Chapter 7
The Impact of Renewable Fuels and Fuel Additives (Dodecanol) on Particulate Mass Emission for Sustainable Mobility

Jyothi Jayakumar, Priyanka Gupta, Nisha Yadav, Jitendra Dixit, and Nikhil Sharma

Abstract Among IC engines, diesel vehicles are the major contributors to particulate mass emissions. Renewable fuels play a major role in reducing both gas phase and particulate mass emissions. In addition to renewable fuels, fuel additives are also investigated by scientists to compensate for the limitations of using renewable fuels. In this book chapter, a review of renewable fuels to be used in compression ignition (CI) engine was carried out. In addition to this, an experimental investigation was carried out in a single cylinder, water cooled variable compression ratio (VCR) diesel engine to make a comparative analysis among baseline diesel fuel and diesel + dodecanol (1% v/v) without renewable fuels. Dodecanol was chosen due to its advantages over other fuel additives. Results pertaining to in-cylinder pressure, hydrocarbon (HC) emission, carbon mono-oxide (CO) emission and particulate mass emission are presented. Soot was collected on a 47 mm quartz filter paper using a dilution tunnel and later analysed for soot morphology using scanning electron microscope (SEM). Energy dispersive spectroscope (EDS) analysis was also performed to find out the presence of metals in soot. Gravimetric analysis shows that Diesel + dodecanol (1% v/v) resulted in 2.62 mg of soot deposited on filter paper whereas diesel fuel showed 1.46 mg of soot deposited on filter paper for a duration of 30 min.

Keywords Renewable fuels · Sustainable mobility · Additive · Particulate mass emission · Filter paper

Abbreviations

BSFC	Brake Specific Fuel Consumption
BTE	Break Thermal Efficiency
CLD	Chemiluminescence Detector
CNG	Compressed Natural Gas

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CO	Carbon Monoxide
CO_2	Carbon Dioxide
DMC	Dimethyl Carbonate
EDS	Energy Dispersive Spectroscope
EGR	Exhaust Gas Recirculation
EGT	Exhaust Gas Temperature
EHN	2-Ethylhexyl Nitrate
FID	Flame Ionisation Detector
H_2	Hydrogen
HC	Hydrocarbon
HHO	Hydrogen-Hydrogen-Oxygen
IC	Internal Combustion
IMEP	Indicated Mean Effective Pressure
LPG	Liquefied Petroleum Gas
NDIR	Non-Dispersive Infrared
NO_x	Oxides Of Nitrogen
PM	Particulate Matter
PODE	Polyoxymethylene Dimethyl Ether
SEM	Scanning Electron Microscope
SI	Spark Ignition
UHC	Un-Burnt Hydrocarbon
VCR	Variable Compression Ratio
WHO	World Health Organisation

7.1 Introduction

World is facing twin crises of fossil fuel shortage and environmental degradation. Globally, diesel engines are a significant source of carbon monoxide (CO), nitrous oxide (NO_x), and hydrocarbon (HC) emissions, contributing to global warming. Diesel engine plays a vital role in current economic development. Diesel engine is still leading a role mainly in long distance cargo, construction, agriculture and transportation sector (Reitz, et al. 2020). The majority of the world population is inhaling unhealthy air containing fine particulates, having a size below the limit suggested by World Health Organisation (WHO). This is now identified as the fourth most probable reason for early deaths and health issues. With the growth of the human population, the use of this conventional energy source is leading to higher environmental degradation.

Diesel engine contributes many harmful emissions such as CO, oxides of nitrogen (NO_x), carbon dioxide (CO_2) and particulate matter (PM). Among all these emissions, PM and NO_x emissions is critical to human health. In developing countries transportation sector is one of the fastest growing sectors and a major contributor of the greenhouse gas emissions. PM is the mixture of all solid and liquid particles suspended in the air. Fine particles travel to the lungs and can also act as carriers for many potentially toxic substances (Eastwood 2008). Alternative fuels are one of the probable reasons to control emission from diesel engines. As compared to the traditional fuels methanol is recommended as a new generation of substitute fuel for internal combustion (IC) engine in the upcoming time and the government of India is promoting the methanol as a fuel. Methanol also known as methyl alcohol is a saturated, single carbon straight chained compound. Methanol is an alcohol and is a polar, neutral, colourless and highly flammable liquid. Methanol mix's with H_2O, alcohols, esters and furthermost other organic solvents. It is only slightly soluble in oils and fats. Methanol contains oxygen which helps in the complete combustion of fuel resulting in eliminating the un-burnt hydrocarbon. It has excellent thermo-physical properties like high latent heat of vaporisation which helps in the reduction of the in-cylinder temperature.

