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ANALYSIS OF THE EFFECT OF DIESEL-ESSENTIAL OIL FUEL MIXTURE ON THE PERFORMANCE, NOISE, VIBRATION OF DIESEL ENGINES

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The increasing demand for diesel fuel causes high levels of air pollution, noise, and vibration. Therefore, we need a mixture of materials that can reduce the environmental effect with low vibration. The purpose of this study was to investigate the effect of a diesel-essential oil mixture on a diesel engine, related to engine performance, noise, and vibration. The research was conducted using a 402 CC Dongfeng diesel engine, a mixture of diesel and essential oils with a percentage of 5 %, 10 %, 15 %, 20 %, engine speed of 1,300 rpm, 1,500 rpm, 1,700 rpm, 1,900 rpm. The noise intensity test uses a sound level meter at 30–130 dBA with a frequency between 20–20,000 Hz. To test the density of smoke, a smoke tester was used. Meanwhile, to measure the rotational speed of the engine, a DT 2234L type tachometer was used. A digital stopwatch was used to measure the processing time with an accuracy of up to 0.01 s. Besides that, a strain gauge was also used to detect vibrations. A measuring cup was used to measure the volume of the mixture of fuel and essential oils. The results showed that in the B10 mixture at 1,300 rpm engine speed, the largest fuel consumption time was 155 s. While the smallest fuel consumption time is found at 1,900 engine speed, which is 106 s. The lowest percentage of exhaust emissions is in the B20 mixture, which is 56.8 %. While the largest percentage of exhaust emissions is in B0 with a value of 79.8 %. The lowest noise value is in the B10 mixture at 1,300 rpm engine speed, which is 105.7 dB. While the highest noise value is at 1,900 engine speed, which is 112.3 dB. The lowest vibration is in the B10 mixture with an engine speed of 1,300 rpm, which is 975.7 Hz. While the highest noise value is in the B10 mixture with 1,900 engine speed, which is 989.8 Hz

Keywords: fuel mixture, diesel, essential oil, performance, noise, vibration, diesel engine

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1. Introduction

The use of fuel that continues to increase has a negative impact on the environment, namely the high level of air pollution due to emissions from the burning process of fossil fuels. Emissions in the form of particulates can cause health problems and damage to the environment. Biodiesel is very environmentally friendly because the exhaust gases from the combustion that are released into the atmosphere will be reabsorbed by plants for photosynthesis purposes. Biodiesel will reduce exhaust emissions without compromising the performance and efficiency of the engine [1]. Meanwhile, essential oils can be dissolved in diesel oil and the results of the analysis of their constituent components contain a lot of oxygen atoms, which is expected to increase the combustion of fuel in the engine. Another thing that is quite important from the structure of the compounds that make up essential oils is that there are compounds in the form of cyclic and open chains, which can reduce the bond strength between molecules that make up diesel fuel so that the combustion process will be more effective.

Several researchers have tested diesel motors, including [2] using a diesel-jatropha fuel mixture to analyze the effect of the composition of the fuel mixture on motor performance and exhaust emissions. The motor has a single cylinder, 4 cycles, with a maximum energy output of 4.4 kW at 2,600 rpm. The percentage of jatropha oil in the fuel mixture is 0 %, 10 %, 30 %, 50 % and 100 %. The test method is carried out on each composition of the fuel mixture with a constant motor rotation of 2,000 rpm, electrical power load of 0 and 2 kW. The test results show that the higher the percentage of castor oil in the fuel mixture, the higher the consumption of fuel and CO_2 and NO_x emissions in exhaust gases, but the lower HC and O_2 emissions and exhaust gas opacity.

[3] conducted a study on the effect of the diesel-biodiesel ratio on diesel engine performance. The biodiesel fuel used is vegetable oil with a ratio of B10, B15, B20, and pure diesel. Rotation from 1,600 rpm to 2,500 rpm was used. The power and torque of the diesel-biodiesel mixture are generally higher than that of pure diesel. But at 2,300 rpm, power and torque for pure diesel are higher than in B15. The highest power and torque are produced by B10 and B20. Pure diesel SFC is lower than in all blends for revolutions up to 2,300 rpm, which means pure diesel is more efficient than blends. However, at 2,500 rpm it is inversely proportional.

