

## Enhancing gasoline fuel characteristics and engine operation criteria using by product octan boosters

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**Abstract.** The increase of energy demand and environmental contaminations hearten the utilization of alcohol-bases as a alternatives fuels in spark ignition (SI) engine. The fusel oil is a byproduct developed from fermentation process with higher alcohol content. It has high-octane and slight exhaust emissions, there for it takes important place between the substitutes fuels. During this study, effect of used mixtures of pure low octane gasoline & fusel oil on engine exhaust emissions & performance have been estimated after water removal from fusel oil. A single-cylinder, four-stroke SI engine has been used in this tests. The inspections execute at different speeds. The test fuels mixed by fusel oil at ratio of 5%, 10%, 20%, and 30%. In each speed, the engine's performance & emissions size have been conducted. During the investigations, it have been observed that the brake power (BP) and specified fuel consuming (SFC) rises as the size of fusel oil risen in the mixture.

**Keywords:** Gasoline, SI engine, Octane number, Fusel oil, Brake power.

### Introduction

Environmental pollution and the speedy decrease of reducing fossil fuels have reasons rising the need to usage substitute fuel in (SI) engines [1]. Hence, biofuels industrial of stuffs can be grown, which have advanced thermal efficiency and lesser emissions of exhaust [2]–[7]. Alcohol based as exchange fuels presently vastly considered. Fusel oil is along chains alcohol group sub-product of alcohol created through the distillation procedure [8]–[12]. Its odor is bad and its tint is dark brown. It has similar properties of alcohol fuel like as high (RON=106), (MON= 103), and also has higher oxygen contented about (30.23)%, with solo ebullition point, but fusel oil has high water contented about (3-20)% [13]–[20]. These advantage indicated that fusel oil may be utilized as substitute fuel or as additive to gasoline for sparkle ignition (SI) engines [21][22]. Sundry studies have scrutinized fusel oil-gasoline mixture impact on the

performance of SI engine and emissions [10]. Calam showed that fusel oil can be used in SI engine as substitute fuel because of its physical & chemical characteristic. Increasing blends effects on torque of engine and fuel consumption, they were debated with many researches [21]. Also Calam and Icingur [21] used other fuel blend (10, 20, 30%) for operate spark ignition engine in diverse speed beneath higher load situations. The results exposed that the BSFC improved in all test situations at a maximum value of about 7.7 % with F30, after the proportion of the fusel oil raised in mixture, engine torque reduced. Furthermore, in wholly fusel oil-blends, NOx emissions reduced compared by pure gasoline for the reason that the decrease in engine exhaust temperature [23]. Calam et al. studied single-cylinder gasoline SI engine, they utilized another fusel oil mixing ratio (0%, 5%, 10%, 20%, 30% & 50%) with different load and stable speed of 3500 rpm. In this study the fusel oil presented as a renewable fuel for SI engine because of its physical-chemical properties. The result showed an

increasing in BSFC and torque with a decrease in NO<sub>x</sub> [21]. Also solmaz claimed that the torque was reduced commonly into 6% and 2% at using of F100 & F50 fuel with adding of fusel oil ,while BSFC raised [24]. Suleyman & Bulent definite that, by addition of fusel oil in to untainted gasoline, engine torque and SFC increased. Furthermore, when fusel oil size increased in the mixture, NO<sub>x</sub>, CO<sub>2</sub> and UHC emission decreased [25]. [26] Other study studied fusel oil at adding ratio of (0, 50 and 100%) to gasoline. The outcomes of the study was collected at speed of 2500 rpm and 4 load level of 25, 50, 75 & 100%. The outcomes showed that when fusel oil content raised the indicated mean effective pressure (IMEP) and heating value reduced because of water in fusel oil. Moreover, NO<sub>x</sub> decreased with 31% for F100 [27]. A study presented by Calam et al. showed important effect of fusel oil and gasoline blend percentage (5, 10 , 20 & 30%) on SI test execution and its emissions. Also Omar [28] presented a study showed the impact of water removal from fusel oil on heating value and engine performance. The test steered on SI motor below 4500 rpm motors speed by using different mixing fraction of gasoline & fusel oil (G100, FBWE10, FBWE20, FAWWE10 and FAWWE20), engine performance and heating value were improved. The results shown that by increasing ratio of fusel oil in mixture, significant increasing in octane number of blended fuel is obtained.

The objective of this study is to show the most suitable use for fusel fuel in SI engine that attain the best engine efficiency at maximum contamination protection. Different ratios of fusel oil and pure gasoline have been employed in this study to specify the better additive ratio.

## Investigational organization

**Experiment fuel.** In this study, engine test was scab with pure gasoline, fusel oil & gasoline mixes after water elimination form (fusel oil) and enhanced gasoline as a threshold for comparison. Fusel oil supplied from Eskişehir sugar factory, that production ethyl alcohol (99.5%) pureness. Pure gasoline fuels have been obtained of native petrol stations in Iraq and indicated as commercial fuel. Pure gasoline (F0%) , (pure gasoline & fusel oil mixtures) applied in the experimentations, and the mixes are show in Table (1).

**Water extraction.** Fusel oil has similar characteristics as alcoholics fuels as (RON = 106), and (MON = 103), it has high oxygen contented,

solo ebullition point, so it can be used as substitute fuel to (SI) engines [21]. However, water content of fusel oil is high (nearly 3-20%) which lead to reduction its heating value, and that lead to an adverse effect on the efficiency of combustion and performance of engine. Fusel oils heating value was (30)(MJ/kg), which is fewer than for pure gasoline that about (44.598 MJ/kg) [29]. In this experiment (H<sub>2</sub>O) contented for fusel oil removed by using center fugue in laboratory of north oil company in Iraq/Kirkuk. After water extraction the heating rate of fusel oil become (33.8) (MJ/kg).

