Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 2	pp. 255-264	2014

Original Research Paper

Emissions and Performance of a Single Cylinder CFR Cetane Engine Using Biodiesel-Water Emulsion

E. Orak, Y. Karagoz* and M. Ozkan
Mechanical Engineering Department, Automotive Subdivision, Yildiz Technical University, Istanbul, Turkey
*Corresponding Author: Y. Karagoz

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 20-10-2013
Accepted: 20-11-2013

Key Words:
Biodiesel-water emulsion
Diesel engine
Specific fuel consumption
Oxides of nitrogen

ABSTRACT

Emulsification technique is one of the most important methods to the reduction of pollutants from diesel engine. In this research, a single cylinder diesel engine was operated with water in canola biodiesel as fuel and the effect of water emulsification on the engine performance and emissions were investigated. Emulsified biodiesel fuels of 3.5 and 10 water/water-biodiesel mixture fuel ratios by volume were used in a light-duty diesel engine, operating at various engine speeds. The results show that the brake engine torque, the brake engine power and the brake thermal efficiency decrease as the water percentage in the emulsion increases but the brake specific fuel consumption (BSFC) increases as the percentage of water increases in the emulsion fuel. In addition, carbon monoxide (CO) and hydrocarbons (HC) increase as the percentage of the water increases in the emulsion fuel. However, exhaust gas temperature, nitrogen oxides (NO_x) and smoke emissions decrease as the percentage of water increases in the emulsion fuel.

INTRODUCTION

Two of the key issues in the development of internal combustion engines are efforts on the development of engine performance and emissions reduction (Samec et al. 2002). Diesel engines have high thermal efficiency and they are suitable for their fuel economy, so these engines are being used in a wide range. Furthermore, diesel engines have rather low levels of CO and HC emission in comparison with gasoline engines. However, nitrogen oxide emissions and soot particles that occur as a result of combustion are main handicaps for diesel engines and these pollutants are quite harmful not only for ecological environment but also for human health, especially on their respiratory system (Subramanian 2011, Pawar et al. 2012, Patel & Kousar 2010, Ingle et al. 2005). Researches are trying to find solution for reducing these emissions, and governments put some limitations with the same aim (Chandra et al. 2011). Therefore, the reduction activities of nitrogen oxides and soot particles constitute a significant portion of the development actions of diesel engines. The formation balance between NO_x emission and soot particles is very complex. The formation balance between NO_x and soot particles is quite complex and this balance can be explained by occurred favourable conditions for soot particle formation as a result of a decrease in the oxidation rate in soot formation phase by decreasing local cylinder temperatures constituted by used NO_x reduction techniques (Tanner et al. 2001). NO_x emissions and soot particle formation is generally have a vice versa form. Formation rate of soot particles can be reduced by some methods as increasing excess air factor and/or extending the phase of pre-mixed combustion, etc. However, this method leads to an increase in NO_X formation which is basically a function of the in-cylinder temperatures (Subramanian 2011). Simultaneous reduction studies for these two pollutants, NOx emissions and soot particles, that have importance in diesel engines are being carried out. However, the use of alternative fuels in internal combustion engines as a result of the rapid rise in fuel prices has come into prominence as an important research area. Different types of oils have been used as an alternative fuel in diesel engines, in previous works on this subject. Because of the advantages as the shorter atmospheric lifetime and nontoxic structure of emitted biodiesel emissions, this fuel is environmentally friendly considering with conventional fuels. Biodiesel fuel can be used directly in the existing diesel engines without significant modifications. Absence of sulphur component in the biodiesel fuel is an important point to meet regulations (Ozkan et al. 2005). Due to the structural nature and the carbon cycle, biodiesel is a fuel that does not contribute to the greenhouse effect. Its structure does not contain aromatics and oxygen constitutes 10-11% by mass of this fuel (Ozkan 2007).

To increase environmental compliance (economy, emissions, noise, etc.) and market requirement (reliability, life expectancy, price, etc.) to the desired level, there are numerous techniques for the use of fuel and lubricant materials in diesel engines by improving their chemistry (Samec et al. 2002). Some methods based on different principles are being used for the reduction of emissions in internal combustion engines. These methods can be divided into two basic methods as: directly affects the combustion mechanism and after treatment. Changing chemical or physical properties, spray characteristics of the fuel or inducing combustion flame temperature reducing materials to the combustion chamber are emission reductive methods that directly affect the combustion mechanism (Knetch 2008). Increasing combustion efficiency increases engine performance, CO, HC emissions and soot formation diminish, formation rate of NO_x emissions increases. CO, HC emissions and soot can turn into complete combustion products as a result of oxidation reaction but for the reduction of nitrogen oxides, NO_x molecules need to be converted into nitrogen and oxygen. The post-combustion NO_x reduction reactions are more difficult than oxidation reactions and require expensive systems. Therefore, reducing the NO_x formation has primary importance for reducing nitrogen oxides emitted by exhaust. Nitrogen oxide formation reaction rate increases with increase in combustion temperature. Nitrogen oxide formation is highly temperature dependent, the majority of NO_x reduction methods aims to reduce the flame temperature by affecting combustion mechanics to reduce NO_x formation rate (Tanner et al. 2001). In diesel engines, length of time between beginning of injection and ignition of the fuel is called as ignition delay. The sudden combustion of accumulated fuel after this period to participate in combustion with the ignition increases the in-cylinder pressure and temperature. Theoretically, it is expressed that the increase in burnt gas temperature increases NO_x formation rate. This is due to the increase in temperature that increases the amount of nitrogen oxides formed at a certain time (Heywood 1988). The reduction of NO_x formation by affecting the combustion is possible by lowering the combustion temperature. Various methods are being used to reduce the combustion temperature. Multiple injection strategies, that capitalize on the advantages provided by electronic diesel injection systems reduces NO_x formation by reducing ignition delay time and the amount of fuel accumulated in the combustion chamber during this period. A pilot fuel injection, just before the main injection, increases the combustion chamber temperature. Thus, it reduces nitrogen oxide formation by shortening the ignition delay that will occur with main injection and limiting the high temperature rise occurring in the pre-mixed combustion phase. In order to reduce the combustion temperature, in addition to the fuel and air, methods as inducing materials that have high thermal capacity into the combustion chamber are widely applied. In water induced methods, the water entering to high-temperature environment evaporates in the combustion chamber, and due to latent heat of evaporation lowers the in-cylinder temperature. The present paper is an attempt to study the use of water with biodiesel in the form of emulsion to reduce the amount of pollutants from the diesel engines.