Based on the research that has been done, no one has conducted research on engine performance using a mixture of essential oils in diesel fuel. Therefore, it is necessary to conduct research on the characterization of essential oil bioadditives and test their performance on diesel engines that use diesel fuel.

2. Literature review and problem statement

Energy is the main thing needed in the industrial production process [4]. However, the availability of energy is decreasing. Therefore, efforts to find new energy sources must be initiated. One alternative energy is biodiesel. Biodiesel is an alternative fuel to replace fuel oil, especially diesel oil, which is made from vegetable oil [5].

Previous research has been conducted to obtain a substitute for diesel fuel or reduce the amount of diesel. One source of vegetable oil that is very promising to be used as raw material for biodiesel is processing jatropha seeds (Jatropha Curcas L). This is because castor oil is not included in the vegetable oil category, so its use as biodiesel will not interfere with the supply of oil needs. The results showed that the mixture of jatropha biodiesel fuel and diesel fuel can be directly used in diesel motors, and the mixture recommended for use is a mixture of jatropha biodiesel with an amount of 40 % (B0).

[6] investigated the use of clove oil as a bioadditive for diesel fuel. This research was conducted in three stages. The first stage is the characterization of diesel oil and bioadditives using GC-MS, the second stage is the physical characterization of diesel bioadditives at various compositions, and the third stage is the determination of the level of consumption in a single-cylinder engine on the laboratory scale. The results showed that clove oil can reduce the rate of fuel consumption by 4.43 % with the addition of 0.6 % bioadditive, 5.07 % turpentine oil with the addition of 10 % bioadditive, 0.16 % nutmeg oil with the addition of 0.4 % bioadditive, and 1.82 % eucalyptus oil with the addition of 3 % bioadditive, while the level of fuel consumption with the addition of gandapura oil and lemongrass oil is higher than for pure diesel. The results showed that clove oil had the highest ability to reduce the rate of consumption of diesel fuel.

The content of NO_x, HC, and particulates resulting from the use of diesel fuel can be reduced by increasing the cetane number (CN) because diesel with a higher cetane number will reduce ignition delay and improve combustion quality [7]. One way to increase the cetane number is to add additives to diesel. The commercial additive, which is an organic nitrate compound, is Ethyl Hexyl Nitrate (EHN). In this study, additives derived from palm oil (NH_4NO_3) were used through an acid-catalyzed process. The reaction results showed the presence of methyl ester (ME), indicating the presence of a NO_2 spectrum at 1,635 cm^{-1}. This shows that ME can be synthesized by nitration and yield method, with a yield of 73 %. The addition of 0.5 % ME into diesel fuel causes an increase in the CN of diesel from 44 to 47.

[8] used coconut oil biodiesel as a fuel. The research focused on the potential properties of coconut oil biodiesel, using variations of coconut oil biodiesel with diesel, namely B5, B10, B15, B20, B25 and pure diesel. The results showed that biodiesel has a lower flash point than diesel. Coconut oil biodiesel also has a higher kinematic viscosity than diesel, the specific gravity of biodiesel is higher than the density of diesel.

[9] investigated the effect of a mixture of seaweed oil biodiesel (Gracilaria verrucose) with diesel fuel on performance and exhaust emissions. Seaweed oil biodiesel was made using the transesterification method. The variations of the biodiesel-diesel mixture were B-0, B-5, B-10, and B-15. The engine speed used is 1,600, 1,800, 2,000, 2,300 and 2,500 rpm. The results showed that the biodiesel B-10 mixture produced the most optimal performance and exhaust emissions compared to other blends.

[10] conducted a study on a mixture of diesel-biodiesel from candlenut seeds. Variations of candlenut biodiesel-diesel fuel are B5, B10, B15, and B20 at different engine speed and load variations. The results showed that the values of torque, power and thermal efficiency in engines using B5, B10, B15, and B20 fuels tended to decrease when compared to pure diesel fuel. Specific fuel consumption when using B5, B10, B15, and B20 increases, maximum power is 3.01 kW, minimum specific fuel consumption is 228.58 g/kWh and maximum thermal efficiency is 37.61 % when using diesel fuel. However, carbon monoxide and hydrocarbon emissions in biodiesel B5, B10, B15, and B20 decreased.