Methanol is one of the friendliest fuels for IC engines, for illustration, (1) methanol can be used for different/high compression ratio internal combustion (IC) engine that could replace diesel in compression ignition (CI) engine; (2) methanol can be used in spark ignition (SI) engine due high good octane number (Zhen et al. 2015). Han et al. (Lu et al. 2019) examined NO_x emission influencing factor in methanol/diesel dual-fuel CI engine. Author conducted a numerical simulation followed by an experiment in which the author observed the effect of methanol concentration and exhaust gas recirculation (EGR). Author found that NO_x emission increases when methanol is present in the premixed reason and the temperature is high in the cylinder. But in the experiment, the author found that the NO_x emission first reduces and then increases with methanol addition. Jamrozik (2017) performed investigation on performance and emission characteristics of a direct injection single cylinder four stroke CI engine that works on the methanol/diesel and ethanol/diesel blend. The concentration of the alcohols varies from 0 to 40% by volume. The increase in the methanol concentration up to 30% in methanol/diesel blend had an optimistic effect on the BTE of the engine. No significant change was observed in mean effective pressure. Furthermore, a reduction was observed in CO, HC and CO_2. Similarly, when ethanol and diesel blend was used in the same engine it was found that the break thermal efficiency (BTE) was increased with constant mean effective pressure inside the cylinder. Also, a reduction was observed in CO and CO_2 and THC emission remained constant.

Elfasakhany and Mahrous (2016) conducted an investigation on the performance and emission characteristics of n-butanol/methanol/gasoline mixtures in spark ignition engines. In this experiment, author prepared the blend in which the concentration of butanol/methanol was 0, 3, 7, and 10% v/v in gasoline. These blends were examined in an engine operating at a speed range of 2600–3400 rpm. Furthermore, the performance and emissions of the methanol and butanol/gasoline mixtures were compared with the pure gasoline fuel. With the increase in the concentration of the butanol/methanol to the pure gasoline, the author found the performance of the engine was degraded. Furthermore, the authors observed that CO_2 emissions were reduced where CO and UHC were increased. Li et al. (2017) investigated emission, performance and combustion characteristics of a single cylinder four stroke

SI engine which worked with different concentrations of methanol, ethanol, and n-butanol blended with pure gasoline. The author found that with alcohols addition in the pure gasoline, combustion phasing get advanced; butanol and gasoline blends exhibited the lesser brake specific fuel consumption (BSFC), ethanol and gasoline blends formed the lowermost UHC emission, and methanol and gasoline blends exhibited the lowermost NO_x emission.

Sharudin et al. (2017) examined the effects of using butanol additives on performance, combustion, and emission characteristics in conventional SI engine. In this experiment, author prepared a blend in which the concentration of butanol was 5, 10, and 15% v/v in methanol/gasoline. These blends were examined in an engine operating at a speed range from 1000 to 2500 rpm fuelled with butanol, methanol and gasoline blends. The author found that with iso-butanol addition to methanol/gasoline blends, the break thermal efficiency (BTE) was enhanced, break specific fuel consumption (BSFC) was reduced and EGT increased with increase in load. Furthermore, for iso-butanol, methanol and gasoline blends, CO and un-burnt hydrocarbon (UHC) emissions reduced, and CO_2 and NO_x emissions were found to increase. Duraisamy et al. (2020) investigated the effect of diesel/methanol and Polyoxymethylene dimethyl ether (PODE)/methanol blend on the performance and combustion characteristics in CI engine. This experiment was conducted on the three cylinders, four strokes and turbocharged direct injection CI engine. This engine was operated at 1500 rpm and a constant break mean effective pressure of 3.4 bar. It was found that the increase in the methanol concentration mass fraction extended the ignition delay and diminished the in-cylinder pressure for both diesel and methanol blends as well as methanol and PODE blend. At the 80% of premixed mass fraction of the blend, the maximum BTE of both diesel and methanol blend as well as methanol and PODE blend was 3.5% higher as compared to the conventional diesel combustion.

Renewable fuels, such as alcohols, compressed natural gas (CNG), Hydrogen (H_2), vegetable oils, biogas, and liquefied natural gas (LNG), have the prospect of substituting petroleum-based fuels in modern IC engines with little to no modification. Compared to fuels made from crude oil refining process, these fuels burn clean, have a lower reliance on conventional fuels and have less production cost (Nouni et al. 2021). Alcohols include methanol, ethanol, propanol and butanol. The specific heating value of gasoline and methanol is less than ethanol (26.8 MJ/kg) and methanol (19.7 MJ/kg). Methanol is also known as wood alcohol derived from natural gas and is considered an IC engine alternative fuel. This fuel is usually produced by steam-reformed natural gas to form synthesis gas. Methanol has chemical properties similar to ethanol as an engine fuel. The properties of methanol, such as lower flammability, make it safer than gasoline. Ethanol is a renewable fuel produced from biomass. It is clear colourless alcohol and is derived from various biomass materials. Ethanol has a boiling point of 78.5 °C and a specific density of 0.789 g/ml at 20 °C. LPG, commonly referred to as “Autogas” in some countries, is a mixture of propane and butane that can also be used as a fuel for vehicles. Auto LPG’s development has only been moderately successful in India despite the economic advantages for the user and being more ecologically friendly than petrol and diesel because there isn’t a supportive governmental system in place (Nouni et al. 2021). Biogas primarily comprises methane and carbon dioxide produced from organic materials such as agricultural waste, manure, plants, green waste, and food waste. Biogas is used as a fuel in stationary engines. However, the main problem is storing the biogas. Another problem with biogas plants is their size, as they require large areas and can only be used for stationary engines (Nouni et al. 2021). Biodiesel is a renewable fuel produced domestically from recycled grease or vegetable oils. Among the numerous bio-fuels discussed above, alcohols are now considered as possible future IC engine fuel when blended with conventional fuels. Krzemiński et al. (2017) reported that ethanol and methanol can be blended with diesel oil to propel the engines. However, at low-temperature diesel blended ethanol have low solubility index.

