Experimental Investigation of Diesel Engine Emissions Fueled with Binary and Ternary Blends of Diesel, Biodiesel, and Ethanol

Muhammad Noman*, Hassaan Ahmad*‡, Ahsan Razzaq*, Muhammad Mubashir Ahsan*, Hafiz Waqas Kahlid*, Muzamil Hussain**, Rana Muhammad Asif*, Muhammad Abubakar***

* Faculty of Engineering and Technology, The University of Lahore, Lahore, Pakistan.

** Mechanical Engineering Department, NFC Institute of Engineering and Technology, Multan, Pakistan.

** Department of Mechanical Engineering, University of Engineering and Technology, Lahore, Pakistan.

(noman321able@gmail.com, hassaanahmad2011@gmail.com, ahsanrazzaq113@gmail.com, mubashirahsan66@gmail.com, waqas.khalid1@tech.uol.edu.pk, muzamilhussain833@gmail.com, muhammad.asif6@tech.uol.edu.pk, muhammadabubakar436@yahoo.com)

Corresponding Author; Second Author, Department of Technology, The University of Lahore, 1-km Raiwind Road, Lahore. hassaanahmad2011@gmail.com

Abstract - Renewable fuels are a potential substitute for high pollutant fuels attained from conventional sources. Due to the complexity of the combustion process inside the engine, the use of renewable fuels can have a disadvantageous effect on the other emissions of the engine. Most of the researchers have focused on the use of renewable fuel in the internal combustion engine to study their effect on the engine emission but these studies are based on steady-state test and these tests can never correlate with the emission generated by the vehicle in a real-world scenario. The study has been performed to observe the effect of the use of biodiesel, ethanol and diesel blend while running the compression ignition engine in transient condition. Carbon monoxide CO, carbon dioxide CO_2, and oxides of nitrogen NOx were analyzed on a 2.289L diesel engine. The results showed that the use of ethanol in a fraction of 15% produce less amount of CO_2, and NOx but a higher amount of CO in the exhaust. Use of biodiesel slightly decreases the CO emission in the exhaust while being operated at low and medium speed condition. While NOx and CO_2 emission increases due to the higher oxygen content in the biodiesel as well as due to a higher temperature in the exhaust. The study has also observed that ternary blends have helped in emission reduction while running the engine in transient condition.

Keywords: Binary blends; Ternary Blends; Diesel Engine; Emissions.

1. Introduction

More than 85% of world's energy is extracted from fossil resources such as rock oil, coal and natural gas [1]. These resources are diminishing due to the mismatch between demand and production. Due to these reasons our energy resources are insecure. To keep the demand rate at a required level the price of fossil fuels increases in the open market. The regular change of crude oil price makes economic structure unstable. It is projected that the fossil fuel shall run out in this century [2]–[4]. Transportation accounts for 25% of the total fuel consumption for energy production. The transportation sector has currently powered by internal combustion engines fuelling with fossil-based fuels at 99.9% ratio The data depicts that the light vehicle is the main driver of fuel energy as compared to other transport vehicle such as rail, marine, airplanes and heavy trucks. The united states are the largest transport energy consumer and utilizes about 13 million barrel of oil per day which accounts for 25% of global energy utilization for transportation. While China and European countries uses about 6.5 million barrel and 9.5million barrel of oil per day respectively. Unlike United States and Europe, the utilization of oil in China is mainly consumed by freight movement. These three regions account for about 50% of world energy demand [5]. Increase in atmospheric pollution due to the growing demand for petroleum fuels has created an alarming situation and has urged the researchers to explore alternative fuels. Biodiesel and ethanol have been proven to reduce engine emissions because of their nontoxicity and reproducibility. Production of biodiesel has been achieved from non-edible sources so that it may not influence the edible food chain. Use of biodiesel is mainly focused on a diesel engine as biodiesel has similar properties like diesel fuel due to which diesel engine needs no modification for biodiesel consumption [6]. Alcohols have also been used as an alternative fuel to petroleum diesel [7]–[9]. The use of alcohols as a blended fuel with petroleum diesel has challenges due to immiscibility. Although alcohols can be used directly in the diesel engine yet low cetane and lubricity values of alcohols need to be overcome using additives. This problem can also be resolved by blending alcohols with biodiesel [10]–[12]. Studies have been performed using biodiesel-methanol and biodiesel-ethanol blend in diesel engine [13]–[16] and comparative study has also been performed between them as an alternative to pure alcoholic fuel [17]–[20].

Many researchers have conducted engine performance and emission investigation studies using biodiesel in the pure form (B100) to binary blend in the various percentage of biodiesel and diesel fuel (B10, B20, B40) [21]–[24]. Many studies have also presented the observation of a ternary blend of biodiesel-ethanol and diesel fuel in the various ratio (B20E3, B40E5, etc.) [25]–[27]. Currently, biodiesel is used to a maximum of 7 % in the diesel fuel at fuel pump stations [28].

Godiganur et al. [29] analyzed the exhaust emission and engine performance utilizing fish oil methyl ester in Kirloskar HA394 diesel Engine. The results showed that for B100 fuel the brake specific fuel consumption is higher than diesel fuel, while it is less for B20 fuel. A linear reduction trend for CO and HC was observed with an increase of blend percentage, while an increase in the emission NO_x for B100 fuel.

Zhu et al. [6] tested the Euro V engine with the binary blend of ethanol and biodiesel. The engine was optimized at five different engine loads. The results show an improved combustion characteristic of blended fuel of 5% ethanol in biodiesel (BE5) as compared to a diesel engine. The results show that the use of biodiesel or the binary blend has led to nitrous oxide (NO_x), carbon monoxide (CO), particulate matter (PM) reduction with an increase of brake thermal efficiency as compared to pure diesel fuel. It was observed that the emission of NO_x, HC, and CO increases with the increase in the percentage of ethanol in the blend.

