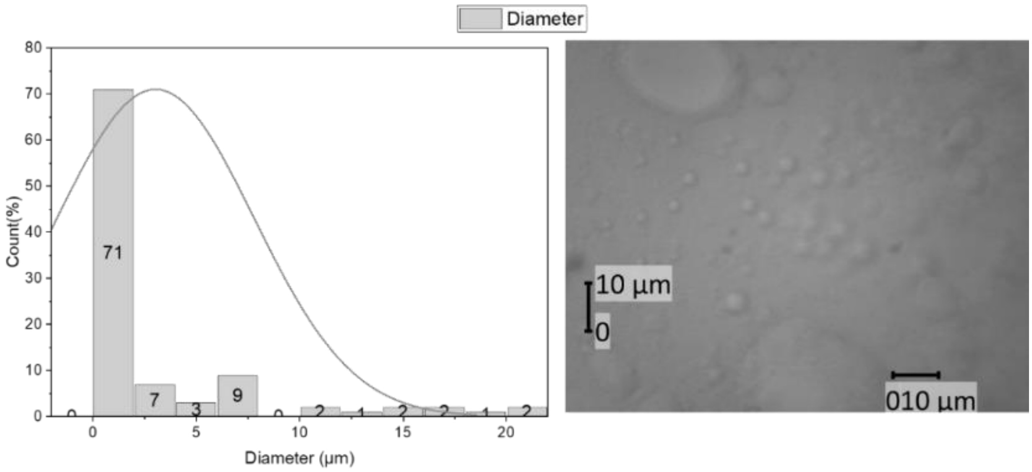


Figure 14. Emulsion particles (3 minutes mixing; 3000 *rpm*; 10 seconds).

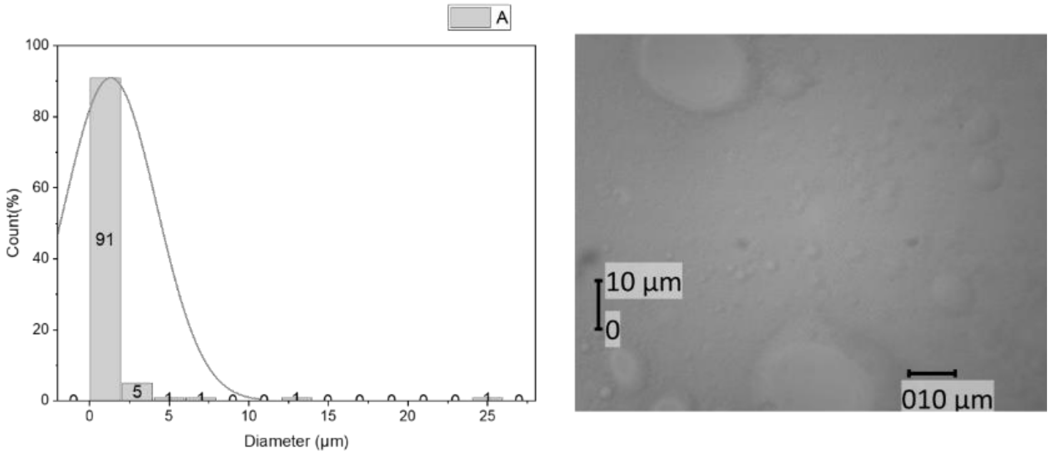


Figure 15. Emulsion particles (3 minutes mixing; 3000 *rpm*; 25 seconds).