Sharma et al. (2020) reported a reduction in CO, HC, and smoke emissions by 58%, 60%, and 49%, respectively. However, due to the addition of HHO, an increase in O_2 concentration resulted in a higher reaction temperature, resulting in a minor NO_x emission increase. Bose and Maji (2009) used EGR technology to lower NO_x levels. The NO_x value for hydrogen enrichment without EGR was 1211 ppm at 80% load, but the NO_x value for hydrogen enrichment with 20% EGR was 710 ppm. Yadav et al. investigated the emissions from a direct injection C.I. engine operating in dual-fuel mode (hydrogen-diesel) with an exhaust gas recirculation system. In the engine, hydrogen-enriched air was used as the intake charge, with 10% and 20% exhaust gas recirculation (EGR), respectively. The outcomes were as follows: At 80% load, the NO_x value for hydrogen enrichment without EGR was 470 ppm, whilst it was 447 ppm for hydrogen enrichment with EGR. The decrease in peak combustion temperature caused by the inert gas in the EGR was attributed to the reduction in NO_x. At 80% load, neat diesel operation had an O_2 concentration of 15.1% by volume. Without EGR, O_2 had a volume concentration of 15.2, 10.4 with 10% EGR, and 9% with 20% EGR. No hydrogen carbon atoms result in low CO and CO_2 emissions (SinghYadav et al. 2012; Baltacioglu et al. 2016). Baltacioglu et al. (2016) conducted an experimental investigation to compare pure Hydrogen and HHO (hydroxy) enriched biodiesel (B10) fuel. This study aims at pilot injection of diesel engine performed when alternative fuels such as pure Hydrogen, HHO, and biodiesel were added. Some of the findings that could be drawn from the diesel engine experiment results: when compared to diesel fuel, H_2 and B10 and HHO and B10 achieved CO emission reductions of 29% and 22%, respectively. H_2 and B10 fuels emit 8.72 and 22.3% less CO_2 than HHO and B10 and ordinary diesel fuels. Saravanan et al. (2008) employs an EGR system based on the principle of recirculating exhaust gases back into the inlet manifold, which combines with new air and dilutes by the intake charge (a diluent). It lowered the combustion chamber's peak combustion temperature, reducing NO_x production. The minimum NO_x concentration was 464 ppm with a 25% EGR (Saravanan et al. 2008).

In another experimental investigation, nano-fuel additives were used in a single cylinder direct injection diesel engine to explore performance and emission characteristics of jatropha biodiesel (Ganesh and Gowrishankar 2011). Interestingly, Dimethyl carbonate (DMC) is well-thought-out as a choice for meeting the oxygenate specifications on gasoline (Pacheco and Marshall 1997). Fayyazbakhsh et al. (2017) investigated the performance of the engine and the properties of the fuel in IC engine with additives. Authors found that the pollutants reduced with increase in engine speed. Le et al. (2020) investigated the effect of cetane number booster mainly 2-ethylhexyl nitrate (EHN) on the performance and emission in IC engine. Authors found that the using EHN CN booster additives improves the overall cetane number of the blend resulting in improved performance of the engine and reduction in the detonation tendency. Cetane number is the measurement of the combustion speed of diesel fuel and diesel fuel components. As a matter of fact, lower cetane number fuels tend to have longer ignition delay periods relative to higher cetane number fuels. Additives such as alkyl nitrate have capability to enhance cetane number significantly. Researchers are working on additives such as 1-tetradecane, nitro ethane, 1-octadecanol, and isobutyl stearate. Yanowitz et al. (2017) have investigated different types of methods to calculate the cetane number of different additives. This author has also suggested some additives have high CN and cost effective which can be used to improves the performance of the IC engine along with able to suppress detonation. At low temperature, solubility of alcohol like fuels changes in diesel like fuels. Additives can enhance the solubility characteristics of diesel with alcohol fuels such as diesel. Dodecanol is known to increase the solubility characteristics of alcohol such as ethanol and methanol with diesel fuel. Table 7.1 shows a comparative analysis for ethanol port fuel injection + gasoline direct injection vs gasoline direct injection engine for engine out emission. There are advanced engine research centres working on the advanced concept and engine emission control using various renewable fuels and advanced engine technologies (Shamun et al. 2020; Belgiorno et al. 2019; Ianniello et al. 2021; Blasio et al. 2022; Dimitrakopoulos et al. 2017; Wang et al. 2015).

