Numerical Investigation on Performance and Emission Characteristics of a Diesel Engine Fired With Methanol Blended Diesel Fuel

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ABSTRACT

The effects of methanol and oleic acid blended diesel fuel on the performance and emissions of the diesel engine are evaluated numerically by commercial software Diesel-RK to simulate a single cylinder, naturally aspirated, direct injection, four-stroke diesel engine. The present study also resolves the problem of the immiscibility of methanol in diesel fuel, as to avoid immiscible nature an optimum percentage of oleic acid and n-butanol is added to make blends stable. The methanol blended diesel fuels are 7%, 12%, and 17% methanol in volume basis (D85M7NB1O7, D75M12NB1O12, and D65M17NB1O17). A drastic reduction in NOx emission is observed due to low combustion temperature however the PM emissions increases which can be controlled by using exhaust after-treatment techniques. The results indicate that: the brake specific fuel consumption increases and brake thermal efficiency decreases with an increase of methanol, oleic acid and n-butanol contents in the blended fuel whereas maximum heat release rate increases and exhaust temperature decreases.

Keywords: *Diesel Fuel, Methanol, Fuel Blending, Diesel-RK, NOx and PM Emissions*

Introduction

The capability of methanol to replace petroleum fuels has been known for a long time, since methanol is a renewable energy, it can be made from waste

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biomass materials. It is a colorless, tasteless, volatile and flammable liquid. Additionally, methanol is recommended as a safer side for transportation and storage since it has a higher auto ignition temperature than mineral diesel. Economically, methanol is favorable candidates among of a huge alcoholic family. It is harder to ignite, creates less radiant heat and burns without producing black smoke. Generally, the use of methanol leads to reduce the NO_X and soot emission, because of high latent heat of vaporization, high oxygen content, low carbon content, free of sulfur and high burning speed [1-6].

Chao et al., [7] examined the emission characteristics on a six-cylinder direct injection diesel engine using diesel fuel blended with up to 15% volume of methanol containing as an additive. It was noted that the NO_X emissions decreases, although carbon monoxide (CO) and total hydrocarbon (THC) emissions increase as the methanol content in the blended fuel increases. However the results of particulate matter were mysterious, particulate matter (PM) emission could increase or decrease, depending on the operating conditions. Moreover, particulate matter is depending on the sulfur, oxygen and aromatic content which is available inherently in the fuel. The special effects of diesel-methanol dual fuel combustion, intake air temperature, and diesel oxidation catalyst on dry-soot and PM emissions were investigated by *Geng et al.,* [8]. Additionally, the intake air temperature reduces with the augment in methanol injection, and the PM reduces by decreasing the intake air temperature. *Canakci et al.,* [9] carried out experimental work to examine the effect of injection pressure on the performance and combustion characteristics with tailpipe emission via using a methanol diesel blends varying from 0% to 15% by volume. Results were taken by varying injection pressure to 180, 200, 220 bar at different loads with constant engine speed. It is observed that NOx emission reduces with increase in CO and THC or vice-versa. *Ciniviz et al.,* [10] carried out experiments on diesel-methanol blends with 0% to 15% of methanol by volume. It was concluded that NO_X emission increases, however, CO and THC emission decreases as compared to pure diesel. The reduction in CO and THC attributed to the inherent oxygen content of methanol, which leads to complete combustion. In addition, the methanol molecule is polar so it cannot be consumed by any non-polar molecule, which causes the lesser possibility of an unburned hydrocarbon. Furthermore, the NO_X increases due to peak temperature achieved inside the combustion chamber. The effects of the different alcohol additions in diesel fuel on the characteristics of combustion, performance, and exhaust emissions of a single-cylinder diesel engine were examined at different load conditions by *Emiroglu and Sen* [11]. It was observed that the addition of alcohol diminishes smoke and CO emissions and slightly augments NOx emissions. A detailed review to explore the characteristics of combustion and emissions products from dual fuels, toxic properties and its effect on engine performance, recognizing favorable alternative fuels for reducing the emissions in diesel engines was presented [12]. The effects of pentanol and biodiesel addition to diesel fuel in different ratios on the combustion and emission of a single-cylinder diesel engine were investigated [13]. Reduction in soot and NOx emissions was achieved by adding pentanol.