Park et al. [30] analyzed the injection and atomization of biodiesel and ethanol-biodiesel blend. The study concluded that ethanol addition decreases the density and viscosity of the fuel. While the atomization of the fuel has been improved with the addition of ethanol as it has low surface tension and kinematic viscosity due to which it interacts with gas in a better way as compared to BD100.

He at al. [31] analyzed the performance of diesel engine blending ethanol with diesel in a ratio of 10% and 30%. The emissions were observed at five different load conditions. At high load, the smoke was reduced significantly with a bit enhancement of CO in the exhaust. NO_x and CO_2 emission also reduced to a certain level. While at low load condition the effect of ethanol blended fuel on the smoke emission was low.

Shahir et al. [32] observed the performance and emission characteristics of a diesel engine using binary and ternary blend bioethanol and of diesel-biodiesel-ethanol. It was observed that the use of diesel-biodiesel-ethanol and bioethanol blend as fuel shall reduce the power out up to 4.4%-8.7% due to decreased cetane number. The low heating value of blended fuel has resulted in higher brake specific fuel consumption. The blended fuel showed a higher brake thermal efficiency. While in the emission side the smoke emission has reduced critically, further a reduction of nitrous oxide and carbon monoxide is observed.

Rakopoulos et al. [33] analyzed the performance and emission characteristics of a six-cylinders turbocharged diesel engine using ethanol-diesel blended fuel. The ethanol used was in 5% to 10% by volume. The test was performed at various engine speed and load condition. It was observed that the brake specific fuel consumption has increased. While there is no significant reduction of nitrous oxide and carbon monoxide emission were observed. The unburnt hydrocarbon emission has increased using ethanol-blended fuel as compared to pure diesel fuel. He et al. [34] analyzed the performance of a diesel engine using biodiesel from different sources to examine there effect on the performance characteristics and emission of the diesel engine. The results showed that the emission biodiesel-diesel blended fuel generated more NO_x emission as compared to biodiesel-diesel-ethanol fuel blend. The results also showed that the generated amount of PM from biodiesel-diesel (B20) blended fuel as compared to the ternary blend of biodiesel-ethanol-diesel (B20E5).

Kalargaris et al. [35] performed an experimental study to analyze the emission generation from a diesel engine using biodiesel and its blends at different engine load. The biodiesel used was based on plastic pyrolysis oil. The results depicted that the engine was capable to run on plastic pyrolysis oil. It was observed that at high engine load the brake thermal efficiency was slightly lower and brake specific fuel consumption was slightly higher than diesel fuel. The NO_x emission was also found to higher in the emissions.

Hürdoğan et al. [36] conducted an experimental study to analyze the effect of using waste tire pyrolysis oil on engine emission and performance characteristics. The results showed that the use of waste tire pyrolysis oil (WTPO) and its blends with diesel engine generated the same amount of torque and power as produced by pure diesel. The emission of carbon monoxide (CO) decrease with the increase of engine speed for WTPO10 and WTPO20 blended fuel. The emission for carbon dioxide (CO_2) for WTPO10 was similar to the diesel engine while it was less in the case of WTPO20 due to the presence of excess oxygen content in WTPO based blended fuel. NO_x emission for WPTO10 and WTPO20 was slightly less than the emission generated based on a diesel engine.

Datta et al. [37] conducted a numerical study to investigate the performance of a compression ignition engine using different biodiesel and ethanol blends. The results have shown a slight increase in brake specific fuel consumption with an increase of brake thermal efficiency as compared to pure biodiesel. NO_x reduction in the emission has also been noticed with a slight increase of particulate matter (PM), ignition delay and heat release rate (HRR).

Wei et al. [38] carried out an investigation to analyze the performance of a diesel engine using blends of biodiesel with ethanol and n-butanol. The composition was set as BE5 (95% biodiesel and 5% ethanol), BE10, BE15, and BBu (95% biodiesel and 5% n-butanol), BBu10, BBu15. The performance and engine emissions were evaluated at five different engine loads. The study revealed that the BE blends have an adverse effect on engine performance as compared to BBu blend. Moreover, the increase of carbon monoxide (CO) emissions increased by 13.7% and 22.8% using BBu and BE respectively. NO_x emission has reduced 6.5% and 28%, PM has reduced 20.7% and 20.6% and particulate concentration from emission has reduced by 22% and 21% using BBu and BE respectively.

Shamun et al. [39] conducted a study to evaluate the performance and emission characteristics of single cylinder light duty compression ignition engine using ternary blends of biodiesel-ethanol-diesel. The blended fuel was used in two different ratios of 68:17:15 and 58:14:30. The results showed that the fuel containing a dominant quantity of ethanol shows indicated efficiency to 52% which was never more than 48% for diesel fuel. On the emission side, reduction in the NO_x emission was observed for fuel greater in ethanol percentage. Where the amount of CO and total hydrocarbon (THC) were greater for the fuel having a greater ratio of ethanol as compared to pure diesel.

Killol et al. [40] performed an experimental study to evaluate the performance and emission characteristics of a diesel engine using biodiesel and n-biodiesel in a diesel engine. Karanja methyl ester was used in different concentration of 5%, 10%, 15% and 20% to the diesel fuel. The fuel was used in an engine producing power output of 4.4 KW at a speed of 1500 rpm. Moreover, an oxygenated fuel diethyl ether (DEE) was used as an additive to the blended fuel to check its effect on the emissions. It was observed that the brake thermal efficiency increased with the increase in the percentage of Karanja methyl ester quantity increased. The increase of butanol quantity reduced the carbon monoxide emission. While the unburnt hydrocarbon decreased with the increase of engine load.

