ADDITION OF n-OCTANOL TO BIODIESELS OBTAINED FROM DIFFERENT OIL SOURCES AND INVESTIGATION OF THE EFFECTS OF THE OBTAINED BLENDS ON FUEL PROPERTIES

by

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Petroleum-based liquid fuels such as gasoline and diesel have dominated the transportation sectors in recent centuries. However, the need to reduce the emission of GHG and the dependency on fossil fuels has motivated researchers across the globe to look for alternative and renewable fuels sources. Vegetable oils, alcohols and fats from animal waste are the potential candidates for biofuel since they are renewable and cleaner burning fuels. Biofuel has higher cetane number, which lowers idle noise and endorses easier start. Biodiesel consists of long-chain fatty acid alkyl esters and is obtained from renewable vegetable oils, recycled cooking oils or animal fats. Biodiesel can be used in Diesel engines with minor or no modifications. Fuels derived from various bio-based feedstocks have attracted great attention in recent decades. Oxygen containing biofuels, such as alcohols, have exhibited considerable promise, because they are renewable and considered neutral with regard to net GHG emissions. The n-octanol is a new promising fuel, which is considered as an alternative to conventional diesel. Octanol has raised a significant amount of interest, where recently new pathways have been described to obtain n-octanol from biomass or bio-oil. In this study, the addition of n-octanol to biodiesels obtained from different oil sources and the effects of the resulting mixtures on the fuel properties will be investigated.

Key words: *different oil sources, biodiesel, n-octanaol, fuel properties*

Introduction

Nowadays, factors such as industrialization, population growth, and rising living standards are increasing the demand for energy. Fossil fuels meet most of the energy needs in the world. Internal combustion engines commonly, used worldwide for transportation, industrial machinery, cogeneration, and agricultural purposes, are among those mainly responsible for the depletion of fossil fuels. The reserves of fossil fuels, including petroleum, coal, and natural gas, are rapidly being depleted. The reserves of fossil fuels, which are limited and finite, are concentrated more in particular regions of the world. In addition, since fossil based fuels cause serious problems to the environment we live in and on human health, heavy limitations are imposed on the exhaust emissions of these fuels [1, 2]. The increasing need for energy in recent years, the awareness of environmental problems such as global warming, the depletion of crude oil reserves faster than ever, the dominance of petroleum-based liquid fuels such as

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gasoline, jet fuel and diesel in transportation sectors, the need to reduce GHG emissions and to eliminate dependence on fossil fuels have forced researchers around the world to search for alternative and renewable fuel sources [3]. Biodiesel fuel, which is methyl ester of vegetable oils, is the mostly preferred alternative fuel among renewable and sustainable alternative fuels. Biodiesel is increasingly used in the market as a fuel in compression ignition (CI) engines [4]. Biodiesel is a green fuel, which is environmentally friendly and can be obtained from renewable raw materials and can be produced from waste vegetable oils and animal fats and is anti-toxic, biodegradable, carcinogenic and sulfur-free and can be easily stored, transported and used with its high flash point and its lubricity feature extends the engine life and is excellent and improves engine characteristic values and can be used in land and sea transportation and has strategic features suitable for using in heating systems and generators and has achieved commercial success [5, 6]. Biodiesel does not contain petroleum, yet it can be used as a fuel in pure form or in mixed form with diesel in any proportion. Pure biodiesel and diesel-biodiesel blends can be used in any Diesel engine without any modification or with minor modifications [7]. Biodiesel strengthens the agricultural industry, and reduces migration from rural areas, and can be attained from agricultural products and wastes, and positively contributes to the ecology by providing diversity in agricultural productions, and creates a sustainable agricultural structure, and provides continuity to the farmer's production, and popularizes the cultivation of oil crops and at the same time supports the closure of the domestic oil deficit, and increases soil fertility by expanding crop rotation, and contains features that can be a panacea for many problems of today [8, 9]. It is often observed that studies have been conducted on the use of biodiesel, which is increasingly widely used in the world, as a substitute for diesel along with some alternative high-chain alcohols [10]. Recently, diesel/biodiesel/alcohol blended fuels have attracted tremendous attention as a potential alternative Diesel engine fuel [11, 12]. Some scientists such as Gulum and Bilgin [13] considered the physicochemical properties of UFO biodiesel/diesel/lower and higher alcohols (C_1-C_5) ternary blends and they showed possible enhancements in blend viscosity at higher and lower temperatures. Atmanli *et al.* [14] reported that n-butanol improved the blending miscibility between diesel and raw cotton oil. In another study, Gulum *et al.* [15] estimated the density of diesel/waste cooking oil biodiesel/alcohol ternary blends using ANN and exponential model. Alcohols have been used for many years either directly or as a blend as an alternative to CI engines. Alcohols are in liquid phase and contain oxygen. Alcohols have a lower cetane number (CN) than diesel fuel depending on the carbon number [16, 17]. Alcohol fuels are widely used in internal combustion engines to improve fuel properties, combustion performance, and reduce harmful exhaust emissions. To use bioalcohol in CI engines, alcohol must be able to dissolve in diesel fuel at any rate. Currently, countries do not make enough investments in alcohol production and consumption for fuel purposes [18, 19].

