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Research Article

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Production and Utilization of Biofuel Emulsions in A Diesel Engine

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ABSTRACT

In this experimental investigation, the combined effects of engine parameters on the performance and emission characteristics of a single cylinder, direct injection(DI) diesel engine, fueled with an upgraded Jatropha Methyl Ester (JME) – Wood Pyrolysis Oil (WPO) emulsion which is referred to as ATJOE15, were studied. The ATJOE15 comprises of 15% WPO and 81% JME and 4% surfactant. Experiments were conducted at three different injection timings viz., 21.5, 23 and 24.5^{o}CA bTDC, and three nozzle opening pressures viz. 200, 220 and 240 bar while the standard compression ratio of 17.5 is maintained during this study. At the standard compression ratio of 17.5 and at standard injection timing, with the higher nozzle opening pressures of 220 bar and 240 bar, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher than that of diesel by about 4.6% and 6.1% respectively at full load. With the retarded injection timing of 21.5 ^{o}CA, the NO emissions of the ATJOE15 emulsion are found to be lower by about 12.8%, compared to that of diesel operation at standard nozzle opening pressure of 200 bar.

Keywords: Biofuel; Diesel engine; Emission; Emulsion; Injection timing; Nozzle opening pressure

INTRODUCTION

The conservation of nature and energy is one of the prime agendas of the modern generation. Biofuels have become attractive alternative to conventional fuel [1]. Biofuels are derived from both the plant and animal sources. The problems associated with the biofuels such as availability, cost and problems related to long-term storage, and cold flow properties limits it uses. Biofuels derived from edible sources are not promoted, as it creates stress on the food economy. Among non-edible sources, Jatropha has high oil content and can be grown in many climatic conditions and environment. But, due to its high flash point, engine using Jatropha oil fuel has starting problem. Fuel pumping is also a problem due to high viscosity of the fuel [2]. The advantage of using biofuels is that they have higher oxygen content in the molecule that will enable a more complete combustion and facilitate fewer emissions [3]. A marginally higher viscosity also helps in providing good lubrication [4]. Wood pyrolysis oil (WPO), a biofuel, is prepared by means of pyrolysis of wood as organic substance. Pyrolysis is a method of converting organic substances into oil, gas and char by thermal decomposition in the absence of oxygen [5]. Biomass can be converted into useful energy by adopting different techniques such as dry combustion, anaerobic digestion, bio photolysis, pyrolysis, liquefaction, gasification, hydrolysis and solvent extraction [6]. The WPO obtained from the pyrolysis of wood, is a free flowing dark-brown organic liquid accompanied by a strong acid smell. Its characteristics like poor volatility, high viscosity and corrosive nature do not enable to use it as a fuel. It is limited to being used as a fuel additive.

It was reported by many researchers through experimentation that advancing the injection timing causes reduction in the brake specific fuel consumption (BSFC). It also increases the brake thermal efficiency (BTE) and NO_x emission with the Jatropha biodiesel operation. However, reducing the injection timing causes an increase in BSFC and smoke and reduction in the BTE and NO_x. Through investigation, they found that, the minimum BSFC, smoke and maximum BTE was achieved, when the Jatropha oil fueled DI diesel engine was operated at 340^{o}CA. They also found a minimum NO_x was achieved, when the same engine fueled with Jatropha oil was operated at 350^{o}CA [7]. When the nozzle opening pressure is increased, the fuel particle diameter will become smaller. Therefore, the fuel-air mixture will become better throughout the combustion period, resulting in lower emissions [8].