If diesel fuel is blended with the liquids having different polarities or different intermolecular interactions will form immiscible blends which will be known as diesel immiscibility. This phase separation in the methanol-diesel blends is a major problem for a diesel engine due to the low solubility of methanol in diesel fuel [7]. Therefore, it is essential to avoid the problem of phase separation before injecting it into the engine. In the present study, it is observed that the phase separation problem can be avoided by adding an oleic acid and n-butanol which act as emulsifying agents. Hence, methanol blended diesel fuels are prepared with 7%, 12% and 17% of methanol concentrations by volume basis and an equal quantity of oleic acid and required a quantity of n-butanol is added to avoid the problem of phase separation, i.e., D85M7NB1O7, D75M12NB1O12, and D65M17NB1O17. The objective of the present research is to numerically investigate the effects of prepared blends on performance and emission parameters in a diesel engine.

Material and Methodology

Table 1 illustrates the concentration of chemicals which are used in the present research. The presence of methanol, oleic acid, and n-butanol causes remarkable changes in physical-chemical properties of the blended fuel. It is noted that lower heating value and sulfur content of the blended fuel decreases, however, the density and viscosity increases. Therefore, the spray characteristics, combustion performance, and engine emissions are affected. Table 2 shows the physical-chemical properties of prepared blends.

Table 1: Concentration of fuels

Fuel	**Concentrations**
D100	Diesel (100%)
D85M7NB1O7	Diesel (85%) Methanol (7%) n-Butanol (1%) Oleic acid (7%)
D75M12NB1O12	Diesel (75%) Methanol (12%) n-Butanol (1%) Oleic acid (12%)
D65M17NB1O17	Diesel (65%) Methanol (17%) n-Butanol (1%) Oleic acid (17%)

Table 2: Physical-chemical properties of fuels

Properties	**ASTM Methods**	**D100**	**D85M7 NB1O7**	**D75M12 NB1O12**	**D65M17 NB1O17**
Density (kg/m^3)	D4052	830	829	830	831
Kinematic viscosity (Cst)	D445	2.749	2.943	3.086	3.439
Calorific value (KJ/Kg)	D2015	42000	34863	33551	29892
Sulfur content (mg/kg)	D4294	37	23	18	07

In this study, the simulation has been carried out using Diesel-RK software. For the simulation, the engine model has to be chosen and incorporated into the software. Diesel-RK software is designed for simulating and optimizing working processes of IC engines. RK-model is used to determine the soot and NOx emissions depending on mixture formation and combustion conditions in a diesel engine [14]. The engine has been considered in the work is the Kirloskar made single cylinder diesel engine. The details of the engine are given in Table 3. The simulation has been performed at a constant speed of 1500 rpm, at the compression ratio of 17.5:1 keeping the static injection timing constant at 23°bTDC. To predict the different performance and emission parameters for blended fuels, the fuel portion needs to be developed by inserting the different fuel properties.

Table 3: Engine specifications

Maker	**Kirloskar**
Model	TV1
Type	Four Stroke
Number of Cylinder	Single cylinder
Bore and Stroke	8705mm × 110mm
Compression Ratio	17.5:1
RPM	1500
BP	3.5 kW
Connecting Rod Length	234mm

Results and Discussions

Performance and emission of a diesel engine are evaluated by using an alternative fuel with respect to its environmental impacts. The effects of a various fraction of methanol-blended diesel fuel are numerically investigated and are discussed in this section.