EARLIER WORK DONE ON USE OF WATER WITH FUELS

Water which is introduced into the combustion chamber takes place in three different ways, while it is used as a heat sink:

1. Water-Oil emulsion technique (Samec et al. 2002, Subramanian 2011): In this technique water-fuel emulsion mixtures are being used. Water and fuel enters to the combustion chamber as a mixture. The disadvantage of this technique is occurring phase separation and instability problems in water-fuel emulsion. Generally surface tension decreases with emulsifier addition to water/fuel mixture and the phase separation of the emulsified mixture slows down.
2. No additional mechanism is required for fuel injection system to inject the mixture into the combustion chamber and there is a separate mixture blending embodiment need for mixture preparation. Mixture preparation and the difficulty that arise from the need for mixture stability until entering into the combustion chamber are restrictive aspects for application of this method.
3. Direct water injection into the combustion chamber is a frequently used technique (Takasaki 1998, Miyamo et al. 1993, Ryu & Oh 2004). The greatest advantages of this method are injected water/fuel ratio and variable injection advance relative to needed motor parameters (speed and load) can be controlled, for example, during engine warm up, it is expected that water/fuel ratio to be zero (Chadwell 2008, Bedford et al. 2000). This method is applied in two different injection methods. The first method is referred to as split injection. In this method, a separate water injector is used for injection into the combustion chamber. The disadvantage of the system, positioning need of second injector causes complicating effect in engine head construction and this significantly limits the applicability of the method. The second method uses a water-fuel hybrid injector as hybrid injection system. The disadvantage of this method is cost of the hybrid injector.
4. Intake manifold water injection (Subramanian 2011, Samec et al. 2000a, Samec et al. 2000b): In literature, sending the water to the combustion chamber by injecting water to intake air stream is carried out by a water

injector that injects water into the intake manifold. Increased injection pressure reduces the diameter of water droplets and forms a more homogeneous mixture, but increases pumping work. In injection method, lack of adequate levels of dimensional homogeneity, increase trend of large-scale droplets to clinging to walls by condensation. This situation decreases the viscosity of lubricating oil as injected water to mix with oil and thus causes an increase at friction and abrasion levels.

The addition of water to fuel approach is believed to be effective for reducing noxious substances in the cylinder and simultaneously slowing down the NO_x and particulate matter (PM) formation in diesel engines (Knetch 2008). Many researchers carried out some studies on the water addition to diesel, biodiesel or gasoline fuels (Subramanian 2011, Tanner et al. 2001, Heywood 1988, Takasaki 1998, Miyamo et al. 1993, Ryu & Oh 2004, Chadwell 2008, Tadashi et al. 1978, Ganeson & Ramesh 2002, Abu-Zaid 2004, Selim & Ghannam 2007, Subramanian & Ramesh 2001, Park et al. 2000, Lee et al. 2008, Tarlet et al. 2009). It has been understood that water vapour to be in combination with involved substances affects combustion physics and chemistry and has a positive influence on reducing heat release rate and pollutant emissions. The water evaporated during the combustion, reduces the flame temperature, changes the composition of reactants by providing high-OH radical concentration to control NO and soot formation of substances and dilutes rich regions in the combustion chamber (Samec et al. 2002).