In the present experimental investigation, an emulsion of JME and WPO is prepared by using a mixture of surfactants, namely Span 80 and Tween 80 [9]. The emulsification of biomass-derived bio-oil in diesel has been carried out to avoid the problem of miscibility and stability of bio-oil and diesel [10]. The experimental results revealed that there is a substantial enhancement in the performance and a reduction in the harmful emissions for the biodiesel emulsion fuels compared to those of biodiesel [11]. The emulsion was acidic in nature and therefore, the emulsion was upgraded by acid treatment. The acid treated emulsion composed of JME 81%, WPO 15% and is referred to as ATJOE15. Different performance and emission parameters were studied in single cylinder, DI diesel engine fueled with ATJOE15, by varying the injection timing and nozzle opening pressure. The results of the performance and emission parameter of the engine fueled with the upgraded emulsion (ATJOE15) were compared with the diesel data and presented in this paper.

EXPERIMENTAL SECTION

Production of WPO

The WPO used in this investigation was produced from the pine wood feed stock by pyrolysis process. The experimental setup and steps involved in production of WPO are described by the authors in their earlier work [9].

Production of JME

The JME used in this investigation was obtained from transesterification of Jatropha oil. In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. The details are given by the authors in their earlier works [9].

Emulsification

The water in oil type emulsion (water dispersed in oil phase) was prepared by adding the mixed surfactant (Span-80 and Tween-80) 4% by volume to emulsify the WPO with the JME. The JOE15 emulsion was prepared by taking 15% by volume of WPO with 81% by volume of JME [12]. The resultant mixture was stirred well with the help of a mechanical stirrer to obtain the stable emulsion.

Acid treatment

The pH of the WPO is low (2–3). It makes it corrosive in nature; therefore it is treated with a base to increase the pH level. The total acid number (TAN) can also be used for measuring the acidity of pyrolysis liquid. The TAN is the amount of potassium hydroxide (KOH) in milligrams that is needed to neutralize the acids in one gram of liquid. Some important properties of ATJOE15 are given in Table 1.

Table 1: **Properties of acid treated JOE15 emulsion**

Properties	ATJOE15
Specific gravity at 15 °C	0.9176
Net calorific value (MJ/kg)	30.82
Kinematic viscosity at 40 °C (cSt)	6.5
Flash point (°C)	148
pH value	7

Engine experimental setup

The schematic diagram of the experimental setup is shown in Figure 1 and the specifications of the test engine are given in Table 2. The experimental setup consisted of a single cylinder, four stroke, air cooled, direct injection, diesel engine coupled to an electrical dynamometer (alternator).

Table 2: Technical features of the test engine

Make/Model	Kirloskar TAF 1
Brake power (kW)	4.4
Rated speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Cooling System	Air cooling
Injection nozzle	MICO Bosch, 3-hole nozzle
Nozzle Opening Pressure (bar)	200
Injection Timing(oCA)	23