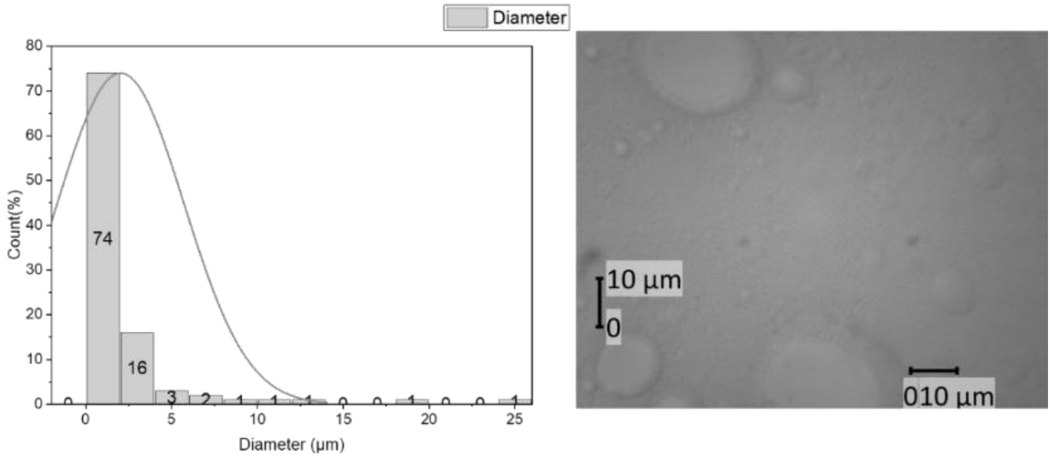


Figure 16. Emulsion particles (3 minutes mixing; 3000 *rpm*; 50 seconds).

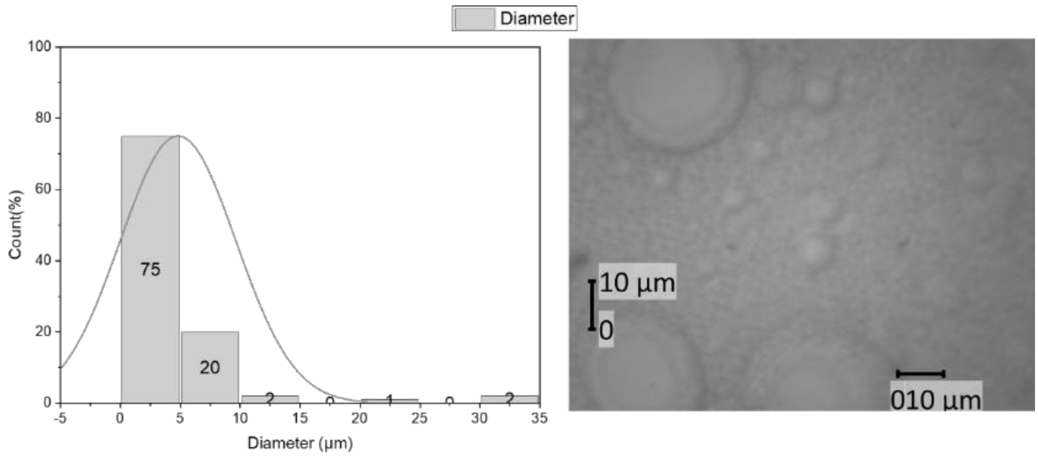


Figure 17. Emulsion particles (3 minutes mixing; 3000 *rpm*; 132 seconds).

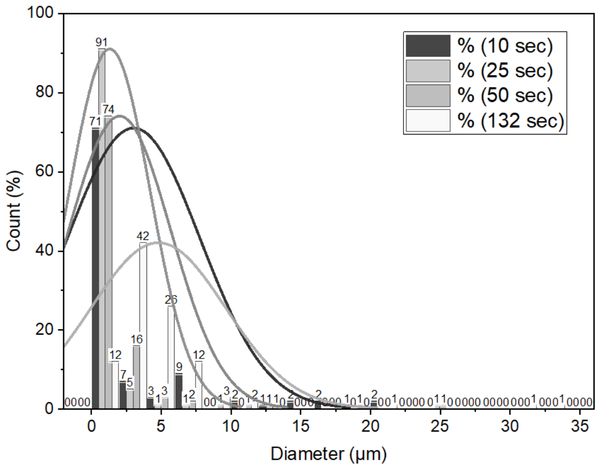


Figure 18. Droplet diameter distribution (2000 *rpm* mixing).