Research is underway to extract high yields of alcohols employing engineered micro-organisms like Escherichia coli and Clostridium species [20, 21]. While short-chain alcohols like methanol and ethanol are suitable for spark-ignition (SI) engines, long chain alcohols above butanol favors utilization in CI engines due to their high energy density and high CN. Higher CN alcohols also present better blend stability due to their less hygroscopic nature. The properties of some higher alcohols in comparison with ethanol and methanol are shown in tab. 1. Several studies have evaluated Diesel engine characteristics using higher alcohols like n-butanol [22-28], isobutanol [22, 29-32], n-pentanol [33-37], and n-hexanol [38] as blend components with fossil diesel. A collective conclusion is that higher alcohol/diesel blends generally increased the ignition delay due to their lower CN and produced higher peaks of incylinder pressure and heat release rates due to an enhanced premixed combustion phase. The pump price of diesel fuel is very low compared to alcohols. The amount of water in the alcohol content has a low corrosive effect on the fuel systems of Diesel engines [39].

It is found that higher alcohols, such as n-octanol, could provide better solubility [40, 41]. The n-octanol, possessing a CN similar to diesel, can be used directly in Diesel engines without the need for equipment modifications [40-43]. Moreover, n-octanol is emerging as a potential biofuel compatible with diesel technology with its basic properties such as CN, calorific value, boiling point, and self-ignition temperature, which are very close to diesel [36]. The experimental research testing neat n-octanol in Diesel engines has demonstrated that it emits almost negligible soot particles. Thus, it is very promising to adopt n-octanol as a blend fuel with diesel or biodiesel for reducing soot emissions [44-48]. Many experimental studies have been conducted to investigate the combustion and emissions characteristics in Diesel engines fueled by biodiesel/n-octanol blends. Devarajan *et al.* [49] tested mustard oil biodiesel/octanol blends in a Diesel engine. The results suggest that blending n-octanol could lower CO and NO_x emissions simultaneously. Mahalingam *et al.* [50] investigated the combustion and emissions characteristics of the Diesel engine fueled by mahua oil biodiesel/n-octanol blends. It was proved that the addition of n-octanol in biodiesel could reduce CO, NO_x, and soot emissions of the engine at the same time. Some other experimental studies have also been carried out to investigate the effects of the ternary blends diesel/biodiesel/n-octanol on the Diesel engines [51, 52]. All these results show that when used in combination with diesel and biodiesel, n-octanol provides several significant advantages such as reduced soot, lower CO and NO_x emissions, increased blend stability and no additional modifications to engine equipment.

Physical and chemical fuel characteristics

In this section, the physical properties and chemical kinetics of methanol, ethanol, n-butanol, n-pentanol, and n-octanol are presented and discussed. First, their molecular structures are introduced, and the physical and chemical characteristics are presented and discussed briefly. The physical and chemical properties of methanol, ethanol, n-butanol, n-pentanol and n-octanol are summarized in tab. 1. As the oxygenated fuels are discussed here as potential candidates for CI engines, diesel fuel is also listed here for comparison. It can be seen that density, ρ, lower heating value, and latent heat of evaporation of these fuel candidates differ only marginally from that of diesel fuel. This prevents extensive engine modifications when using the biofuels in conventional engines. For the temperature dependent physical properties like heat of evaporation, liquid density, and surface tension, tabulated values as function of temperature are used in the simulations. As expected, strong variations in CN are reported for the fuels. Table 1 shows the properties of diesel n-octanol and other lower alcohols.

The molecular structures of methanol, ethanol, n-butanol, n-pentanol and n-octanol are presented in fig. 1.