From the above discussion, it can be said that both "renewable fuels" and "additives" play a vital role in improving the characteristics of fuel. In this book chapter, a review of renewable fuels to be used for CI engine was done. There are many research articles that discuss the comparative analysis of diesel/renewable fuel/diesel

Table 7.1 Comparison of emission characteristics for ethanol port fuel injection + gasoline direct injection vsersu gasoline direct injection engine

Authors (ethanol port fuel injection + gasoline direct injection vs. gasoline direct injection engine)	Emissions characteristics				
	CO	HC	NO_x	PM	PN
Kim et al. (2015)	Increase	Mixed trend	Mixed trend	Decrease	Decrease
Liu et al. (2015)	N.A	N.A	N.A	N.A	Decrease
Qian et al. (2019)	Increase	Decrease	Decrease	N.A	N.A
Sun et al. (2019)		Decrease	N.A	N.A	Decrease
Kalwar et al. (2020)	Decrease	Increase	Decrease	Decrease	Decrease

+ renewable fuels/diesel + renewable fuels + fuel additives. There is limited literature available on diesel + additives fuel (without the addition of bio-fuels) to be used in IC engine. The present experimental investigation explores the use of additives in diesel fuel and its effect on particulate mass emissions. A single cylinder 661.5 cc diesel engine was selected to perform experimental investigation. A comparative analysis among baseline diesel fuel and diesel + dodecanol (1% v/v) without renewable fuels was carried out. Many of the industry issues (purity, blending, transport and storage of these fuels) with renewable can be addressed with the use of appropriate fuel additives. In this experimental investigation, dodecanol was chosen due to its advantages over other additives. Results pertaining to in-cylinder pressure, HC emission, CO emission and particulate mass emission are presented. Soot was collected on a 47 mm quartz filter paper and later analysed for soot morphology using scanning electron microscope (SEM). Energy dispersive spectroscope (EDS) analysis was also performed to find out the presence of metals in soot. This study provides valuable insights into particulate mass emission from I.C engine.

7.2 Experimental Setup and Procedure

This section is divided into two parts. (a) Engine experimental setup, (b) Experimental procedure.

Engine Experimental Setup

A single cylinder 661.5 cc diesel engine was selected for this experimental investigation. The specifications of the engine to be used for the experiments are given in Table 7.2. Schematic of the experimental setup is shown in Fig. 7.1. An eddy current dynamometer was coupled to the engine. A standalone panel box is used, which contains an airbox, two fuel tanks, a fuel measurements unit, a manometer, transmitters for measuring air and fuel flow rates, an engine indicator and rotameters for measuring water flow in a calorimeter and cooling water. Brake power, indicated power, frictional power, brake mean effective pressure (BMEP), indicated mean effective pressure (IMEP), thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, and air/fuel (A/F) ratio could be used to measure the performance of VCR engines using the setup. Additionally, the AVL digital analyzer measures the concentration of smoke emissions, nitric oxide, carbon monoxide and hydrocarbons.

Experimental procedure

Engine was made to operate for 20 min prior to taking any reading. At a given test condition, exhaust gas temperature (EGT) and coefficient of variance (CoV) in IMEP were monitored to achieve steady state condition. Two vacuum pumps each of 15 LPM were used to suck exhaust gas from the engine tail pipe and made to pass through a dilution tunnel. The filter paper was kept in between the two flanges of the dilution tunnel. The exhaust was diluted with 2 LPM flow rate to avoid any condensation in the

Table 7.2 Engine specifications used in this experiment

Parameters	Specifications
MFG and model of the engine	Kirloskar Engine oil Ltd., Model TV1
Number of cylinders	Single
Fuels used	Diesel, diesel doped with dodecanol
Bore × Length	8.75 cm × 11 cm
Connecting rod's length	23.4 cm
Maximum rating of power	3.5 kW
Number of strokes	Four
Revolution per minute	1500
Injection point	0°–25° BTDC
Compression ratio	12:1 to 22:1