In pharmaceutical, cosmetic and food industry areas usually three-phase (F/W/F or W/F/W) emulsions are being used, but in internal combustion engine applications emulsions are generally used as two-phase (W/F). It is more difficult to sustain the stability of the mixture in the three-phase applications. Therefore, content and amount of the used emulsifier and used additive materials, changes the hydrophilic lipophilic balance (HLB) or water/fuel mixture rate and emulsification stability of three-phase emulsion mixture. So, appropriate proportions to improve diesel fuel, emulsifier and an additive substance combinations must be examined systematically (Lin & Wang 2004). Emulsions are used as fuel for internal combustion engines by mixing diesel, gasoline or carbonaceous fuels with carbonless substances such as water and/or carbonaceous compounds other than conventional fuels. If the carbon containing fuel is mixed with larger amount of water, mixture is referred to as water-based mixture. If water is mixed with a larger amount of carbonaceous fuel, mixture is referred to as a fuel based mixture. Many researchers who study emulsions as a form of pollutant control measure, found that it is more difficult to implement water-based emulsions than fuel-based emulsions. This is because internal combustion engines, which run on water-based emulsions, must be re-engineered in order to run on such type of emulsion. Since water-based emulsions are corrosive to an engine's internal components, such emulsions require agents to enhance lubricity and to operate without significant power loss. Therefore, engines have to be modified to handle the large quantity of water present in the emulsion (Takasaki 1998). On the other hand, oil-based emulsion fuels, generally do not require any substantial modification of the engine (Gunnerman 2003). This is because they are not considered to be more corrosive on engine parts or system than regular fuel. Furthermore, due to the presence of water during the combustion process, the resulting combustion emissions from emulsion fuel contain lesser amounts of harmful pollutants. Some researchers found that the engine performance and the brake thermal efficiency decrease with using the water/biodiesel emulsified fuel although some of them found that the engine performance and the brake thermal efficiency increase with using water emulsified fuel. Subramanian (2011) made a study for comparing the intake manifold water injection and water/fuel emulsion systems and reported a reduction in thermal efficiency for both systems due to the deterioration of combustion arise from drop in charge temperature. However, Tsukahara et al. (1992) have also reported a reduction in brake specific fuel consumption (BSFC) in a diesel engine fuelled by emulsion fuel. The reduction in BSFC with water emulsified diesel may be attributed to formation of a finer spray due to rapid evaporation in the water, longer ignition delay results in more fuel burning in premixed combustion and suppression of thermal dissociation due to lower cylinder average temperature. The evaporation and additional mass of water cause the cylinder average temperature to become lower as the water amount was increased (Tsukahara et al. 1992). However, Tadashi et al. (1978), have expressed a slight increase in specific fuel consumption due to overcooling and overmixing of the charge in his study while comparing water/fuel mixture and diesel fuel at low loads. Increasing the water amount may decrease the combustion temperature of the water/fuel mixture (Tsukahara et al. 1992). Ganesan et al. (2002) found that the emulsion (0.3:1 mass) led to an improvement in brake thermal efficiency of ≈ 3% over the use of diesel fuel for a single cylinder air cooled diesel engine. Abu-Zaid (2004) found that whilst the percentage of water in the emulsion increases, simultaneously the brake engine torque and brake engine power increase. This may be ascribed to the additional force on top of the piston provided by the pressure used by the steam. When the charge is fired in the cylinder, the water would turn to high pressure steam (Samec et al. 2000b). Furthermore, the higher viscosity of the emulsified fuel than that of the base fuel and the presence of water promote a finer, cloud like atomization of the emulsified mixture during injection (Sawa & Kajitani 1992) resulting in improving combustion efficiency significantly. Dryer (1976) states that the water in the emulsified fuel improves the combustion process owing to the simultaneous additional braking of the droplets, to the increase in evaporation surface of the droplets and to better mixing of the burning fuel in air. Selim et al. (2007) have made a study on Ricardo E6 single cylinder 4 stroke engine with divided combustion chamber, for preparing stable emulsion and to investigate the effects of these emulsions at various operation and design characteristics. They have reported that brake specific fuel consumption increase with increasing water ratio. They also emphasized that the increasement occurred in brake specific fuel consumption based on power reduction arising from added water. A drop in power, specific fuel consumption and the addition of water was reported to have increased. They stated that water addition to diesel fuel shows a major effect on reducing heat flux on combustion chamber components, metal temperatures and thermal loads. Selim & Elfeky (2001) reported an experimental investigation to study the effects of using water/diesel emulsion fuel on heat flow and thermal loading in a diesel engine. Subramanian & Ramesh (2001), carried out a study on a single-cylinder diesel engine at low loads and encountered with an increase in CO and HC emissions and stated a decrease in thermal efficiency while injecting water/diesel emulsion. Subramanian (2011), made a comparative study on a single cylinder, 4 stroke, air cooled diesel engine, to determine the differences of intake manifold water injection system and water/fuel emulsion system. He used the same proportions of water/fuel by mass as 0.4:1 for both the methods. It was reported that thermal efficiency reduces for all operational conditions, because of the deterioration arise from overcooling of the charge. According to the obtained results, Subramanian (20011) has stated an increase in HC and CO emissions when it is compared with base diesel as a result of incomplete combustion and low thermal efficiency. However, they also reported a significant reduction in NO_x emissions and soot particles. Biodiesel fuels have a positive effect on emissions and performance of engine. Labeckas & Slavinkas (2006) analysed the emission characteristics of four-stroke, four-cylinder, direct injection, unmodified, naturally aspirated diesel engine when operating on neat rapeseed methyl ester and its 5%, 10%, 20% and 35% blends with diesel fuel. They found that carbon monoxide, hydrocarbon and visible emissions have decreased while an oxide of nitrogen emissions increased for methyl ester compared to diesel. On the other hand, diesel engines suffer from high NO_x and smoke emissions. For this reason, water-biodiesel emulsion would improve the exhaust gas emissions, so in this study, a biodiesel fuel which is composed of canola methyl ester was used as fuel in water/biodiesel emulsion.

A disagreement can be seen between researchers that carry out experimental studies relevant to mixtures in diesel engines about engine torque, engine power, specific fuel consumption and thermal efficiency. In this study, water/biodiesel two-phase mixture fuels were used in a single cylinder CFR engine and engine performance characteristics and emissions experimentally investigated. After preparation of water/biodiesel emulsion mixtures, no instability was observed within 10 minutes. Thus, it was not necessary to use emulsifier during the experiments.

MATERIALS AND METHODS

During the study, a single cylinder, four stroke, water cooled TDF2 CFR engine was used and the engine specifications are listed in Table 1. Engine torque was measured using the REP Transducers S-type load cell with a capacity of 300 kg adapted to the DC dynamometer force arm. Engine speed was measured with an encoder which is connected cam shaft, the intake air temperature was measured with T-type thermocouple on the intake manifold, and exhaust temperature was measured by using a K-type thermocouple on exhaust manifold. Engine fuel consumption was measured with SIKA-turbine type flow meter. In addition, CO, HC, CO_2, NOx and O_2 emissions in the exhaust gases was measured with AVL Dicom 4000 gas analyser, and the soot emission was measured with an AVL 415S smoke meter. The engine was allowed to warm up before the experiments were conducted to ensure parameters were being analysed at steady-state. Engine speeds were designated as three different speed conditions and the studies performed at 1365, 1700 and 1915 rpm. During the tests, the engine torque, engine power, specific fuel consumption, CO, CO_2, HC, NOx emissions, soot particle numbers and exhaust gas temperatures were measured. Schematic diagram of experimental system is shown in Fig. 1. The total uncertainties of the measurements were calculated for entire speed range of the test engine according to Kline and McClintock method. The accuracies of the measurements and the uncertainties are presented in Table 2.

Biodiesel/water emulsion mixtures were obtained by mixing with electrical mixer system. Electrical mixer system is shown in Fig. 2. In addition, no emulsifier was used in mixtures. The engine run on diesel fuel until it reaches to the regime temperature, then 0%, 3.5% and 10% by volume of water/water-biodiesel emulsion mixtures was prepared and experiments were carried out with this three different

Table 1: Specifications of the original engine.

Engine Type	CFR,TD2, Single cylinder, water cooled diesel engine
Aspiration	Natural
Bore [mm]	90
Strok [mm]	120
Scavenge volume [cc]	765
Compression ratio	19 (adjusted for this study)

Table 2: Accuracies of the measurements and the uncertainties in the calculated results.

Measured parameter	Measurement device	Accuracy
Engine torque	Load cell	±0.05 Nm
Engine speed	Incrementalencoder	±5 rpm
Fuel flow rate	Sika VZ 0.2	±1%
CO	AVL DiCom 4000	0.01 % Vol.
CO_2	AVL DiCom 4000	0.1 % Vol.
HC	AVL DiCom 4000	1 ppm
NO_x	AVL DiCom 4000	1 ppm
Smoke	AVL 415S	0.4% Vol.
Calculated results		Uncertainty (entire speed range)
Power		±0.34 ÷ 0.79%
BSFC		±1.05 ÷ 1.27%

fuels. The tests were performed on various engine loads and fuel injection advance of the engine was 22° BTDC.

