Combustion, Performance and Emission Analysis of VCR Diesel Engine Using Water Emulsion in Flaxseed-Based Biodiesel Blend

S. Ganesan, J. Hemanandh, Sundarasetty Venkatesh, and Phani Kumar

Abstract Biodiesel are produced from plant derivatives and are highly potent in usage instead of diesel in diesel engines due to their low emissions which significantly reduce the environmental impacts and can use as fuel for diesel engines deprived of any alterations. The major drawback of biodiesel is associated with NO_x and smoke reduction. Emulsified fuels are known to have high potent in reducing harmful emissions into atmosphere. Nitrogen oxides (NO_x) and smoke are the major pollutants released through diesel combustion. Using water emulsions in biodiesel reduces the nitrogen oxide and smoke emissions. Span 80 is used as surfactant during emulsion to stabilise the whole blend. Nanoparticles increases the combustion rate and provides the combustion stability. Water is mixed with biodiesel in different proportions to study the emulsion stability, characteristics and performance. Water in biodiesel emulsion contains water range of about 5–15%. By literature survey and experimental analysis, we found that 5% water emulsion in biodiesel blend.

Keywords Water in biodiesel · Nitrogen oxides (NO_x) · Smoke · Nanoparticles · Surfactant

1 Introduction

Nowadays, pollution is becoming as major threat to the environment and life on the planet. This is due to release of materials and energy released into atmosphere which effects environment eventually leads to show a potent effect on human life, animal life, natural resources and eco-system [1–5]. Air pollution is recorded as major environmental threats for life. In developing countries like India more than 90% of children under 5 years age are exposed to toxic air [6, 7]. A World Health Organisation (WHO) study states that in 2016 over one lakh children in India are dead due to air pollution. Atmosphere is mainly composed of toxic gases and dust

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particles [8–11]. These are mainly produced due pollutants released by automobiles. Diesel is majorly used as a fuel for of automobiles. Diesel engines are necessary but their emissions and its impacts on environment drives us to search for an alternate fuel which can be used instead of diesel which facilitates the lower emissions and low environmental impacts [12–17].

Biodiesel is emerged as an alternate fuel for diesel due to its low emissions compared to diesel and can be manufactured easily. This reduces the urge for fossil fuels and stops the extinction of fossil fuels [18–23]. This provides fossil fuel conversation for future use. The main drawback of biodiesel is its inability to reduce the NOx and smoke. This drawback can be overcome by mixing a tiny amount of water in biodiesel. By using water emulsions in biodiesel, the peak temperature during the combustion process is reduced this is because a part of heat during combustion is utilised by water to vaporise [24–29]. This ultimately reduces the NO_x generation because the NO_x is generated at higher temperatures, addition of water decreases the peak temperature rise in cylinder. Generally, water and diesel are both immiscible liquids. Both the liquids get separated within no time. Hence, a surfactant named SPAN 80 is used for proper emulsion [30–34]. This surfactant makes the water molecules to get binded against the diesel molecules. This provides proper emulsion stability. We blended the surfactant and biodiesel blend using ultrasonic sonicator [35–38].

Here flaxseed oil extract is used for biodiesel preparation. Flaxseed oil is also known as linseed oil. Flaxseed oil consists of high amount of linoleic acid (40–60%). Various researchers have researched on reduction of exhaust emissions. When the emulsion ratio increases NO_x and smoke decreases [39]. Because the water content absorbs the heat and gets vaporised resulting in lower peak temperature in cylinder and provides enhanced mixing by micro-explosions [40–43]. Balanced water emulsified fuel creates lower BSFC compared with the non-water emulsified fuels. The best results for water emulsified fuels are found at 5% compared to all the remaining concentrations. Using nanoparticles like aluminium oxide nanoparticles are one of the most competent catalysts. When added these increases the combustion speed and combustion stability [44–48], this facilitates complete combustion. Thus, aluminium oxide nanoparticles helps in reducing the smoke emission rates.

2 Preparation of Biodiesel Blend

In this experiment, we extracted oil from flaxseed and the obtained flaxseed oil is converted into biodiesel in the presence of catalyst to form methyl esters. The obtained biofuel is mixed in diesel to form a biodiesel blend (B20) of composition 20% flaxseed biofuel + 80% diesel. This blend preparation is done in ultrasonic homogeniser. The resulting biodiesel blend properties are identified and are shown below.