Brake specific fuel consumption

Brake specific fuel consumption (BSFC) is defined as the fuel consumed to produce unit power. Figure 1 illustrates the variation of brake specific fuel consumption with respect to brake power for different tested fuels. It is observed that the brake specific fuel consumption increases with a decrease in brake power as methanol fraction increases in the diesel fuel. i.e., BSFC increases 34% with 24% reduction in BP for D85M7NB1O7 blend, BSFC increases 48% with 28% reduction in BP for D75M12NB1O12 blend, BSFC increases 73% with 39% reduction in BP for D65M17NB1O17 blend, with respect to 100% diesel fuel (D100). The reason behind this is: the increase of methanol fraction causes a reduction in the calorific value of the blends which is responsible for the reduction in brake power and augment in BSFC.

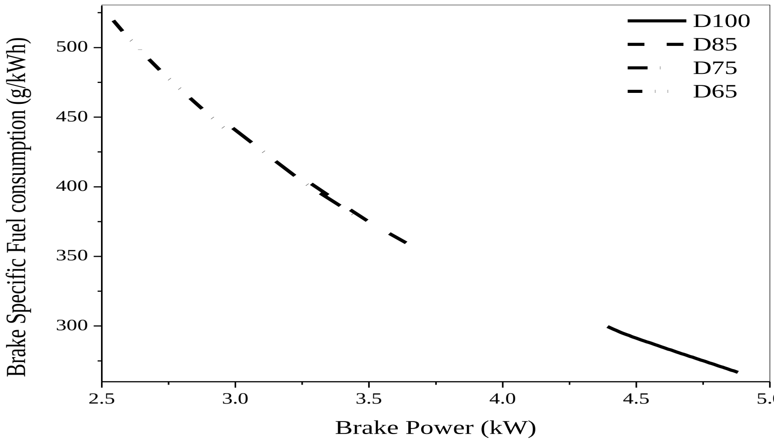

Figure 1: Brake specific fuel consumption versus brake power

Brake thermal efficiency

The comparison of the Brake thermal efficiency (BTE) with Brake power (BP) for different fuels is shown in Figure 2. It is noted that with the addition of methanol and oleic acid in the diesel fuel leads to decreases the brake thermal efficiency i.e., BTE decreases by 9% for D85M7NB1O7 blend, BTE decreases by 10% for D75M12NB1O12 blend, BTE decreases by 15% for D65M17NB1O17 blend, with respect to 100% diesel fuel (D100). Methanol has wider flammability limit which leads to the lean burning operation and increases the brake thermal efficiency however due to the addition of oleic acid in the blend for fuel miscibility causes decrease in brake thermal efficiency due to the higher viscosity of oleic acid. The higher viscosity of oleic acid causes poor fuel atomization which reduces the spray cone angle and results in the bigger droplet. So combined effect of methanol and oleic acid in the blends results in the decrease in brake thermal efficiency with respect to diesel fuel.