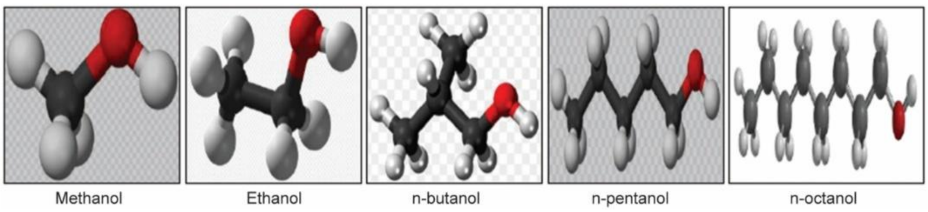

Figure 1. Molecular structures of methanol, ethanol, n-butanol, n-pentanol, and n-octanol

Table 1. Properties of n-octanol in comparison with diesel and other lower alcohols [53-55]

Properties	Diesel	Methanol	Ethanol	n-butanol	n-pentanol	n-octanol
Molecular formula	C_xH_y	CH_3AOH	C_2H_5AOH	C_4H_9AOH	$C_5H_{11}AOH$	$C_8H_{17}AOH$
Molecular weight [$kgk^{-1}mol^{-1}$)	190-211.7	32.04	46.07	74.12	88.15	130.23
C [wt.%]	86.13	37.48	52.14	64.82	68.13	73.72
H [wt.%]	13.87	12.48	13.02	13.49	13.61	13.82
O [wt.%]	0	49.93	34.73	21.59	18.15	12.29
Stoichiometric A/F ratio	14.67	6.47	9.01	11.21	11.76	12.71
Lubricity (lm corrected wear scar)	315	1100	1057	591	670.5	404
Cetane number	52	5	8	17	18.2-20	39
Self-ignition temperature [°C]	254–300	463	420	345	300	270
Density [kgm^{-3}] at 15 °C	835	791.3	789.4	809.7	814.8	827
Viscosity at 40 °C [mms^{-2}]	2.72	0.58	1.13	2.22	2.89	7.3
Lower heating value [$MJkg^{-1}$]	42.49	19.58	26.83	33.09	34.65	37.53
Latent heat of evaporation [$kJkg^{-1}$]	276	1162.64	918.42	581.4	308.05	408
Vapor pressure [mmHg]	0.4	127	55	7	6	0.08
Solubility in water [gL^{-1}]	Immis-cible	Miscible	Miscible	77	22	4.6
Boiling point [°C]	180-360	64.7	78.3	117.5	137.9	195
Flash point [°C]	>55	11–12	17	35–37	49	81

Black atoms are carbon atoms, grey ones are hydrogen atoms and red ones denote the oxygen atoms.

Materials and methods

In this study, after the oils and n-octanol used in this study were obtained from commercial companies, these oils were converted into biodiesel under appropriate conditions in the Fuel Analysis Laboratory of Batman University Technical Sciences Vocational School, Department of Chemistry and Chemical Processing Technologies. The n-octanol was added to the produced biodiesel at the rate of 5% and 10% and mixed with ultrasonic homogenizer device until a homogeneous mixture was obtained. The fuel properties of the obtained fuel mixtures were tested by means of the devices in the same laboratory and the results were reported.

Results and discussion

Fuel properties

Table 2 shows the density, viscosity, flash point and CI values of biodiesels produced from safflower, canola, corn, olive, and sunflower oils and n-octanol in pure form and blends obtained by adding 5% and 10% n-octanol.

Table 2. Properties of test fuels.

	Fuels	Density [kgm^{-3}] at 15 °C	Viscosity [mms^{-2}] at 40 °C	Flash point [°C]	Cetane index
Pure Fuels	n-Octanol	829	5,701	81	40
	Safflower	885	4,600	140	54
	Canola	879	4,401	167	53
	Corn	878	4,420	170	56
	Olive	882	4,530	177	58
	Sunflower	881	4,300	178	50
5% n-Octanol	Safflower	883	4,620	135	52
	Canola	865	4,430	125	52
	Corn	875	4,440	165	55
	Olive	880	4,550	172	56
	Sunflower	878	4,330	173	48
10% n-Octanol	Safflower	877	4,660	129	51
	Canola	850	4,560	110	51
	Corn	871	4,470	156	54
	Olive	877	4,590	168	54
	Sunflower	874	4,370	169	46