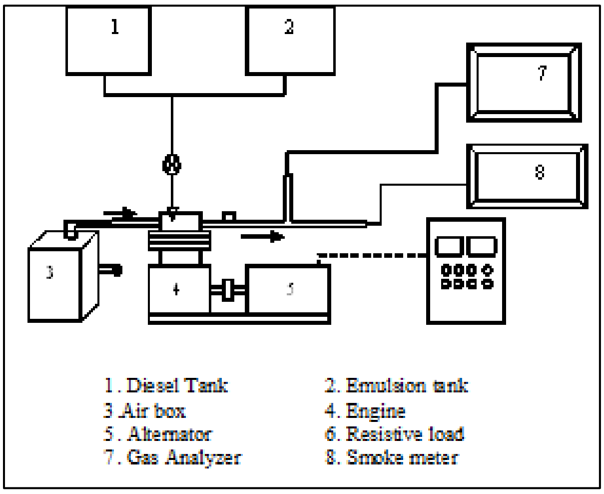

Figure 1: Schematic diagram of experimental setup

Fuel consumption was measured with the help of a solenoid controlled automatic burette. Air consumption was measured by a differential pressure sensor fitted in the air box. A surge tank was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. A non-contact type sensor was connected near the flywheel of engine to measure the speed. The AVL 444 Di Gas analyzer and AVL 437C diesel smoke meter were positioned in the exhaust manifold to measure the exhaust emissions, such as nitric oxide (NO), carbon monoxide (CO), and unburnt hydrocarbons (HC) and the smoke opacity. A calibrated K-type chrome-alumel thermocouple was installed in the immediate exhaust of the diesel engine to measure the exhaust gas temperature. Initially the engine was operated with neat diesel fuel for obtaining reference data. Further the engine was tested with the JME (100% Jatropha methyl ester). The performance and emission parameters were evaluated in the engine fuelled with ATJOE15 and compared with values obtained when fuelled with diesel under same condition.

RESULTS AND DISCUSSION

Performance parameters

The variation of brake thermal efficiency with brake power for the ATJOE15 emulsion in comparison with the JME and diesel, at different injection timings and nozzle opening pressures, is depicted in Figure 2. It is seen from the figure that, for all the injection timings and nozzle opening pressures tested the brake thermal efficiency of the ATJOE15 emulsion increases with an increase in the load. With the standard injection timing and nozzle opening pressure, the ATJOE15 emulsion produced a maximum thermal efficiency of 32.98% which is higher by about 3.6% compared to that of diesel operation. For the same injection timing, with the higher nozzle opening pressures of 220 bar and 240 bar, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher than that of diesel by about 4.6% and 6.1% respectively, at full load. The increase in the brake thermal efficiency of the ATJOE15 emulsion is due to better combustion, caused by the proper atomization and air entrainment, as a result of the nozzle opening pressure [13].

When the injection timing is retarded to 21.5^{o}CA bTDC, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher by an average of 2.5% at all nozzle opening pressures, at full load. With the advanced injection timing of 24.5^{o}CA bTDC, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher by an average of 5.5% at all nozzle opening pressures. Overall, the maximum thermal efficiency is noticed with the injection timing of 23^{o}CA bTDC and nozzle opening pressure of 240 bar.

The variation of brake specific fuel consumption (BSFC) with brake power for the ATJOE15 emulsion, JME and diesel at various injection timings and nozzle opening pressures, is depicted in Figure 3. It is apparent from the figure, that the BSFC values of the ATJOE15 emulsion are found to be higher than those of diesel and the JME operations at all injection timings and nozzle opening pressures, which is attributed to the lower calorific value of the ATJOE15 emulsion. The BSFC values of the ATJOE15 emulsion are comparatively higher with the retarded injection timings and at lower nozzle opening pressures. The lowest value of the BSFC obtained for the ATJOE15 emulsion at 24.5^{o}CA bTDC is 0.3177 kg/kWh at a nozzle opening pressure of 240 bar, which is higher by about 17.8%, compared to that of diesel operation. At the standard injection timing of 23^{o}CA bTDC and higher nozzle opening pressure of 240 bar, with the ATJOE15 emulsion, the minimum BSFC of 0.3254 kg/kWh is obtained, which is higher by about 20.6% compared to that of diesel. The minimum BSFC value of

0.3017 kg/kWh is obtained at the injection timing of 21.5°CA bTDC and the nozzle opening pressure of 240 bar, which is higher by about 21.2% compared to that of diesel, at full load. The minimum BSFC values were obtained with increased nozzle opening pressures, because of improved atomization and better mixing process [14].

