Simultaneous reduction of nitric oxide and smoke emissions in a jatropha biodiesel fuelled CI engine with water emulsion

V Rajasekar¹, C Prabhu², T Prakash²

¹ Department of Mechanical engineering. SRM Institute of Science and Technology, Kattankulathur, India
² Department of Automobile engineering. SRM Institute of Science and Technology, Kattankulathur, India

Email: rajesekv@srmist.edu.in

ABSTRACT. Aiming towards mitigating the pervasive effect of the fossil fuel and its environmental pollution crisis, the present work aims to decrease nitric oxide and smoke emissions simultaneously using water emulsion in a jatropha oil methyl ester (JOME) fuelled compression ignition (CI) engine. Biodiesel derived from biomass is the viable alternate fuel due to its availability and renewable nature. JOME is derived from jatropha oil through transterification process and emulsified with water in the ratio of 5%, 10% and 15%. Tests were carried out in a one cylinder, liquid cooled, direct injection (DI) engine delivering 5.2 kW at full load. Results indicate a significant reduction in NO and smoke release with water emulsion at all loads. With JOME85+W15, NO emission decreases by 21.1% and 23.9% compared to diesel and JOME respectively at maximum load. With JOME85+W15, smoke emission decreases by 15.8% and 5.5% compared to diesel and JOME respectively at maximum load. However increasing the quantity of water in the emulsion decreases the brake thermal efficiency (BTE), in-cylinder pressure and net heat release rate (NHR).

1. Introduction
In today’s world, air pollution is one of the major environmental problems in urban areas where the concentrated air borne pollutants originate. Automobiles are responsible for smoke, HC emissions, NOx emissions and CO emissions in urban areas. It is generally believed that burning of petroleum derived fuels, required by the transport, is the main source of pollutants, which may worsen global warming. At the same time, the energy requirement is increasing, and is expected to triple over the next 25 years. CO, soot, NO, and unburned hydrocarbons also directly affect the health of organisms that inhale the emissions.

The fast depleting nature of petroleum reserves, mounting oil rates, vehicular pollution caused by conventional fuels have directed to the hunt for substitute fuels [1]. Replacement of diesel is a biodiesel that is produced by refining vegetable kernel oil, animal fat, or waste cooking oil. Various studies have shown that there is a notable increase in NO emission with biodiesel as fuel and decrease in CO, HC and particulate matter [2]. Artificial advance in injection timing due to biodiesel’s high bulk modulus, lower air-fuel ratio, high flame temperature, fuel bound oxygen and radiative heat transfer which are the possible reasons for NO increase with biodiesel. Several techniques were proposed by numerous researchers to reduce NO emission in a CI engine such as use of oxygenates, antioxidant additives, emulsion, EGR (exhaust gas recirculation) and SCR (selective catalytic reduction). However, the techniques, while decreasing NO emission, increases the smoke emission significantly due to the trade-off relationship between them.

Jatropha curcas is a huge tree fits to the family of Euphorbiaceae occurring almost throughout India. Jatropha plant can grow rapidly almost anywhere even on gravelly, sandy and saline soils. It has hardly
any special requirement with regard to climate and soil. Jatropha curcas has been identified as the most suitable source of biodiesel [3] due to its favorable traits such as non-edible crop, short gestation duration, quality of oil and the high oil recovery. Cetane number of Jatropha oil is high in comparison with diesel, which makes it as an apt alternative source for CI engine in comparison with other biofuels. Senthilkumar et al (4) studied the various methods of using jatropha biodiesel in a single cylinder naturally aspirated CI engine. Various methods like blending, transesterification and dual fuel operation have been employed in this work. In dual fuel operation, the JOME ratio was maintained as 3:7 on the volume basis. They concluded that BTE increased from 27.4% with neat Jatropha oil to 29% with the methyl ester, and 28.7% with dual fuel operation.

Simultaneous reduction of NO and smoke is achieved diesel-water emulsion {with progress in specific fuel consumption [5]. Normal injection system is used to directly feed the emulsion into the engine cylinder. In-cylinder temperature decreases by using water which in turn reduces the NOx emissions. NOx emissions decreases due to chemical reactions [6]. Smoke emissions decreases due to microexplosion [7] and chemical effect [8] of water. BTE increases slightly on account of water emulsion. Also rise in CO, HC and delay period is witnessed with water diesel emulsions [9]. Water to diesel proportion is in the middle of 0.4 and 0.5:1 by mass have been proposed based on starting, performance, emulsion constancy and viscosity [10]. In this research work, an attempt has been made to decrease the NO and smoke emission simultaneously in a jatropha biodiesel fuelled CI engine with water emulsion.