Table 1 Properties of fuels

Properties	Diesel	Blend20 (B20)	5% water emulsion + B20	10% Water emulsion + B20	15% Water emulsion + B20	Method
Calorific value(MJ/kg)	42.5	39.7	38.78	37.89	37.1	ASTM D240
Density (kg/m^3)	810	842	852	869	884	ASTM D4052
Flash point (°C)	48	84	86	89	92	ASTM D93
Cetane index	46	36	47.5	48.58	44.03	ASTM D976

By comparing the biodiesel blend and diesel properties, we found that the properties of both the properties are almost similar and the flaxseed biodiesel can be used as an alternate fuel for diesel engines.

The resultant biodiesel blend water is added in different proportions with 3% surfactant (SPAN 80) to provide a homogeneous mixture. The water composition is varied from 5%, 10%, 15%, whereas the span 80 remains constant at 3% for all the three samples (Table 1). 25 ppm of aluminium oxide nanoparticles are added to each sample. The aluminium oxide acts as catalyst and provides combustion stability. NO_x and smoke emissions are scaled down by using water emulsions in fuels. After preparation of various samples, the properties of each sample are then identified.

3 Experimental Setup

The variable compression ratio (VCR) is a four-stroke diesel engine consists of single cylinder (Fig. 1). To this engine, an eddy current type dynamometer is connected to facilitate the electric start motion. We can change the compression ratio even without stopping the engine this is because of specially designed tilting chamber block arrangement. The engine specifications are listed in Table 2.

4 Results and Discussion

Various tests were conducted to evaluate the Engine characteristics at different flaxseed biodiesel blends. Fuel samples such as diesel and bio diesel were fuelled in different proportions in a VCR diesel engine. CO, CO_2, O_2, NO_X and HC emissions were measured as the loads varied. Samples of bio diesel were compared and analysed.

Fig. 1 VCR engine setup

Table 2 Engine specifications

Make	Kirloskar, 4 stroke
Rated power	3.5 kW with 1500 rpm
Bore diameter (D)	87.5 mm
Stroke (L)	110 mm
Compression ratio	17.5:1
Injection timing	17° BTDC

4.1 Specific Fuel Consumption

Figure 2 shows the comparison between the specific fuel consumption (SFC) and brake power (BP) of various blends of biodiesel and pure diesel. From the graph, we noticed that pure diesel has the low SFC compared to all the blends. The SFC for the for the flaxseed biodiesel blend (B20) is higher than diesel. SFC is of an engine is going on increase with increase in water content of the biodiesel blend. Flaxseed biodiesel blend with 15% water shows the highest SFC compared to all the blends [49–52].

4.2 Brake Thermal Efficiency

Figure 3 shows the graph comparison of brake thermal efficiency (BTHE) with BP. At beginning, the BTHE for all the sample blends remains similar as the load increases, the BTHE varies differently for different blends. Here pure diesel has the highest BTHE compared to all the blends. BTHE is reduced gradually upon the increase of