**Table 1.** Structure of Fuel Mixtures.

Sample	Structure
(F0%)	Pure Gasoline
(FWE5%)	(5%) Fusel Oil + (95%) Pure Gasoline
(FWE10%)	(10%) Fusel Oil + ( 90%) Pure Gasoline
(FWE20%)	(20%) Fusel Oil + ( 80%) Pure Gasoline
(FWE30%)	(30%) Fusel Oil + (70%) Pure Gasoline
(FS)	Enhanced Gasoline Structure



**Figure 1.** Center fugue

**Engine test.** Tentative experiments implemented on a small four-cycle sparkle engine kind Robin (EH17) spark timing and compressing ratio are

fixed. Table (2) shows advise characteristic of used engine in implement the experiments for this exploration. Engine load arrangement comprises of a hydraulic dynamo meter fixed on a usual experiment basis. The quantity of water stock requisite to hydraulic dynamo meter extent is specified as a lower than (5) (L/min) in (1bar). Cell of electric burden kind (S) by a full burden ability of (15) N.m is attuned over with control measure [30].

**Table 1.** Engine characteristics.

Factors	Specifications
(Displacement)	(172) Cm
(Bore) × (cycle)	(67)mm × ( 49) mm
Arrangement	four cycle, sparkle - ignition, solo cylinder
Connect shaft length	(85) mm
Fuel	Gasoline
Compression percentage	(8. 5 :1)



**Figure 2.** Engine test rig

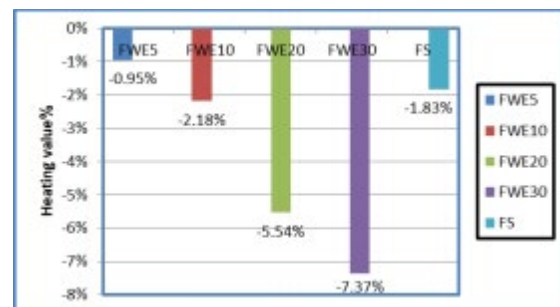
## Results and discussion

The current conclusions of experiment contain; physical & chemical feature, heating value,(RON) research octane number, density and viscosity adding to investigational experiments of engine performance ( BP, BSFC and BTE). The research done by using pure Gasoline fuel (F0) and (gasoline & fusel oil) mix (F5%,F10%,F20%,F30%) & enhanced gasoline (FS) in a single -cylinder, four-

cycle spark engine Robin ( EH 17) working in speeds range of (1500 - 2700) rpm by a rise (300 rpm) & (100%) valve open (WOT). The engine operative settings were kept similar in nearly all experimentations as surroundings temperatures of ambient and air pressure & humidity.

**Test fuel quality investigation.** The properties for the fuel used in processing of internal burning engines indicates the extreme significant factors in relatives of competence and superiority of burning [31]-[39]. Chemical & physical properties scaled and debated in such paper comprised (heating value, octane number, density and viscosity). The objects calculated to seven fuel tested samples (Fusel oil (F), pure gasoline (F0), F5, F10, F20, F30, FS). The physical and chemical properties have been examined in laboratory of north oil company in Kirkuk.

**Heating value.** Heating rate is amount of ability which one kilo gram Of fuel produces after its completely burned that scaled by ( MJ/kg) unity by used oxygen bombs calorimeter. It is represent an important indicator for the fuel suitability to operate IC engine efficiently [40]-[48]. Fig (3) shows the experiment effects. The heating value for fusel oil (F) after H<sub>2</sub>O removal equal (33.8MJ/kg), however for pure gasoline F0 equal to (44.598 MJ/kg), so heating rate for enhance gasoline equal to (43.781 MJ/kg) and the heating value of F5 equal to (44.173 MJ/kg) it reduced about (-0.95%), and F10 was (43.625 MJ/kg) reduced about (-2.18%), and F20 was (42.125 MJ/kg) it reduced about (-5.54%), and F30 was (41.307 MJ/kg) it reduced about (-7.37%). The outcomes of the research tested fuels shown that heating rate was suggestively decreased by adding fusel oil because of its low heating rate.



**Figure 3.** % Heating value change for tested fuel samples

**Research octane number (RON).** Research octane number (RON) is a measure of the fuel opposition

to knockout of (SI) spark engines. The high octane (RON) for gasoline is the better ability of the gasoline to fight natural spark through compression & earlier sparkle ignition [49][50]. Advanced compression makes high temperature & high pressure which may be completed inside the cylinder of engine & takes in high engine energy. Fig(4) shows the outcomes for inspection of the(%) increasing of (RON) for tested fuels (F, F0, F5, F10, F20, F30, and FS). Fusel oil has aloft octane number (106) before water removal, therefore (RON) for tested fuel rise. RON of fuel (F0) was (86), and it increased when the fusel oil added. By adding F5 the octane number RON increased about (10.9%), it become (95.4), also by adding ( F10 ) fuel, (RON) increased about (12.4%) to (96.7), the octane number RON for fuel (F20) increased about (11.6%) and found to be (96), and (F30) increased about (12.9%) to be (97.1).