[11] used a diesel-range fuel mixture to analyze the effect on motor performance and exhaust emissions. This study uses a single-cylinder motor, four cycles, with a maximum energy output of 4.4 kW at 2,600 rpm, driving a generator as an electrical power load. The percentage of castor oil in the mixture.

3. The aim and objectives of the study

The aim of this study was to investigate the effect of the diesel fuel-essential oil mixture on the diesel engine.

To achieve the aim, the following objectives were set:

– to analyze the effect of adding essential oils to diesel fuel on the performance of diesel engines;

– to analyze the effect of adding essential oils to diesel fuel on the noise level and vibration of diesel engines.

4. Materials and methods

Essential oil biodiesel-diesel in a ratio of B5, B10, B15, B20, and pure diesel were used. Diesel engine rotation variations were from 1,600 rpm to 2,500 rpm. Dongfeng diesel engine was used. A sound level meter was used to measure the noise intensity of 30–130 dBA with a frequency between 20–20,000 Hz. A smoke tester was used to determine the density of smoke in diesel engines with units of %. A tachometer was used to measure engine rotation speed, type DT 2234L, and a digital stopwatch was used to measure runtime with an accuracy of up to 0.01 s. In addition, a strain gauge was used to detect the vibration of an object with units (Hz). A measuring cup was used to measure the volume of liquid diesel and essential oils. The specifications of the diesel engine used in the study can be seen in Table 1.

Diesel fuel is obtained from processing petroleum. Crude oil is separated in the distillation process and produces a diesel fraction with a boiling point between 250 °C to 300 °C, cetane number 43 and sulfur content between 3,000 to 3,500 ppm. The analysis of diesel oil using GC-MS indicates that the diesel oil used in this study contains many components. All components are alkane compounds or saturated carbon chains with C atoms ranging from 14 to 19. Some of the compounds that are predicted to be present in diesel oil can be seen in Table 2.

For the fuel mixture, essential oils are used. Essential oils can be made from various types of plants through a distillation process. Essential oils can be used as bio-additives for blends in fuels. Using bio-additives from essential oils can improve the quality of these fuels and reduce air pollution due to exhaust gas emissions from vehicle engine combustion. In general, the additives used in fuel, namely Tetra Ethyl Lead (TEL) and Tetra Methyl Lead (TML), contain heavy metal Pb, which is very dangerous for health. The analysis of essential oils using GC-MS showed that the essential oils used in this study contain many components. The components of the essential oils are shown in Table 3.

Table 1

Diesel engine specifications

Model	R180
Type	4 steps
System	Navel chamber combustion chamber
Number of cylinders	1 cylinder
Cylinder volume	0.402
Compression ratio	22:1
Maximum power/RPM	8 HP/2,000
Average power	7.5 HP/2,000
Fuel consumption	292.7
Oil content capacity	2.5 L
Cooling system	Water with hopper
Lubrication system	Pressure/splash

Table 2

Compounds in diesel oil

Molecular formula	Compound name	Retention time (minutes)	Abundance (%)
$C_{14}H_{30}$	Tetradecane	14.278	3.60
$C_{15}H_{32}$	Pentadecane	16.071	4.18
$C_{16}H_{34}$	Hexadecane	17.770	4.67
$C_{17}H_{36}$	Heptadecane	19.428	9.28
$C_{18}H_{38}$	Octadecane	20.925	6.95
$C_{19}H_{40}$	Nonadecane	22.363	5.03

Table 3

Essential oil components

No.	Compound	RT (%)	Fresh	Sun-drying	Shade-drying	Oven-drying
1	Citronellal	16.55	0.60	2.06	2.03	3.01
2	Geraniol	15.46	0.53	0.86	0.95	1.31

5. Research results on the effect of diesel-essential oil fuel mixture on diesel engines

5. 1. Effect of adding essential oils to diesel fuel on the performance of diesel engines

The diesel engine performance can be viewed from the fuel consumption and exhaust emissions of diesel engines. Fuel consumption can be tested on variations in engine speed with respect to fuel consumption time. This is done on a variation of the mixture of diesel fuel with essential oils.