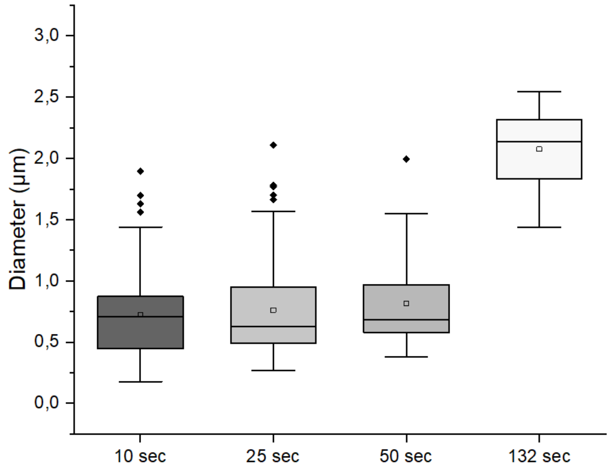


Figure 19. Droplet diameter at a certain time (mixing, 2000 *rpm*).

4. CONCLUSION

Research has been carried out by completing the design of a water-diesel emulsion mixer and performing visual and quantitative tests by measuring the droplet diameter. Based on the study, the recommended mixing time that produces a stable mixture for all mixing speeds is 3 minutes, with the achievement of visible and microscopic test results that can be mixed evenly at a stirring time of 3 minutes. Stirring for 1 minute can also produce a stable emulsion, but only at 3000 *rpm*. The emulsion tends not to be mixed and separates immediately so that the diameter of the droplet cannot be measured. The recommended mixing speed to produce a stable emulsion is 2000 rpm and 3000 *rpm* because the visual test results are evenly mixed, and microscopic photos can still show clearly visible grains. The smallest droplet diameter is (0.3 *µm*) obtained at a mixing speed of 2000 *rpm*. Thus, biodiesel and water emulsion fuel can be produced with the lowest stirring speed at 2000 *rpm* without additional surfactants. Furthermore, this research will be carried out by developing a mixing method so that the droplet diameter distribution is more even and testing the application of RTES mixers on diesel engines so that RTES mixers can be developed into ready-to-use technology.

CONFLICTS OF INTEREST

The author declares no competing financial interests or personal relationships that could have appeared to impact the work reported in this paper.

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REFERENCES

[1] W. Knecht, "Diesel engine development in view of reduced emission standards", *Energy*, vol. 33, no. 2, pp. 264–271, 2008. https://doi.org/10.1016/j.energy.2007.10.003.

[2] D. Clausse, F. Gomez, C. Dalmazzone, and C. Noik, "A method for the characterization of emulsions, thermogranulometry: Application to water-in-crude oil emulsion", *Journal of Colloid Interface Sciences*, vol. 287, no. 2, pp. 694–703, 2005. https://doi.org/10.1016/j.jcis.2005.02.042.

[3] N.G. Eskandar, S. Simovic, and C.A. Prestidge, "Interactions of hydrophilic silica nanoparticles and classical surfactants at non-polar oil-water interface", *Journal of Colloid Interface Sciences*, vol. 358, no. 1, pp. 217–225, 2011. https://doi.org/10.1016/j.jcis.2011.02.056.

[4] F. Paesani and G.A. Voth, "The properties of water: Insights from quantum simulations", *The Journal of Physical Chemistry B*, vol. 113, no. 17, pp. 5702–5719, 2009. https://doi.org/10.1021/jp810590c.

[5] S.K. Hoekman, A. Broch, C. Robbins, E. Ceniceros, and M. Natarajan, "Review of biodiesel composition, properties, and specifications", *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 143–169, 2012. https://doi.org/10.1016/j.rser.2011.07.143.

[6] K.A. Sorate, and P. V. Bhale, "Biodiesel properties and automotive system compatibility issues", *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 777–798, 2015. https://doi.org/10.1016/j.rser.2014.08.079.