Density change

Density (specific gravity) is an indication of the density or weight per unit volume of fuel. Density is a fundamental parameter. As density increases, the amount of energy per unit volume increases. Given a constant amount of fuel injected, the energy supplied to the engine increases with density, which improves engine performance. However, exhaust emissions and especially particulates increase under full load due to the richer mixture. On the other hand, volumetric fuel consumption increases as density decreases [56]. In addition, density is an important parameter for fuel quality and fuel injection systems in diesel and biodiesel fuels [57]. Many performance characteristics, such as CN and heating value, are related to density. This property influences the efficiency of fuel atomization. On the other hand, diesel fuel injection systems measure the fuel by volume. Therefore, the changes in the fuel density influence engine output power due to a different mass of fuel injected. The density and viscosity of the fuels affect the start of injection, the injection pressure, and the fuel spray characteristic, so they influence the engine performance, combustion, and exhaust emissions [58-60]. After the physical effect of density is analyzed in detail, it can be said that higher density diesel fuel causes a larger amount of fuel to be injected, which in turn changes the dynamic timing. The large amount of fuel injected into the combustion chamber, *i.e.* the rich mixture created, causes the combustion chamber wall temperature to increase and therefore reduces the ignition delay time. The density of fuels is known to be one of the most important factors in the formation of particulate and NO_x emissions. Especially in experiments conducted under transition conditions, this effect can be seen more clearly. When the physical effect of density is analyzed in detail, it can be said that diesel fuel with higher density causes more fuel to be sprayed and the dynamic timing changes accordingly. The power increase in Diesel engines is directly related to the fuel density delivered to the cylinders. Since the desired mixture cannot be achieved at full load, carbon deposits are high as a result of combustion and the amount of smoke in the exhaust increases and displays a sooty appearance [61]. Among hydrocarbons, aromatics have the highest density. Therefore, they burn sooty because they have the highest thermal value per unit volume. If the aromatic percentage of the fuel sprayed into the combustion chamber is high, soot forms especially on the valve stem and trays and injector nozzle tips due to the large number of carbon deposits formed as a result of combustion, causing the volume of the combustion chamber to decrease [62]. Too much residue accumulated in the combustion chamber leads to a decrease in combustion efficiency and a decrease in performance values. For this reason, especially in jet fuels, the weight of aromatics is not desired to be more than 25%. Reducing the ratio of aromatic compounds in diesel fuel reduces hydrocarbon emission. The decrease in the amount of aromatics for the fuel corresponding to a 10 number increase in the CN is 4% in the total amount of aromatics and approximately 2% in the amount of polyaromatics [63]. Density in the present study was measured using an Anton Paar DMA 4200 M density meter at 15 °C, fig. 2, according to the ASTM D941 standard test method.

Figure 2. The DMA 4200 M density meter

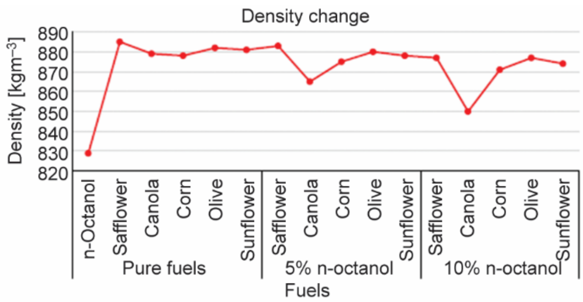

Figure 3. Changes in the density of additives used in pure form and the specified proportions

The density of n-octanol we used in the study is between the petroleum-based diesel (EN 590) and biodiesel (EN 14214) standards, and is considerably lower than biodiesel fuels. Therefore, as shown in fig. 3, when we added 5%-10% n-octanol to biodiesel and analyzed the densities of the mixtures that we obtained, it was found that the density of the mixture decreased relatively as the amount of n-octanol in the mixture increased. This tells us that the use of biodiesel blends with n-octanol additives causes the density of the blend to decrease and therefore the density of the fuel affects the engine calibration and power because the mass injected per stroke varies according to the density of the diesel. This affects the combustion and emission timing of the engine. Similarly, particulate matter (PM) emissions generally increase with an increase in diesel fuel density, which can alter the efficiency and performance of the generator set. The increase in density also increases the dynamic injection timing, and diesel fuels with high-density also have higher viscosity, which is responsible for changes in the injection process.