Abed et al. [21] conducted a study to investigate the performance and emission characteristics of waste cooking oil in a diesel engine. The blends of biodiesel were used in different ratios of 10%, 20% and 30% of the diesel fuel. The performance characteristics and emission were analyzed at various engine load. The results showed a decrease in brake thermal efficiency as compared to a diesel engine. While the specific fuel consumption was found to be higher as compared to diesel fuel. Carbon dioxide (CO_2) and NO_x emission were found to be higher as compared to emissions generated by diesel fuel. Emissions of carbon monoxide (CO), particulate matter (PM), hydrocarbon emission (HC) and smoke opacity were found to decrease with the blended fuel.

Sidhu et al. [41] evaluated the performance of binary blends of biodiesel-diesel and their glycerin emulsion in a compression ignition engine. The test was performed varying engine speed and load. The results showed that with the addition of glycerin in the biodiesel resulted in the increase of brake specific fuel consumption as well as brake thermal efficiency. An increase in the emission of carbon monoxide (CO) and unburnt hydrocarbon was observed. Moreover, a decrease in the emission of NO_x was observed as the temperature in the exhaust dropped down. Smoke opacity decreased up to 80% with the addition of glycerin at an engine speed of 3000 rpm.

Manigandan et al. [42] carried out an experimental investigation to analyze the performance characteristics and engine emission from a diesel engine using corn oil methyl ester with oxygenated additives. The additives used to increase the performance and to reduce engine emission of the diesel engine was pentanol and titanium oxide. Multiple blends of corn vegetable methyl ester were used to perform the test. The study found that the use of corn oil methyl ester with 20% pentanol and 5% titanium oxide gave better results as compared to other mixtures. It was found that the brake specific fuel consumption decreased by 6.3%. Reduction in the emission of carbon monoxide (CO), hydrocarbon (HC) and smoke opacity. Moreover, the reduction in the emission of NO_x and PM was observed to be 16%.

Patil et al. [43] performed an analysis to conduct a performance investigation of engine emission and performance characteristics of Jatropha oil blends with different additives. The results by adding ceramic oxide with 15% of biodiesel showed an increase of brake thermal efficiency with a decrease in brake specific fuel consumption. Further, the study found a decrease in the emission of NO_x, CO, HC, and smoke. While for the B20 the brake specific fuel consumption increases with a decrease in brake thermal efficiency. Moreover, the emission NO_x, HC, CO, and smoke has decreased.

Rajkumar et al. [44] performed an experimental study on the engine to reduce NO_x and soot emission using Karanja, coconut oil as biodiesel, their blends and hydrogenated Karanja oil. The test study was performed at various load and speed condition. The study achieved a reduction of NO_x emission of up to 18% with the blended fuel using binary blends of coconut and Karanja oil as compared to pure Karanja oil. the trend of decrease of NO_x emission increase with the increased percentage of coconut oil in Karanja oil.

Agarwal et al. [45] conducted an experimental study to analyze engine emission and performance characteristics of a diesel engine using biodiesel blends. The biodiesel was based on a number of sources which were Jatropha curcas, Karanj, and rubber. The results show a reduction of carbon monoxide emission (CO) up to 30%. For an increase of

20% of ethanol in the fuel, the amount of nitrous oxide and hydrocarbons decreases with an increase of NO_x in the emission.

Monyem et al. [46] conducted a study to observe the performance and emission from a diesel engine while using oxidized biodiesel. The percentage of biodiesel used was 20% in the diesel fuel. The performance and emission were varied at two different load condition that was 100% and 20% and at three different injection timings (3° advanced, standard, 3° retard). The brake specific fuel consumption of oxidized biodiesel was found to be greater than plain biodiesel. The results showed a reduction of 15% and 16% of carbon monoxide (CO) and hydrocarbons (HC). There was no significant difference between the oxidized and non-oxidized biodiesel.

Nabi et al. [47] conducted an analysis to optimize the performance and engine emission of a diesel engine using biodiesel and its blends. The study found a lower emission of carbon monoxide (CO) and smoke. While the emission of NO_x was greater as compared to pure diesel. Using exhaust gas recirculation technique, the amount of NO_x emission reduced as compared to a pure diesel engine.

Laperta et al. [48] performed an experimental study to investigate the effect of biodiesel on engine emission and performance characteristics. The results showed an increase of brake specific fuel consumption up to 14%. The results showed no specific variation of thermal efficiency of the engine. The NO_x increased to a level of 8% using pure biodiesel and it decreased with the reduction of biodiesel in the blend. The particulate matter, carbon monoxide, and hydrocarbons were decreased using biodiesel and its blends.

Most of the researchers have focused on the use of renewable fuel in the internal combustion engine to study their effect on the engine emission but these studies are based on steady-state test and these tests can never correlate with the emission generated by the vehicle in a real-world scenario. Study-related emission response for a binary and ternary blend of biodiesel, ethanol, and diesel while operating the engine in the transient condition is scarce. This study focusses on the investigation of emission characteristics of binary and ternary blends of biodiesel, ethanol and diesel fuels while running the engine in transient condition. A binary and ternary blend of biodiesel, ethanol, and diesel were prepared using the design of experiment technique. Engine response for NO_x, CO and CO_2 are observed. The exhaust emission generated by binary and ternary blends of biodiesel, ethanol, and diesel are compared with the diesel fuel.