[7] M.T. Ghannam, and M.Y.E. Selim, "Stability behavior of water-in-diesel fuel emulsion", *Petroleum Science and Technology*, vol. 27, no. 4, pp. 396–411, 2009. https://doi.org/10.1080/10916460701783969.

[8] A. Sartomo, B. Santoso, Ubaidillah, and O. Muraza, "Recent progress on mixing technology for water-emulsion fuel: A review", *Energy Conversion Management*, vol. 213, no. February, p. 112817, 2020. https://doi.org/10.1016/j.enconman.2020.112817.

[9] D.A. Sugeng, W.J. Yahya, A.M. Ithnin, M.A. Abdul Rashid, N.S. Mohd Syahril Amri, H. Abd Kadir, and M.N. Abdul Halim, "Diesel engine emission analysis using fuel from diverse emulsification methods", *Environmental Science and Pollution Research*, vol. 25, no. 27, pp. 27214–27224, 2018. https://doi.org/10.1007/s11356-018-2760-1.

[10] S. Carrillo De Hert, and T. L. Rodgers, "On the effect of dispersed phase viscosity and mean residence time on the droplet size distribution for high-shear mixers", *Chemical Engineering Science*, vol. 172, pp. 423–433, 2017. https://doi.org/10.1016/j.ces.2017.07.002.

[11] V. Vashisth, K.D.P. Nigam, and V. Kumar, "Design and development of high shear mixers: Fundamentals, applications and recent progress", *Chemical Engineering Science*, vol. 232, p. 116296, 2021. https://doi.org/10.1016/j.ces.2020.116296.

[12] W. J. Yahya, S. A. Norazni, H. A. Kadir, S. L. Kamis, A. M. Ithnin, and N. R. Abdullah, "Durability studies of real-time non-surfactant emulsion fuel supply system", *Journal of Tribology*, vol. 27, no. December, pp. 102–115, 2020. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Durability+studies+of+real-time+non-surfactant+emulsion+fuel+supply+system&btnG=.

[13] A. Sartomo, B. Sanioso, and Ubaidillah, "Consumption, power number, and power curve characteristic of water diesel fuel emulsion mixer", *AIP Conferences Proceeding*, vol. 2296, no. November, 2020. https://doi.org/10.1063/5.0030372.

[14] N.A. Ramlan, W.J. Yahya, A.M. Ithnin, H. Abd Kadir, K.A.A. Kassim, H.A. Rahman, A.F.E. Chan, N.A. Mazlan, M.A.A. Rashid, and D.A. Sugeng, "Emissions and performance analysis of diesel powered road vehicle equipped with real-time non-surfactant emulsion fuel supply system", *Fuel*, vol. 273, no. January, p. 117257, 2020. https://doi.org/10.1016/j.fuel.2020.117257.

[15] N. Kumar, H. Raheman, and R. Machavaram, "Performance of a diesel engine with water emulsified diesel prepared with optimized process parameters", *International Journal of Green Energy*, vol. 16, no. 9, pp. 687–701, 2019. https://doi.org/10.1080/15435075.2019.1618309.

[16] H. Soukht Saraee, S. Jafarmadar, H. Taghavifar, and S. J. Ashrafi, "Reduction of emissions and fuel consumption in a compression ignition engine using nanoparticles", *International Journal of Environmental Science and Technology*, vol. 12, no. 7, pp. 2245–2252, 2015. https://doi.org/10.1007/s13762-015-0759-4.

[17] R. Gambhir, and A. K. Jha, "Brushless DC Motor: Construction and Applications", *International Journal of Engineering Sciences*, vol. 2, no. 5, pp. 72–77, 2013. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Brushless+DC+Motor%3A+Construction+and+Applications&btnG=.

[18] B. Stojanović, and N. Miloradović, "Development of timing belt drives", *Mobility and Vehicle Mechanics*, vol. 35, no. 2, pp. 31–36, 2009. https://scholar.google.com/scholar?cluster=11108108210169926803&hl=en&as_sdt=0,5.