Test fuel and emulsion stability: The physico-chemical properties of the fuel tested are given in Table 3. According to the test results, the lower heating value of canola biodiesel is lower than conventional diesel fuel. Also, the lower heating values of water-biodiesel mixtures decrease with water addition. For this reason, engine power and engine torque decrease with water addition. The flash point of biodiesel is higher than conventional diesel fuel which makes the fuel safer to store. The cetane index, which directly influences the combustion efficiency of biodiesel, is the approximate value of conventional diesel fuel.

Emulsions are visually homogeneous but in fact heterogeneous systems, formed by the dispersion of two liquids immiscible with each other. They are not durable thermodynamically. The reason for lack of durability of emulsions is large surface area between inner and outer phase and internal energy proportional with these surface area (Acartürk et al. 2007). Some physical instability problems can occur before the emulsion as fuel is introduced into cylinder. These are called as creaming, flocculation, coalescence, phase separation and phase transformation. However, when emulsions used as fuel, stability of prepared emulsion must be ensured until the fuel entirely consumed. Therefore, when prepared emulsion mixture will wait for a long time before being consumed in order to increase resistance of

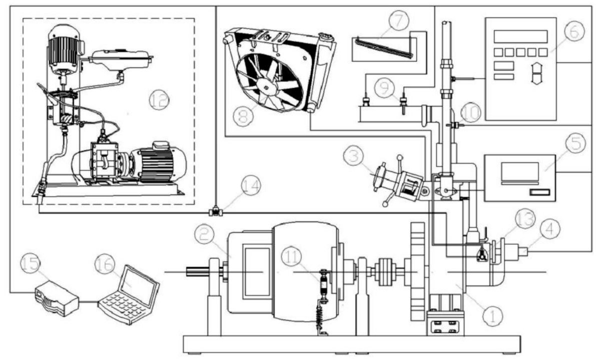


Fig. 1: Schematic diagram of experimental system.1. CFR Engine, 2. DC Dynamometer, 3. Compression Ratio Adjusting Equipment, 4. Incremental Encoder, 5. Emission Analyzer, 6. Smoke Analyzer 7. Manometer, 8. Cooling System, 9. Intake Air Temperature Measuring Thermocouple, 10. Exhaust Gas Temperature Measuring Thermocouple, 11. Loadcell, 12. Electrical Mixer System, 13. Diesel Fuel Pump, 14. Fuel Flow meter, 15. Data Acquisition System, 16. Data Acquisition Software

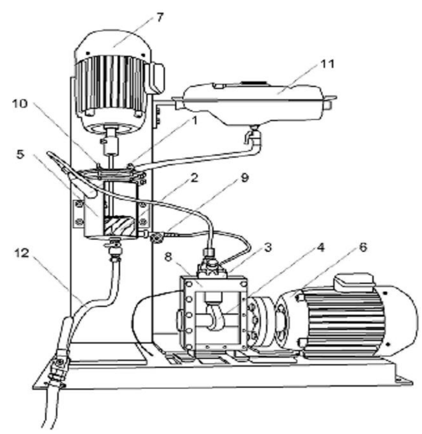


Fig. 2: Electrical mixer system. 1. Injector, 2. Blender propeller, 3. Diesel fuel pump, 4. Cam profile 5. Mixing chamber, 6. Electrical motor, 7. Electrical motor for blender, 8. Cam/Pump housing, 9. Needle valve, 10. Oveflow line, 11. Fuel tank, 12. Fuel line to the engine.

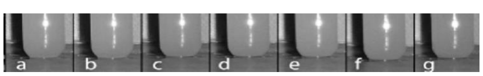
emulsion, emulsifiers can be added to the mixture (Acartürk et al. 2007). The system shown in Fig. 1, allows instant production and consumption of the water/fuel mixture and need for stability of the prepared mixture before consumption is limiting point of the system. Use of emulsifiers may be added to the mixtures is not commercially widespread. In this study, the prepared mixture will be consumed before a physical instability has been occurred, any emulsifier was not added into the mixtures. The most important step in the preparation of durable emulsion is the formation of an emulsion (emulsification) process. The addition order of two phases to each other, temperature, mixing intensity and duration are influencing factors on the resulting emulsification stability (Acartürk et al. 2007). Biodiesel fuel which is used as the external phase of prepared emulsion has a

Table 3: Physico-chemical properties of the canola biodiesel tested.

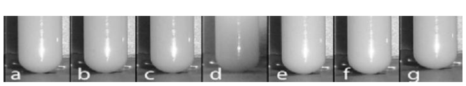
Specification	Units	Test Method	EN 14214 limit min	EN 14214 limit max	Test Results
Speciûc gravity at 150°C	kg/m^3	EN ISO 12185	860	900	893,2
Cetane index	Calc	EN ISO 5165	51	-	51.2
Water content	mg/kg	EN ISO 12937	-	500	327
Flash point	°C	EN ISO 3679	120	-	156
Oxidation stability at 110°C	hours	EN ISO 14112	6	-	7.14
Lower heating value	kJ/kg	-	-	-	39510
Acid value	KOH/g	EN ISO 14104	-	0.5	0.05
Ester content	% (mass/mass)	EN ISO 14103	96.5	98.6	97,5

The analysis of canola biodiesel was performed by The Scientific and Technological Research Council of Turkey Laboratories (TUBÝTAK).

lipophilic structure. The water to be added as the inner phase to the prepared emulsion has a hydrophilic structure. In such mixtures to the internal phase water must be slowly added to the fuel (Acartürk et al. 2007). Emulsification process has been carried out at 20°C ambient temperature. Downsizing the diameter of the prepared emulsion droplets is important to ensure the characteristics to be liken to each other. In their study, Park et al. (2000) stated that the size of droplets of emulsion fuels is important for substantiation of optimum combustion characteristics. Mixing intensity and duration seriously affect the droplet sizes (Acartürk et al. 2007). Water/biodiesel and water/diesel mixtures were obtained as mixing them by electrical mixer. The water contents in the total mixture volume are determined as 3.5% and 10%. In the following parts of this study, these fuels will be referred to as B3.5 and B10 respectively, according to water percentage consisting inside the mixture. In literature, it is expressed that appliances such as mechanical mixers, homogenizers, colloid mills and ultrasonification equipments are used to ensure stabilization of the emulsion (Acartürk et al. 2007). The mixer used in this study was designed to combine the characteristics of both mechanical mixer and homogenizer type of equipments. An impeller in the mixing chamber driven by an electric motor, shows the characteristics of a mechanical mixer. Injecting the liquid dispersion from a very small orifice under high pressure will show the characteristics of homogenizer, and a single cylinder diesel fuel pump is used and integrated with a diesel injector. Electrical mixer system is shown in Fig. 2. Cam profile that drives the diesel fuel pump for delivering fuel



a) %3.5 W/B mixture by volume – B3.5



b)%10 W/B mixture by volume – B10

Fig. 3: Water/water-biodiesel emulsion mixtures.

and mixer impeller was actuated by two separate electric motor operating at 1400 rpm.

