

Experimental investigation of fuel consumption and emissions of diesel engine fueled with ternary fuel blends of diesel, biodiesel and bioethanol

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ABSTRACT

Biodiesel and bioethanol are two popular biofuels that commonly are used in combination with diesel and gasoline fuels respectively in diesel engines and gasoline engines. Diesel and biodiesel fuels have similar characteristics. However, they have different characteristics compared to bioethanol. Also high proportions of bioethanol cannot be solved in diesel fuel. Then using bioethanol and diesel fuel blends and the effects on diesel engine performance needs further investigation. Biodiesel as a co-solvent is used in bioethanol and diesel fuel mixtures to increase lubricity and cetane number of the blends. In this study, a 4-stroke, 4-cylinder diesel engine coupled with a dynamometer was used for the investigation of diesel engine emission and fuel consumption. Fuels B10E10D80, B10E15D75, B10E20D70, and D100 were used in this study at different speeds (from 1200 to 2400 rpm with 200 rpm increment) on 50% and 100% engine loads were measured. Here, B, E, and D respectively represent biodiesel, bioethanol, and diesel fuel and numbers indicate the percentage of those fuels. Fuel consumption and emissions (CO, CO₂, NO_x, and C₆H₁₄) were measured. Average changes of emissions of CO, CO₂, NO, NO₂ and C₆H₁₄ on different loads and speeds were decreased respectively by 20–38%, 1–6%, 11–14%, 9%, and 3–24%, respectively. The average diesel engine fuel consumption using B10E10D80 and B10E20D70 fuels was only higher by 2% and 3% than that of using pure diesel fuel and with using B10E15D75 fuel it was equal to that of using pure diesel fuel. In conclusion, using ternary fuel blends instead of pure diesel fuel significantly decreases diesel engine emissions for CO, CO₂, and NO. Fuel consumption negligibly increased by using ternary fuel blends instead of pure diesel fuel. As a result, ternary fuel blends could be considered as alternatives to diesel fuel.

1. Introduction

Oil, natural gas, coal, and other types of fossil fuels account for about 88% of the global energy supply (Jahirul et al., 2014). With the depletion of fossil fuels and the increasing global pollution due to their extensive use, other alternatives like environmentally friendly biofuels need to be considered for use. High oxygen content in bioethanol makes it a reliable fuel, which increases the compression ratio and simultaneously decreases the burning time in engines (Tutak et al., 2016). Biodiesel is a clean burning ester-based oxygenated fuel, renewable, sulfur-free, biodegradable, and non-toxic fuel (Dincer, 2008; Mosarof et al., 2016; Ganjehkaviri et al., 2016; Rahman et al., 2014). It potentially minimizes environmental pollution and global warming effects (Mofijur et al., 2015; Bhuiya et al., 2016). It can be blended at any

proportion with diesel fuel, and the mixture can be used in modern engines without issues (Mofijur et al., 2012). From bioethanol and biodiesel which are two of the most popular biofuels, biodiesel can easily be used on its own in diesel engines as it has similar characteristics to diesel fuel. Adding 20% waste cooking biodiesel to diesel fuel clearly decreases the harmful emissions of diesel engines. But because bioethanol has higher latent heat of vaporization than pure diesel fuel, it can decrease the temperature at the end of the combustion process if it is added to diesel fuel in a diesel engine (Mofijur et al., 2019). This would reduce NO_x emissions. Lower carbon/hydrogen (C/H) ratio and higher oxygen content of ethanol/diesel fuel mixture can improve complete combustion in diesel engines which causes a reduction in smoke, unburned hydrocarbon (UHC), and CO emissions (Shadidi et al., 2014). There were about 806 million cars and light trucks on the road around