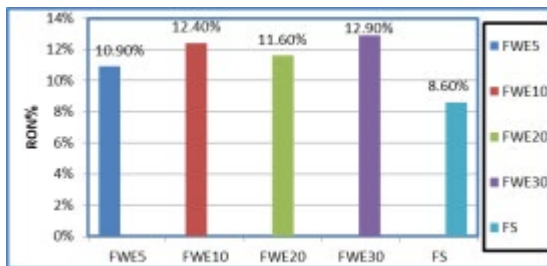


Figure 4. % RON change for tested fuel samples

**Density.** Density is the ratio among cluster and extend of fuel, it is a fuel physical feature which characters fuel frugality for engine through substitute procedure of equivalent burning and aloft density rises ability of density for a fuel [40], [51]-[55]. Also, high density produces high viscosity, that in order gifts bad burning and effect on engine performance & emission [56]-[63]. Fig(5) shows (%) fuel density increasing for (F5, F10, F20, F30, and FS) which found to be (769, 782, 789, 794, 774 kg/m<sup>3</sup>) respectively and raised about (0.9,2.6,3.5,4.1)% and(1.6%)for FS . The tested fuel densities were scaled at (20)Co by using (Digital Density Gage).

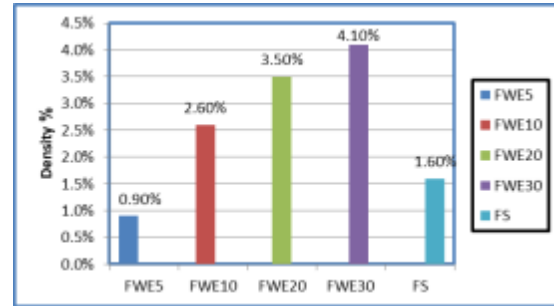


Figure 5. % Density change for tested fuel samples

**Viscosity.** Viscosity is a measure of internal rubbing or fuel fight to flowing, viscosity is a quite important quality for fuel, and it effect procedure treatment of fuel structure tools [38], [64]-[66]. The Kinematic viscosities of tested fuels were measured according (38C0) by using a viscometer. The viscosity of tested fuels (F, F0, F5, F10, F20, F30, and FS) were (2.896, 0.467, 0.514, 0.521, 0.594, 0.732, and 0.468) mm<sup>2</sup>/sec respectively. Because of fusel oil (F) high viscosity compared with pure gasoline, viscosity of pure gasoline increased with the addition of fusel oil. Fig (6) shows the % increasing of viscosity.

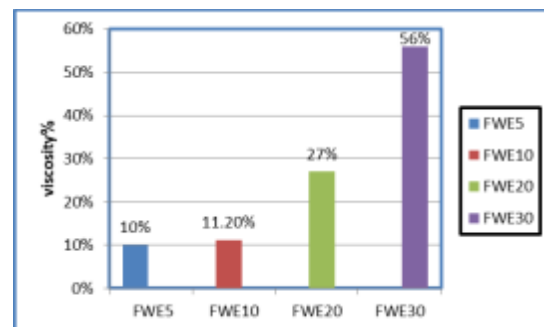


Figure 6. % Viscosity change for tested fuel samples

## Engine performance

**Brake power (BP).** The engine brake power competence studied based brake torque of engine per rapidity [55], [67]-[73]. Engine torque rises by addition of fusel oil and increasing the speed of engine. At compared (fusel oil & gasoline) mixes of (F5, F10, F20, and F30) with pure gasoline (F0), the engine torque presented a little increase. The reason of engine torque increasing at the increasing of quantity of fusel oil, considered to high oxygen contain of the fusel oil which led improved combustion. Fig (7) shows % brake power for tentative engine trials with used tested fuels (F5,



F10, F20, and F30) and compare between the outcomes of a experiential trials and enhanced gasoline at the alike working conditions of the engine. Brake power is improved when speed of the engine raised [43], [74]-[76]. Brake power for pure gasoline (F0) is lower than that of enhanced gasoline and it improved by addition of fusel oil at all engine speeds. The best improvement of a brake power complete in speed (2700 rpm) by (F5).

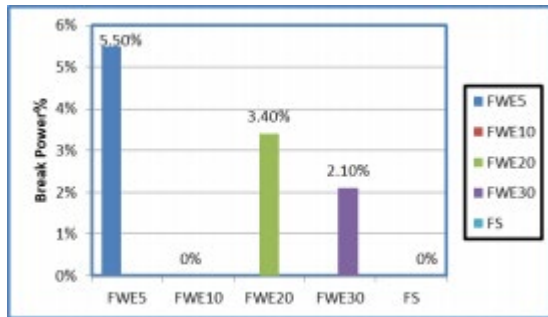


Figure 7. % BP change for tested fuel samples

**Brake specific fuel consumption (BSFC).** Variance in the (BSFC) for engine tested fuels comparative different the speed of engine in completely open choke (WOT). The relation of (BSFC) for totally tested fuels that used in tentative engine trials in speeds was higher. While engine effort in lower speed lead to an influence of weakly burning & refrigerating is vigorous that leads up to high scale of (BSFC) to completely tested fuel. By increase the speed of engine, (BSFC) decreases for lowest led to a slow improvement in burning process, so increasing the total energy operation (BSFC) initiates increase slowly when the speed of engine increases for totally tested fuels. Fig. (8) shows the reduced (BSFC) accomplished to (F5) in many speeds of engine compare by (FS). This improvement in (BSFC), because of the increase into energy density [77], and fusel oils higher octane number.