2. Experiments
The engine used for the test was a Kirloskar (TV1), single cylinder, four stroke, DI, water cooled and naturally aspirated CI engine with power output of 5.2 kW at the graded speed of 1500 rpm. Table 1 shows the specifications of the test engine. Eddy current dynamometer was connected to the engine and other instruments were connected to get the combustion and emission characteristics. The fuels tested in this work include standard diesel fuel, JOME, JOME - water emulsion was prepared with the ratio of 95:5, 90:10 and 85:15 by volume. The blended fuel contains 5%, 10% and 15% by volume of water identified as JOME95+W5, JOME90+W10 and JOME85+W15 respectively. Properties of test fuels are revealed in Table 2.
Experiments were conducted with diesel, JOME, JOME95+W5, JOME90+W10 and JOME85+W15 emulsion from 0% load to 100% load in a constant speed engine runs at 1500rpm. The experimental setup with necessary instrumentation was shown in Fig.1.

Table-1 Engine specifications

| Make and model     | Kirloskar, TV1 |
|--------------------|----------------|
| No. of cylinder    | 1              |
| Cycle              | 4 strokes      |
| Bore               | 87.5 mm        |
| Stroke             | 110 mm         |
| Displacement volume| 661 cm³        |
| Compression ratio  | 17.5:1         |
| Combustion chamber | Hemispherical  |
| Rated power        | 5.2 kW @ 1500 rpm |
| Injection timing   | 23° BTDC       |
Table-2 Fuel properties

| PROPERTY                  | DIESEL | JOME | JOME95+W5 | JOME90+W10 | JOME85+W15 |
|---------------------------|--------|------|-----------|------------|------------|
| Density @ 15°C (g/cc)     | 0.84   | 0.88 | 0.852     | 0.86       | 0.867      |
| Kinematic Viscosity @40°C (cSt) | 2.95   | 4.57 | 3.53      | 3.61       | 3.79       |
| Lower heating value (kJ/kg) | 42,500 | 38,450 | 35,615 | 36,555     | 37,745     |

Figure 1 Schematic diagram of the experimental setup
3. Emulsification

An emulsion is a fine dispersion of minute droplets of one liquid in another in which it is not soluble or miscible. Water cannot be blended with jatropha oil biodiesel directly. It requires additional compound called surfactant which is used to mix two immiscible liquids. Span 20, Tween 20, Span 20(90%)-Tween 20(10%), Triton X100, Span 80 and Span 80(90%)-Tween 80(10%) are the different surfactants used for stability test. The stability of each surfactant varies with its composition and its HLB number.

Of all the surfactants tested, the combination of Span 80(90%) and Tween 80(10%) has given the best stability. 2% by volume of surfactant was added to the solution of jatropha oil biodiesel and water and the solution was stirred in a mechanical stirrer for three hours at constant speed of 2000 rpm at room temperature. The emulsion formed was stable for more than 24 hours.

4. Results and Discussion

Figure 2 illustrates the NO emission variation with BP for diesel, JOME, JOME95+W5, JOME90+W10 and JOME85+W15. At maximum load, it can be observed that NO emission of JOME (2068 ppm) is greater than diesel (1989 ppm) due to the availability of O₂ in the fuel. NO emissions decreases significantly with the addition of water with JOME. With the emulsion of 5%, 10% and 15% of water with JOME, NO emissions were 1780, 1647, and 1570 ppm, respectively at maximum load. Decrease in NO emission is due to the lower in-cylinder temperature caused by high latent heat of vaporisation of water. Increase in water concentration leads to reduction of NO may also be due to the formation of OH ion concentration, during the combustion chemical reactions between water and JOME.

![Figure 2 Variation of NO emission with BP](image-url)
Smoke opacity variation with BP from 25% load to 100% load is shown in figure 3. Smoke emission of JOME (45.2%) is less than diesel (50.7%) due to the presence of O₂ in the fuel that promotes oxidation of soot. With the addition of 5%, 10% and 15% water with JOME, smoke opacity is 44.7, 43.2 and 42.7 %, respectively, at maximum load. It is evident from the data, smoke opacity decreases with surge in H₂O content in the blend, due to the presence of O₂ in the JOME and water emulsion which helps in the oxidation of soot. Further, micro explosion of the emulsion leads to more fine fragmentation of the fuel oil emulsion thereby increasing the surface area. The effective mixing of air-fuel-oil emulsion eventually shortens the diffusion phase of combustion leads to lower smoke emissions.

Table 3 shows the NO-smoke variation for JOME-water emulsion in comparison with diesel at 100% load. It is obvious that with increase in water proportion in the blend, both NO and smoke decreases simultaneously. JOME85+W15 record the lowest NO and smoke emission.

**Table 3** Changes in NO-smoke emission for water emulsion compared to diesel

| Fuel          | Change in NO emission (%) | Change in smoke emission (%) |
|---------------|---------------------------|------------------------------|
| JOME          | +4                        | -10.8                        |
| JOME95+W5     | -10.5                     | -11.8                        |
| JOME90+W10    | -17.2                     | -14.8                        |
| JOME85+W15    | -21.1                     | -15.8                        |
Table 4 Changes in NO-smoke emission for water emulsion compared to JOME

| Fuel       | Change in NO emission (%) | Change in smoke emission (%) |
|------------|---------------------------|-----------------------------|
| JOME95+W5  | -13.8                     | -1.1                        |
| JOME90+W10 | -20.2                     | -4.4                        |
| JOME85+W15 | -23.9                     | -5.5                        |

Table 4 shows the NO-smoke variation for JOME-water emulsion in comparison with JOME at 100% load. It can be observed that with surge in quantity of water in the mixture both NO and smoke emissions declines simultaneously. In both the cases, the optimum blend was found to be JOME85+W15. The maximum reduction of NO and smoke with JOME85+W15 in comparison with diesel and JOME are 21.1%, 15.8%, and 23.9%, 5.5 %, respectively.