Waste cooking was for the production of biodiesel. Transesterification has been performed for converting free fatty acids tri-esters into methyl esters. Transesterification was performed using conical flask and the solution is mixed using magnetic stirrer. The waste cooking oil was preheated to 60 °C, sodium hydroxide (NaOH) 1% was added in the WCO which act as catalyst, methanol solution 6:1 molar ratio was added. The reaction is carried out in three steps. The base catalyst reacts with the methanol to form an alkoxide anion. In the first step the nucleophile will react with alkoxide anion in the carboxylic group of glycerides to form diglyceride then in the second step this process is repeated to form monoglyceride and the reaction is completed in the third step when complete glycerol is produced. The solution was set in the flask for 90 minutes for the reaction process. The properties of the biodiesel are given in Table 1.

Table 1 properties of test fuel

Specification	Biodiesel	Ethanol	Diesel
Density 15 °C (kg/m^3)	890	785	830
Flash Point °C	176	12	72
Cetane Index	61.25	6	64
Lower heating value (MJ/kg)	38.835	26.75	44.102
Viscosity 25 °C	4.5	1.4	2.7
Oxygen (wt%)	11	34.8	0.0
Hydrogen (wt%)	12.1	13	13.1

2. Experimental setup

Transient analysis has been performed using 2.289L, 4-stroke, 4-cylinder natural aspirated diesel engine. The specification of the engine is given in Table 2. Error! Reference source not found. shows a schematic of an engine testing facility. To measure engine load and torque the engine was attached to an eddy current dynamometer. To measure engine emissions, an emission analyzer TESTO 350 was used. The analyzers were mounted both on the upstream of the exhaust after treatment. To measure the mass of intake air, a mass air flow sensor (MAF) Superflow SF-110 flow bench was used. The fuel used was measured by weighing the fuel before and after the test was performed on a calibrated scale. The dynamometer was used to measure engine speed. AVL 415s dynamic fuel balance was used to measure the fuel consumption of the engine. Thermocouples and pressure transducers were used to measure the engine temperature and pressure respectively. Before running the engine on the binary and ternary blend, the engine was run on diesel for warmup.

Table 2 Engine specifications

Engine Type	**4-stroke, Diesel engine**
No. of cylinders	4
Bore (mm) × Stroke (mm)	89 (mm) × 92 (mm)
Total Displacement (liters)	2.289 L
Compression Ratio	21.9:1
Injection Type	Direct
Aspiration	Natural
Maximum Torque (Nm)	134.55 Nm at 2000 rpm
Maximum Power output	48 KW at 3600 rpm
Method of cooling	Water cooled

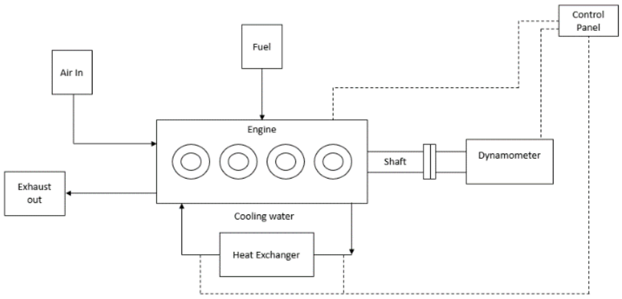

Fig. 1. Schematic diagram of test bed

2.1. Design of Experiment

The blends of diesel, biodiesel and ethanol were prepared in batches of 3L on volume basis. To ensure the homogeneity of the blend, the mixture was kept for 24 hours in a sealed container to observe its physical appearance. A mixture of biodiesel, ethanol, and diesel has been made following the design of experiment approach. The individual effect of diesel, biodiesel, and ethanol, as well as their cumulative effect in the form of binary and ternary blend, were observed. According to the adopted design of experiment, the sum of all the fuel mixture must be equal to unity. If a_1, a_2, a_3……. a_p denote the proportion of individual fuel then

$$0 \le a_i \le 1 \text{ where, } i = 1,2,3,4\ldots, p \quad (1)$$

$$a_1 + a_2 + a_3 \ldots .. a_p = 1 \quad (2)$$

The maximum percentage of ethanol and biodiesel was taken 15% cumulatively.

$$\begin{aligned} a_D &= 0.85, a_B = 0.12, a_E = 0.03 \\ a_D &= 0.85, a_B = 0.03, a_E = 0.12 \\ a_D &= 0.90, a_B = a_E = 0.05 \\ a_D &= 0.95, a_B = 0.02, a_E = 0.03 \\ a_D &= 0.85, a_B = 0.15, a_E = 0.0 \\ a_D &= 0.85, a_B = 0.0, a_E = 0.15 \\ a_D &= 1.00, a_B = 0.0, a_E = 0.0 \end{aligned} \quad (4)$$

Where a_D represents the fractional components for diesel, a_E represents the fractional component for ethanol and a_B represents the fractional component for biodiesel.

Data has been collected while running the engine in the transient condition. The engine is operated at four specific speeds, extra high, high, medium and low speed. Braking action, stop and acceleration were applied considering the transient cycle. **Error! Reference source not found.** shows the variation of speed with time. The torque values against the engine speed are presented in **Error! Reference source not found.**.