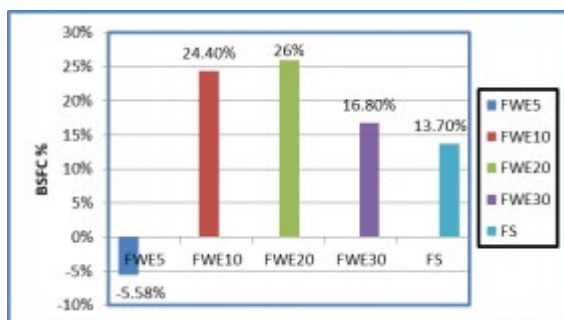


Figure 8. % BSFC change for tested fuel samples

**Brake thermal efficiency.** The BTE is ratio for a brake power formed of engine to complete thermal energy of a fuel [4][55]. BTE is a measure of estimation for engine process using tested fuels [53], [65], [66], [78]-[85]. Mono of presentation factors used for consider capacity of engine's for transform heat energy of the fuel for mechanical energy that higher assessment of engine performance of fuel consuming of diverse used fuels in tentative tests. Fig (9) shows %(BTE) changes at completely tested fuels that variation with use of fusel oil in tested. This rises in brake thermal efficiency is on reason of higher octane number for fusel oil, and its higher oxygen contains [86]-[91].

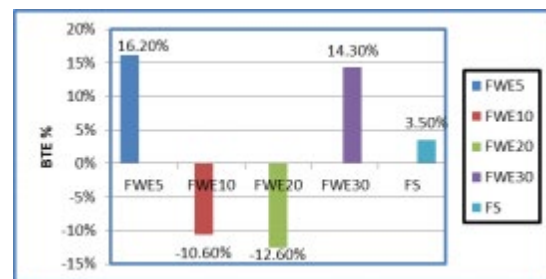


Figure 9. % BTE change for tested fuel samples

## Conclusion

With this study, experimental research of an effect of a different proportion of (fusel oil & gasoline) mixtures were used as fuel for (SI) a spark-ignition engines, with different reaching for speeds of engine that was from (1500 - 2700) (rpm) with increasing of (300) (rpm), check valve opening 100% (WOT) under different act conditions. A pure gasoline fuel and tested mixtures properties (octane number, heating rate, density and viscosity), and engine performance (BP), (BSFC), (BTE), and engine exhaust emissions, were studied. Based on this work, most important conclusion summarized as following:

1. Fusel oil adding to pure gasoline increase octane number & viscosity of tested fuels liken with a pure gasoline.
2. Compare to pure gasoline, fuel mixtures (F5%, F10%, F20%, F30%) mixes improved engine power.

3 . The heating value for fusel oil was (30MJ/kg), after water elimination it raised to (33.8 MJ/kg), it was lesser than that of pure gasoline that (44.598 MJ/kg), so that lead to reduction heating value of tested fuel and an increase (SFC) by growing quantity of (fusel oil) into mixes, except fuel (F5) reduction BSFC at most speeds compare with the pure gasoline (F0).

4 . (BP) and (BTE) were raise with adding of (fusel oil) compare with a pure gasoline fuels.

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#### Competing Interests

The authors declare that there are no competing interests.