Figure 4 illustrates the variation of BTE with BP for diesel, JOME, JOME95+W5, JOME90+W10 and JOME85+W15. BTE of JOME and diesel are 32.24% and 34.34% respectively. BTE is lower for JOME in comparison with diesel, due to its lower calorific value and sluggish burning nature of JOME. BTE of JOME95+W5, JOME90+W10 and JOME85+W15 is 31.68%, 29.84% and 28.49% respectively, at maximum load. At all loads, progressive decrease in BTE is observed with the growing proportion of water emulsion in the blend, due to the presence of water in the blend decreases the calorific value that leads to decrease in cylinder temperature.
that the peak pressure is maximum for diesel compared to other fuels and decreases gradually with the increasing proportion of water in the blend from 5% to 15%.

![In-cylinder pressure vs crank angle graph]

**Figure 5** Change of In-Cylinder pressure with CA at 100% load

The variation of HRR with CA for all the fuels and its blends is shown in Figure 6. From the data it is observed that at maximum load HRR of JOME (44.3%) is lower than diesel (47.5%) due to lower calorific value of JOME. At 100% load, HRR for JOME95+W5, JOME90+W10 and JOME85+W15 is 42.51, 40.1 and 38.36 J/°CA, respectively. Due to lower cetane number and calorific value of water emulsion, the HRR is lower. In addition, the latent heat of vaporization of JOME85+W15 blend is higher in comparison with that of diesel, JOME, JOME95+W5, JOME90+W10 and subsequently heat energy released during combustion becomes lower resulting in lower NO emission.
5. CONCLUSION

In the present research work, experimental investigations were carried out to simultaneously control the nitric oxide and smoke emissions in a jatropha biodiesel fuelled compression ignition engine using water emulsion.

• Simultaneous reduction of NO and smoke is achieved with all three blends of JOME and water. NO emissions decreases by 21.1%, 17.2%, 10.5% for JOME85 + W15, JOME90 + W10 and JOME95 + W5 respectively, compared to diesel at maximum load operation.

• At 100% load, smoke emissions decreases by 15.8%, 14.8%, 11.8% for JOME85 + W15, JOME90 + W10 and JOME95 + W5 respectively, compared to diesel.

• BTE decreases significantly with the surging quantity of water in the emulsion, due to the lower calorific value which subsequently increases the mass flow rate of fuel for generating the similar power output.

• With increasing quantity of water in the blend, HRR decreases considerably, compared to diesel and JOME at all loads. Lower HRR of water emulsion is due to the reduced thermal energy released during combustion because of high specific heat of water.

REFERENCES

[1] Chauhan BS, Kumar N, Pal SS, Jun YD. Experimental studies on fumigation of ethanol in a small capacity diesel engine. Energy 2011;36: 1030-8.

[2] United States Environmental Protection Agency, (2002), “A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions,” Technical Report No. EPA420-P-02-001, Environmental Protection Agency, Research Triangle Park, North Carolina.
[3] Fattah, I. R., Masjuki, H. H., Liaquat, A. M., Ramli, R., Kalam, M. A., & Riazuddin, V. N. (2013). Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions. Renewable and Sustainable Energy Reviews, 18, 552-567.

[4] Senthilkumar. M, Ramesh. A, Nagalingam. B, An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine, Biomass & Bioenergy, 2003, 309-318.

[5] K.A. Subramanian, A. Ramesh,”A study on the use of water diesel emulsion in a DI diesel engine”, SAE 2001-28-0005, 2001.

[6] P. Mello and A.M. Mellor, "NOx Emissions from Direct Injection Diesel Engines with Water/Steam Dilution", SAE paper No. 1999-01-0836.

[7] H.Z. Sheng et al., The droplet group micro explosions in water-in-oil emulsion sprays and their effects on diesel engine combustion”, 25th Symbosium (International) on Combustion/ The Combustion Institute, 1994/pp. 175-181.

[8] K. Muller-Dethlefs and A.F. Schlader, "The effect of steam on Flame Temperature, Burning Velocity and Carbon Formation in Hydrocarbon Flames", Combustion and Flame 27, 205-215 (1976).

[9] Tadashi Murayama, Yasushi Morishima, Inoru Tsukahara and Noboru Miyamoto, Experimental reduction of NOx, Smoke and BSFC in a Diesel engine using uniquely produced water (0-80%) to fuel emulsion”, SAE paper No. 780224.

[10] Minoru Tsukahara et al., " W / Q emulsion realizes low smoke and efficient operation of DI engines without high Pressure injection”, SAE paper No.890449.