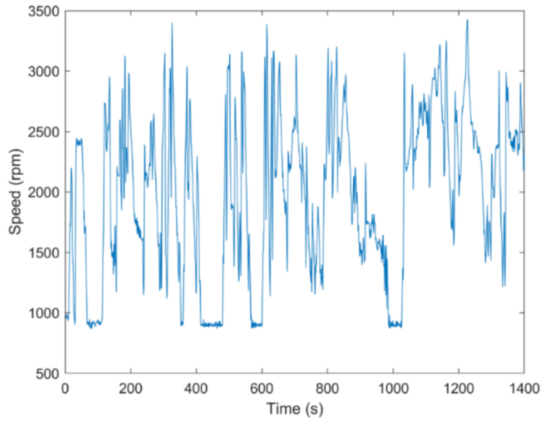

Fig. 2. Variation of engine speed with time

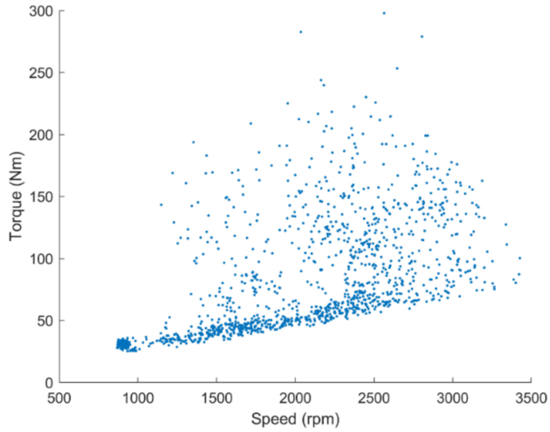

Fig. 3. Engine torque vs engine speed

3. Results and discussion

The test was performed to observe the engine response on three exhaust emissions including CO, CO_2, and NO_x. The observed emissions are discussed below in detail.

3.1. NOx emissions

NO_x is produced in the presence of oxygen and nitrogen at elevated temperature. NO_x emissions are dependent on peak cylinder temperature and oxygen concentration. At higher temperature the nitrogen separates from the air molecules and join with oxygen molecules which results in the formation of NO_x. **Error! Reference source not found.** shows that NO_x emission increases with the increase of engine speed due to high in-cylinder turbulence which resulted in the homogenous air-fuel mixture. An increasing trend of NO_x emission with engine speed was also observed by [49] and [50]. From **Error! Reference source not found.** it can be observed that the NO_x emission generated by the binary blend of biodiesel and diesel fuel is higher as compared to D100 fuel emission. It was observed that B15 fuel generated 3.2% higher NO_x emission as compared to D100 fuel. Higher NO_x emission has resulted due to higher oxygen content and unsaturated compound present in the biodiesel. Binary blend of ethanol and diesel fuel in a percentage of 15% has resulted in 3.9% less NO_x emission as compared to the other fuel blends which is least among all blended fuel. The decreased emission is the result of high latent heat of evaporation of ethanol fuel which minimizes the peak cylinder temperature [51]. Binary blend of ethanol has low cetane value further ethanol and diesel have miscibility issues which requires emulsifier to be added in the binary blend of ethanol and diesel fuel. Biodiesel act as an emulsifier which reduces the miscibility issues of ethanol and diesel fuel. A ternary blend of biodiesel, ethanol and diesel helps to achieve better fuel combustion due to higher oxygen content. **Error! Reference source not found.** depicts the decrease of NO_x emission with the increase of the percentage of ethanol in the ternary blend. The NO_x emission produced by B2E3, B5E5 and B3E12 are 1%, 3%, 4% lower than D100 fuel while B12E3 produced 0.5% higher than D100 fuel respectively.

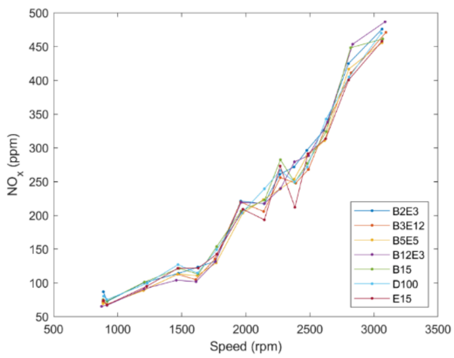

Fig. 4. Variation of NOx emission with engine speed

3.2. CO emissions

CO is produced in the exhaust due to an inadequate amount of oxygen and low gas temperature during the combustion process. Addition of biodiesel in diesel aids incomplete combustion due to access amount of oxygen content in biodiesel. **Error! Reference source not found.** shows the variation of CO emission with the engine speed. The CO emission decreases steadily with the increase of engine speed 2500 rpm then the CO emission increases with the increase of speed. At high engine speed CO emissions increases due to less time available for the combustion process and results in incomplete combustion. **Error! Reference source not found.** shows that B15 fuel generated the minimum amount of CO emission among all the fuel blends which are 5.1% less than the D100 fuel. **Error! Reference source not found.** also shows that E15 fuel has generated the highest amount of CO as compared to other fuel blends which are 128.1% higher than D100 fuel. Similar results related to a binary blend of diesel and ethanol are observed by [26]. The increase of CO emission is due to the ignition delay which results from low cetane number of ethanol fuel. The high latent heat of evaporation of ethanol fuel decreases the gas temperature which hinders the combustion process even in the presence of an excess amount of oxygen [52]. For the ternary blend of biodiesel, ethanol, and diesel, it was observed that as the percentage of biodiesel increases the CO emission decreases. The CO emission produced by B3E12, B2E3, B5E5, B12E3 are 53%, 25.6%, 22.8% and 4.9% higher than D100 fuel respectively.