#### References

- [1] S. Simsek, B. O.- Energies, and undefined 2018, "Improvements to the composition of fusel oil and analysis of the effects of fusel oil-gasoline blends on a spark-ignited (SI) engine's performance and emissions," mdpi.com, doi: 10.3390/en11030625.
- [2] O. Awad, M. Xiao, M. Kamil, Z. Bo, O. M. Ali, and S. Shuai, "A Review of the Effects of Gasoline Detergent Additives on the Formation of Combustion Chamber Deposits of Gasoline Direct Injection Engines," SAE Int. J. Fuels Lubr., vol. 14, no. 04-14-01-0002, pp. 13-25, 2021.
- [3] O. I. Awad et al., "Alcohol and ether as alternative fuels in spark ignition engine: A review," Renew. Sustain. Energy Rev., vol. 82, pp. 2586-2605, 2018.
- [4] H. Sharudin, N. R. Abdullah, A. M. I. Mamat, O. M. Ali, and R. Mamat, "An overview of spark ignition engine operating on lower-higher molecular mass alcohol blended gasoline fuels," J. Teknol., vol. 76, no. 5, 2015.
- [5] O. M. Ali, R. Mamat, H. H. Masjuki, and A. A. Abdullah, "Analysis of blended fuel properties and cycle-to-cycle variation in a diesel engine with a diethyl ether additive," Energy Convers. Manag., vol. 108, pp. 511-519, 2016.
- [6] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Analysis of blended fuel properties and engine cyclic variations with ethanol additive," J. Biobased Mater. Bioenergy, vol. 9, no. 2, pp. 108-114, 2015.
- [7] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Analysis of blended fuel properties and engine performance with palm biodiesel-diesel blended fuel," Renew. Energy, vol. 86, pp. 59-67, 2016.
- [8] O. I. Awad, R. Bin Mamat, O. M. Ali, and I. M. Yusri, "Effect of fuel oil-gasoline fusel blends on the performance and emission characteristics of spark ignition engine: A review," J. Sci. Res. Dev., vol. 3, no. 5, pp. 31-36, 2016.
- [9] O. I. Awad, Z. Zhang, M. Kamil, X. Ma, O. M. Ali, and S. Shuai, "Wavelet analysis of the effect of injection strategies on cycle to cycle variation GDI optical engine under clean and fouled injector," Processes, vol. 7, no. 11, p. 817, 2019.
- [10] A. N. Abdalla, O. M. Ali, O. I. Awad, and H. Tao, "Wavelet analysis of an SI engine cycle-to-cycle variations fuelled with the blending of gasoline-fusel oil at a various water content," Energy Convers. Manag., vol. 183, pp. 746-752, 2019.
- [11] O. M. Ali, "Utilisation of Chemical Waste Additives with Low Octane Commercial Gasoline Fuel to Enhance the Performance of SI Engines," Int. J. Automot. Mech. Eng., vol. 18, no. 1, pp. 8612-8620, 2021.
- [12] O. I. Awad et al., "Using fusel oil as a blend in gasoline to improve SI engine efficiencies: A comprehensive review," Renew. Sustain. Energy Rev., vol. 69, pp. 1232-1242, 2017.
- [13] O. I. Awad et al., "The effect of adding fusel oil to diesel on the performance and the emissions characteristics in a single cylinder CI engine," J. energy Inst., vol. 90, no. 3, pp. 382-396, 2017.
- [14] O. M. Ali, R. Mamat, and C. K. M. Faizal, "Review of the effects of additives on biodiesel properties, performance, and emission features," J. Renew. Sustain. energy, vol. 5, no. 1, p. 12701, 2013.
- [15] O. I. Awad et al., "Response surface methodology (RSM) based multi-objective optimization of fusel oil-gasoline blends at different water content in SI engine," Energy Convers. Manag., vol. 150, pp. 222-241, 2017.
- [16] A. N. Abdalla et al., "Prediction of emissions and performance of a gasoline engine running with fusel oil-gasoline blends using response surface methodology," Fuel, vol. 253, pp. 1-14, 2019.
- [17] O. M. Ali, R. Mamat, M. G. Rasul, and G. Najafi, "Potential of Biodiesel as Fuel for Diesel Engine," in Clean Energy for Sustainable Development, Academic Press, 2017, pp. 557-590.
- [18] O. I. Awad, R. Mamat, T. K. Ibrahim, O. M. Ali, K. Kadirgama, and A. M. Leman, "Performance and combustion characteristics of an SI engine fueled with fusel oil-gasoline at different water content," Appl. Therm. Eng., vol. 123, pp. 1374-1385, 2017.
- [19] O. I. Awad, X. Ma, M. Kamil, O. M. Ali, Z. Zhang, and S. Shuai, "Particulate emissions from gasoline direct injection engines: A review of how current emission regulations are being met by automobile manufacturers," Sci. Total Environ., vol. 718, p. 137302, 2020.
- [20] O. I. Awad, X. Ma, M. Kamil, O. M. Ali, Y. Ma, and S. Shuai, "Overview of polyoxymethylene dimethyl ether additive as an eco-friendly fuel for an internal combustion engine: Current application and environmental impacts," Sci. Total Environ., vol. 715, p. 136849, 2020.
- [21] A. Calam, Y. İçingür, H. Solmaz, and H. Yamk, "A comparison of engine performance and the