Kinematic viscosity change

Viscosity is the internal resistance of a fluid to flow due to the forces of attraction and friction. In this respect, viscosity, or internal friction manifests itself in the difficulty encountered in the movement of the various layers of a fluid over each other. In other words, the degree of viscosity is a measure of the internal friction of a liquid. Viscosity decreases with increasing temperature and increases with increasing pressure. Viscosity plays a great role in diesel fuels in cold weather. Viscosity is a natural property similar to density and is a characteristic of fuels. High viscosity leads to poor atomization of the fuel, poor flow, clogged injectors, carbon build-up in the piston rings and deterioration of the lubricating oil. High viscosity reduces pumpability and injector spray [64, 65]. Diesel fuel must lubricate some of the moving parts of the injectors and fuel pumps. Therefore, the viscosity of the fuel is an important characteristic and must be within certain limits. Figure 4 shows the kinematic viscosity meter. Fuel that is not of the appropriate viscosity will cause wear on these materials. A small amount of anti-wear additive is also added to the fuel to form a protective film on the lubricated surfaces. Inadequate lubrication is not the only cause of wear in the Diesel engine fuel system [66]. Inorganic particles in the fuel also cause wear in the fuel system and piston segments. In addition, organic acids cause corrosive wear in the fuel system; and excess sulfur compounds increase the wear mechanism. Viscosity affects injector lubrication and fuel atomization; and fuels with low viscosity do not provide adequate lubrication in the injection system, resulting in wear and leakage [67, 68]. On the other hand, high viscosity fuels form large droplets in the injection, cause poor combustion and lead to soot from the exhaust and increased emissions. Fuels that are not within specification limits reduce engine performance [69]. Fuel viscosity is specified in the diesel fuel standard in a very narrow range. Hydrocarbon fuels in the diesel boiling range easily meet this viscosity requirement [70]. Most diesel fuel injection systems compress the fuel for injection using a simple piston and cylinder pump called a piston and barrel. To develop the high pressures needed in modern injection systems, the clearances between the piston and barrel are about ten thousandths of an inch. Despite this small clearance, a significant portion of the fuel passes through the piston and barrel during compression. If the fuel viscosity is low, the leakage will be enough to cause a significant loss of power for the engine. If the fuel viscosity is high, the injection pump cannot supply enough fuel to fill the pumping chamber. The effect is again loss of power [71, 72]. The viscosity should be low enough to allow the fuel to flow easily even at low operating temperatures and high enough to lubricate the pump-injector system. For Otto (gasoline) engines, viscosity is not very important. Because gasoline maintains its normal fluidity even at low temperatures. In Diesel engines, however, viscosity is important as the fuel is sprayed into the combustion chamber under high pressure. For diesel vehicles, the viscosity of the fuel must be at a level that allows the injection pump to work properly.

If the viscosity is low:

- Since the fuel will flow easily, it may cause leaks in the fuel pump.
- The fuel film between the fixed and moving parts in the pump cannot be maintained and the lubrication of the moving parts is not fully realized.
- Although it provides good atomization, it causes sealing problems and wear of the pump elements [73, 74].

If the viscosity is too high:

- Injectors cannot atomize the fuel into small enough drops to ensure good evaporation and combustion and combustion is incomplete.
- Spray line pressure and the amount of fuel delivery are also affected by viscosity.
- It increases the ignition delay, as it makes the pumping work difficult and cause the particles to be coarse after spraying. In addition, the amount of soot increases [75-77].

As can be seen in fig. 5, although the kinematic viscosity of n-octanol that we used in the study is partially higher than the petroleum-based diesel (EN 590) and biodiesel (EN 14214) standards, when the kinematic viscosities of the blends obtained by adding 5%-10% n-octanol to biodiesels were analyzed, it was observed that as the amount of n-octanol in the mixture increased, the kinematic viscosities of the blends increased relatively at a very low level. However, when 10% n-octanol was added to the biodiesel, the kinematic viscosity values of the blends obtained were found to meet EN 14214 standards.

Figure 4. Kinematic viscosity meter

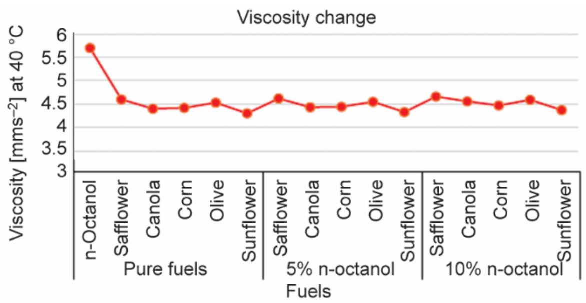

Figure 5. Changes in the kinematic viscosity of additives used in pure form and the specified proportions

