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Model Analysis of the Effect of Ethanol Blended Diesel Fuels in Diesel Engines on Ignition Delay and Combustion

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ABSTRACT

The research of alternative fuels in diesel engines is being studied by many researchers. These studies annoy the researchers in terms of time and cost. In this study, Diesel-RK software, used as commercial software, is used to compare 3 different alcohols Butanol (C_4H_9OH), Methanol (CH_3OH) and propanol (C_3H_8H)) Diesel fuel and 5%, 10% and 15% mixture ratios are modeled as single-cylinder direct injection diesel engines. The most appropriate blended fuels for diesel fuel are compared with diesel fuel in terms of ignition delay and combustion duration at maximum torque cycle. The values obtained are the maximum engine torque (2800 min^{-1}) obtained as 0.4% with B5 fuel, 1.8% with M15 fuel and 1.6% with P15 fuel. In the ignition delays of the fuels modeled at the same engine speed, the ignition delays are also increased by the increasing ratio of butanol, propanol and methanol alcohols to that of diesel fuel. It has been determined that the combustion time is increased in all ratios of methanol alcohol compared to other alcohols.

Keywords: Methanol, Butanol, Propanol, Ignition delay, Diesel engine

Nomenclature:

D2	Standart Diesel fuel
B5	Standard diesel fuel with 5% Butenol added fuel
B10	Standard diesel fuel with 10% Butenol added fuel
B15	Standard diesel fuel with 15% Butenol added fuel
M5	Standard diesel fuel with 5% Methanol added fuel
M10	Standard diesel fuel with 10% Methanol added fuel
M15	Standard diesel fuel with 15% Methanol added fuel
P5	Standard diesel fuel with 5% Propanol added fuel
P10	Standard diesel fuel with 10% Propanol added fuel
P15	Standard diesel fuel with 15% Propanol added fuel
SCF	Specific fuel consumption
°CA	Crank angle
C (%)	Carbon (Proportional)
H (%)	Hydrogen (Proportional)
O (%)	Oxygen (Proportional)
min^{-1}	rev / min

I. INTRODUCTION

Diesel engines are indispensable for public transportation, agricultural and industrial equipment, work machines and electricity generation due to their higher fuel transformation efficiency, higher power output, higher moment capacity, higher durability and safety compared to petrol engines [1]. Fear for depletion of fossil fuels, fluctuations in oil prices, increasing energy demand, strict emission regulations have sought researchers to find renewable alternative biofuels for use in diesel engines. Among fuels such as bio-gas, bio-alcohol and bio-diesel, alcohols appear to be the most attractive. Bio-gas requires high pressure for use in automobiles and can be dangerous in case of leakage. Biodiesel from vegetable oils may cause scarcity in catering food [2]. With partial combustion, they can be produced from anything that can be transformed into carbon monoxide and hydrogen[3]. Alcohols, agricultural wastes (rice straw, corn stalks and sugar cane pulp), forestry (wood pulp, saw mill and paper mill) can be obtained without dependence on food products by fermentation of lignocellulosic biomass [2]. In addition, domestic wastes can provide high support for alcohol production as much as raw materials for alcohol production. Recently, higher alcohols, lower alcohols such as methanol and ethanol, have attracted great interest among researchers due to their high energy density, high cetane number, good mixing stability and less natural moisture when compared to other common studies. Increase the length of the carbon chain that improves the firing quality of alcohol molecules [4]. Methanol fueled internal combustion engines took place in active researches in the 1980s and early 1990s. Methanol has a latent evaporation temperature, does not include oxygen-free sulfur and has a high combustion rate. When burned at high temperatures, it may reduce smoke and nitrogen oxide emissions from diesel engines. The main problems in applying methanol in engine vehicles are difficulties in cold start and high aldehyde emissions in cold start, warm up and low load operations [5]. Propanol is a 3-carbon strong chain alcohol, compound mixed with diesel fuel with high energy density and high cetane number, which is a potential alternative fuel to high-chain alcohols such as ethanol and methanol. Propanol is now produced by oxo synthesis of the most cost-effective petrochemicals [6]. Due to concerns about the depletion of fossil fuels, various sustainable ways to produce this alcohol have been developed. Propanol can be produced from raw materials such as biomass or domestic solid waste [7]. Butanol is a strong-chain alcohol with 4 carbons that can be produced from petroleum or biomass. Butanol, produced from petroleum and domestic raw materials, has similar chemical properties and has similar effect when used in engines. It has been reported by many researchers that butanol is more advantageous than other alcohols [1]. Mishra et al. [8], observed proponal use in a mixture of 10%, 20%, 30% with a tropical vegetable oil, rated engine speed of 1500 min^{-1} at 9 different engine loads and indicated an increase in the propanol ratio in the oil and a slight increase in the ignition delay and a decrease in the maximum cylinder pressure. Moss et al. [9] measured the ignition delay times for n-butanol, 2-butanol, isobutanol and tert-butanol with a common mixture compound and pressure, and indicated that the ignition delay times varied from long to short in the order of butanol, 2-butanol, isobutanol and n-butanol. Prashant et al. [5], carried out experiments to determine the ignition delay, maximum pressure increase rate, heat release rate, temperature and maximum cylinder pressure with a 4-cylinder diesel-powered methanol mixture and the increase in methanol ratio in the fuel results in increase of ignition delay, increase in maximum cylinder pressure and 3 factors are consistent with experiments .