Fig. 1 shows the effect of engine speed on fuel consumption time on variations in the diesel-essential oil fuel mixture. This shows that the higher the engine speed, the lower the consumption time of the diesel-essential oil fuel mixture. This can be seen in the B10 mixture with 1,300 rpm engine speed, the fuel consumption time is 155 s. At 1,500 rpm engine speed the fuel consumption time is 150 s, at 1,700 rpm engine speed the fuel consumption time is 123 s, and the smallest fuel consumption time at 1,900 rpm engine speed is 106 s.

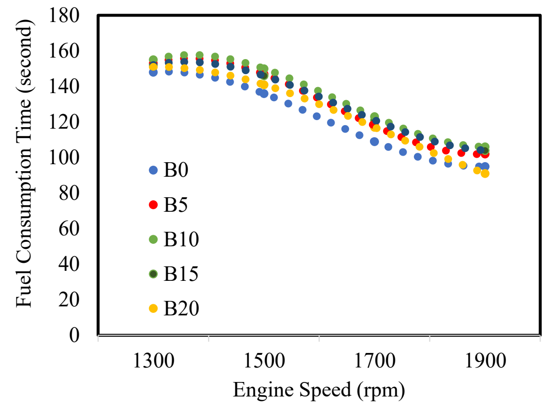

Fig. 1. Relationship between engine speed and fuel consumption time in the variation of the mixture

While the performance of the diesel engine is based on exhaust emissions, testing of the diesel engine on variations in engine speed (rpm) on exhaust emissions is carried out. The test is carried out using a smoke tester machine so as to produce the percentage of exhaust gas density. Fig. 2 shows the effect of the fuel mixture on variations in engine speed on exhaust emissions.

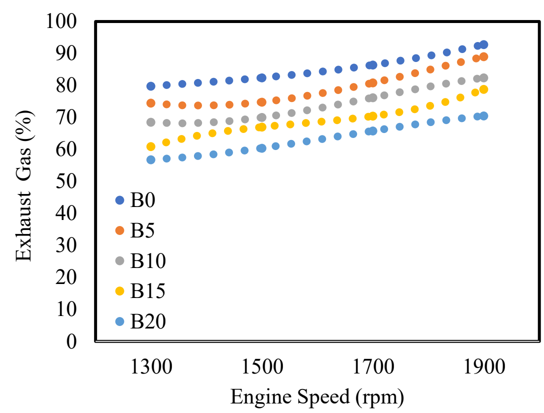

Fig. 2. Relationship between engine speed and the percentage of exhaust emissions in the variation of the diesel-essential oil mixture

Fig. 2 shows that the greater the percentage of the diesel-essential oil fuel mixture, the lower the percentage of emissions. This can be seen at 1,300 rpm engine speed. The B0 mixture has the largest percentage of exhaust gas emissions of 79.8 %. In the B5 mixture, it is 74.5 %, in the B10 mixture – 68.5 %, in the B15 mixture – 60.9 %. While the B20 mixture has the largest exhaust emission percentage value of 56.8 %.

5. 2. Effect of adding essential oils to diesel fuel on the noise level and vibration of diesel engines

The results of the noise level tests carried out on variations in diesel engine speed are shown in Fig. 3. The noise level shows the size of sound energy in decibels, abbreviated as dB. Measurement of the noise level was made using a sound level meter.