Flash point change

Flash point is used as a general guide to determine the flammability or combustibility of a substance. By similar definition, flash point is the minimum temperature at which a liquid emits enough vapor to ignite at the surface of the liquid, or flash points are measured by heating a substance to a specified temperature under controlled conditions, fig. 6. According to another definition, the vapors of a volatile liquid mix with air and the mixture ignites when there is a flame contact at a certain vapor/air ratio. The temperature at this moment is the flash point. The flash point value is inversely proportional to the volatility of the fuel [78, 79]. The most important criterion for determining the hazard of flammable liquids is the flash point [80]. To measure a substance's flash point, it is necessary to introduce an ignition source, as this allows the volatile substance to reach a particular temperature before it *flashes* or ignites. There are two methods to determine flash points: The first one is the closed-cup test or open-cup test. The second is open-cup method, which measures flash points in a vessel that is exposed to outside air, while the closed-cup method takes place in a closed vessel that is not affected by the external atmosphere. These different flash point testing methods are designed to reflect the workplace environment and the conditions of storage for the substances [81]. The flash point temperature of diesel fuel is the minimum temperature at which the fuel flashes upon application of an ignition source [82]. One of the most important advantages of biodiesel is that its flash point is greater than that of diesel fuel, which is reflected in the specifications in the standards [83]. The flash point of biodiesel must be a minimum 120 °C and 130 °C, according to EN 14214 and

ASTM 6751, respectively. This parameter was determined in the present study according to the ASTM D93 standard test method [84]. As can be seen in fig. 7, although the flash point of n-octanol is quite low compared to the flash points of the fuels we used in the study, it is seen that there is no significant decrease in the flash points of the new blends obtained when n-octanol is mixed with other fuels at 5%-10% ratios and the results are within the biodiesel standards (EN 14214). Therefore, it is predicted that the new fuels obtained by adding pure n-octanol at the aforementioned ratios to the biodiesel used in the study will not pose any safety problem during transportation.

Figure 6. Flash point tester

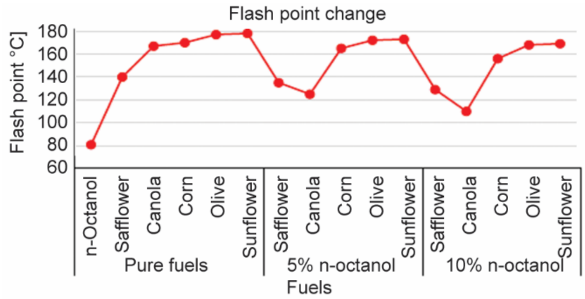

Figure 7. Changes in the flash point of additives used in pure form and the specified proportions

Cetane index change

One of the important characteristics of diesel fuel is the CN, which describes the complete combustion of the fuel and therefore leads to the easy operation of the engine. The CN, which is an indicator of the self-ignition quality of diesel fuel, ensures that the fuel ignites easily and burns quickly. It can also be defined as a measure of the knocking tendency of a diesel fuel. The CN is related to the ignition delay time, which is the time interval between the start of injection and the start of combustion. As the CN increases, the ignition delay decreases and the main combustion phase (diffusion-controlled combustion) increases [85, 86]. Long ignition delay is not acceptable since it causes diesel knock [87]. If the CN of diesel fuel is too high, this fuel may ignite in a short distance to the injector nozzle and cause excessive heating of the injector. As a result of the intense heating, cooked fuel particles inside the injector may plug the injector nozzle [88].

In a Diesel engine, as a result of variables such as piston compression pressure, ambient temperature or coolant temperature being low, the compression temperature will also decrease, so, a high CN is required for easy operation of the engine and full combustion of the fuel. If there is no complete combustion, fuel is expelled from the exhaust in the form of smoke. In modern Diesel engines, it is desirable that this value be at least 40 (ASTM D 975). After the engine starts, the temperature of the combustion chamber is still low, and the injected fuel cannot be fully burned. As a result, unburned fuel and partially burned fuel particles are expelled from the exhaust as a white smoke (mist). This problem is not encountered when a fuel with a high CN is used. The ignition time of a fuel is determined by the components it contains, *i.e.* its chemistry. In a hot engine, the latency is independent of the physical properties of the fuel (such as density, viscosity). The CN apply only to distilled fuels, not to fuels containing petroleum residues (marine fuels). Engine noise is based on two reasons: combustion noise and mechanical noise. The properties of the fuel are effective only in the noise of combustion. The high CN ensures timely combustion of fuel and reduces noise generation [89]. The CN is determined experimentally in a special test engine. However, due to the fact that this process is very expensive and the experimental work is difficult and time consuming, such an engine is not always available or there is not enough fuel sample; accordingly, alternative methods to CN have been developed. One of these methods, the cetane index, has been developed in order to differentiate the values obtained from the values obtained from engine tests. Today, the cetane index is used instead of the CN of diesel fuel. The cetane index is calculated based on the density of the fuel and the distillation range (ASTM D86). The ASTM D4737-21 is the standard test method for cetane index calculated by a four-variable equation [90]. The cetane index is a measure of the ignition quality of a fuel and influences white smoke and combustion roughness. The cetane index is based on specific gravity and 10%, 50%, and 90% distillation temperatures of the fuel. This parameter was calculated according to ASTM D4737 standard test method in the present study.