In this study, 3 different alcohol types with 5%, 10% and 15% blended fuels were modeled with D2 fuel at different engine revolutions in standard spraying advance with Diesel-RK software. The results are evaluated as power, moment and SFC at three engine cycles at which maximum torque was obtained and evaluated for the spray droplet diameter, combustion time and ignition delay of the fuel mixture that provided the closest performance to the diesel fuel model.

II. MATERIALS AND METHODS

Diesel-RK is a modeling and simulation software especially developed for internal combustion engine simulation. Diesel-RK software was developed at Moscow State Technical University Internal Combustion Engines Department in 1981/1982. It is specially designed to optimize the working processes of all kinds of internal combustion engines with imitation and multiplication. This software enables modeling using a variety of parameters from torque curve, engine performance estimates, fuel consumption estimates, emission analysis and optimization of fuel injection profiles including multiple injection in DI diesel engine model, injection design and position as well as piston bowl shape optimization [10] .

The characteristics of the fuels modeled in the simulator are given in Table1, the engine characteristics modeled in Table2.

TABLE I

PHYSICAL PROPERTIES OF THE MODELED FUELS

Properties	D2	B5	B10	B15	M5	M10	M15	P5	P10	P15
Molecular weight (kg/kMol)	210	203.2	196.4	189.6	201.1	192.2	183.3	202.5	195	187.5
C (%)	86.13	0.85	0.839	0.829	0.836	0.812	0.788	0.848	0.835	0.822
H (%)	13.87	0.138	0.138	0.138	0.138	0.137	0.136	0.138	0.138	0.137
O (%)	0	0.01	0.021	0.032	0.024	0.049	0.074	0.013	0.026	0.039
Cetane number	52	50.25	48.5	46.75	49.65	47.3	44.95	50	48	46
Density (kg/m^3) 15 °C	835	833.73	832.47	831.2	832.81	830.63	828.44	833.43	831.87	830.3
Viscosity (mm/s^2) 40 °C	2.72	2.69	2.67	2.64	2.61	2.506	2.39	2.67	2.62	2.57
Thermal value (Mj/kg)	42.49	42.02	41.55	41.08	41.34	40.19	39.05	41.89	41.3	40.71
Evaporation heat	375	385.32	395.64	406	414.38	453.76	493.15	392.64	410.29	427.9

TABLE III

FEATURES OF MODELED INTERNAL COMBUSTION ENGINE

Engine Type	Four Timed Diesel Engine
Number of cylinders / valves	1 cylinders / 2 valves
Diameter x Stroke	70 mm x 55mm
Compression Ratio	18
Max. Engine speed	3200 min^{-1}
Cooling system Ignition Advance Spraying Pressure	Air Cooled 23 °CA 200 Bar