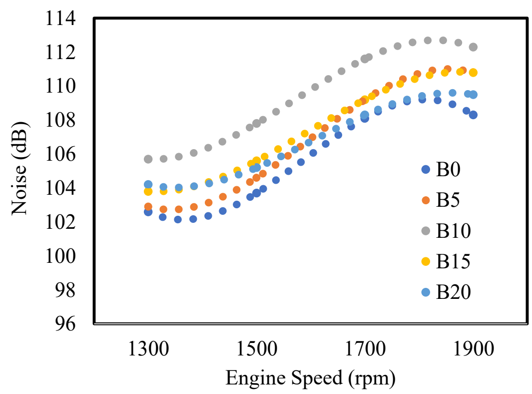

Fig. 3. Relationship between engine speed and noise in various diesel-essential oil mixtures

Fig. 3 shows that the B10 mixture has the largest noise value compared to other mixtures. For the B10 mixture at 1,300 rpm engine speed, the noise value is 105.7 dB. At 1,500 rpm engine speed – 107.8 dB. At 1,700 rpm engine speed – 111.6 dB, and the highest noise value of 112.3 dB is found at 1,900 rpm engine speed.

The diesel engine vibration tests were carried out on variations in engine speed for the diesel fuel-essential oil mixture. Fig. 4 shows the results of the research on the effect of engine speed on engine vibration on various diesel-essential oil mixtures.

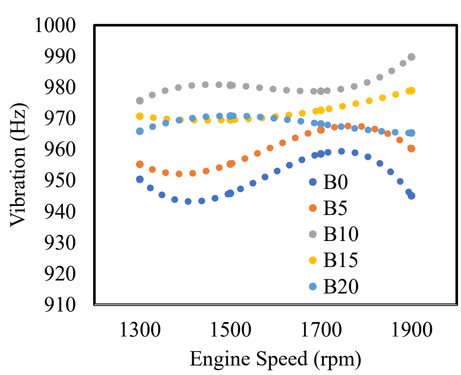

Fig. 4. Relationship between engine speed and engine vibration on various diesel-essential oil mixtures

Fig. 4 shows that the B10 mixture has the largest vibration value compared to the others. Meanwhile, the higher the engine speed, the greater the noise value. It can be seen that at 1,300 rpm engine speed, it has a high vibration value, which is 975.7 Hz. At 1,500 rpm engine speed – a high vibration value of 980.7 Hz. At 1,700 rpm engine speed – a high vibration value of 978.8 Hz, and the highest noise value is found at 1,900 engine speed, which is 989.8 Hz.

6. Discussion of experimental results on the effect of the diesel-essential oil fuel mixture on diesel engines

A mixture of diesel and essential oils produces a more complete combustion reaction compared to diesel alone. This is because the essential oil contains citronellal of 16.55 % (Table 3). Hexadecane reaction with citronellal will result in complete combustion in the combustion chamber. So that it produces a large engine power. Complete combustion results in low fuel consumption, environmentally friendly exhaust emissions, low noise levels, and smoother engine vibration.

The decrease in fuel consumption timeout occurs in the B15 and B20 fuel mixtures because the higher cetane index will result in an increase in fuel combustion performance and improve engine performance. The cetane index is an indicator of the combustion speed of diesel fuel and the compression required for ignition. At the beginning of combustion, very fine fuel particles evaporate and mix with air so that an easy mixture is formed. So the pressure rises constantly in accordance with the crank motion. In addition, another factor that causes a decrease in the graphic values in B15 and B20 is because the cetane index of the biodiesel mixture is higher than that of diesel. The increase in the cetane index of the biodiesel mixture causes the combustion process in the combustion chamber to improve.

This study is in line with research conducted by [12] where the results can increase the use of fuel mixtures, because the calorific value of the soybean oil diesel fuel mixture is lower than that of pure diesel fuel. [13] stated that fuel consumption in the B15 mixture can save fuel consumption of around 6.792 kg/hour, which is better than pure diesel compared to other biodiesel mixtures. The longest time required in this study related to fuel consumption was found in the B10 fuel mixture with a time of 155 s (Fig. 1).

Fuel consumption ends at a peak, for fuel that has not been burned will continue burning. If this period is too long, the exhaust gas temperature will increase and the power will decrease. $C_{16}H_{34}+C_{10}H_{16}O$ is the result of a mixture of diesel fuel and essential oils. Where the molecular value of the diesel molecule of each percentage decreases and the attrition oil has an increase in the molecular value of each percentage. So that the fuel mixture is flammable during combustion. The flammability of the fuel mixture is due to the mixture of air and fuel entering the combustion chamber containing more sulfur and oxygen, so the opacity released is more environmentally friendly than diesel.