[19] H. Wang, "Design and implementation of brushless DC motor drive and control system", *Procedia Engineering*, vol. 29, pp. 2219–2224, 2012. https://doi.org/10.1016/j.proeng.2012.01.291.

[20] R.S. Khurmi, and J.K. Gupta, "A Textbook of Machine Design", Machine Design, vol. 1, no. I, p. 200, 1982, [Online]. Available: https://docs.google.com/file/d/0B7OQo6ncgyFjbW53VEJEclZuSzQ/edit.

[21] A. M. Ithnin, W.J. Yahya, M.A. Ahmad, N.A. Ramlan, H.A. Kadir, N.A.C. Sidik, and T. Koga, "Emulsifier-free Water-in-Diesel emulsion fuel: Its stability behaviour, engine performance and exhaust emission", *Fuel*, vol. 215, no. December, pp. 454–462, 2018. https://doi.org/10.1016/j.fuel.2017.11.061.

[22] S.A. Norazni, W.J. Yahya, A.M. Ithnin, H. Abd Kadir, I.F. Abd Razak, N.D. Bahar, D.A. Sugeng, and N.A. Ramlan, "Stability behavior of non-surfactant water-in-diesel emulsion fuel using microscopic observation", *MATEC Web Conferences*, vol. 90, 2016. https://doi.org/10.1051/matecconf/20179001059.

[23] A.B. Hardian, D.V. Megarani, W. P. Nugrahani, and I. P. Rahmawati, "Perbandingan Akurasi Berbagai Metode Kalibrasi Skala Pengukuran dalam Morfometri Eritrosit Elang Ular Bido (Spilornis cheela)", *Indonesia Medicus Veterinus*, vol. 9, no. 1, pp. 68–79, 2020. https://doi.org/10.19087/imv.2020.9.1.68.

[24] D.J. Mundfrom, D.G. Shaw, and T.L. Ke, "Minimum Sample Size Recommendations for Conducting Factor Analyses", *International Journal of Testing*, vol. 5, no. 2, pp. 159–168, 2005. https://doi.org/10.1207/s15327574ijt0502_4.

[25] D.F. Williamson, R.A. Parker, and J.S. Kendrick, "The box plot: a simple visual method to interpret data", *Annals of internal medicine*, vol. 110, no. 11, pp. 916–921, 1989. https://doi.org/10.7326/0003-4819-110-11-916.

[26] E.L. Paul, V.A. Atiemo-obeng, and S.M. Kresta, Handbook of Industrial Mixing, vol. 1, no. 1. 2015.

[27] M. Shah, "Process Engineering: Agitation & Mixing", Dep. Chemical Engineering Dharmsinh Desai University, pp. 1–164, 2012, [Online]. Available: http://www.dduanchor.org/site/wp-content/uploads/2014/11/Process-Engineering-Agitation-Mixing.pdf.

[28] L. Doucet, G. Ascanio, and P.A. Tanguy, "Hydrodynamics characterization of rotor-stator mixer with viscous fluids", *Chemical Engineering Research and Design*, vol. 83, no. 10 A, pp. 1186–1195, 2005. https://doi.org/10.1205/cherd.04254.

[29] T.S.T. Ariffin, E. Yahya, and H. Husin, "The rheology of light crude oil and water-in-oil-emulsion", *Procedia Engineering*, vol. 148, pp. 1149–1155, 2016. https://doi.org/10.1016/j.proeng.2016.06.614.

[30] J. Y. Syu, J.Y. Syu, Y.Y. Chang, C.H. Tseng, Y.L. Yan, Y.M. Chang, C.C. Chen, and W.Y. Lin, "Effects of water-emulsified fuel on a diesel engine generator's thermal efficiency and exhaust", *Journal of the Air & Waste Management Association*, vol. 64, no. 8, pp. 970–978, 2014. https://doi.org/10.1080/10962247.2014.905508.