- emission of fusel oil and gasoline mixtures at different ignition timings," *Int. J. Green Energy*, vol. 12, no. 8, pp. 767–772, Aug. 2015, doi: 10.1080/15435075.2013.849256.
- [22] F. W. WELSH and R. E. WILLIAMS, "Lipase Mediated Production of Flavor and Fragrance Esters from Fusel Oil," *J. Food Sci.*, vol. 54, no. 6, pp. 1565–1568, 1989, doi: 10.1111/j.1365-2621.1989.tb05161.x.
- [23] S. Mohammad, S. Ardebili, H. Solmaz, and M. Mostafaei, "Optimization of fusel oil – Gasoline blend ratio to enhance the performance and reduce emissions," *Appl. Therm. Eng.*, vol. 148, pp. 1334–1345, 2018, doi: 10.1016/j.applthermaleng.2018.12.005.
- [24] H. Solmaz, "Combustion, performance and emission characteristics of fusel oil in a spark ignition engine," *Fuel Process. Technol.*, vol. 133, pp. 20–28, 2015, doi: 10.1016/j.fuproc.2015.01.010.
- [25] S. Simsek and B. Ozdalyan, "Improvements to the Composition of Fusel Oil and Analysis of the Effects of Fusel Oil-Gasoline Blends on a Spark-Ignited (SI) Engine's Performance and Emissions," *mdpi.com*, doi: 10.3390/en11030625.
- [26] O. I. Awad et al., "Using fusel oil as a blend in gasoline to improve SI engine efficiencies: A comprehensive review," *Renew. Sustain. Energy Rev.*, vol. 69, no. April 2016, pp. 1232–1242, 2017, doi: 10.1016/j.rser.2016.11.244.
- [27] A. Calam, H. Solmaz, A. Uyumaz, ... S. P.-J. of the energy, and U. 2015, "Investigation of usability of the fusel oil in a single cylinder spark ignition engine," *J. Energy Institute*, pp. 1–8, 2014.
- [28] O. Awad, R. Mamat, T. Ibrahim, ... F. H.-E. conversion and, and undefined 2017, "Calorific value enhancement of fusel oil by moisture removal and its effect on the performance and combustion of a spark ignition engine," Elsevier.
- [29] O. Awad, R. Mamat, T. Ibrahim, M. K.-R. energy, and undefined 2018, "Effects of fusel oil water content reduction on fuel properties, performance and emissions of SI engine fueled with gasoline-fusel oil blends," Elsevier.
- [30] A. A. Hussein, O. M. Ali, A. Sh Hasan, and O. Majeed Ali, "Evaluation of SI engine performance and emissions using local gasoline fuel and ethanol additive."
- [31] M. H. M. Yasin, R. Mamat, G. Najafi, O. M. Ali, A. F. Yusop, and M. H. Ali, "Potentials of palm oil as new feedstock oil for a global alternative fuel: A review," *Renew. Sustain. Energy Rev.*, vol. 79, pp. 1034–1049, 2017.
- [32] H. Sharudin, N. I. K. R. Abdullah, A. M. I. Mamat, and O. M. Ali, "Recent advances in the application and challenges of methanol fuels in spark ignition engine," *ARPN J. Eng. Appl. Sci.*, vol. 11, pp. 7588–7595, 2016.
- [33] I. M. Yusri et al., "Retraction: Combustion and emissions characteristics of a compression ignition engine fueled with n-butanol blends (2015 IOP Conf. Ser.: Mater Sci Eng. 100 012048)," *Mater. Sci. Eng.*, vol. 100, no. 1, p. 12071, 2019.
- [34] M. H. M. Yasin et al., "Study of diesel-biodiesel fuel properties and wavelet analysis on cyclic variations in a diesel engine," *Energy procedia*, vol. 110, pp. 498–503, 2017.
- [35] I. M. Yusri et al., "The combustion of n-butanol-diesel fuel blends and its cycle to cycle variability in a modern common-rail diesel engine," *J. Eng. Appl. Sci.*, vol. 11, no. 4, pp. 2297–2301, 2016.
- [36] O. M. Ali, R. Mamat, and C. K. M. Faizal, "Palm biodiesel production, properties and fuel additives," *Int. Rev. Mech. Eng.*, vol. 6, no. 7, pp. 1573–1580, 2012.
- [37] O. M. Ali, N. M. Salih, and J. I. Musa, "Optimum Engine Performance with Waste Cooking Oil Biodiesel-diesel Blended Fuel," *J. Adv. Res. Dyn. Control Syst.*, vol. 10, no. 12, pp. 494–501, 2018.
- [38] O. M. Ali, R. Mamat, G. Najafi, T. Yusaf, and S. M. Safieddin Ardebili, "Optimization of biodiesel-diesel blended fuel properties and engine performance with ether additive using statistical analysis and response surface methods," *Energies*, vol. 8, no. 12, pp. 14136–14150, 2015.
- [39] H. Sharudin, N. R. Abdullah, M. Yusoff, H. H. Masjuki, and O. M. Ali, "Investigation of the emission characteristics of iso-butanol additives on methanol-gasoline blends using spark ignition engine," *J. Mech. Eng.*, 2017.
- [40] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Investigation of blended palm biodiesel-diesel fuel properties with oxygenated additive," *J. Eng. Appl. Sci.*, vol. 11, no. 8, pp. 5289–5293, 2016.
- [41] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Investigation of blended biodiesel fuel properties with diethyl ether additive," *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 8, pp. 5289–5293, 2016.
- [42] O. M. Ali, R. Mamat, C. H. E. K. U. M. Faizil, and A. F. Yusof, "Influence of oxygenated additive on blended biodiesel-diesel fuel properties," in *Applied Mechanics and Materials*, 2013, vol. 393, pp. 487–492.
- [43] O. M. Ali, T. Yusaf, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Influence of chemical blends on palm oil methyl esters' cold flow properties and fuel characteristics," *Energies*, vol. 7, no. 7, pp. 4364–4380, 2014.
- [44] O. M. Ali, R. Mamat, and C. K. M. Faizal, "Influence of 1-Butanol additives on palm biodiesel fuel characteristics and low temperature flow properties," in *Applied Mechanics and Materials*, 2014, vol. 465, pp. 130–136.
- [45] O. M. Ali and R. Mamat, "Improving engine performance and low temperature properties of blended palm biodiesel using additives. A review," in *Applied Mechanics and Materials*, 2013, vol. 315, pp. 68–72.
- [46] O. M. Ali, F. H. Hasan, and A. Z. Khalaf, "Improving Diesel Engine Efficiency and Emissions Using Fuel Additives," *DIYALA J. Eng. Sci.*, vol. 11, no. 2, pp. 74–78, 2018.
- [47] O. M. Ali and R. Mamat, "Improvement of High Blend Palm Biodiesel-Diesel Fuel Properties Using Ethanol