To show the variation of time dependent emulsion stabilities of 3.5% and 10% water/water-biodiesel mixture fuels, photos were taken with one minute intervals as shown in Fig. 3. The prepared mixture in the electrical mixer system is consumed in the engine in about 6 minutes. Therefore, the mixture must remain stable at least for 6 minutes. For determining the water/water-biodiesel volumetric ratios which remain stable at least 6 mins after preparation. Electrical mixer system mixed different water/water-biodiesel ratios for 5, 7.5 and 10 min mixing durations and moisture gradient of mixture was determined by using Mettler Toledo DL39 model Karl Fischer water content determination equipment by volumetric titration method and instability occurring times observed. The obtained results are given in Fig. 4. Accordingly, when water/biodiesel volumetric mixture ratio is 10%, no instability problem was observed in the mixture for 14 minutes.

There was no instability problem in water-biodiesel mixture observed within the first 14 minutes after preparation. So, the use of any emulsifier is not necessary. Moreover, the images shown in Fig. 3, which were taken with one minute intervals of B3.5 and B10 fuel mixtures, do not have any sign of instability.

TEST RESULTS

Engine torque and power: All tests had been carried out at full load conditions. In the experiments, B0 fuel, B3.5 and B10 fuel emulsion mixtures that contain 3.5% and 10% water ratios of the total injected fuel volume are compared. Effect of the water/fuel mixture at various engine speeds on engine torque is shown in Fig. 5. According to the results, the engine torque and hence power, decreased by addition of water to the fuel at all engine speeds and it was observed that increasing water ratio multiplies the occurred decrease. In the experiments, B3.5 and B10 fuels compared with B0 fuel at 1700 rpm and as can be seen in Fig. 5, results show

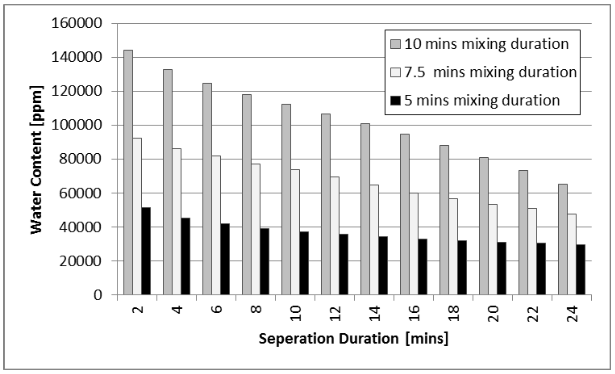


Fig. 4: Time dependent variation of water content in biodiesel fuel for different mixing durations .

that a decrease in the engine torque was occurred at the levels of 4.9% and 10.6%, respectively. Water in emulsified fuel mixture, reduces heat content of the fuel by decreasing the total energy output in the fuel mass. For this reason, a decrease in the engine torque was observed.

Fig. 6 shows the effect of various water biodiesel mixtures on engine power. Results show that engine power decrease with the use of water/biodiesel mixtures and with the increasing water content in the mixture. According to the obtained experimental results, B3.5 and B10 fuels compared with B0 fuel at 1700 rpm show a decrease in engine power at the levels of 5.1% and 10.4%, respectively. The reason for the decline in power is injected 3.5% and 10% water ratios in the total injected fuel volume for per cycle reduce the amount of fuel entering the combustion chamber and causes combustion deterioration.

Brake specific fuel consumption and thermal efficiency: Specific fuel consumption values derived by experimental measurements while operating on full load with various engine speeds and water/biodiesel emulsion mixtures are shown in Fig. 7. It shows that an increase in water content of the mixture, also increases the specific fuel consumption. This is because adding more water to the mixture, reduces the biodiesel volume and increases the water volume and proportionally less biodiesel by volume enters to combustion chamber. This results in increased fuel consumption. While operating under low operating loads, heat losses from combustion chamber cylinder walls will be very excessive and as a result the combustion efficiency will be reduced, and consequently increased fuel consumption would result in (Abu-Zaid 2004). In the experiments, with B3.5 and B10 fuels compared with B0 fuel at 1700 rpm an increase was observed in specific fuel consumption at the levels of 12.8% and 20.1%, respectively.

Fig. 8 shows effect of various water biodiesel mixtures on thermal efficiency. Obtained thermal efficiency values of B3.5 and B10 fuels are lower than B0 fuel and it is observed that increasing water amount decreases the thermal efficiency. In the experiments, with B3.5 and B10 fuels compared with B0 fuel at 1700 rpm a decrease was observed in thermal efficiency at the levels of 11.4% and 16.8%, respectively.

Exhaust emissions: Fig. 9 shows the effect of various water biodiesel mixtures on CO emission. In comparison, CO emissions show a rising trend by the use of B3.5 and B10 fuels with respect to B0 fuel, but there is no significant change. As can be seen in Fig. 9, increasing water content of the mixture also increases the CO emission at 1365 rpm, from 1.55 g/kWh to 1,78 and 1.80 g/kWh, respectively. Factors such as high latent heat of vaporization, which causes deterioration of the combustion, may be responsible for the low CO oxidation reaction rate and increased CO formation (Qj et al. 2010). But, it is not proper to express a significant increase in CO because of rather small level results.

Fig. 10 shows the effect of various water biodiesel mixtures on CO_2 emissions. As shown in Fig. 10, increasing water content of the mixture decreases CO_2 emissions. In the experiments with B3.5 and B10 fuels compared with B0 fuel at 1365 rpm a decrease was observed in CO_2 at the levels of 7.1% and 12.4%, respectively. The decrease occurred in CO_2 can be explained by the lower carbon to hydrogen ratio of emulsion compared to neat biodiesel fuel.