This research is in line with research conducted by [14] on the ability test of diesel-biodiesel fuel mixtures from kapok seed oil. The results obtained are that there is an effect of a mixture of diesel fuel with biodiesel from cottonseed oil with a better effect than diesel fuel from engine performance. A mixture of biodiesel from kapok seed oil in diesel fuel is proven that the fuel is more environmentally friendly and can reduce opacity by 35.8 % in the B17.5 mixture. While the research conducted in [15–17] obtained results for the addition of a mixture of biodiesel from cottonseed oil to diesel fuel, which can reduce opacity by 5.340 % with a decrease of 66.67 % at 2,500 rpm.

The biodiesel blend of essential oils in this study proved that the fuel is more environmentally friendly and can reduce the opacity by 56.8 % in the B20 mixture (Fig. 2).

The high noise value is due to the extended delay in combustion or at this time the evaporation event is too fast. So that the fuel will immediately ignite and in the second period there will be an excessive spread of fire. This will result in a pressure rise that is too rapid, resulting in a high sound. This event is known as knocking on a diesel motor. In addition, diesel engines have high compression so that they produce high power, and result in an engine sound that is too noisy.

The high value of vibration is also caused by the knocking event on the diesel motor. Another factor of the high value of engine vibration is that there is no engine mount or holder that functions as a vibration damper when the engine is running. So that there is no mounting on the engine resulting in excessive vibration in the engine frame. Vibration in this study is included in the uncomfortable category because the highest vibration value is 989.8 Hz (Fig. 4). Vibration values that exceed the threshold value can cause occupational diseases. Personal protective equipment needs to be used when performing work related to vibration in order to prevent or reduce the adverse effects of vibration on health.

Limitations in this study include: the diesel engine used is Dongfeng 402CC; the volume of fuel is 10 ml; performance in question is the specific fuel requirements and exhaust emissions.

The development of this research should be carried out in relation to the comparison of other biodiesel materials. This development is to find a substitute for fossil fuels (diesel fuel) with vegetable plants that are easily available environment.

7. Conclusions

1. Diesel engine performance:

a) the largest fuel consumption time is in the B10 mixture with 1,300 rpm engine speed, which is 155 s. While the smallest fuel consumption time is found in the B10 mixture with 1,900 engine speed, which is 106 s;

b) the lowest percentage of exhaust emissions is in the B20 mixture, which is 56.8 %. While the largest percentage value of exhaust emissions is in B0 with a value of 79.8 %.

2. Noise and vibration on the machine:

a) the lowest noise value is in the B10 mixture at 1,300 rpm engine speed, which is 105.7 dB. While the highest noise value is found at 1,900 engine speed, which is 112.3 dB;

b) the lowest vibration is in the B10 mixture with 1,300 rpm engine speed, which is 975.7 Hz. While the highest noise value is in the B10 mixture with 1,900 engine speed, which is 989.8 Hz.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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References