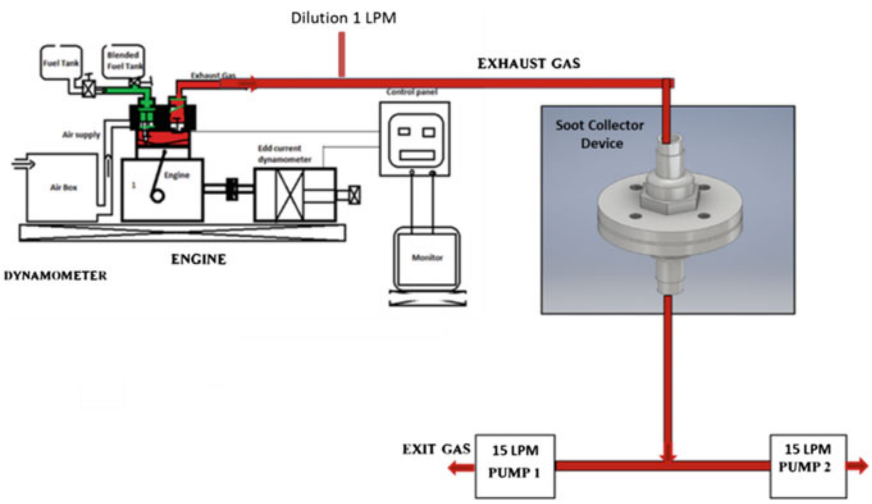


Fig. 7.1 Schematic of the experimental set for soot loading

dilution tunnel. Stick protocol was followed and it was ensured that no dust particles entre into the filter paper or sampling device. Upper half of the tunnel was attached with the exhaust pipe of the engine using a metal pipe and lower half is connected with inlets of two parallel vacuum pumps using high temperature resistance tubes. Table 7.3 shows the experimental points and test procedure. A comparative analysis among baseline diesel fuel and diesel + dodecanol (1% v/v) without renewable fuels was carried out at 16 Nm engine load@1500 rpm. A solenoid injector was used with a single fuel injection per cycle.

To check the outlet velocity of exhaust gases passed through filter paper, an anemometer was used. Air velocity at the exhaust must be between 0.35 and 0.80 m/s.

Table 7.3 Experimental parameters

RPM	1500	1500
Load (Nm)	16	16
Running time (min)	30	30
Fuel used	Diesel	Diesel + Dodecanol (1% v/v)
Flow rate of pump (lpm)	30	30

Anemometer showed 0.75 m/s air velocity at the end of exhaust pipe. This difference in air velocity is because of pressure drop across the filter paper. The engine was operated for 30 min for each sample (diesel fuel and diesel fuel with dodecanal). The PM collector tunnel is connected with the exhaust pipe of the engine using a metal pipe having half inch diameter and is fastened to the top part of the tunnel. The weight of the soot loaded in 30 min was noted through a high precision weighing machine. The weight of the unloaded filter paper was also noted to know the weight difference for the gravimetric test. To know the morphology and chemical composition of each PM-loaded filter paper, SEM and EDS tests were performed. Soot is essentially non-conductive in nature. To make soot samples conductive, a sputtering machine was used for gold coating on the samples. Once the soot sample becomes conductive, emission of secondary electrons takes place and soot sample conducts evenly and creates a homogeneous surface for analysis and imaging. Thereafter, SEM and EDS were performed.

7.3 Results

Physical chemical properties of dodecanol and renewable fuel play a vital role on emissions. To improve the solubility of ethanol in diesel fuel, additive is required. One such additive widely used for this purpose is dodecanol ($CH_3(CH_2)_{11}OH$). Chemical structure of dodecanol is shown in Fig. 7.2. 1-dodecanol molecule contains a total of 38 bonds. There are 12 non-H bond, 10 rotatable bonds, 1 hydroxyl group and 1 primary alcohol.

Using additive in diesel increases the solubility index of primary alcohol in diesel fuel at low temperatures. Dodecanol has higher octane number than the diesel so it is also used as an octane number booster by mixing it into low cetane fuel

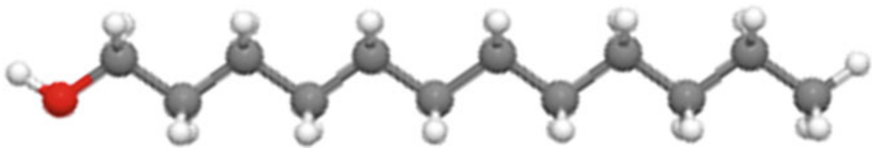


Fig. 7.2 3D chemical structure of 1-dodecane

Table 7.4 Comparison of properties between dodecanol and diesel (Gangwar et al. 2017)

Property	Diesel	1-Dodecanol
Molecular formula	$C_{12}H_{24}$	$C_{12}H_{26}O$
Molecular weight (kg/kmol)	170	186
Cetane number	48	63.6
Stoichiometric fuel/air ratio	0.6924	0.07462
Flash point (°C)	52	127
Ignition temperature (°C)	235	527
Lower heating value (MJ/kg)	42.74	39.86
Density (g/cm^{-3})	0.84	0.831
Oxygen (% wt)	0	8.6

Table 7.5 Measurement methods for different emissions (Hu et al. 2012)

Gas Component	Measurement principle
CO	Non-dispersive infrared (NDIR)
HC	Flame ionisation detector (FID)
NO_x	Chemiluminescence detector (CLD)
PM	Partial/Full flow Dilution Tunnel

(diesel) (Duraisamy et al. 2020). Table 7.4 shows a comparison of properties between dodecanol and diesel.

In order to control different types of emission, first emission should be measured accurately. These emissions increase environmental and health risk. A wide range of measurement techniques is available for regulated emissions. A few of the important methods are given in Table 7.5.