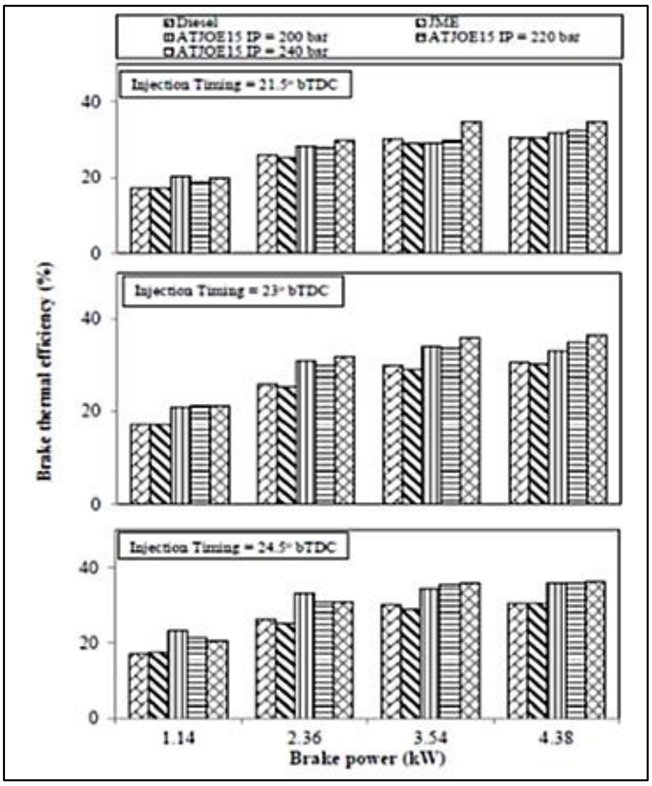

Figure 2: Variation of brake thermal efficiency with brake power

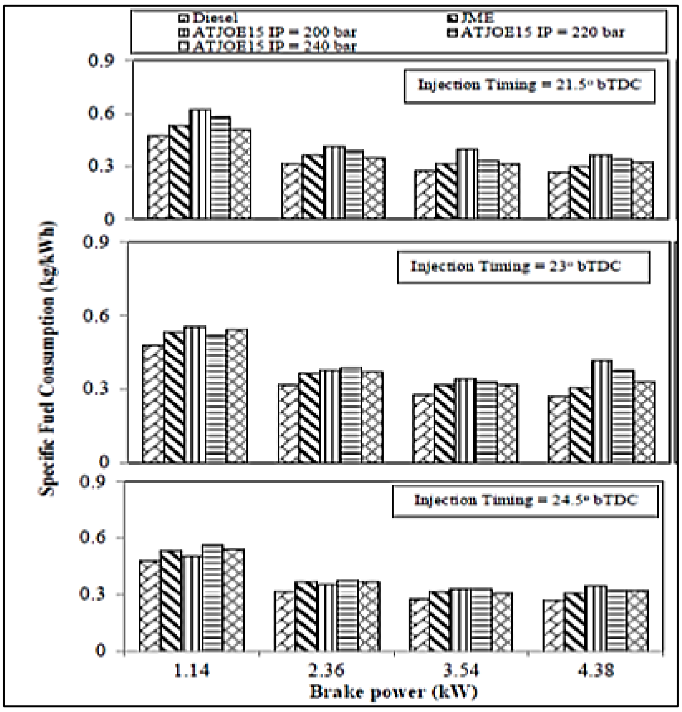

Figure 3: Variation of BSFC with brake power

Emission parameters

Figure 4 depicts the variation of brake specific nitric oxide (BSNO) emissions with respect to the brake power for the ATJOE15 at different injection timings and nozzle opening pressures. It is apparent from the figure that the BSNO emissions are found to be higher by about 29% and 2% in the JME and ATJOE15 operations, compared to those of diesel at full load, standard injection timing and nozzle opening pressure. Under the same operating condition, a higher nozzle opening pressure leads to further increase in the NO emissions by about 29.6% and 39.1% in comparison with diesel at full load. In comparison with the JME, the NO emissions from the ATJOE15 emulsion are found to be lower in the order of 1.3% to 8.1% at an injection timing of 23°CA and different nozzle opening pressures.