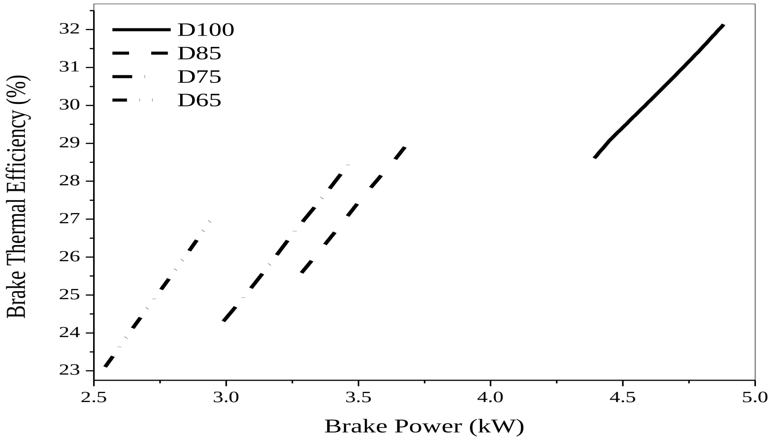

Figure 2: Brake thermal efficiency versus brake power

Cylinder pressure

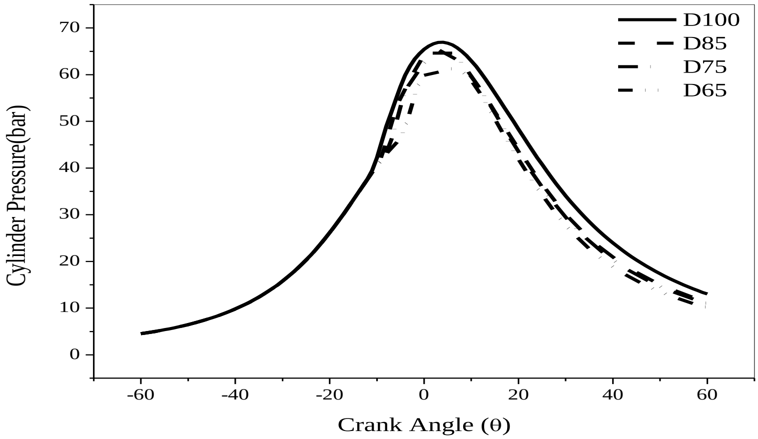

Figure 3: Cylinder pressure versus crank angle

Figure 3 represents the variation in the cylinder pressure vs crank angle. It is observed that the addition of methanol and oleic acid in the diesel fuel reduces the in-cylinder peak pressure. The point of peak pressure and the start of combustion shifts towards the right for blends as compared to diesel fuel. The reason behind this is the combustion starts late and the ignition delay period increases by firing blended fuel as compared to diesel fuel as shown in Figure 4.

Ignition delay

The ignition delay time is related to the cetane number of the fuel. Higher the cetane number, the shorter is the ignition delay or vice versa [15]. The ignition delay in a direct injection diesel engine is of great interest due to its direct impact on the heat release as well as its indirect effect on the formation of pollutants and engine noise. The ignition delay period is composed of physical delay, including atomization, vaporization, and mixing, coupled with a chemical delay.

Ignition delay periods are 8.68, 11.41, 14.52 and 24.14 for D100, D85M7NB1O7, D75M12NB1O12, and D65M17NB1O17 respectively.

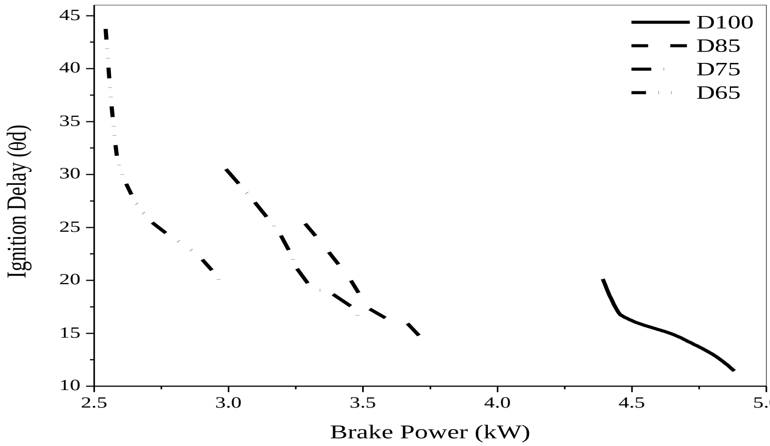

Figure 4: Ignition delay versus brake power

Heat release rate

The maximum heat release rate shifts toward right because of retarded combustion in blended fuels. As the percentage of methanol and oleic acid increases the maximum heat release rate increases because of longer ignition delays which are justified from figure 4. The heat release by diesel fuel starts earlier due to lower ignition delay, whereas the maximum heat release rate is higher in the case of blended fuels because the fuel accumulates during combustion process with in the combustion chamber.