1. Taghizadeh-Alisaraei, A., Ghobadian, B., Tavakoli-Hashjin, T., Mohtasebi, S. S., Rezaei-asl, A., Azadbakht, M. (2016). Characterization of engine's combustion-vibration using diesel and biodiesel fuel blends by time-frequency methods: A case study. Renewable Energy, 95, 422–432. doi: https://doi.org/10.1016/j.renene.2016.04.054
2. Biswas, S., Kakati, D., Chakraborti, P., Banerjee, R. (2021). Assessing the potential of ethanol in the transition of biodiesel combustion to RCCI regimes under varying injection phasing strategies: A performance-emission-stability and tribological perspective. Fuel, 304, 121346. doi: https://doi.org/10.1016/j.fuel.2021.121346
3. Uyumaz, A. (2018). Combustion, performance and emission characteristics of a DI diesel engine fueled with mustard oil biodiesel fuel blends at different engine loads. Fuel, 212, 256–267. doi: https://doi.org/10.1016/j.fuel.2017.09.005
4. Karagöz, M., Ağbulut, Ü., Sarıdemir, S. (2020). Waste to energy: Production of waste tire pyrolysis oil and comprehensive analysis of its usability in diesel engines. Fuel, 275, 117844. doi: https://doi.org/10.1016/j.fuel.2020.117844
5. Romantsova, S. V., Nagornov, S. A., Kornev, A. Y. (2019). Composition of additives for improving the performance of contemporary biodiesel fuel. Proceedings of Universities Applied Chemistry and Biotechnology, 3 (9), 547–556. doi: https://doi.org/10.21285/2227-2925-2019-9-3-547-556
6. Ravi, M., Kumar, K. V., Murugesan, A. (2016). Performance, emission, noise and vibration characteristics of biogas – diesel dual fuel compression ignition engine. Journal of Advances in Chemistry, 12 (12), 4588–4592. doi: https://doi.org/10.24297/jac.v12i12.793
7. Wu, G., Ge, J. C., Choi, N. J. (2020). A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines. Applied Sciences, 10 (22), 8015. doi: https://doi.org/10.3390/app10228015
8. Prabakaran, B. (2021). Experimental investigation of compression ignition engine fueled with Biobutanol and upgraded waste engine oil for performance. Cleaner Engineering and Technology, 4, 100202. doi: https://doi.org/10.1016/j.clet.2021.100202
9. Sakthivel, G., Sivaraja, C. M., Ikua, B. W. (2019). Prediction OF CI engine performance, emission and combustion parameters using fish oil as a biodiesel by fuzzy-GA. Energy, 166, 287–306. doi: https://doi.org/10.1016/j.energy.2018.10.023
10. Santo Filho, D. M. do E., De Abreu, F. L. B., Pereira, R. G., dos Santos Júnior, J. J. P., Siqueira, J. R. R., Ferreira, P. L. S. et. al. (2010). The Influence of the Addition of Oils in the Diesel Fuel Density. Journal of ASTM International, 7 (8), 102791. doi: https://doi.org/10.1520/jai102791
11. Hazar, H., Tekdogan, R., Sevinc, H. (2021). Investigating the effects of oxygen enrichment with modified zeolites on the performance and emissions of a diesel engine through experimental and ANN approach. Fuel, 303, 121318. doi: https://doi.org/10.1016/j.fuel.2021.121318

12. Sarıdemir, S., Ağbulut, Ü. (2019). Combustion, performance, vibration and noise characteristics of cottonseed methyl ester-diesel blends fuelled engine. Biofuels, 13 (2), 201–210. doi: https://doi.org/10.1080/17597269.2019.1667658
13. Yildizhan, Ş., Uludamar, E., Özcanli, M., Serin, H. (2018). Evaluation of effects of compression ratio on performance, combustion, emission, noise and vibration characteristics of a VCR diesel engine. International Journal of Renewable Energy Research, 8. doi: https://doi.org/10.20508/ijrer.v8i1.6573.g7284
14. Santhosh, S., Velmurugan, V., Paramasivam, V., Thanikaikarasan, S. (2020). Experimental investigation and comparative analysis of rubber engine mount vibration and noise characteristics. Materials Today: Proceedings, 21, 638–642. doi: https://doi.org/10.1016/j.matpr.2019.06.730
15. Aytav, E., Koçar, G., Teksan, A. E. (2020). Experimental Comparison of Biogas and Natural Gas as Vibration, Emission, and Performance in a Diesel Engine Converted to a Dual Fuel. SAE International Journal of Fuels and Lubricants, 13 (1). doi: https://doi.org/10.4271/04-13-01-0004
16. Heidary, B., Hassan-beygi, S. R., Ghobadian, B., Taghizadeh, A. (2013). Vibration analysis of a small diesel engine using diesel-biodiesel fuel blends. Agricultural Engineering International: The CIGR e-journal, 15 (3), 117–126.
17. Ağbulut, Ü., Karagöz, M., Sarıdemir, S., Öztürk, A. (2020). Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine. Fuel, 270, 117521. doi: https://doi.org/10.1016/j.fuel.2020.117521