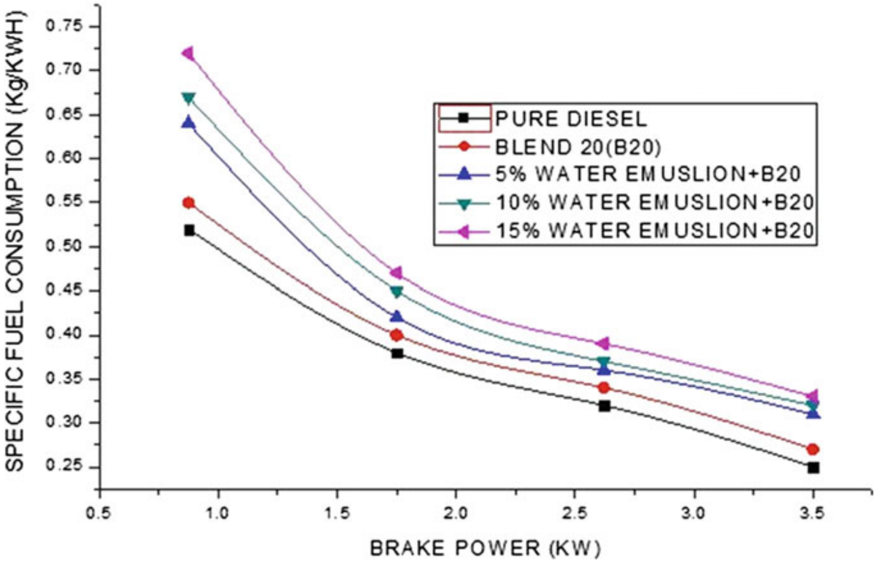

Fig. 2 BP versus SFC

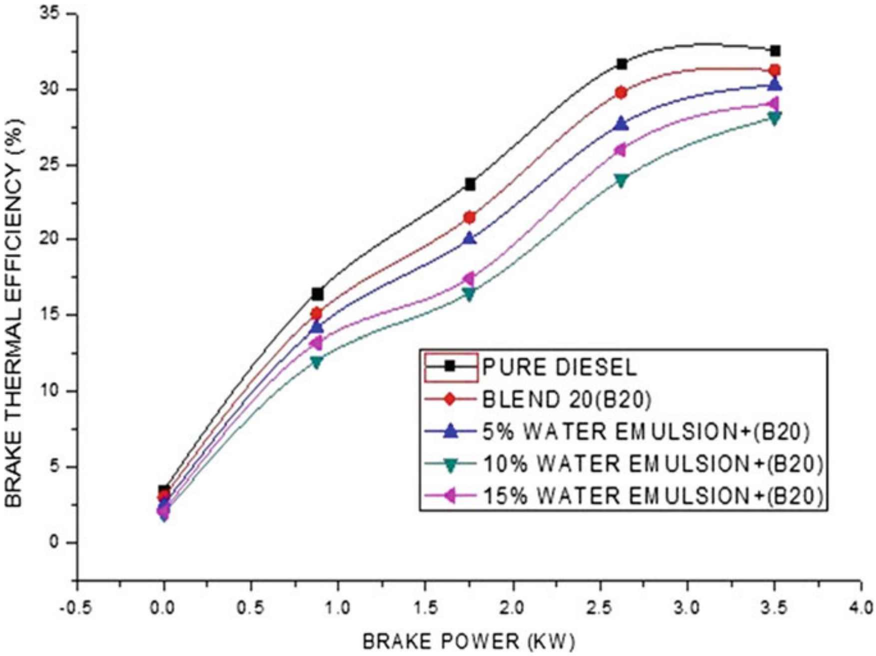

Fig. 3 BP versus BTHE

water content in biodiesel blend. 10% water emulsified biodiesel blend shows the least BTHE performance. This lowering of BTHE than pure diesel is because of heat utilisation of water content present in biodiesel blends. Due to water, a part of heat is lost for vaporisation. In general, brake thermal efficiency refers to the ratio of heat input to heat produced by the fuel during combustion [53–55]. Due to this loss of heat nearly 19% of heat is lower than pure diesel for 5% water emulsified biodiesel blend.

4.3 Nitrogen Oxide (NOx)

Figure 4 shows the comparison graphs for nitrogen oxide (NO_x) and BP for all the different concentrations of water emulsions in flaxseed biodiesel blend, flaxseed biodiesel blend (B20), pure diesel. From the above graph, it is absorbed that the NO_x emission is reduced as the water content in the blend gets increases. The flaxseed biodiesel blend (B20) shows an increase in NO_x production than the pure diesel while adding water to the same flaxseed biodiesel blend (B20) shows a drastic difference in reducing the NO_x production. Here 15% water emulsified biodiesel B20 shows least NO_x production compared to all the blends shown above. There is an effective reduction of 27% NO_x (ppm) with 15% water emulsified biodiesel blend than