Fig. 11 shows the effect of various water biodiesel mixtures on HC emissions. HC is an important parameter in determining the behaviour of the engine emissions. In comparison HC emissions show a rising trend by the use of B3.5 and B10 fuels respect to B0 fuel. Furthermore, the HC emissions also increase with the increasing water content of the mixture. HC emission levels emitted into the atmosphere by using B3.5 and B10 fuels at 1700 rpm increased from 0.026 g/kWh to 0.05 and 0.068 g/kWh respectively. But, it is not proper to express a significant increase in HC because of rather small level results.

Fig. 12 shows the effect of various water biodiesel mixtures on the exhaust gas temperature. The exhaust gas temperature also decreases with the increasing water amount in the mixture. At 1700 rpm, there is a reduction in levels of exhaust gas temperature in B3.5 and B10 fuels by 3.7% and 12.5% respectively as compared to B0. Abu-Zaid (2004) stated in his study that increasing water amount in the mixture, decreases the exhaust gas temperature. He expressed that the exhaust gas temperature reduction derives from heat absorption by water which was added into the mixture. Besides, he told that the evaporation of water will cool the air/fuel mixture due to latent heat of water and by the in-

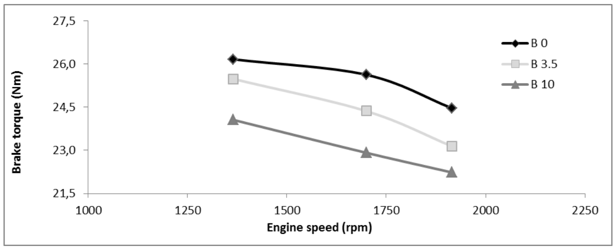


Fig. 5: Engine torque output versus engine speed using water-biodiesel emulsions.

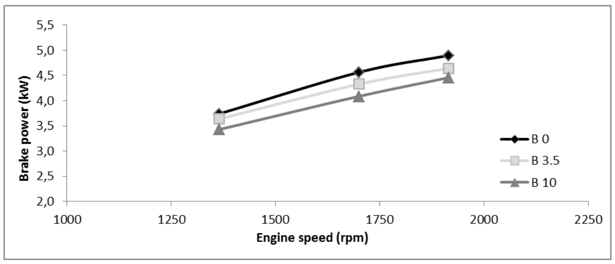


Fig. 6: Engine brake power output versus engine speed using water-biodiesel emulsion.

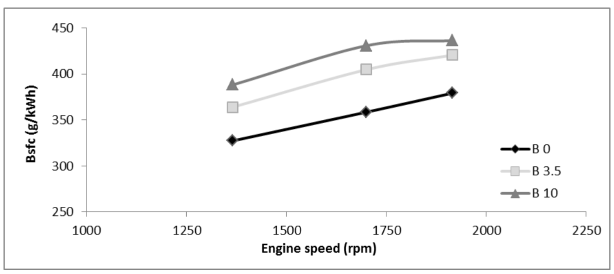


Fig. 7: Brake specific fuel consumption versus engine speed using water-biodiesel emulsions.

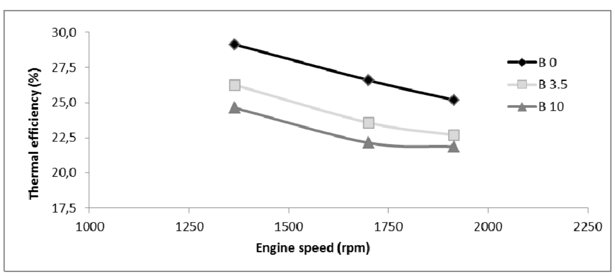


Fig. 8: Brake thermal efficiency versus engine speed using water-biodiesel emulsions.

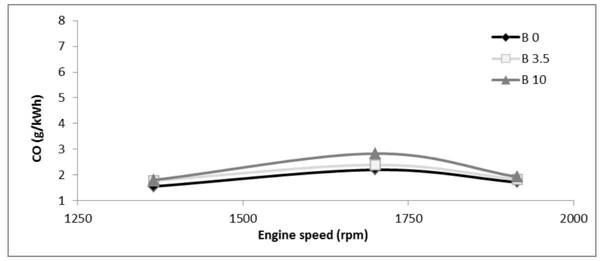


Fig. 9: CO emissions versus engine speed using water-biodiesel emulsion.

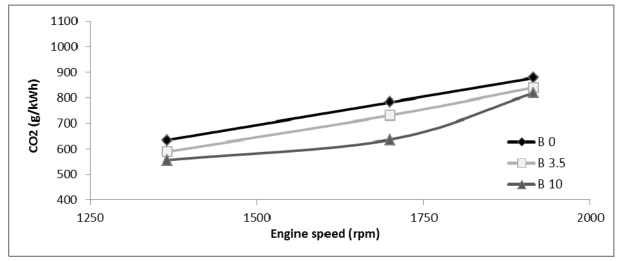


Fig. 10: CO_2 emissions versus engine speed using water-biodiesel emulsion.

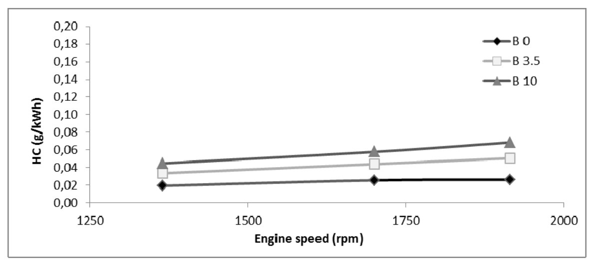


Fig. 11: HC emissions versus engine speed using water-biodiesel emulsion.

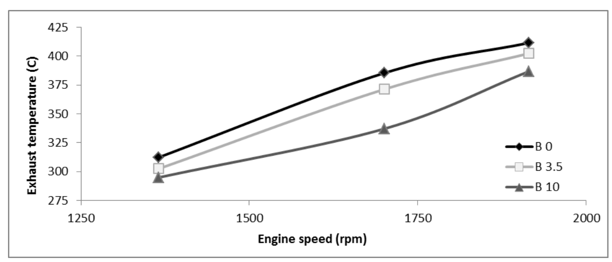


Fig. 12: Exhaust gas temperature versus engine speed using water-biodiesel emulsion.

creasing water amount cylinder average temperature values will be lower after injection.