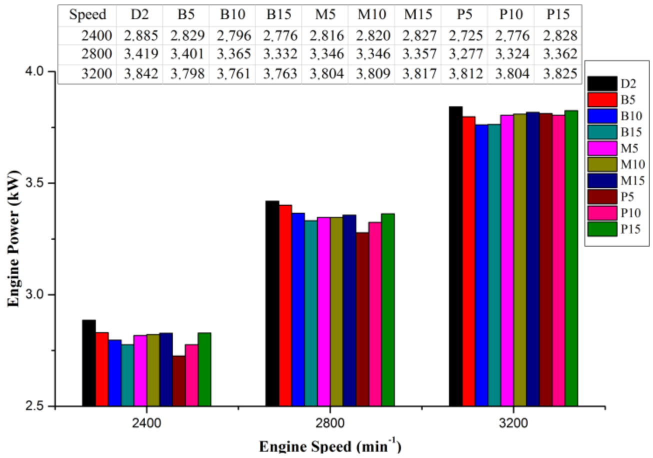
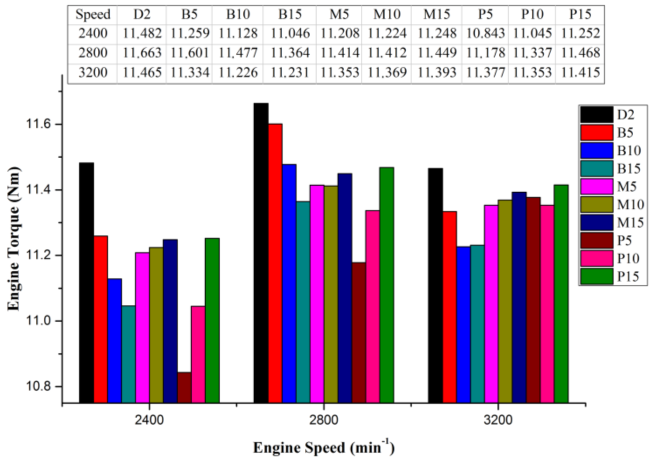


Figure 1: The effect of fuels on engine power compared to engine revolution

III. FINDINGS AND DISCUSSIONS

Figure 1 shows the engine power change of different fuel mixes at 3 different engine revolutions. When the graph is examined, engine power increases with increasing engine revolutions. Maximum power loss is at rated engine speed of 2400 min^{-1} (95% diesel, 5% proponal) obtained with P5 fuel, the minimum power loss is at engine speed of 200 min^{-1} obtained with P15 fuel (85% diesel, 15% proponal).

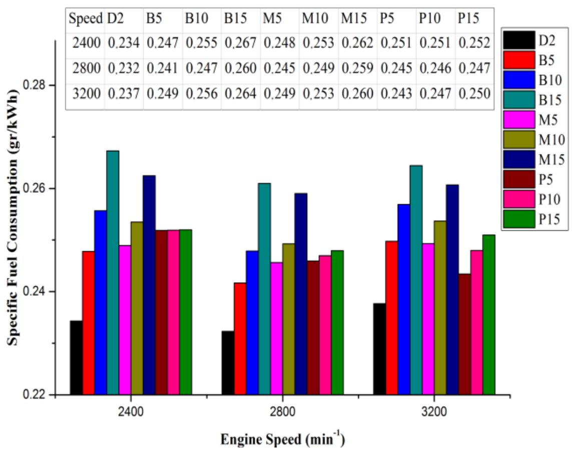
The minimum power loss in all the fuel mixtures modeled is obtained in the fuel ratio of B5 at the butanol additive, in M15 at methanol additive and in P15 fuel ratios at propanol additive. Minimum power loss of these fuel additives with B5 fuel 0.5% at engine speed of 2800 min^{-1}, with M15 fuel 0.6% at engine speed 3200 min^{-1} comparing to diesel fuel and with P15 fuel 4% at engine speed of 3200 min^{-1} . This reduction in engine power is due to the fact that the lower heat values of the alcohols used as alternative fuels (Fig. 7-b) are lower than diesel fuels [1].



Speed	D2	B5	B10	B15	M5	M10	M15	P5	P10	P15
2400	11.482	11.259	11.128	11.046	11.208	11.224	11.248	10.843	11.045	11.252
2800	11.663	11.601	11.477	11.364	11.414	11.412	11.449	11.178	11.337	11.468
3200	11.465	11.334	11.226	11.231	11.353	11.369	11.393	11.377	11.353	11.415

Figure 2: The fuel effect on torque according to the engine revolution

Figure 2 shows a graph of torque variation with increasing engine speed of the modeled fuel mixtures. Maximum engine torque in all fuels is observed at rated engine speed of 2800 min^{-1} with increasing engine speed. Related to experiments with P5 fuel, the maximum engine torque is at 3200 min^{-1} . Maximum engine torque with diesel fuel is observed at the engine speed of 2800 min^{-1} and in case of using B5 fuel, the torque value nearest to the diesel fuel is obtained. It is observed that using butanol fuel mixtures with B5 fuel at engine speed of 2800 min^{-1}, 0.53% comparing to diesel fuel, using fuel mixtures with methanol, with M15 fuel 0.62% at engine speed of 3200 min^{-1} and using fuel with proponal additive, with P15 fuel at the engine speed of 3200 min^{-1} and a decrease of 0.43% in engine speed.