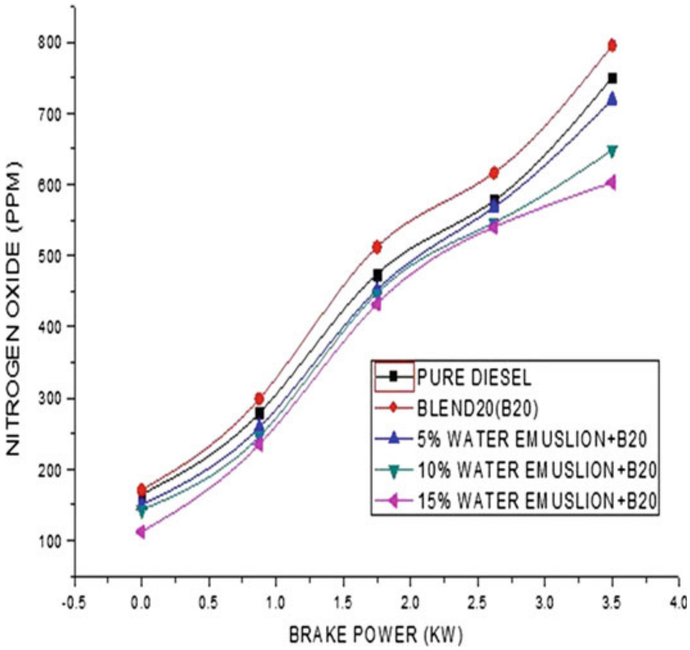

Fig. 4 BP with NO_x emission

pure diesel [56, 57]. This effective reduction is because of water content present in biodiesel blend and aluminium oxide nanoparticles because water content helps in reducing the peak temperature rise and aluminium nanoparticles acts as catalyst and facilitates smooth and fine combustion.

4.4 Hydrocarbon

Figure 5 shows a graphical comparison between hydrocarbon (HC) and BP with the blends of biodiesel. Here pure diesel has the least HC emission compared to all the blends. The blends other than diesel shows a drastic increase in HC emissions compared to pure diesel emissions [58–60]. The above graph clearly shows that with addition of water the HC emission percentage gets increased and has a maximum HC emission at 15% water emulsion + B20 in the above graph, 5% water emulsion in flaxseed biodiesel (B20) shows a minimum HC emission among all the biodiesel blends.