Fig. 13 shows the effect of various water biodiesel mixtures on NO_X emission. The NO_x emissions decreased with the increasing volumetric water rate in mixture. During the evaporation water acts as a heat sink in the combustion chamber and NO_x formation evidently is controlled by this cooling effect (Takasaki 1998). Furthermore, when the amount of water in the mixture increases, the exhaust gas temperature reduces. In the engine simulations made by Bedford et al. (2000), they stated that evaporation of water has the specific heat of gas around the flame to increase and thus nitrogen oxide formation slows down and a decrease in soot formation was observed. Musculus et al. (2002) showed that heat absorption, caused by evaporation of water, will result in a decrease in the adiabatic flame temperature so

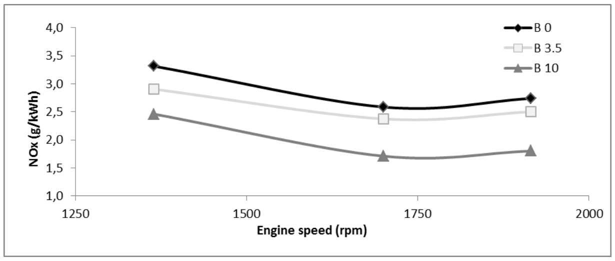


Fig. 13: NO_x emissions versus engine speed using water-biodiesel emulsion.

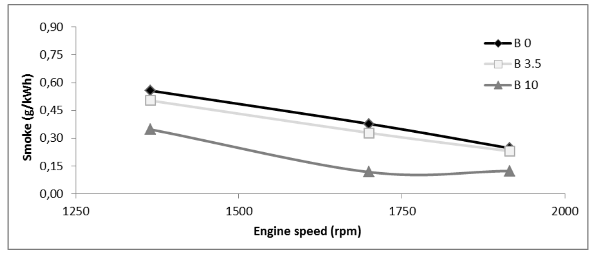


Fig. 14: Smoke particles versus engine speed using water-biodiesel emulsion.

gas phase chemical reactions, which are necessary for the NO formation, will decrease. Hsu (1987) indicated that under normal engine loads, water lowers the in-cylinder average temperature. In this study, with B3.5 and B10 fuels the NO_x formation quantities and NO_x emissions decreased 8.7% and 34.21% respectively at 1915 rpm.

The effect of the water/biodiesel mixture on soot formation is shown in Figure 14. And this figure shows that, increasing water rate in the mixture, decreases soot formation. Water droplets in the emulsion have a lower specific boiling point than the fuel. By sudden expansion of evaporating water, the fuel surrounding the water droplet explodes and reduces the soot formation by improving air/fuel mixing. This interaction is also called as micro-explosions theory (Kegl & Pehan 2001, Lee et al. 2008, Jeong & Lee 2008, Tarlet et al. 2009). Additionally, with a specific injection rate, use of water/fuel mixture increases the total injection mass and hence injection duration become longer. Thus, the local air excess coefficient increases and consequently reduces the PM formation (Tauzia et al. 2010). Ryu et al. (2004), carried out a study on RCEM and he told that, when water/fuel mixture injected, soot slightly increased with the increasing water amount, but by retardating the injection advance for 2 CA, soot particle number decreases. In the experiments, B3.5 and B10 fuels compared with B0 fuel at 1700 rpm and a decrease was observed in soot particles at the levels of 12.8% and 69%, respectively.

RESULTS

Engine performance and exhaust emissions of a diesel engine that is using biodiesel and water/bio-diesel mixtures as fuel, were experimentally compared and the following results were obtained:

- Fuel mixtures are obtained by using an electrical mixer. B3.5 and B10 water/biodiesel mixtures were used as fuel, along with B0 fuel. In addition, despite a phase separation encountered in water/diesel mixture after a short while from mixture was prepared, there was no instability problem in water/biodiesel mixture observed within the first 14 minutes after preparation. So, the use of any emulsifier is not necessary.
- With B3.5 and B10 fuels at 1700 rpm, engine torque decreased at the levels of 4.9% and 10.6%, respectively. A decrease was also observed in engine power at the levels of 5.1% and 10.4%, respectively.
- B3.5 and B10 fuels also decrease thermal efficiency at the levels of 11.4% and 16.8%, respectively, and an increase in specific fuel consumption at the levels of 12.8% and 20.1% at 1700 rpm, respectively.
- The increasing water content of the mixtures also increases the CO and HC emission levels. But, it was not significant increase. Furthermore, a decrease was observed in CO_2 at the levels by combustion deterioration.
- During the combustion of B3.5 and B10 fuels, exhaust gas temperatures decreased resulting in the decreased NO_x emissions.
- With B3.5 and B10 fuels a decrease was also observed in soot particles.

REFERENCES

Abu-Zaid, M. 2004. Performance of single cylinder, direct injection diesel engine using water fuel emulsions. Energy Conversion and Management, 45: 697-705.

Acartürk, F., Aðabeyoðlu, Ý., Çelebi, N., Deðim, T., Deðim, Z., Doðanay, T., Takka, S., Týrnaksýz, F. Modern Farmasötik Teknoloji 2007. TEB Eczacýlýk Akademisi, ISBN 975-507-146-6, Ch. 15.

Bedford, F., Rutland, C., Dittrich, P., Raab, A. and Wirbeleit, F. 2000. Effects of Direct Water Injection on DI Diesel Engine Combustion, International Fall Fuels and Lubricants Meeting and Exposition, SAE 2000-01-2938.

Chadwell, C. J. 2008. Effect of diesel and water co-injection with real-time control k6on diesel engine performance and emissions. SAE paper No. 2008-01-1190.

Chandra, A., Saha, G., Goswami, S., Saha, A., Roy, S.S., Ganguly, P., Ghosh, A., Banerjee, K., Saraf, R., Banerjee, A. and Mitra, A.K. 2011. Effectivity of vehicular banning and its reflection in disease incidence in Kolkata. Nature Environment and Pollution Tehcnology, 10(3): 491-496.

Dryer, F. L. 1976. Water addition to practical combustion system-concepts and applications. 16th Combust. Symp. (Int.) 1976: 279-295.

Ganeson, S. and Ramesh, A. 2002. An experimental study of the characteristics of a LPG-based dual-fuel engine using a water/diesel emulsions as the pilot fuel. J. Inst. Energy, 75(502): 2-10.

Gunnerman, R. W. 2003. Water-in-oil emulsion fuel. US patent application 20030041507.