Combustion data was acquired for both the test fuels as explained in the experimental section. Figure 7.3 shows in-cylinder combustion pressure for diesel and diesel + dodecanol (1% v/v) along with 47 mm soot loaded filter paper. In-cylinder pressure for both the test fuel was found to be nearly the same. At TDC, diesel + dodecanol was found to have slightly higher in-cylinder pressure. On combustion of diesel fuel, the engine produces a mixture of gases containing elemental carbon, sulphur compounds and hydrocarbons. The collected samples using diesel and diesel + dodecanol (1% v/v) as a fuel are shown in Fig. 7.3. As seen in Fig. 7.3, uniform deposition of PM particle was observed and soot loading looks nearly the same.

Gravimetric Test Results

For gravimetric test, samples obtained from operating the engine with diesel and diesel + dodecanol (1% v/v) were measured using a high precision weighing machine. The difference in filter paper weight before and after soot loading was compared. Results obtained are given in Table 7.6.

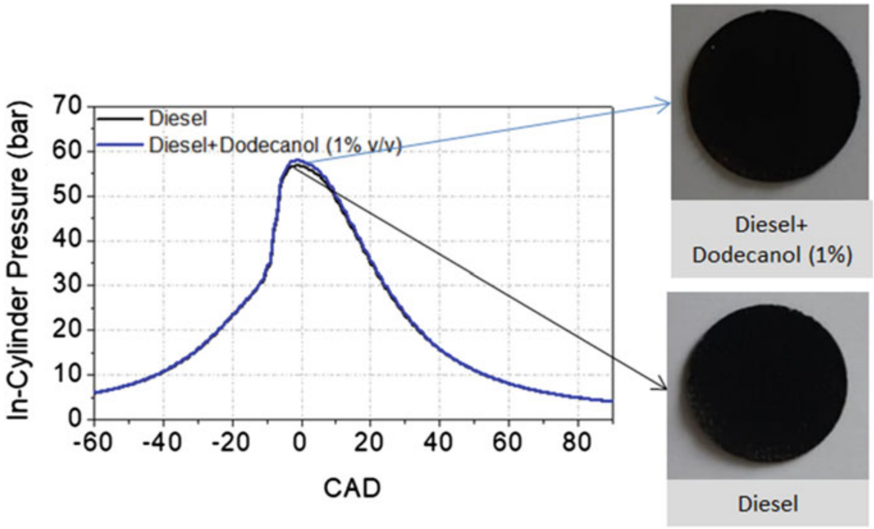


Fig. 7.3 In-cylinder combustion pressure for diesel and diesel + dodecanol (1% v/v) along with 47 mm soot loaded filter paper

Table 7.6 Gravimetric result for the samples collected using diesel and DD as the fuel

Fuel Used	Sample-1 (Diesel)	Sample-2 (Diesel + dodecanol (1% v/v))
Weight before loading the PM (mg)	142.84	142.66
Weight after loading the PM (mg)	144.93	145.28
Total weight of the PM collected (mg)	2.09	2.62
% change in weight	1.46	1.84

Morphological Test Results

To know the morphology and chemical composition of each PM-loaded filter paper, SEM and EDS were performed. The results of SEM and EDS testing for sample 1, i.e. diesel as a fuel and sample-2, Diesel + dodecanol (1% v/v) as the fuel are given in Fig. 7.4.

SEM Result for Sample Number-1

For the diesel sample, SEM imaging was done for different magnifications for observing the morphological properties of the PM. PM particles tend to take a spherical shape where the particle size was observed to be in the range of 50–80 nm. But the individual particles bind with the adjacent particles and form a chain-like