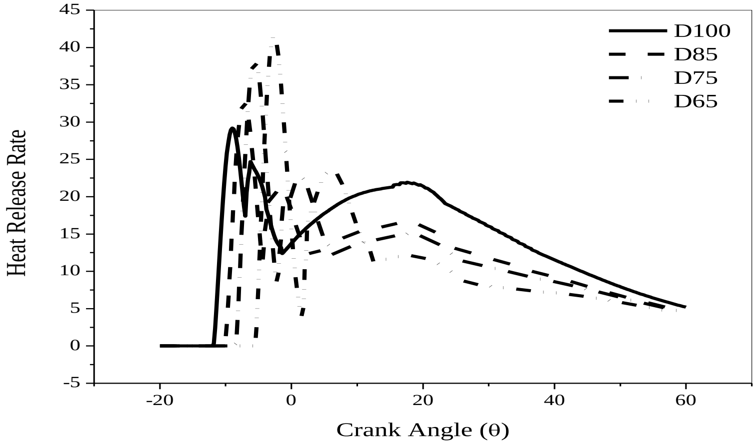

Figure 5: Heat release rate versus crank angle

Exhaust temperature

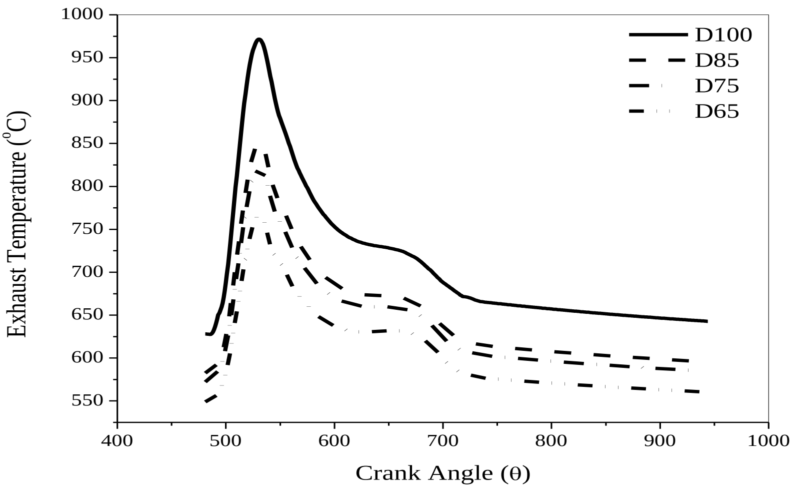

Figure 6: Exhaust temperature versus crank angle

Figure 6 illustrates the variation in the exhaust gas temperature with a crank angle for diesel fuel and different blends. It is observed that the exhaust gas temperature for diesel fuel is higher as compared to the blended fuels. The reason behind this is the in-cylinder temperature is higher for diesel fuel during the combustion process as compared to blended fuels.

NOx emission

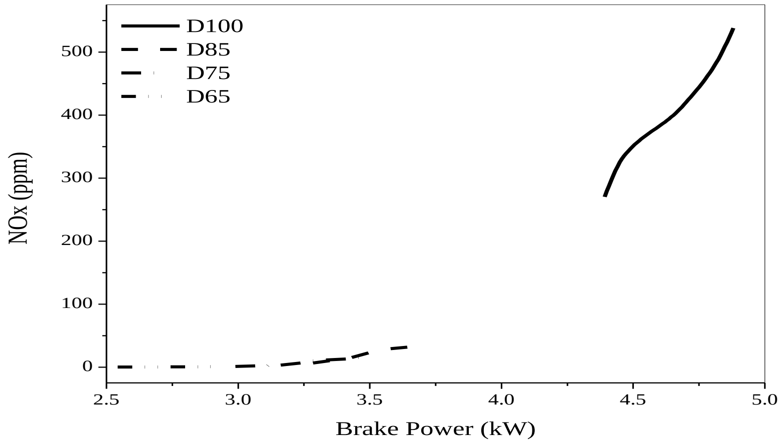

Figure 7: NOx emission versus brake power

Figure 7 shows the variation of NOx emission with brake power for diesel fuel and different blends. A drastic reduction is noted for NOx emission which is 93% reduction for D85M7NB1O7 blend, 97% reduction for D75M12NB1O12 blend, 99% reduction for D65M17NB1O17 blend, with respect to 100% diesel fuel (D100). NOx formation is a function of cylinder temperature and pressure. Higher in-cylinder temperature and pressure leads to the formation of more nitrogen and oxygen atoms from dissociation of air which ultimately creates more NOx emission in the tail pipe. Therefore higher in-cylinder temperature and pressure are responsible for the formation of higher NOx in case of diesel fuel. However the excessive reduction in the formation of NOx is noted for blended fuels which are due to the cooling effect of methanol which eventually lowers the combustion temperature and pressure which quashes the formation of NOx [16].