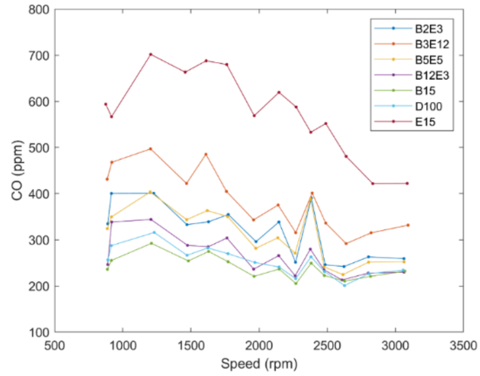

Fig. 5. Variation of CO emission with engine speed

3.3. CO_2 Emissions

CO_2 emissions from the external combustion engines are associated with complete combustion of air-fuel mixture. **Error! Reference source not found.** shows the variation of CO_2 emission along with the engine speed. The CO_2 emission increases steadily then start decreasing at higher engine speed. At higher engine speed the time availability for combustion process decreased and incomplete combustion resulted in less CO_2 emissions as compared to low engine speed. It can be seen from **Error! Reference source not found.** that the binary blend of diesel and ethanol fuel has resulted in less amount of CO_2 as compared to other fuel blends. Ethanol produced 2.8% less CO_2 emission as compared to D100 fuel. Low CO_2 is due to limited carbon content per unit of energy in the ethanol fuel. The higher oxygen content in ethanol also helps in the combustion process but low hydrocarbon atomic ratio limits the CO_2 generation. Whereas binary blend of diesel and biodiesel generated the highest amount of CO_2 as compared to other blended fuels which are 6.3% greater than D100 fuel. Biodiesel has higher oxygen content which promotes complete combustion process. Increase of CO_2 emission towards the binary blend of biodiesel and diesel was also reported by [49].A decreasing trend of CO_2 emission was observed with the increase of ethanol in the ternary blend of biodiesel, ethanol and diesel. The CO_2 emission produced by B12E3, B5E5, B2E3, B3E12 are 6.1%, 5.6%, 4.8% and 3.9% higher than D100 fuel respectively.

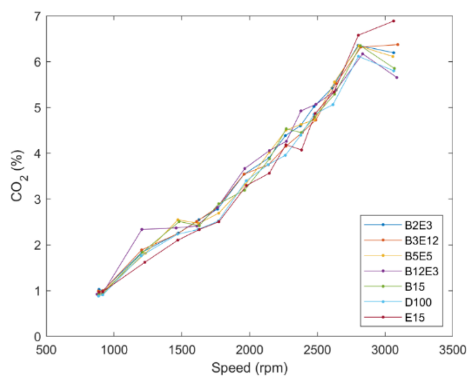

Fig. 6 Variation of CO_2 emission with engine speed

4. Conclusion

The study was conducted to observe the effect of the use of a binary and ternary blend of diesel, biodiesel, and ethanol on the engine emission while running the engine in transient condition. The blend was prepared according to the design of experiment DOE procedure. The analysis has been conducted using seven different blends of fuel and tests have been performed to observe the effect of each fuel on the emission level. The results showed that the use of ternary blends helped in reducing emission generation while running the engine on transient condition. The results have shown that the design of experiment DoE is a useful tool to develop the blend ratios between diesel, biodiesel, and ethanol. The results showed that the addition of ethanol in lower quantity can effectively reduce the emission of NO_x in the tailpipe emissions, but the higher quantity of ethanol would result in decreased cetane number and this has resulted in increased emission level of CO in the exhaust. Addition of biodiesel in fractional percentage more than 12% have resulted in decreased emission of CO but the lower fraction of biodiesel would not help much in the reduction of CO in the emission. The addition of ethanol in the fuel has also resulted in the reduction of CO_2 in the emissions as ethanol has less amount of carbon per unit energy production. The higher oxygen content in the ethanol results in better combustion and results in the emission of CO_2 but this is offset to the number of carbon atoms released per unit energy production. The use of biodiesel in the blend has also resulted in better combustion of fuel but also resulted in the increased emission of CO_2 in the emissions due to the presence of higher oxygen content in the biodiesel. Also, the use of biodiesel in the blend has resulted in increased emission of NO_x in the emission this is because the biodiesel results in the increased temperature in the exhaust and the use of ethanol have resulted in reduced emission of NO_x because of high latent heat of evaporation of ethanol.

5. Acknowledgement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

[1] Ü. Ağbulut, "Turkey's electricity generation problem and nuclear energy policy," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 41, no. 18, pp. 2281–2298, Sep. 2019.

[2] S. Sarıdemir and Ü. Ağbulut, "Combustion, performance, vibration and noise characteristics of cottonseed methyl ester–diesel blends fuelled engine," *Biofuels*, pp. 1–10, Sep. 2019.

[3] M. Hussain *et al.*, "Influence of laser processing conditions for texturing on ultra-high-molecular-weight-polyethylene (UHMWPE) surface," *Case Stud. Therm. Eng.*, vol. 14, no. June, p. 100491, 2019.

[4] H. Ullah, M. Hussain, N. Abbas, H. Ahmad, M. Amer, and M. Noman, "Numerical investigation of modal and fatigue performance of a horizontal axis tidal current turbine using fluid-structure interaction," *J. Ocean Eng. Sci.*, 2019.

[5] "Düzce University Journal of Science & Technology," vol. 7, pp. 25–36, 2019.

[6] L. Zhu, C. S. Cheung, W. G. Zhang, and Z. Huang, "Combustion, performance and emission characteristics of a di diesel engine fueled with ethanol-biodiesel blends," *Fuel*, vol. 90, no. 5, pp. 1743–1750, 2011.

[7] Ü. Ağbulut and S. Sarıdemir, "A general view to converting fossil fuels to cleaner energy source by adding nanoparticles," *Int. J. Ambient Energy*, pp. 1–6, Dec. 2018.