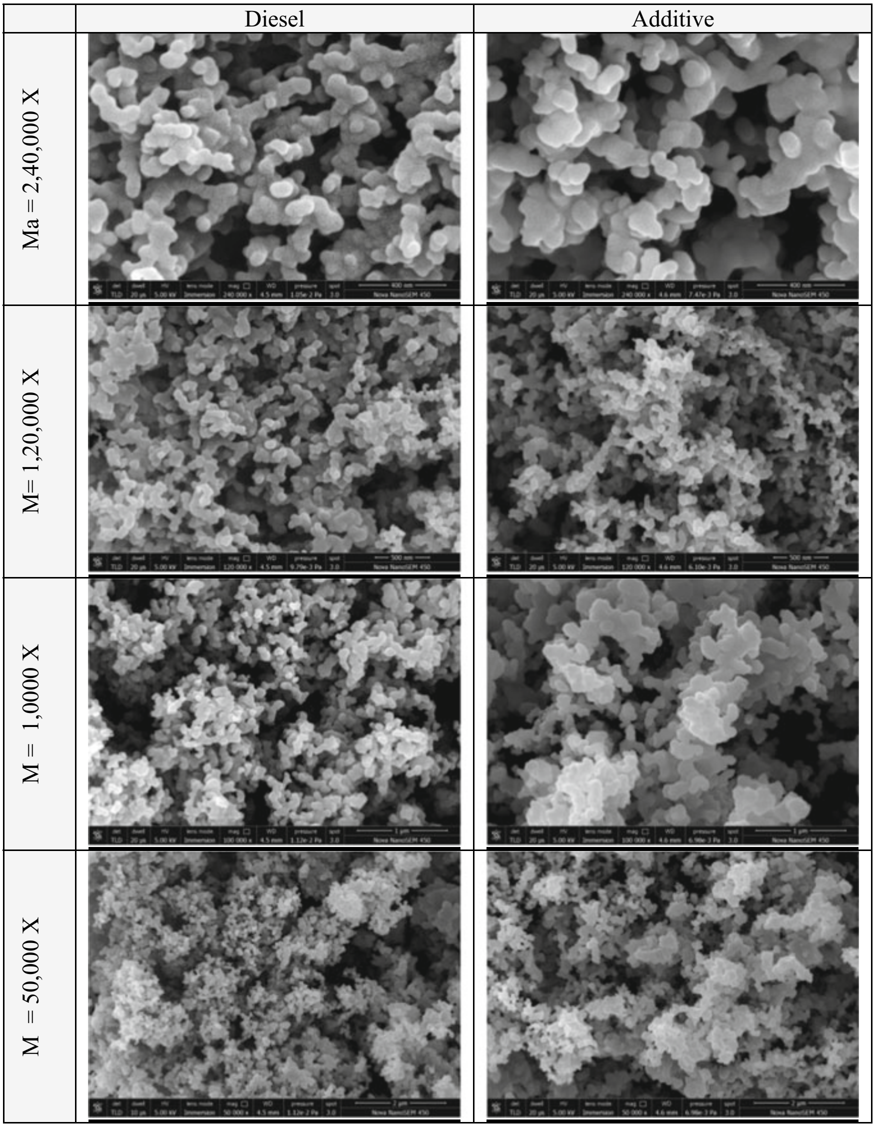


Fig. 7.4 SEM images of soot samples for two different test fuels

structure. The individual size of particles is in nanometre. Due to the aggregation of PM particles their size and shape both change. The shape and size of PM particles depend on the chemical composition of the test fuel.

SEM Result for Sample Number-2

When additive was mixed in diesel engine, chemical composition of the fuel changed. Because of this change in chemical composition, PM morphology also got changed. The particle size in this case varies from 60 to 90 nm evidently greater compared to the diesel fuel.

Comparison of the SEM Results

The comparison morphology of both the samples collected is given in Fig. 7.4. Change in PM morphology can be seen clearly. As diameter of PM particles are larger than the PM particles of diesel engine. Aggregation of PM particles in case of diesel + dodecanol (1% v/v) fuel is more than diesel fuel, whereas PM particles of diesel fuel are forming a cylindrical shape after aggregation, PM particles of diesel + dodecanol (1% v/v) fuel are forming a more complex structure which indicates that the aspect ratio of diesel PM particles is greater than that of DDPM particles.

The particulate emissions from diesel engines consist of carbon, condensed hydrocarbons and sulphate. The PM generation is due to various factors like improper (or) incomplete combustion, fuel injection pressure, etc. *SEM* images of particulates showed that at higher magnification clear particle boundaries were visible, which was neither fused nor fully matured.

EDS Test

Metals are adsorbed on the soot emitted from the engine. Metals are essential for the survival of humans, animals and plants. However, metals inhalation with soot in large quantity may result in dangerous health effects. Cd, Hg and As are poisonous. Fe and Zn are known to induce cancer. Therefore, it is important to investigate the presence of metals in particulate emitted by diesel engines, especially when they are being fuelled with additives (dodecanol). Sources of metals in soot are metals in fuel itself, additives present in lubricating oil and wear debris emanating from engine components. EDS test was performed to know the chemical composition of soot particles. Other than unburned carbon, PM contains silicon, various hydrocarbon, lead, sulphur compounds, etc. EDS test was performed on the same machine where the previous test was performed.

EDS FOR SAMLE Number-1

For filter paper loaded with particles of diesel fuel, EDS result is shown in Fig. 7.5. It represents the peak composition of materials observed during the test.

The sample of diesel fuel PM contains carbon; silicon and oxygen. The weight percentage of various elements of PM is represented in Table 7.7.

Apart from carbon, oxygen and silicon, there are many other elements present in the soot sample which are not shown in the EDS testing graph as these are very less in amount as compared to those mentioned above. The sources of these elements are lubricant used in the engine, leakages, metal elements because of wear and tear.

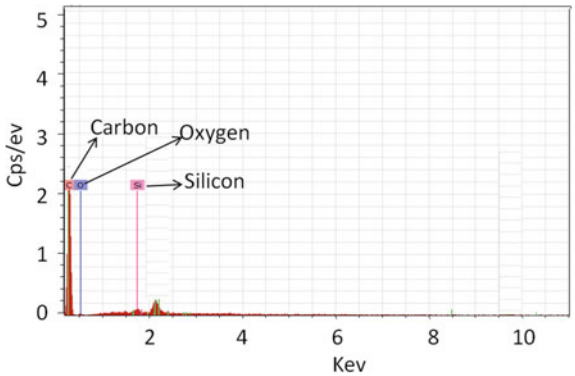


Fig. 7.5 Chemical composition of PM collected from diesel fuel

Table 7.7 Composition of PM sample of diesel fuel

Element	Element (% weight)	Atom (%)
Carbon	78.6	96.22
Oxygen	1.77	1.63
Silicon	1.52	0.8

EDS for Sample Number-2

EDS result obtained with the sample-2 using Diesel + dodecanol (1% v/v) as the fuel is represented in Fig. 7.6.