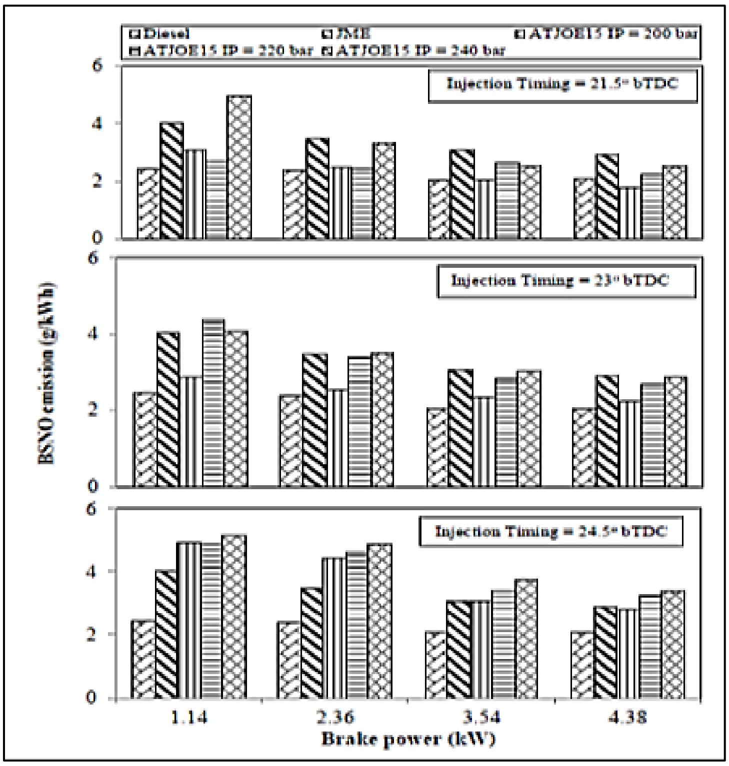

Figure 4: Variation of NO emissions with brake power

The increase in the nozzle opening pressure decreases the particle diameter and causes the ATJOE15 emulsion fuel spray to vaporize quickly. So, a higher nozzle opening pressure initially generates faster combustion rates, resulting in higher temperatures. As a consequence, the NO concentrations are observed more at higher nozzle opening pressures [15].

With the retarded injection timing of 21.5°CA, the NO emissions of the ATJOE15 emulsion are found to be lower by about 12.8%, compared to that of diesel operation at the standard nozzle opening pressure of 200 bar. With the higher nozzle opening pressures of 220 and 240 bar, the NO emissions from the ATJOE15 emulsion are found to be higher by 8.9% and 21.4% respectively in comparison with diesel. In comparison with the JME operation, the NO emissions of the ATJOE15 emulsion are found to be lower in the range between 13.9% and 38.2%. Retarding the injection timing decreases the peak cylinder pressure and peak temperatures. As a consequence, the NO concentration starts to diminish. With the advanced injection timing of 24.5°CA, the NO emissions from the ATJOE15 emulsion are found to be higher in the range of 36.4% to 64.3% compared to that of diesel.

Figure 5 depicts the variation of smoke opacity with respect to the brake power for the diesel, JME and the ATJOE15 emulsion operations, at different injection timings and nozzle opening pressures. The smoke emissions from JME are found to be lower than those of diesel, as a consequence of the oxygen content in the JME reducing the formation of smoke. In the case of ATJOE15, the smoke opacity is found to be higher by about 8.9% with the standard injection timing and standard nozzle opening pressure of 200 bar. When the nozzle opening pressure is increased to 220 bar and 240 bar, the smoke opacity of the ATJOE15 is found to be reduced by about 3.9% and 26.4% respectively, compared to that of diesel operation at full load. The values of smoke opacity of the ATJOE15 emulsion at nozzle opening pressures of 200 and 220 bar are higher in the range of 28% and 45.2% compared to that of JME operation at full load. With the 240 bar nozzle opening pressure, the smoke opacity of the ATJOE15 emulsion is found to be lower by 1.9% compared to that of JME at full load. With the retarded injection timing of 21.5°CA, the smoke opacity of ATJOE15 emulsion at all the nozzle opening pressures is found to be higher in the range between 24.5% and 45.5% compared to that of diesel operation at full load.