Cetane index = f(density, distillation temp.) [90, 91]. In ASTM D4737, two equations are given to estimate CN.

$$CI = 45.2 + 0.0892T_{10\text{N}} + (0.131 + 0.901B)T_{50\text{N}} + (0.0523 - 0.420B)T_{90\text{N}} + \\ + 0.00049(T^2_{10\text{N}} - T^2_{90\text{N}}) + 107B + 60B^2 \quad (1)$$

$$CI = -399.90\rho + 0.1113T_{10} + 0.1212T_{50} + 0.0627T_{90} + 309.33 \quad (2)$$

In ASTM D976, CN is estimated by [91-93]:

$$CI = 474.74 - 1641.416\rho + 77.74\rho^2 - 0.554T_{50} + 97.803[\log(T_{50})] \quad (3)$$

These equations use the recovery temperatures, T [°C], from distillation curve data (ASTM D86) at various percentages of recovery, 10% for T_{10}, 50% for T_{50}, and 90% for T_{90}. These temperatures are modified in eq. (1), where $T_{10\text{N}} = T_{10} - 215$, $T_{50\text{N}} = T_{50} - 260$, and $T_{90\text{N}} = T_{90} - 310$. The density, ρ [gmL^{-1}] at 288 K is used in eqs. (2) and (3) and modified in eq. (1) where $B = + \exp[-3.5(\rho - 0.85)] - 1$. Equation (3) can be used for military diesel fuel, with a lower limit of 43 [94]. All three equations are acceptable methods for the jet fuel specification, but the requirement is *report only*. The ASTM D4737 method says that eqs. (1) and (2) were derived from fuels meeting ASTM D975 specifications [92]. Equation (1) was derived from 111 No. 2-D S500 diesel fuels with sulfur levels between 15 ppm and 500 ppm and validated for 980 diesel fuel samples with a similar sulfur range. Equation (2) was derived from 1129 fuels including diesel, refinery blending components, and fuels derived from oil sands, shale, and coal. It would be likely that eq. (2) would apply to a wider variety of fuels than eq. (1). The optimal range is 32.5-56.5 CN with an error of ±2 CN for 65% of distillate fuels evaluated [91, 92]. For eq. (3), the error is also ±2 of CN for CN from 30 to 60 [91, 93]. As seen in fig. 8, when the cetane index of the pure fuels used in the study are examined, it is seen that the cetane index of n-octanol is partially lower than the other fuels. When 5%-10% pure n-octanol was blended with other fuels and tested, it was found that there was a very slight decrease in the cetane index of the new blends. However, these results did not significantly affect the quality of the fuel blends (in terms of CN/cetane index). Since the cetane index values of all of the new fuel blends obtained were 51 and above, it was also determined that they met the biodiesel standard EN 14214.

Figure 8. The CFR F5 cetane rating unit

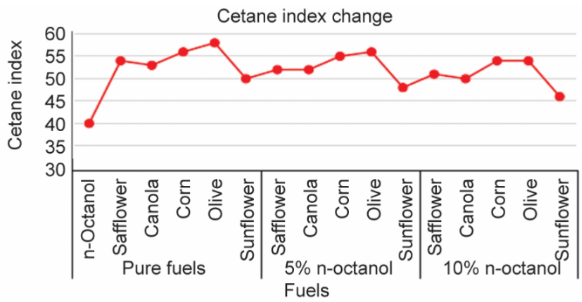

Figure 9. Changes in the cetane index of additives used in pure form and the specified proportions