Particulate matter

The variation of particulate matter emission with brake power for diesel fuel and different blends are shown in Figure 8. Increments in PM are 52%, 70%

and 192% for D85M7NB1O7, D75M12NB1O12, and D65M17NB1O17 blends respectively, with respect to 100% diesel fuel (D100). Particulate matters (PM) are formed due to improper combustion and burning of lubricating oil. The increasing composition of methanol and oleic acid in the blended fuel effect the combustion process which leads to improper combustion, therefore, a significant increment in particulate matter formation is observed for D65M17NB1O17 blend.

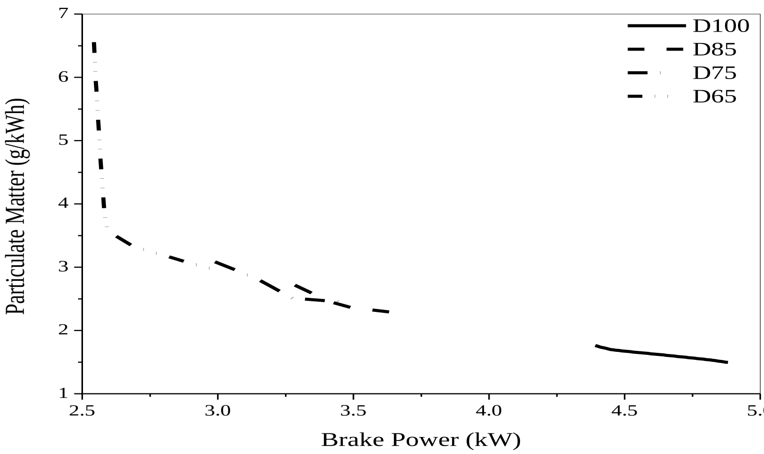

Figure 8: Particulate matter versus brake power

Conclusions

The numerical investigations on the diesel engine performance and emission characteristics with various blends have been carried out and the following conclusions can be drawn:

- Methanol can be blended with mineral diesel with help of emulsifying agents i.e., oleic acid and n-butanol to avoid phase separation.
- The addition of methanol and oleic acid in diesel fuel has a significant effect on the engine performance and emission characteristics.
- The use of methanol and oleic acid in conventional diesel engine decreases its brake torque and brake thermal efficiency.
- BSFC increases with the percentage of methanol and oleic acid in the fuel.

- Cylinder peak pressure decreases and ignition delay period increases with the increase in the composition of methanol and oleic acid.
- Maximum heat release rate increases and exhaust temperature decreases due to the addition of methanol and oleic acid in diesel fuel.
- A drastic reduction in NOx emission is achieved with the use of methanol and oleic acid blended fuel as compared to diesel fuel.
- An increase of methanol and oleic acid ratio in the fuel augments the PM emissions in the tail pipe of the engine.

This study concludes with the fact that the use of methanol and oleic acid in the diesel fuel affect significantly the performance parameters whereas resulting positively in the NOx emissions. On the key note, it can be recommended that blend with D85M7NB1O7 composition will results in low-temperature combustion, consequently reducing NOx emissions in the exhaust stream of the diesel engine by a compromise with PM and performance parameters when used in actual conditions. The study also establishes the fact that without going for actual experimentation, simulating software such as Diesel-RK can give results for engine performance and emission parameters under optimized conditions which save fuel, time, environment factors and the overall cost for actual experiment work.

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