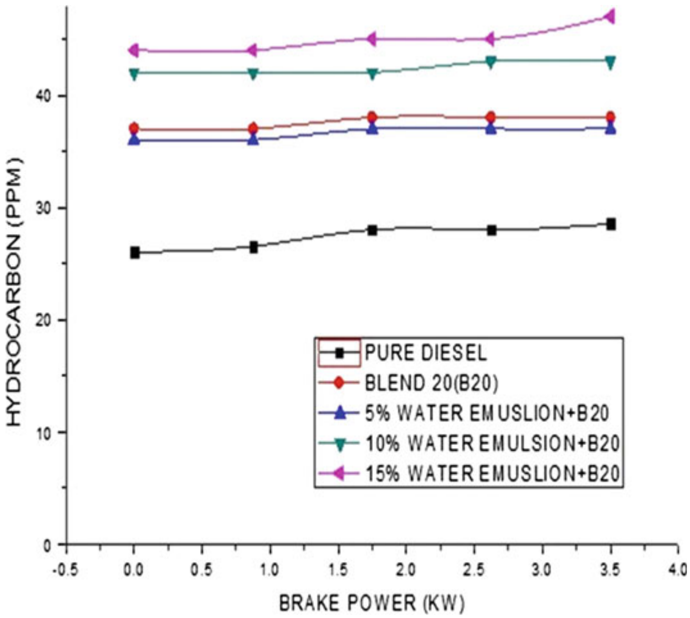

Fig. 5 BP with HC emission

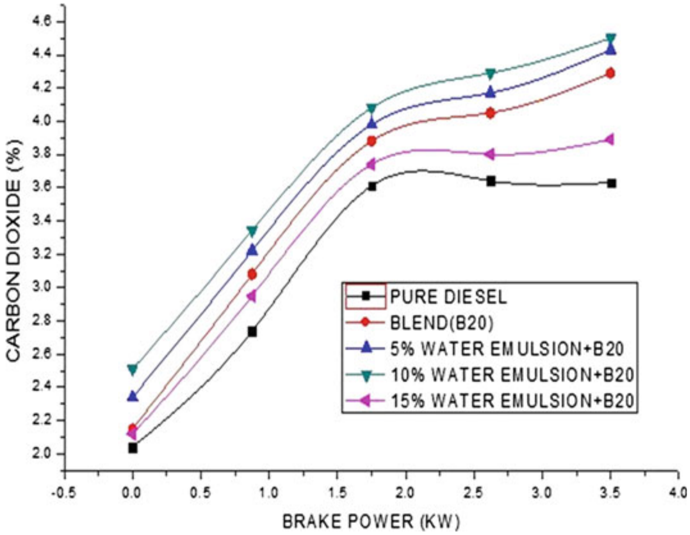

Fig. 6 BP with CO_2 emission

4.5 Carbon Dioxide

Figure 6 shows the graphical comparison with carbon dioxide (CO_2) emission and BP for various blends of biodiesel and pure diesel. From the above graph, it is clearly stated that with addition of water content the CO_2 emission is increased because of micro-explosion phenomenon of water molecules which facilitate the more homogeneous mixing of fuel and air and facilitate the smooth and complete combustion process. Nanoparticles also show major factor influencing the CO_2 emission because of its ability to perform smooth and faster combustion rates. Here 10% water emulsified flaxseed biodiesel blend shows a higher CO_2 emission compared to all the blends above while pure diesel shows a least CO_2 emission. This increase in CO_2 emission is nearly 30% higher than the pure diesel. But gets decreased upon addition of more water because of lowering the temperature during the combustion. So optimum usage of water should be used for increasing smooth combustion [61, 62].

4.6 Smoke Opacity

Water emulsified fuels show the continuous reduction in Fig. 7 and show the variation of brake power with smoke. Pure diesel emissions of smoke are less than blended biodiesel (B20). Increase the water micro-emulsion in blended biodiesel the smoke emission is decreased gradually. We can conclude that 5, 10, 20% composition water emulsion with biodiesel blend is lesser than the pure diesel and blend 20 (b20). But

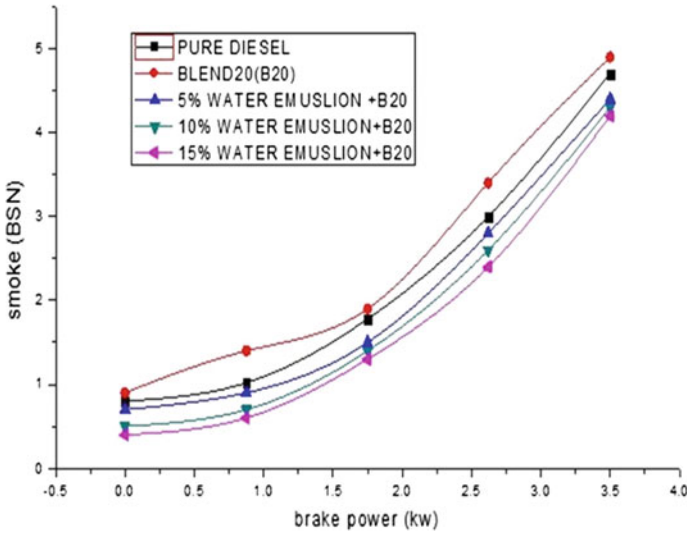

Fig. 7 BP versus smoke opacity

blend 20 is increase smoke emission then pure diesel. This reduction smoke is nearly 10, 13 and 15% by using 5, 10 and 15% water emulsions with blend (B20). The aluminium nanoparticles help in smooth and complete combustion of the resultant blend.

5 Combustion Analysis

5.1 Crank Angle Versus Pressure

Figure 8 describes various peak pressure rise of various samples with respect to crank angle. Here 5%, 10%, 15% water emulsified fuels are taken and are tested for their peak pressure rise. Here blend 20 shows a higher peak pressure than any other sample at full load. It shows nearly 15% pressure rise than any other sample. On the other hand, 15% water emulsified fuel shows a higher peak pressure than other samples it shows nearly 10% higher than other water emulsions with biodiesel blend. The pressure rise of diesel is higher than other samples.