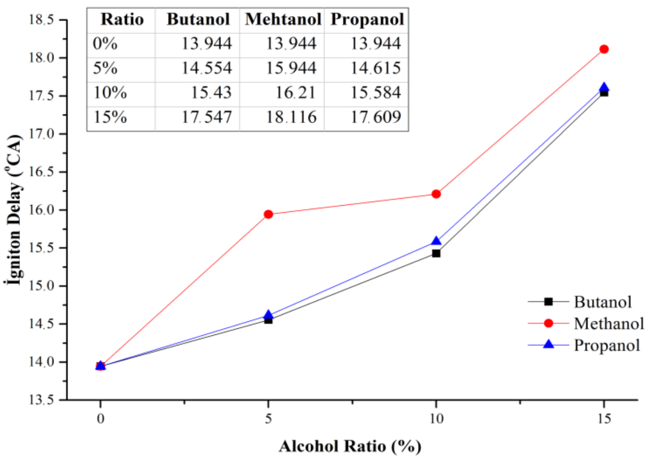
Speed	D2	B5	B10	B15	M5	M10	M15	P5	P10	P15
2400	0.234	0.247	0.255	0.267	0.248	0.253	0.262	0.251	0.251	0.252
2800	0.232	0.241	0.247	0.260	0.245	0.249	0.259	0.245	0.246	0.247
3200	0.237	0.249	0.256	0.264	0.249	0.253	0.260	0.243	0.247	0.250

Figure 3: The effect of fuels on specific fuel consumption relative to engine dynamics

Figure 3 illustrates a graph of the change in the SFC of different fuel mixtures according to the increasing engine speed. It is observed that in all fuel mixtures, there is an increase in the values of SFC rather than diesel fuel. Minimum score increase is observed 2.4% at engine speed 3200 min^{-1} with P5 fuel. Maximum increase about 14% in SFC is observed with B15 fuel at engine speed of 2400 min^{-1}.

The values obtained are compared with each other in terms of engine power and momentum, and the maximum engine torque is obtained (2800 min^{-1}) Engine momentum and power were observed as 0.4% with B5 fuel, 1.8% with M15 fuel and 1.6% with P15 fuel. This reduction is consistent with the results obtained in different experiments [1,11,12,13]. A change in the specific fuel consumption of preferred fuel mixtures preferred in terms of power and momentum was found to be 4% for B5 fuel use, 11% for M15 fuel and 6% for P15 fuel. It is observed that the lower thermal values of the modeled fuels given in Figure 7-a are lower than diesel fuel. Low thermal value of the fuel causes the increase of specific fuel consumption. The consumption of more fuel to achieve the same power leads to an increase in the value of specific fuel consumption [14,15].

The fuel mixtures B5, M15 and P15 fuels evaluated for power and providing the closest performance values for diesel fuel are compared in terms of ignition delay and combustion duration effects.



Ratio	Butanol	Mehtanol	Propanol
0%	13.944	13.944	13.944
5%	14.554	15.944	14.615
10%	15.43	16.21	15.584
15%	17.547	18.116	17.609

Figure 4: Effect of fuels on ignition delay according to alcohol ratios

In Fig. 4, the ignition delay times are given according to the alcohol ratios of the modeled fuels. It is observed that the increasing ratio of total alcohol in diesel fuel results in increase of ignition delay time. As the ratio of butanol in the diesel fuel increases, it is observed at 14.5, 15.4 and 17.5 °CA, respectively. When the methanol ratio is increased, it is at 15.9, 16.2 and 18.1 °CA, in order. As popanol is increased, it's observed at 14.6, 15.5 and 17.6 °CA respectively The maximum ignition delay was obtained with fuel mixture M15 (15% methanol + 85% diesel) and minimum ignition delay with B5 (5% butanol + 95% diesel) fuel. The main reason for the increase in ignition delay is due to the low cetane number of the modeled fuels [1]. Also the high evaporation temperature of modeled alcohol fuels causes an increase in ignition delay [5]. It is observed that ignition delay in all fuel mixtures increases according to diesel fuel. The maximum ignition delay increase is found in the use of methanol as alcohol in the diesel fuel compared to the other alcohols (butanol, propanol). It is shown in Table 1 that the methanol fuel used as the alcohol has higher evaporation temperature compared to the alcohol + diesel mixture modeled with other alcohols. The high evaporation temperature causes a slight decrease in the compression end temperature at the start of injection[16]. The decrease in compression end temperature and the lower cetane number of methanol (Fig. 7-c) are thought to cause a further increase in the ignition delay.