- Additive," *Eng. Technol.*, vol. 2, no. 5, pp. 324–328, 2015.
- [48] O. M. Ali, R. Mamat, C. Ku, and M. Faizal, "Improvement of Blended Biodiesel Fuel Properties with Ethanol Additive," *Int. J. Adv. Sci. Technol.*, vol. 55, pp. 21–32, 2013.
- [49] H. Liu, Z. Wang, J. Wang, X. H.- Fuel, and undefined 2014, "Effects of gasoline research octane number on premixed low-temperature combustion of wide distillation fuel by gasoline/diesel blend," Elsevier.
- [50] T. Cerri, G. D'Errico, A. O.- Fuel, and undefined 2013, "Experimental investigations on high octane number gasoline formulations for internal combustion engines," Elsevier.
- [51] O. M. Ali, R. Mamat, N. R. Abdullah, A. Adam, N. R. Abdullah, and A. A. Abdullah, "Analysis of Blended Fuel Properties and Engine Cyclic Variations with Ethanol Additive Utilization of Fusel Oil as Alternative fuel for Spark-Ignition Engines View project Fuel spray View project Analysis of Blended Fuel Properties and Engine Cyclic Varia," *Artic. J. Biobased Mater. Bioenergy*, vol. 9, pp. 1–7, 2015, doi: 10.1166/jbmb.2015.1505.
- [52] J. Deelstra, "Estimation of water harvesting potential for a semiarid area using GIS and remote sensing," 1997.
- [53] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Commercial and synthesized additives for biodiesel fuel: a review," *ARN J. Eng. Appl. Sci.*, vol. 11, pp. 3650–3654, 2016.
- [54] O. Awad, R. Mamat, O. Ali, & I. Y.-J. of S. R., and undefined 2016, "Effect of fuel oil-gasoline fusel blends on the performance and emission characteristics of spark ignition engine: a review," *core.ac.uk*.
- [55] O. M. Ali, R. Mamat, N. R. Abdullah, A. A. Abdullah, F. Khoerunnisa, and R. E. Sardjono, "Effects of different chemical additives on biodiesel fuel properties and engine performance. A comparison review," in *MATEC Web of Conferences*, 2016, vol. 38, p. 3002.
- [56] O. I. Awad, O. M. Ali, A. T. Hammid, and R. Mamat, "Impact of fusel oil moisture reduction on the fuel properties and combustion characteristics of SI engine fueled with gasoline-fusel oil blends," *Renew. energy*, vol. 123, pp. 79–91, 2018.
- [57] W. S. Ghanim, O. K. Ahmed, and O. M. Ali, "Gasoline Engine Simulation Software: A Comparison Review," in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1076, no. 1, p. 12070.
- [58] M. A. Taha, O. Ali, and M. M. Weis, "Fusel Oil as A Fuel Additive with Gasoline to Operate Spark Ignition Engine, A Comparative Review," *NTU J. Eng. Technol.*, vol. 1, no. 1, pp. 63–66, 2021.
- [59] O. I. Awad, R. Mamat, O. M. Ali, M. F. Othman, and A. A. Abdullah, "Experimental Study of Performance and Emissions of Fusel Oil-Diesel Blend in a Single Cylinder Diesel Engine," *Int. J. Eng. Technol.*, vol. 9, no. 2, p. 138, 2017.
- [60] M. S. M. Zaharin, N. R. Abdullah, H. H. Masjuki, O. M. Ali, G. Najafi, and T. Yusaf, "Evaluation on physicochemical properties of iso-butanol additives in ethanol-gasoline blend on performance and emission characteristics of a spark-ignition engine," *Appl. Therm. Eng.*, vol. 144, pp. 960–971, 2018.
- [61] A. A. Hussein, O. M. Ali, and A. S. Hasan, "Evaluation of SI engine performance and emissions using local gasoline fuel and ethanol additive," *J. Xi'an Univ. Archit. Technol.*, vol. 12, no. 4, pp. 3983–3991, 2020.
- [62] O. M. Ali, "Evaluation of diesel engine performance with high blended diesel-biodiesel fuel from waste cooking oil," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 518, no. 3, p. 32054.
- [63] M. S. M. Zaharin, N. R. Abdullah, N. H. Badrulhisam, F. Hamzah, and O. M. Ali, "Estimation method of heating value properties on variations of alcohol-gasoline blends and volume percentages," *J. Mech. Eng.*, vol. 5, no. 2, pp. 20–35, 2016.
- [64] O. Ali, N. Abdullah, R. Mamat, A. A.-E. Procedia, and undefined 2015, "Comparison of the effect of different alcohol additives with blended fuel on cyclic variation in diesel engine," Elsevier.
- [65] O. M. Ali, R. Mamat, N. R. Abdullah, and A. A. Abdullah, "Characteristic of blended fuel properties and engine cycle-to-cycle variations with butanol additive," in *AIP Conference Proceedings*, 2015, vol. 1660, no. 1, p. 70006.
- [66] O. M. Ali, R. Mamat, and O. I. Awad, "Characterization of high blended palm biodiesel fuel properties with chemical additive," *J. Pure Appl. Microbiol.*, vol. 9, no. Special Edition 2, pp. 505–512, 2015.
- [67] J. I. Musa, E. A. Eesaa, and O. M. Ali, "Enhancement of SI engines performance operating with gasoline fuel using high octane additives from waste materials," in *AIP Conference Proceedings*, 2020, vol. 2213, no. 1, p. 20032.
- [68] A. Shukur Hadi, O. Khalil Ahmed, and O. Majeed Ali, "Enhancement of Gasoline Fuel Quality with Commercial Additives to Improve Engine Performance," *Mater. Sci. Eng.*, vol. 745, no. 1, p. 12065, 2020.
- [69] A. H. Ahmed, O. M. Ali, A. E. Mohammed, R. W. Daoud, and T. K. Ibrahim, "Enhancement of engine performance with high blended diesel-biodiesel fuel using iso-butanol additive," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 518, no. 3, p. 32013.
- [70] W. N. Maawa, R. Mamat, G. Najafi, O. M. Ali, and A. Aziz, "Engine performance and emission of compression ignition engine fuelled with emulsified biodiesel-water," in *IOP Conference Series: Materials Science and Engineering*, 2015, vol. 100, no. 1, p. 12061.
- [71] Y. Ahmad Fitri, M. Rizalman, M. Hafizil, M. Yasin, and O. M. Ali, "Effects of Particulate Matter (Pm) Emissions of Diesel Engine Using Diesel-Methanol Blends," *J. Mech. Eng. Sci.*, vol. 6, pp. 959–967, 2014.
- [72] O. M. Ali, R. Mamat, C. Ku, and M. Faizal, "Effects of Diethyl Ether Additives on Palm Biodiesel Fuel Characteristics and Low Temperature Flow Properties," *Int. J. Adv. Sci. Technol.*, vol. 52, pp. 111–120, 2013.