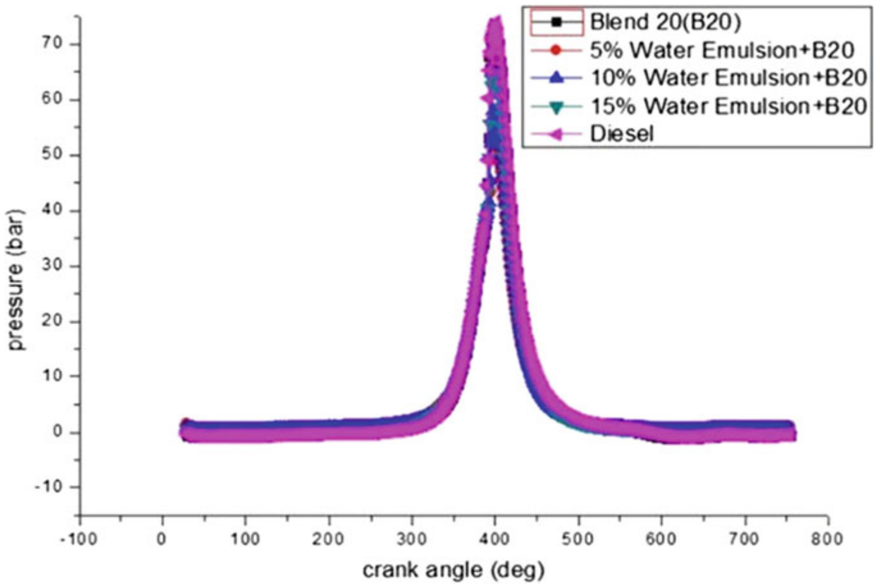

Fig. 8 Crank angle versus pressure

5.2 Net Heat Release

Figure 9 describes the net heat release of various samples with respect crank angle. Here various samples with different water emulsified biodiesel blends are taken and are tested for determining the net heat release of each sample. In above graph, blend 20 shows a maximum heat release than other samples. It is approximately 20% more heat is released than other samples at full load. This is because the heat released during the combustion process is utilised by water molecules for its vaporisation. This results in lower net heat release of water emulsified biodiesel blends. This lower net peak heat rise results in lowering the NO_x emissions because NO_x is generally produced at higher temperatures. So by using water emulsified fuels the NO_x production is reduced to a greater extent. Here the net heat release of blend 20 is higher than any samples, and it is nearly 50% more than the pure diesel.

6 Conclusion

By using water emulsions in flaxseed biodiesel, we obtained the emission and performance results through VCR single cylinder engine and AVL smoke meter for various compositions of water emulsions (5, 10 and 15%) in flaxseed-based biodiesel blend.

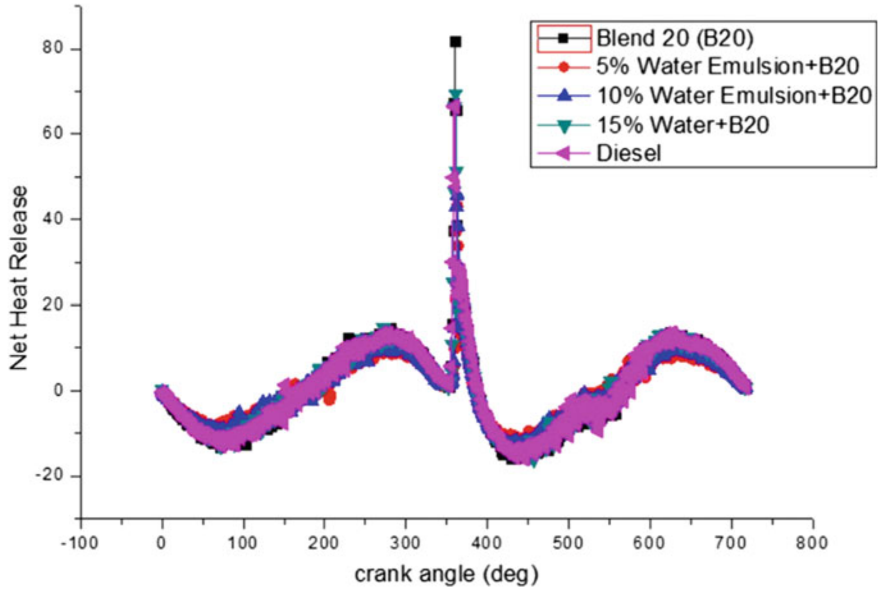

Fig. 9 Crank angle versus net heat release

1. Water emulsions cut down the peak temperature rise while combustion because, a part of heat is consumed by the water molecules for vaporisation. Generally, NO_x gases are produced at very higher temperatures. So, the NO_x generation is reduced.
2. Aluminium oxide nanoparticles are one of the most competent catalysts. When added these increases the combustion speed and combustion stability. This facilitates complete combustion. Thus, aluminium oxide helps in reducing the smoke emission rates.
3. From the results, we can say that 5% water emulsion in flaxseed biodiesel blend shows a better reduction in NO_x and smoke emissions.
4. Water emulsion in biodiesel results in reduction of smoke. This is because upon addition of water, during combustion micro-explosions takes place. Due to micro-explosions, the complete mixing of air fuel mixture takes place.

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