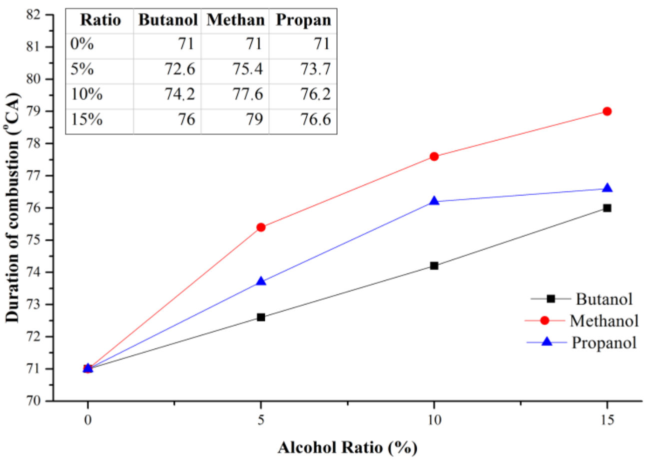


Figure 5: The effects of the fuels on combustion duration of combustion to the alcohol ratio

The effect of the modeled fuel mixtures on the duration of combustion is given in Fig. 5. It is observed that the increase of the alcohol ratio in the diesel fuel increases the combustion duration. The maximum increase in combustion time is obtained with M15 fuel at 79 °CA. Fuel with different alcohol ratios and minimum combustion duration are obtained by using butanol alcohol. When B15 fuel is used, it is 76 °CA and with B5 fuel , 72.6 °CA. In diesel engines, combustion involves complex physical and chemical events from the onset of fuel injection to the combustion chamber has begun when combustion products are thrown out, until the onset of the exhaust stroke. [17]. It is stated that these physical and chemical events should be at 70-80 °CA, a standard diesel engine combustion time [18]. The increase in combustion time affects the oxygen content of the alcohol used. The higher the ratio of oxygen, the higher the combustion efficiency. Huang, Z. et al. [19] reported that the ignition delay and the total duration of combustion increased with the increase of the methanol mass fraction in the fuel mixture (oxygen mass fraction). The ratio of oxygen is given in the fuel mixtures produced in the modeled fuel properties (Table 1). It is observed that oxygen in the fuel mixtures formed with butanol is closest to the diesel fuel. When the combustion durations are compared, the fuel mixture providing the fastest combustion time to diesel fuel is observed in the B5 fuel model with butanol alcohol. One of the parameters physically affecting the combustion duration is the droplet diameter of the injected fuel. It is thought that the droplet diameter is reduced, the fuel is more atomized in the cylinder, and the oxygen is in contact with the fuel, thereby extending the combustion time.

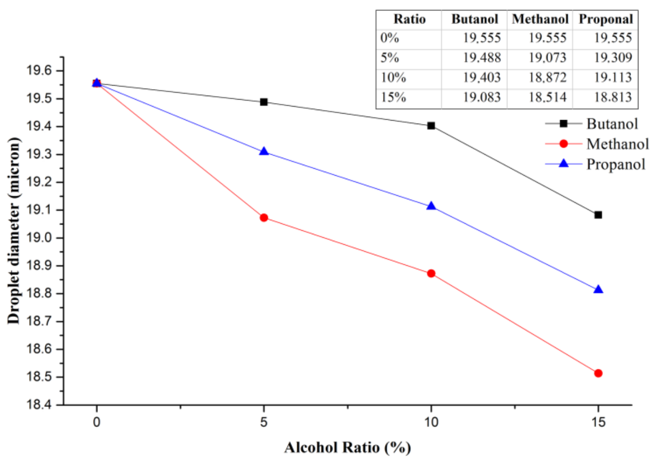


Figure 6: Effect of fuels on droplet diameter according to alcohol ratio

Figure 6 shows the effect of model fuels on the fuel droplet size of alcohol types. When the figure is examined, it is seen that the fuel droplet diameter decreases with the increase of all alcohol proportion in diesel fuel. When the droplet diameter of the fuel is evaluated among the alcohols, it appears to be at the minimum level when using fuels with methanol additives. The maximum fuel droplet diameter is obtained using butanol fuel. The ratio of butanol in diesel fuel is stated 19.488 µm, 19.403 µm and 19.083 µm, in order. The fuel droplet diameter is proportional to the density of the fuel (Figure 7-a). The high fuel density causes increase in the fuel droplet diameter [20].