- [73] R. Mamat et al., "Effects of Diesel-Biodiesel Blends in Diesel Engine Single Cylinder on the Emission Characteristic," in *MATEC Web of Conferences*, 2018, vol. 225, p. 1013.
- [74] O. Ali, R. Mamat, ... N. A.-I. J. of, and undefined 2013, "Effects of blending ethanol with palm oil methyl esters on low temperature flow properties and fuel characteristics," *earticle.net*.
- [75] O. Ali, R. Mamat, C. F.-A. M. and Materials, and undefined 2014, "Characterization of blended biodiesel fuel properties With small portion of butanol as a fuel additive," *Trans Tech Publ*.
- [76] O. Ali, R. Mamat, C. F.-A. M. and Materials, and undefined 2014, "Influence of 1-Butanol additives on palm biodiesel fuel characteristics and low temperature flow properties," *Trans Tech Publ*.
- [77] , A. E., "Performance and emissions analysis on using acetone-gasoline fuel blends in spark-ignition engine ", *Engineering Sci. Technol. an Int. J.*, vol. 19, no. 3, pp. 1224–1232, 2016.
- [78] I. M. Yusri, R. Mamat, W. H. Azmi, A. I. Omar, M. A. Obed, and A. I. M. Shaiful, "Application of response surface methodology in optimization of performance and exhaust emissions of secondary butyl alcohol-gasoline blends in SI engine," *Energy Convers. Manag.*, vol. 133, pp. 178–195, 2017.
- [79] O. M. Ali, R. Mamat, C. Ku, and M. Faizal, "Effects of blending on biodiesel characteristics and low temperature flow properties," *Energy Educ. Sci. Technol. Part A Energy Sci. Res.*, vol. 31, no. 3, pp. 1209–1218, 2013.
- [80] F. Y. Hagos, O. M. Ali, R. Mamat, and A. A. Abdullah, "Effect of emulsification and blending on the oxygenation and substitution of diesel fuel for compression ignition engine," *Renew. Sustain. Energy Rev.*, vol. 75, pp. 1281–1294, 2017.
- [81] C. W. M. Noor, R. Mamat, O. Ali, G. Najafi, and W. N. D. Mansor, "Cyclic Variation Analysis of Palm Biodiesel Fuel in Low Compression Marine Diesel Engine," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 75, no. 2, pp. 43–58, 2020.
- [82] O. M. Ali, N. R. Abdullah, R. Mamat, and A. A. Abdullah, "Comparison of the effect of different alcohol additives with blended fuel on cyclic variation in diesel engine," *Energy Procedia*, vol. 75, pp. 2357–2362, 2015.
- [83] A. S. Hadi, O. K. Ahmed, and O. M. Ali, "Comparison of local gasoline fuel characteristics and SI engine performance with commercial fuel additives," in *AIP Conference Proceedings*, 2020, vol. 2213, no. 1, p. 20087.
- [84] O. M. Ali, R. Mamat, and C. K. M. Faizal, "Characterization of blended biodiesel fuel properties With small portion of butanol as a fuel additive," in *Applied Mechanics and Materials*, 2014, vol. 465, pp. 137–141.
- [85] H. H. Hamed, A. E. Mohammed, O. A. Habeeb, O. M. Ali, O. S. Aljaf, and M. A. Abdulqader, "Biodiesel Production From Waste Cooking Oil using Homogeneous Catalyst," *Egypt. J. Chem.*, vol. 64, no. 6, pp. 2827–2832, 2021.
- [86] R. Tariq, N. Ahmed, J. Xamán, and A. Bassam, "An innovative air saturator for humidifi cation-dehumidifi cation desalination application," vol. 228, no. July, pp. 789–807, 2018, doi: 10.1016/j.apenergy.2018.06.135.
- [87] I. Policies, I. Action, C. Change, and T. Waters, "ABOUT UN-WATER," pp. 9–10, 2020.
- [88] S. Senevirathna, S. Ramzan, and J. Morgan, "A sustainable and fully automated process to treat stored rainwater to meet drinking water quality guidelines," *Process Saf. Environ. Prot.*, vol. 130, pp. 190–196, Oct. 2019, doi: 10.1016/j.psep.2019.08.005.
- [89] G. M. Ayoub, M. Al-Hindi, and L. Malaeb, "A solar still desalination system with enhanced productivity," *Desalin. Water Treat.*, vol. 53, no. 12, pp. 3179–3186, 2015, doi: 10.1080/19443994.2014.933040.
- [90] M. A. R. S. Al-Baghdadi, "A simulation model for a single cylinder four-stroke spark ignition engine fueled with alternative fuels," *Turkish J. Eng. Environ. Sci.*, vol. 30, no. 6, pp. 331–350, 2006, doi: 10.3906/tar-1110-28.
- [91] S. Ardebili, H. Solmaz, D. İpci, A. Calam, M. M.- Fuel, and U. 2020, "A review on higher alcohol of fusel oil as a renewable fuel for internal combustion engines: Applications, challenges, and global potential," Elsevier.