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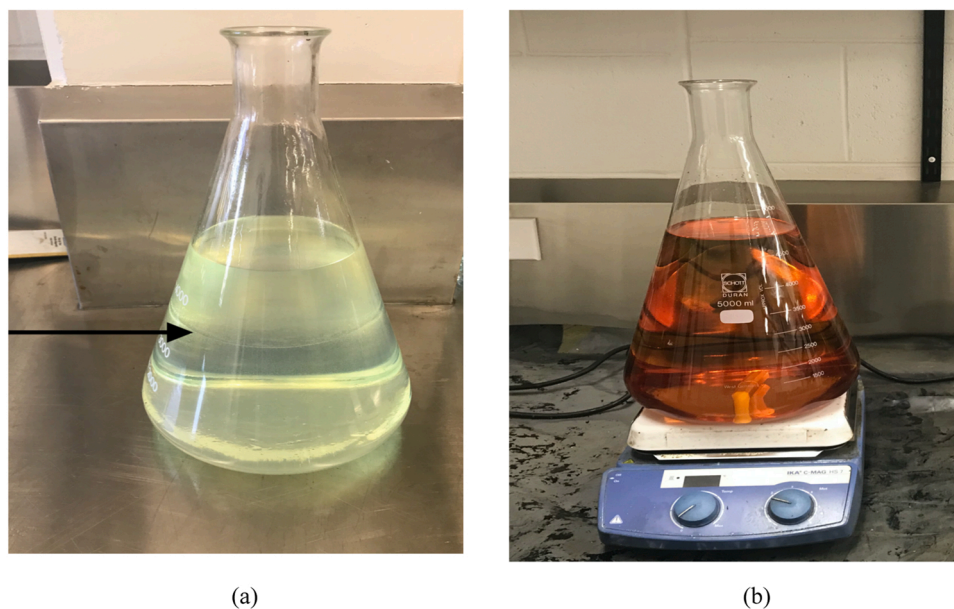


Fig. 1. (a) Phase separation in bioethanol and diesel mixture. (b) Dissolving bioethanol in diesel fuel after adding biodiesel to the mixture.

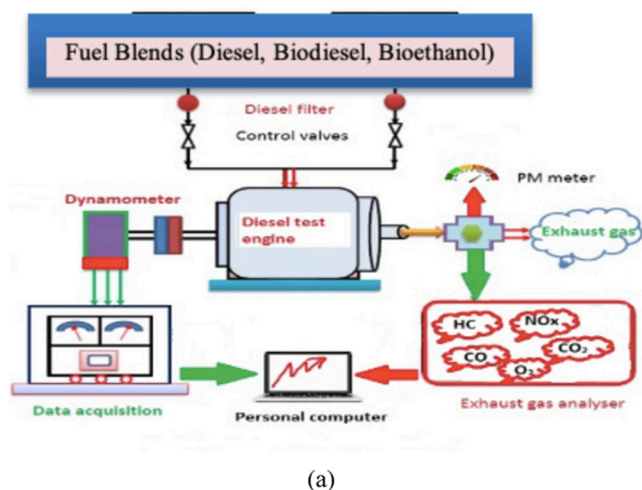


Fig. 2. (a) Schematic diagram of experimental set up. (b) Experimental set up at CQ university-Rockhampton Australia.

the world in 2007 (Plunkett, 2008). This was projected to increase to 1.3 billion by 2030 and to over 2 billion vehicles by 2050 (WBCSD, 2004). The transport sector which accounts for some 57% of global oil consumption creates 30% of CO₂ emissions in developed countries (Sustainable Transport Conference, 2021). This will affect the global climate, the stability of the ecosystem, and global oil reserves (Yusaf et al., 2010). Consequently, finding the sustainable and renewable fuel blends is crucial to protect the environment and save the available resources. The weaker combustion characteristics of biofuels compared with fossil fuels are one of the obstacles against their commercialization. Conventional engines might need some modifications to be able to use biofuels. However, adding a small proportion of biofuels to fossil fuels in a way that doesn't adversely affect engine performance is one of the methods for the biofuel commercialization.

2. Fuel preparation and experimental procedure

Ternary fuel blends including B10E10D80, B10E15D75, B10E20D70, and D100 were used for this investigation. Diesel fuel was

obtained from a conventional Australian Gas station in Rockhampton city. Bioethanol was made from an extremely refined sugarcane process, produced locally in Australia with 99.7% purity. Finally, the biodiesel used in the blends was locally produced in Australia from used cooking oil sources. The lubricating characteristics and cetane number of diesel fuel decreases with adding bioethanol to it (Chacartegui et al., 2007). As a result, biodiesel is added as a co-solvent in a diesel-bioethanol mixture to prevent phase separation and to increase the lubricity and cetane number of the fuel blends. Tongroon et al. (2019) used B3E5, B7E5, and B10E10 fuel blends in engine to analyse the engine performance. They observed greenhouse gas emissions can be reduced by 3–10% with adding bioethanol into biodiesel-diesel blends. Bioethanol and diesel fuel are not dissolvable. By increasing bioethanol to the diesel-bioethanol-biodiesel blend, more biodiesel is required to prevent phase separation on the blend. Biodiesel also increases the lubricity and the cetane number of the blends. Fig. 1(a) shows how bioethanol separates from diesel fuel in a mixture. To have a uniform liquid, a constant volume of biodiesel is added to the blend and the mixture was mixed for 20 min before being added to the diesel engine tank (Fig. 1(b)).