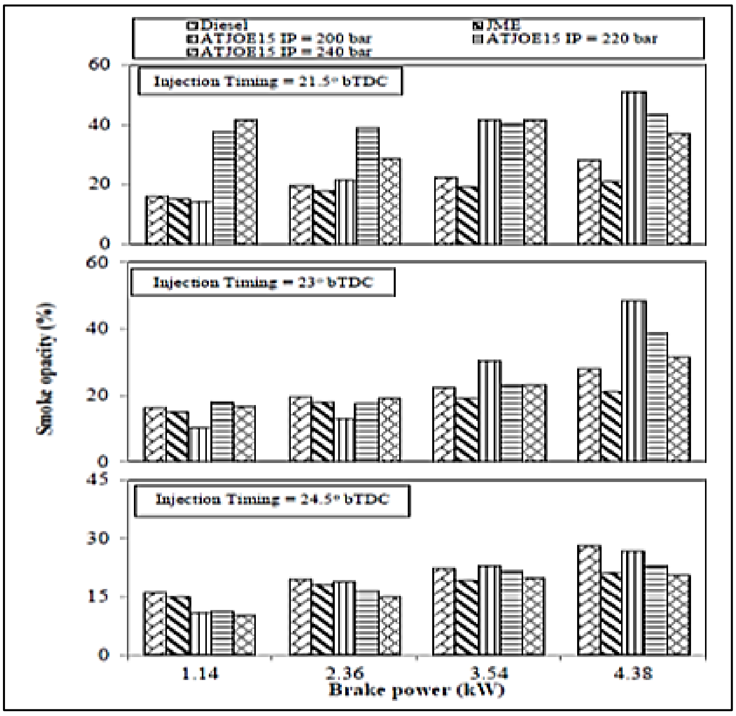

Figure 5: Variation of Smoke opacity with brake power

With the advanced injection timing of 24.5°CA, the smoke opacity of the ATJOE15 emulsion is found to be lower by about 5.3% to 26.7% at all the nozzle opening pressures compared to that of diesel. The smoke opacity decreases with an advancement in the injection timing, due to the existence of a higher combustion temperature which promotes soot oxidation, compared to that of standard injection timing operation, and this is vice versa in case of retarded injection timing. When the nozzle opening pressure is increased, the fuel particle diameter will become smaller. Therefore, the fuel-air mixture will become better throughout the combustion period, and hence, the smoke opacity will be lower [16].

CONCLUSION

The following conclusions are obtained from the experimental results of a single cylinder DI diesel engine fuelled with ATJOE15, operated at different injection timings and nozzle opening pressures:

At the standard injection timing, with the higher nozzle opening pressures of 220 bar and 240 bar, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher than that of diesel by about 4.6% and 6.1% respectively at full load. When the injection timing is retarded to 21.5 °CA bTDC, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher by an average of 2.5% at all nozzle opening pressures at full load. With the advanced injection timing of 24.5 °CA bTDC, the brake thermal efficiency of the ATJOE15 emulsion is found to be higher by an average of 5.5% at all nozzle opening pressures.

The lowest value of the BSFC obtained for the ATJOE15 emulsion at 24.5 °CA bTDC is 0.3177 kg/kWh at nozzle opening pressure 240 bar, which is higher by about 17.8% compared to that of diesel operation.

With the retarded injection timing of 21.5°CA, the NO emissions of the ATJOE15 emulsion are found to be lower by about 12.8%, compared to that of diesel operation at standard nozzle opening pressure of 200 bar.

With the retarded injection timing of 21.5°CA, the smoke opacities of ATJOE15 emulsion at all the nozzle opening pressures found to be higher in the range between 24.5% and 45.5% compared to that of diesel operation.

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