Conclusions

- Since high carbon n-octanol has a CN/cetane index close to diesel fuel, it can be used directly in Diesel engines without any modification of engine equipment.
- In addition, n-octanol emerges as a potential biofuel compatible with diesel technology with its basic properties such as calorific value, boiling point, and self-ignition temperature, which are very close to that of diesel.
- The experimental research testing neat n-octanol in Diesel engines demonstrated that it emits almost negligible soot particles. Thus, it is very promising to adopt n-octanol as a blend fuel with diesel or biodiesel for reducing soot emissions.
- Many experimental studies have been conducted to investigate the combustion and emissions characteristics in Diesel engines fueled by biodiesel/n-octanol blends.
- Previous studies tested mustard oil biodiesel/n-octanol blends in a Diesel engine. The results showed that n-octanol blend could reduce CO and NO_x emissions simultaneously.
- Some other experimental studies were also carried out to investigate the effects of the ternary blends diesel/biodiesel/n-octanol on the Diesel engines. When used in combination with diesel and biodiesel, all these results showed that n-octanol provided several significant advantages such as reduced soot, CO and NO_x emissions, increased blend stability and no additional modifications to engine equipment.
- The density of n-octanol that we used in the study was between the petroleum-based diesel (EN 590) and biodiesel (EN 14214) standards and was considerably lower than biodiesel fuels.
- When we examined the densities of the mixtures obtained by adding 5%-10% n-octanol to the biodiesel fuels that we used in the study, it was found that the density of the mixture decreased relatively as the amount of n-octanol in the mixture increased.
- The use of biodiesel blends with n-octanol additives caused the density of the blend to decrease and therefore the density of the fuel affected the engine calibration and power because the mass injected per stroke varied according to the density of the diesel.
- This affected the combustion and emission timing of the engine. Similarly, PM emissions generally increased with an increase in diesel fuel density, which could alter the efficiency and performance of the generator set. The increase in density also increased the dynamic injection timing, and high-density diesel fuels also had higher viscosity, which is responsible for changes in the injection process.

- Although the kinematic viscosity of the n-octanol we used in the study was partially higher than the petroleum-based diesel (EN 590) and biodiesel (EN 14214) standards, when the kinematic viscosities of the blends obtained by adding 5%-10% n-octanol to biodiesel were examined, it was observed that the kinematic viscosities of the blends increased relatively very slightly as the amount of n-octanol in the blend increased. However, it was observed that the kinematic viscosity values of the blends obtained when 10% n-octanol was added to biodiesel met EN 14214 standards.
- One of the most important advantages of biodiesel was that its flash point was higher than diesel fuel. This was reflected in the specifications in the standards. Although the flash point of n-octanol was quite low compared to the flash points of the fuels we used in the study, it was seen that there was no significant decrease in the flash points of the new blends obtained when n-octanol was mixed with other fuels at a ratio of 5%-10% and the results were within the biodiesel standards (EN 14214). Therefore, it is predicted that the new fuels obtained by adding pure n-octanol to the biodiesel used in the study at the rates mentioned above will not pose any safety problem during transportation.
- One of the important characteristics of diesel fuel is the CN, which describes the complete combustion of the fuel and therefore leads to the easy operation of the engine. The CN, which is an indicator of the self-ignition quality of diesel fuel, ensures that the fuel ignites easily and burns quickly. It can also be defined as a measure of the knocking tendency of a diesel fuel. The CN is related to the ignition delay time, which is the time interval between the start of injection and the start of combustion.
- The CN is determined experimentally in a special test engine. However, due to the fact that this process is very expensive and the experimental work is difficult and time consuming, such an engine is not always available or there is not enough fuel sample, alternative methods to CN have been developed. One of these methods, the cetane index, has been developed in order to differentiate the values obtained from the values obtained from engine tests. Today, the cetane index is used instead of the CN of diesel fuel. The cetane index is calculated based on the density of the fuel and the distillation range (ASTM D86). The ASTM D4737-21 is the standard test method for cetane index calculated by a four-variable equation.
- When the cetane index of the pure fuels used in the study were examined, it was seen that the cetane index of n-octanol was slightly lower than the other fuels. When 5%-10% pure n-octanol was blended with other fuels and tested, it was found that there was a very slight decrease in the cetane index of the new blends. However, these results did not significantly affect the quality of the fuel blends (in terms of CN/cetane index). Since the cetane index values of all of the new fuel blends obtained were 51 and above, it was also determined that they met the biodiesel standard EN 14214.

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