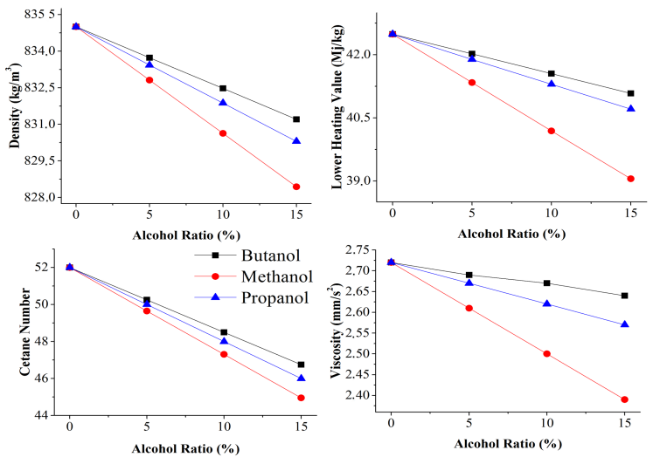


Figure 7: The effect of the fuels to the density, lower heat value, cetane number and viscosity according to the ratio of alcohol in them

IV. RESULTS

In the study, 5%, 10% and 15% of propanol, methanol and butanol alcohols are added in diesel fuel and combustion duration and ignition delay were compared.

Engine power is obtained respectively P15 (85% + 15% P), M15 (85D + 15M) and B5 (95D + 5B) fuels with the minimum power loss when compared with diesel fuel. A power loss of 0.4% with P15 fuel, 0.6% with M15 fuel and 1% with B5 fuel.

The engine momentum with minimum moment loss is obtained with P15 (85D + 15P), M15 (85D + 15M) and B5 (95D + 5B) fuels when compared with diesel fuel. A reduction of 0.4% with P15 fuel, 0.6% with M15 fuel and 1.4% with B5 fuel.

The specific fuel consumption with the minimum increase is observed 2.5% with P5 fuel when compared to diesel fuel. While consumption of B5 and M5 fuels showed a 5% increase in specific fuel consumption.

The addition of propanol, methanol and butanol alcohols at certain ratios in diesel fuel resulted in a maximum ignition delay of 18 °CA with M15 fuel. The minimum specific fuel consumption is obtained with B15 fuel at 17 ºCA. The low evaporation temperature of alcohols considered as alternative fuels affects positively the ignition delay period in diesel engines.

With the increasing alcohol proportion in the diesel fuel, the fuel droplet diameter is reduced. 19,083 microns with B15 fuel, 18,813 microns with P15 fuel and 18,514 microns with M15 fuel. The low density of alcohols added to the diesel fuel reduces the droplet size of the injected fuel.

Combustion time is 76 °CA, 76.6 °CA , 79 °CA with diesel fuel with B15 fuel, P15 fuel and M15 fuel, respectively. The fact that the evaporation heat of the fuel increases the ignition delay and the combustion duration.

In case of considering alcohols such as butanol, propanol and methanol as alternative fuels, the use of butanol alcohol up to certain ratios has a disadvantage that engine power and fuel consumption can be overlooked. Parameters such as ignition delay, combustion duration and fuel droplet diameter show positive results. The use of mixtures of butanol alcohol compared to other alcohol mixtures can minimize the disadvantages in the moving parts of the engine (fatigue and stresses in the material).

Considering all this statistics, it is observed that alcohol has significant effects on the viscosity and density of the fuel. Combinations of biodiesel fuel and alcohol mixtures, especially mixtures with high cetane numbered biodiesel, are thought to have beneficial effects on combustion efficiency and ignition delay.

The use of alcohols as alternative fuels in diesel engines is thought to produce beneficial results in ignition delay and ignition delay and combustion duration by reducing injection advance.

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