Table 1
Diesel engine specifications.

Model	V3300- Kubota
Type	4-stroke, Vertical, 4-cylinder
Bore × stroke	98 × 110 (mm)
Total displacement	3.318 L
Compression ratio	22.6
Rated torque	230/1400 (N·m/rpm)
Rated power	53.9/2600 (kW/rpm)
Injection	Direct Mechanical
Combustion system	E-TVCS
Intake system	Non-turbocharged
Emissions certification	Tier 2
Cooling system	Water cooled

Table 2
Exhaust gas analyser.

Measured gas	Measurement		
	Range	Resolution	Accuracy
HC	0–30,000 ppm	1 ppm	± 1 ppm abs.
CO	0–15%	0.001%	± 0.02% abs.
CO ₂	0–20%	0.001%	± 0.3% abs.
NO _x	0–5000 ppm	1 ppm	± 1 ppm abs.

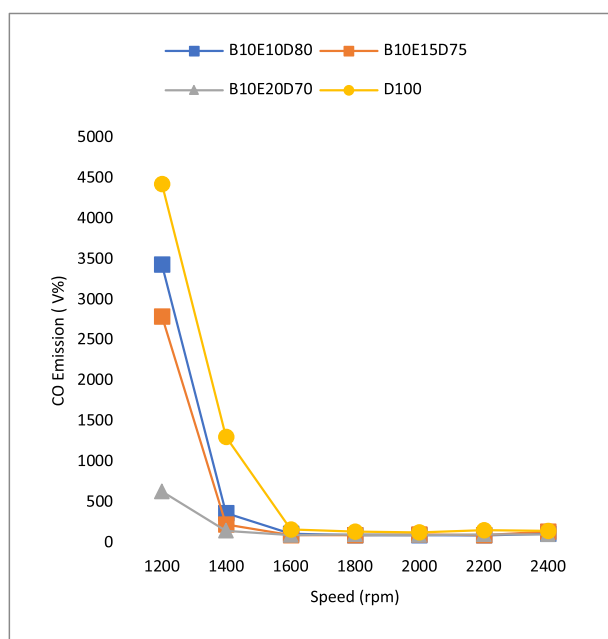
The experimental setup consists of a 4-cylinder, 4-stroke and non-turbocharged diesel engine (Kubota, model V3300). Fig. 2(a) shows the schematic diagram of the experimental set-up. The engine is coupled with a dyno dynamometer (Fig. 2(b)). Emission Analyzer and data logger PC were used to measure engine emission and performance outputs. Table 1 shows the diesel engine specification. An exhaust gas analyser was used to measure the exhaust emissions including CO, NO₂, NO, C₆H₁₄, and CO₂. Table 2 represents the specifications of the gas analyzer.

The engine run with pure diesel fuel for about 20 min to warm up. The engine performance and emissions data were collected at two loads (50% and 100%) from 1200 rpm (close to maximum rated torque) to 2400 rpm (close to maximum rated power) with an increment of 200 rpm. The engine was fueled with different biodiesel - bioethanol -

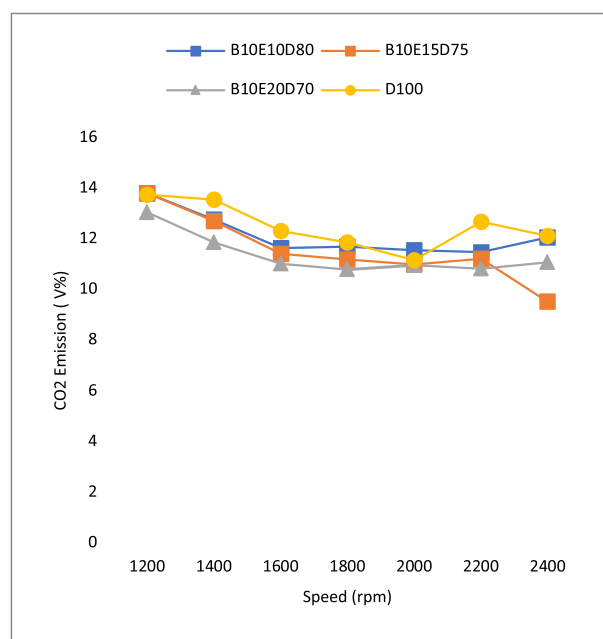
diesel blends. A LABVIEW software was used to convert those console-measured data to display on the computer monitor. A CODA 5 gas analyzer was used to measure the exhaust gas emissions NO_x and HC in ppm, while CO and CO₂ in vol%.