The sample of Diesel + dodecanol (1% v/v) fuel PM contains carbon and oxygen. The weight percentage of various elements of soot is given in Table 7.8. The amount of increase in the elemental percentage is evidently seen in the results confirming the conclusion that the addition of additives increases the soot emissions. The silicon peak was not observed in EDS using sample-2.

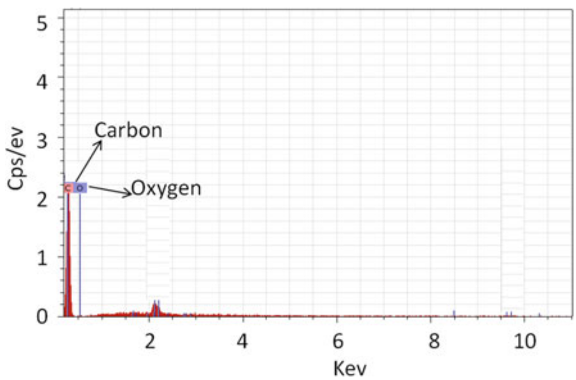


Fig. 7.6 Chemical composition of PM collected from DD fuel

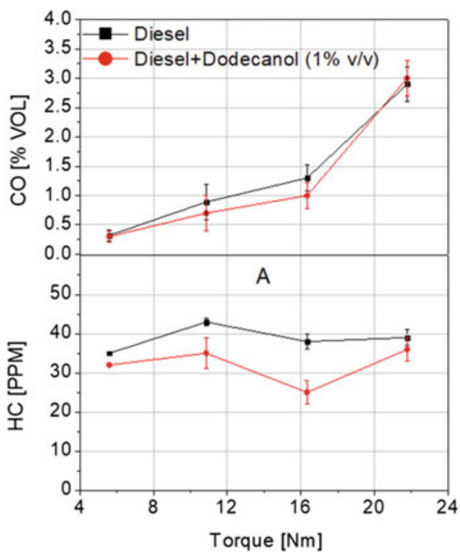
Table 7.8 Composition of PM sample of DD fuel

Element	Element (% weight)	Atom (%)
Carbon	81.11	97.68
Oxygen	1.12	1.02

There is an observed difference of carbon content by 2.51% and oxygen content is reduced implying more hydrocarbon compounds (PM is majorly un-burnt hydrocarbon) being released when the additive is mixed even if it increases the combustion rate.

Figure 7.7 shows CO and HC emission for both the test fuels. It was found that, for both the test fuel, CO emission increases with an increase in engine load. Also, Diesel + dodecanol (1% v/v) showed relatively less CO emission compared to diesel fuel. At high engine load, a trend was found to be the opposite, i.e. Diesel + dodecanol (1% v/v) showed higher CO emission compared to diesel fuel. Throughout the engine operating condition, HC emission was found to be lower for Diesel + dodecanol (1% v/v) relative to diesel fuel. Also, HC emissions were range bound independent of the engine load. The possible reason for the decrease in HC and CO emission for Diesel + dodecanol (1% v/v) is the presence of oxygen in dodecanol which helps in relatively complete combustion.

Fig. 7.7 CO and HC emission from test fuels



7.4 Conclusions

Experimental investigation was carried out in a single cylinder, water cooled variable compression ratio (VCR) diesel engine to make a comparative analysis among baseline diesel fuel and diesel + dodecanol (1% v/v) without renewable fuels.

- In the gravimetric test, a significant weight increase is seen in PM-loaded filter of Diesel + dodecanol (1% v/v) fuel compared to that of diesel fuel. This shows that altering the composition of fuel results change in particulate emission. When additives are mixed in the fuel, certainly it improves the combustion but it also increases the emission.
- In morphological analysis, it is found that the morphology of PM particles collected from diesel fuel is different from Diesel + dodecanol (1% v/v) fuel. This indicates that the composition of fuel affects the morphology of the particles. Here in this case, when the additive is mixed in diesel fuel, the tendency of PM particles to get aggregated increases and as a result of its morphology of PM particles of Diesel + dodecanol (1% v/v) fuel is more complex than that of diesel fuel.
- In EDS test analysis it is found that the amount of carbon in PM collected from Diesel + dodecanol (1% v/v) fuel is more than that of diesel fuel which shows the alteration of the chemical composition of exhaust gas on adding additives in fuel.
- Both HC and CO emissions were found to be lower with the use of Diesel + dodecanol (1% v/v) fuel in a diesel engine. Overall, this experimental investigation results may be beneficial for scientists working in fuel-related industries. Certainly, more work is required to be done to explore the use of additives and their implementation on a large scale.
- Net greenhouse gas emission by using renewable fuels is comparatively lower and contributes comparatively lesser to climate change and emits relatively lower CO_2 emissions.

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