Heywood, J. B. 1988. Internal Combustion Engine Fundamentals. McGraw-Hill Book Company, ISBN 0-07-100499-8.

Hsu, B.D. 1987. Combustion of water-in-diesel emulsion in an experimental medium speed diesel engine. SAE paper 860300.2.285-96.

Ingle, S.T., Pachpande, B.G., Wagh, N.D., Patel, V.S. and Attarde, S.B. 2005. Exposure to vehicular pollution and respiratory impairment of traffic policemen in Jalgaon cityk6, India. Industrial Health, 43: 656-662.

Jeong, I.C. and Lee, K.H. 2008. Auto-ignition and micro-explosion behaviors of droplet arrays of water-in-fuel emulsion. International Journal of Automotive Technology, 9: 735-740.

Kegl, B. and Pehan, S. 2001. Reduction of diesel engine emissions by water injection. SAE paper No. 2001-01-3259.

Knetch, W. 2008. Diesel engine development in view of reduced emissions standards. Energy, 33: 264-271.

Labeckas, G. and Slavinskas, S. 2006. The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions. Energy Conversion and Management, 47: 1954-1967.

Lee, C. F. F., Wang, K. T. and Cheng, W. L. 2008. Atomization characteristics of multi-component biofuel systems under micro-explosion conditions. SAE paper No. 2008-01-0937.

Lin, C. Y. and Wang, K. H. 2004. Effects of an oxygenated additive on the emulsification characteristics of two-and three-phase diesel emulsion. Fuel, 83: 507-515.

Musculus, M. P., Dec, J. E., Tree, D. R., Daly, D., Langer, D., Ryan, T. W. and Matheaus, A. C. 2002. Effects of water-fuel emulsions on spray and combustion processes in a heavy-duty DI diesel engine. SAE Technical Paper No. 2002-01-2892.

Miyamo, H., Yasueda, S., Tayama, K., Tabeishi, M., Tosa, Y. and Nagoe, Y. 1993. Development of stratified fuel-water injection system for low-NOx diesel combustion. SAE D24.

Özkan, M. 2007. Comparative study of the effect of biodiesel and diesel fuel on a compression ignition engine's performance, emissions, and its cycle by cycle variations. Energy & Fuels, 21: 3627-3636.

Özkan, M., Ergenç, A. T. and Deniz, O. 2005. Experimental performance analysis of biodiesel, traditional diesel and biodiesel with glycerine. Turkish J. Eng. Env. Sci., 29: 89-94.

Park Jae, W., Huh Kang, Y. and Park Kweon, H. 2000. Experimental study on the combustion characteristics of emulsified diesel in a RCEM. Seoul 2000 FISITA World Automotive Congress.

Patel, A.M. and Kousar, H. 2010. Assessment of air pollution in Shivamogga city, Karnataka. Nature Environment and Pollution Tehcnology, 9(3): 643-644.

Pawar, A.C., Naik, S. J. K. and Kumari, S.A. 2012. Assessment of ambient air quality in urban environments of Hyderabad, India. Nature Environment and Pollution Tehcnology, 11(3): 457-459.

Qj, D. H., Chen, H., Matthews, R. D. and Bian, Y. Z. H. 2010. Combustion and emission characteristics of ethanol-biodiesel-water micro-emulosions used in a direct injection compression ignition engine. Fuel, 89: 958-964.

Ryu, K. and Oh, Y. 2004. Effect of water induction on the performance and exhaust emissions in a diesel engine (II). KSME International Journal, 18(9): 1640-1647.

Samec, N. and Dibble, R.W. 2000. The strategies for reducing emission from heavy duty diesel vehicles. Urban Transport, 2000, Cambridge, UK.

Samec, N., Dibble, R.W., Chen, J.Y. and Pagon, A. 2000. A reduction of NOx and soot emission by water injection during combustion in a diesel engine. FISITA 2000, Seoul, Korea.

Samec, N., Kegl, B. and Dibble, R. W. 2002. Numerical and experimental study of water/oil emulsified fuel combustion in a diesel engine. Fuel paper No. 2035-2044.

Sawa, N. and Kajitani, S. 1992. Physical properties of emulsion fuel (water-oil-type) and its effect on engine performance under transient operation. International Congress and Exposition. Detroit, pp. 97-107.

Selim, M. Y. E. and Ghannam, M. T. 2007. Performance and engine roughness of a diesel engine running on stabilized water diesel emulsion. SAE paper No. 2007-24-0132.

Selim, M. Y. and Elfeky, S. M. 2001. Effects of diesel/water emulsion on heat flow and thermal loading in a precombustion chamber diesel engine. Appl. Thermal Engg., 21(15): 1565-82.

Subramanian, K. A. and Ramesh, A. 2001. A study on the use of water-diesel emulsions in a DI diesel engine. In: 2nd International SAE-India Mobility Conference. IIT Madras, SAE paper no. 2001-28-0005.

Subramanian, K.A. 2011. A comparison of water-diesel emulsion and timed injection of water into the intake manifold of a diesel engine for simultaneous control of NO and smoke emissions. Energy Conversion and Management, 52: 849-857.

Tadashi, M., Minoru, T., Yaushi, M. and Noboru, M. 1978. Experimental reduction in NOx, smoke and BSFC in a diesel engine using uniquely produced water (0-80%) to fuel emulsion, Society of Automotive Engineers. SAE paper no. 780224.

Takasaki, T. 1998. Verbesserung der Verbemung in Diselmotoren durch geschicchtete Wasser-einspritzung. MTZ, 59(4): 276-284.

Tanner, F. X., Brunner, M. and Weisser, G. 2001. A Computational Investigation of water injection strategies for nitric oxide reduction in large-bore DI diesel engines. SAE International, 2001-01-1069.

Tarlet, D., Belletre, J., Tazerout, M. and Rahmouni, C. 2009. Prediction of micro-explosion delay of emulsified fuel droplets. International Journal of Thermal Science, 48: 449-60.

Tauzia, X., Maiboom, A. and Shah, S. R. 2010. Experimental study of inlet manifold water injection on combustion and emissions of an automotive direct injection diesel engine. Energy, 35: 3628-3639.

Tsukahara, M. and Yoshimoto, Y. 1992. Reduction of NO_x, smoke, BSFC and maximum combustion pressure by low compression ratio in a diesel engine fuelled by emulsion fuel. International Congress and Exposition. Detroit, Publ., SAE: pp. 71-77.