3. Results and discussion

The engine was warmed up before performing the tests to achieve steady condition and provide more accurate and reliable data. The engine was loaded gradually to reach the selected speeds. Each test was performed at a selected speed for 2–3 min and results were recorded. The engine runs at different speeds with changing engine load by a dynamometer. A diesel engine was fueled with ternary fuel blends B10E10D80, B10E15D75, B10E20D70, and D100. Engine parameters (emissions and fuel consumption) were recorded for each engine speed/blend under different load conditions. Speed was varied in the range from 1200 rpm to 2400 rpm with an increment of 200 rpm. Fig. 3(a) and 3(b), shows CO and CO₂ emissions produced from pure diesel fuel on 100% engine load is higher than that of other fuel blends at almost all engine speeds. With adding bioethanol into the intake port of a heavy-duty diesel engine, CO emissions increase (Han et al., 2020). However, in this investigation average CO emission (at all loads and all speeds) for blends B10E10D80, B10E15D75, and B10E20D70 is respectively 21%, 20%, and 38% less than that of pure diesel fuel. This can be the result of adding biodiesel to the blends which prevents bioethanol from adversely affecting diesel engine operation. This shows that by adding biodiesel and bioethanol together at the mentioned proportions to diesel fuel, engine combustion enhances significantly. The best improvement in engine operation occurred by using fuel blend B10E20D70 on 100% diesel engine load. According to Fig. 4(a) and 4(b), NO emission from the engine using blends B10E10D80, B10E15D75, and B10E20D70 was respectively 11%, 14%, and 14% less than that of pure diesel fuel. The blends associated with biofuels in most loads and speeds emitted less NO compared to that of pure diesel fuel. However, as Fig. 5(a) and (b) show, NO₂ had an irregular emission pattern. In some engine loads and speeds emitted NO₂ was higher using diesel fuel however in some other loads and speeds, it was opposite, and biofuels blends produced more NO₂ gas than that of pure diesel fuel. The average value of NO₂ emission using

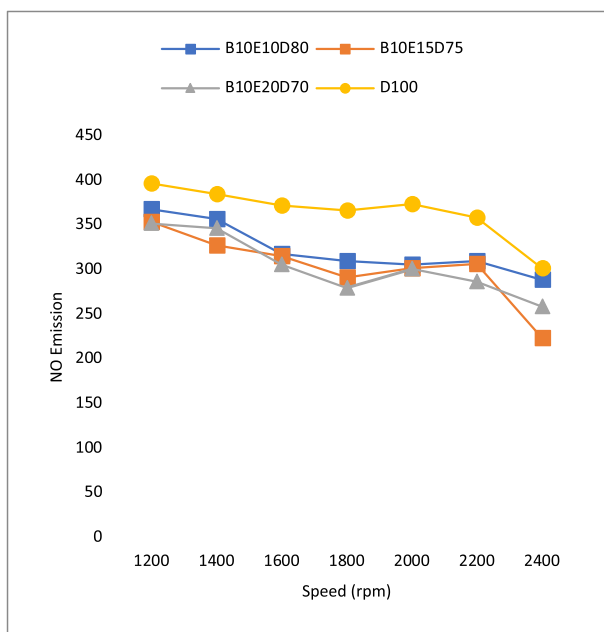


(a)

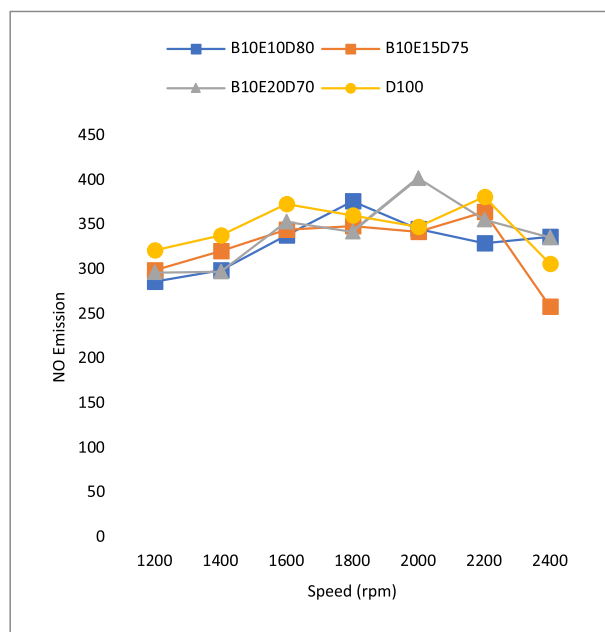


(b)

Fig. 3. (a) CO Emission at 100% engine load. (b) CO₂ Emission at 100% engine load.