[8] C. Srinidhi, A. Madhusudhan, and S. V Channapattana, "Comparative analysis of exhaust gas recirculation and nanoparticles on the performance and emission of diesel engine fuelled with Neem biodiesel blend," *Int. J. Ambient Energy*, pp. 1–10, Jun. 2019.

[9] T. Aized and H. Ahmad, "CFD-Based Comparative Performance Analysis of Different Nanofluids Used in Automobile Radiators," *Arab. J. Sci. Eng.*, 2019.

[10] C. Srinidhi, A. Madhusudhan, and S. V Channapattana, "Parametric studies of CI engine at various injection strategies using biodiesel blended nanoparticles as fuel," *Int. J. Ambient Energy*, pp. 1–11, Jun. 2019.

[11] C. S. Cheung, L. Zhu, and Z. Huang, "Regulated and unregulated emissions from a diesel engine fueled with biodiesel and biodiesel blended with methanol," *Atmos. Environ.*, vol. 43, no. 32, pp. 4865–4872, 2009.

[12] M. Sufyan, M. Hussain, H. Ahmad, N. Abbas, J. Ashraf, and N. Zahra, "Bulge micro-textures influence on tribological performance of ultra-high-molecular-weight-polyethylene (UHMWPE) under phosphatidylcholine (Lipid) and bovine serum albumin (BSA) solutions," *Biomed. Phys. Eng. Express*, vol. 5, no. 3, p. 35021, 2019.

[13] P. C. Srinidhi, A. Madhusudhan, and S. V Channapattana, "E ff ect of NiO nanoparticles on performance and emission characteristics at various injection timings using biodiesel-diesel blends," *Fuel*, vol. 235, no. March 2018, pp. 185–193, 2019.

[14] K. V. Garzoli and R. W. Skinner, "Design and Economic Evaluation of a Solar Greenhouse.," 1984, vol. 2, no. 2, pp. 1202–1206.

[15] M. M. Rafique, "Design and Economic Evaluation of a Solar Household Electrification System," *Int. J. Smart Grid-ijSmartGrid*, vol. 2, no. 2, pp. 135–

141, 2018.

[16] B. Zafar, "Design of a Renewable hybrid photovoltaic-Electrolyze-PEM/Fuel Cell System using Hydrogen Gas," *Int. J. Smart Grid-ijSmartGrid*, vol. 3, no. 4, pp. 201–207, 2019.

[17] L. Zhu, C. S. Cheung, W. G. Zhang, and Z. Huang, "Science of the Total Environment Emissions characteristics of a diesel engine operating on biodiesel and biodiesel blended with ethanol and methanol," *Sci. Total Environ.*, vol. 408, no. 4, pp. 914–921, 2010.

[18] C. Srinidhi and A. Madhusudhan, "A Diesel Engine Performance Investigation Fuelled with Nickel Oxide Nano Fuel-methyl Ester," vol. 7, no. 2, 2017.

[19] T. Sakagami, Y. Shimizu, and H. Kitano, "Exchangeable batteries for micro EVs and renewable energy," in *2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2017, pp. 701–705.

[20] A. Bouhouta, S. Moulahoum, N. Kabache, and I. Colak, "Simplicity and Performance of Direct Current Control DCC Compared with other Identification Algorithms for Shunt Active Power Filter," in *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2018, pp. 1352–1357.

[21] K. A. Abed, A. K. El Morsi, M. M. Sayed, A. A. E. Shaib, and M. S. Gad, "Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine," *Egypt. J. Pet.*, 2018.

[22] B. F. Lin, J. H. Huang, and D. Y. Huang, "Experimental study of the effects of vegetable oil methyl ester on DI diesel engine performance characteristics and pollutant emissions," *Fuel*, vol. 88, no. 9, pp. 1779–1785, 2009.

[23] T. Baba, Y. Mizuno, K. Fujio, Y. Tanaka, and N. Matsui, "Evaluation of An Island Operation Method Smart Grid Using A Power Emulation System," in *2018 International Conference on Smart Grid (icSmartGrid)*, 2018, pp. 98–101.

[24] Y. Tominaga, M. Tanaka, H. Eto, Y. Mizuno, N. Matsui, and F. Kurokawa, "Design Optimization of Renewable Energy System Using EMO," in *2018 International Conference on Smart Grid (icSmartGrid)*, 2018, pp. 258–263.

[25] S. Fernando and M. Hanna, "Development of a novel biofuel blend using ethanol-biodiesel-diesel microemulsions: EB-diesel," *Energy and Fuels*, vol. 18, no. 6, pp. 1695–1703, 2004.

[26] H. N. Kim and B. C. Choi, "Effect of ethanol-diesel blend fuels on emission and particle size distribution in a common-rail direct injection diesel engine with warm-up catalytic converter," *Renew. Energy*, vol. 33, no. 10, pp. 2222–2228, 2008.

[27] M. Lapuerta, O. Armas, and R. García-Contreras, "Stability of diesel-bioethanol blends for use in diesel engines," *Fuel*, vol. 86, no. 10–11, pp. 1351–1357, 2007.

[28] G. Khoobbakht, G. Najafi, M. Karimi, and A. Akram, "Optimization of operating factors and blended levels of diesel, biodiesel and ethanol fuels to minimize exhaust emissions of diesel engine using response surface methodology," *Appl. Therm. Eng.*, vol. 99, no. 2016, pp. 1006–1017, 2016.

[29] S. Godiganur, C. Suryanarayana Murthy, and R. P. Reddy, "Performance and emission characteristics of a Kirloskar HA394 diesel engine operated on fish oil methyl esters," *Renew. Energy*, vol. 35, no. 2, pp. 355–359, 2010.