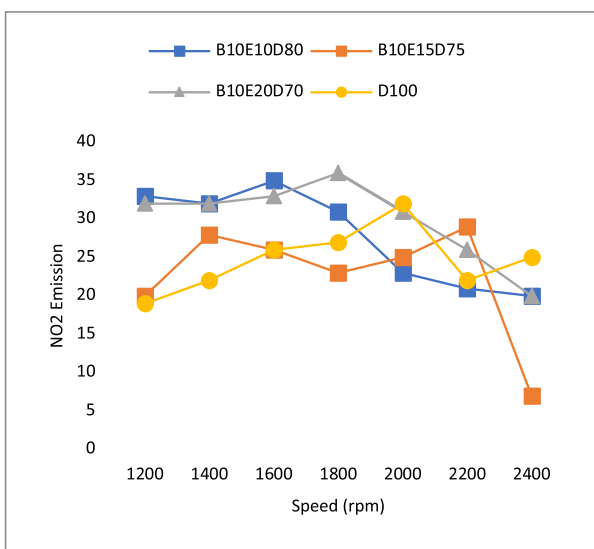


(a)

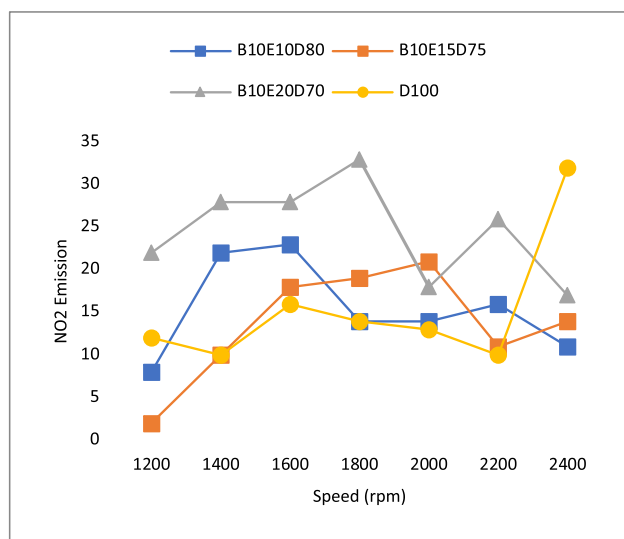


(b)

Fig. 4. (a) NO Emission at 50% engine load. (b) NO Emission at 100% engine load.



(a)



(b)

Fig. 5. (a) NO₂ Emission at 50% engine load. (b) NO₂ Emission at 100% engine load.

B10E10D80, B10E20D70, and B10E15D75 was respectively higher by 5% and 29% and less by 9% than that of diesel fuel.

By using B10E10D80, B10E15D75, and B10E20D70 as fuels in diesel engine, correspondingly 1%, 5%, and 6% less CO₂ was emitted than that of pure diesel fuel (Fig. 6(a)). However, B10E10D80 and B10E20D70 respectively emitted 24% and 3% less C₆H₁₄ while B10E15D75 emitted 16% more C₆H₁₄ than that of pure diesel fuel (Fig. 6(b)).

4. Conclusions

In this study, the performance and emission characteristics of a 4-stroke, 4-cylinder diesel engine was investigated and compared with that of pure diesel fuel. The following conclusions are drawn from this investigation:

- With taking the diesel engine emissions (CO, CO₂, NO, NO₂) into consideration, fuel B10E15D75 had the lowest emission amongst all the other fuel blends, and pure diesel fuel.
- The average diesel engine fuel consumption using B10E10D80 and B10E20D70 fuels was only higher by 2% and 3% than that of using pure diesel fuel and by using B10E15D75 fuel it was equal to that of using diesel fuel. The calorific value of bioethanol is about 35% lower than that of diesel fuel (Rahimi et al., 2009). Then the rate of diesel engine fuel consumption is expected to increase by adding bioethanol to diesel fuel. However, adding biodiesel to bioethanol-diesel blends in this study balanced the adverse effects and ternary fuel consumption in diesel engine only negligibly increased compared to that of pure diesel.