[30] S. H. Park, H. K. Suh, and C. S. Lee, "Nozzle flow and atomization characteristics of ethanol blended biodiesel fuel," *Renew. Energy*, vol. 35, no. 1, pp. 144–150, 2010.

[31] B. Q. He, S. J. Shuai, J. X. Wang, and H. He, "The effect of ethanol blended diesel fuels on emissions from a diesel engine," *Atmos. Environ.*, vol. 37, no. 35, pp. 4965–4971, 2003.

[32] S. A. Shahir, H. H. Masjuki, M. A. Kalam, A. Imran, and A. M. Ashraful, "Performance and emission assessment of diesel-biodiesel-ethanol/bioethanol blend as a fuel in diesel engines: A review," *Renew. Sustain. Energy Rev.*, vol. 48, pp. 62–78, 2015.

[33] D. C. Rakopoulos, C. D. Rakopoulos, E. C. Kakaras, and E. G. Giakoumis, "Effects of ethanol-diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine," *Energy Convers. Manag.*, vol. 49, no. 11, pp. 3155–3162, 2008.

[34] B. Q. He, "Advances in emission characteristics of diesel engines using different biodiesel fuels," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 570–586, 2016.

[35] I. Kalargaris, G. Tian, and S. Gu, "Combustion, performance and emission analysis of a DI diesel engine using plastic pyrolysis oil," *Fuel Process. Technol.*, vol. 157, pp. 108–115, 2017.

[36] E. Hürdoğan, C. Ozalp, O. Kara, and M. Ozcanli, "Experimental investigation on performance and emission characteristics of waste tire pyrolysis oil–diesel blends in a diesel engine," *Int. J. Hydrogen Energy*, vol. 42, no. 36, pp. 23373–23378, 2017.

[37] A. Datta and B. K. Mandal, "Engine performance, combustion and emission characteristics of a

compression ignition engine operating on different biodiesel-alcohol blends," *Energy*, vol. 125, pp. 470–483, 2017.

[38] L. Wei, C. S. Cheung, and Z. Ning, "Effects of biodiesel-ethanol and biodiesel-butanol blends on the combustion, performance and emissions of a diesel engine," *Energy*, vol. 155, pp. 957–970, 2018.

[39] S. Shamun, G. Belgiorno, G. Di Blasio, C. Beatrice, M. Tunér, and P. Tunestål, "Performance and emissions of diesel-biodiesel-ethanol blends in a light duty compression ignition engine," *Appl. Therm. Eng.*, vol. 145, pp. 444–452, 2018.

[40] A. Killol, N. Reddy, S. Paruvada, and S. Murugan, "Experimental Studies of a Diesel Engine run on Biodiesel n-Butanol blends," *Renew. Energy*, 2018.

[41] M. S. Sidhu, M. M. Roy, and W. Wang, "Glycerine emulsions of diesel-biodiesel blends and their performance and emissions in a diesel engine," *Appl. Energy*, vol. 230, no. June, pp. 148–159, 2018.

[42] S. Manigandan, P. Gunasekar, J. Devipriya, and S. Nithya, "Emission and injection characteristics of corn biodiesel blends in diesel engine," *Fuel*, vol. 235, no. October 2017, pp. 723–735, 2019.

[43] A. R. Patil, A. D. Desai, A. D. Madavi, S. A. Kamble, S. B. Navale, and V. U. Dhutmal, "Comparative study on Effect of Biodiesel on CI Engine Performance and Emission Characteristics," *Mater. Today Proc.*, vol. 5, no. 2, pp. 3556–3562, 2018.

[44] S. Rajkumar and J. Thangaraja, "Effect of biodiesel, biodiesel binary blends, hydrogenated biodiesel and injection parameters on NOx and soot emissions in a turbocharged diesel engine," *Fuel*, vol. 240, no. November 2018, pp. 101–118, 2019.

[45] A. K. Agarwal, "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines," *Prog. Energy Combust. Sci.*, vol. 33, no. 3, pp. 233–271, 2007.

[46] A. Monyem and J. H. Van Gerpen, "The effect of biodiesel oxidation on engine performance and emissions," *Biomass and Bioenergy*, vol. 20, no. 4, pp. 317–325, 2001.

[47] M. N. Nabi, M. S. Akhter, and M. M. Z. Shahadat, "Improvement of engine emissions with conventional diesel fuel and diesel-biodiesel blends," *Bioresour. Technol.*, vol. 97, no. 3, pp. 372–378, 2006.

[48] M. Lapuerta, O. Armas, and J. Rodríguez-Fernández, "Effect of biodiesel fuels on diesel engine emissions," *Prog. Energy Combust. Sci.*, vol. 34, no. 2, pp. 198–223, 2008.

[49] A. Sanjid, M. A. Kalam, H. H. Masjuki, M. Varman, N. W. B. M. Zulkifli, and M. J. Abedin, "Performance and emission of multi-cylinder diesel engine using biodiesel blends obtained from mixed inedible feedstocks," *J. Clean. Prod.*, vol. 112, pp. 4114–4122, 2016.

[50] M. El-kasaby and M. A. Nemit-allah, "Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel," *Alexandria Eng. J.*, vol. 52, no. 2, pp. 141–149, 2013.

[51] A. Gharehghani, M. Mirsalim, and R. Hosseini, "Effects of waste fi sh oil biodiesel on diesel engine combustion characteristics and emission," *Renew. Energy*, vol. 101, no. 2017, pp. 930–936, 2020.

[52] Ü. Ağbulut, S. Sarıdemir, and S. Albayrak, "Experimental investigation of combustion , performance and emission characteristics of a diesel engine fuelled with diesel – biodiesel – alcohol blends," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 8, 2019.