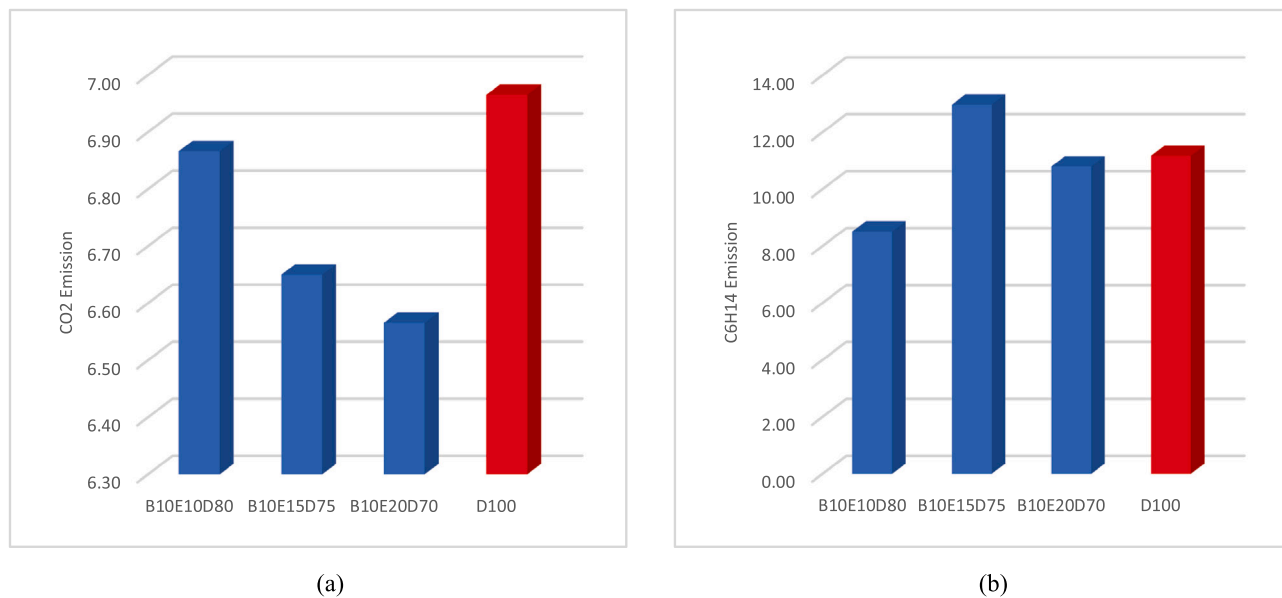


Fig. 6. (a) Average CO₂ at all loads and speeds. (b) Average C₆H₁₄ at all loads and speeds.

- Average changes of emissions CO, CO₂, NO, NO₂, and C₆H₁₄ in different loads and speeds were decreased respectively by 20–38%, 1–6%, 11–14%, 9%, and 3–24%. Adding bioethanol to diesel fuel increases the CO and HC emissions as bioethanol adversely affects the combustion process in diesel engines (Park et al., 2011). However, adding biodiesel to the bioethanol - diesel blends in this study has changed this attitude and CO and C₆H₁₄ associated with other emissions decreased in many loads and speeds at almost all ternary fuel blends.
- By using B10E10D80, B10E15D75, and B10E20D70 as fuels in diesel engine, correspondingly 1%, 5%, and 6% less CO₂ was emitted than that of pure diesel fuel.
- B10E10D80 and B10E20D70 respectively emitted 24% and 3% less C₆H₁₄ while B10E15D75 emitted 16% more C₆H₁₄ than that of pure diesel fuel.

Overall, emissions of CO, CO₂, NO (at all blends) and C₆H₁₄ (at B10E10D80 and B10E20D70 blends) decreases significantly using ternary fuel blends instead of pure diesel fuel. Fuel consumption negligibly increases by using ternary fuel blends. In conclusion, the ternary fuel blends could be considered as an alternative to diesel fuel.

CRedit authorship contribution statement

Ayazi Mahdi: Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Writing – original draft, Writing – review & editing. **Rasul Mohammad:** Supervision. **Khan Masud:** Supervision. **Hassan Nur:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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