Scientific Journal of Impact Factor (SJIF): 5.71

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 7, Issue 09, September -2020

Experimental investigation of the performance and emission characteristics of DI diesel engine using blended biodiesel and water emulsion under varying load condition.

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Abstract — *The experimental work aims to prepare biodiesel-diesel blend emulsion fuel and investigate its characteristics with different levels of water concentration (5% and 15%) and their effects on performance and emissions of a light-duty diesel engine. The engine was operated at engine speeds of 1500 rpm. At this speed, four loads (25%, 50%, 75% and 100%) were applied. Diesel and biodiesel-diesel blends were emulsified with two different levels of water concentration (5% and 15%). Emulsifiers Sorbitan Monoleate (Span 80) and Polyoxyethylene Sorbitan Monoleate (Tween 80) were used to prepare emulsion fuels. Engine performance (brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE)) and emissions were investigated. An increase in BTE was observed with increased water content in emulsions. A reduction in exhaust gas temperature (EGT) with an increase in water content was achieved. The nitrogen oxides (NOx) and smoke emissions were also significantly reduced with the increase in water content. Emulsion fuel containing a higher water content revealed a considerable increase in carbon monoxide (CO) emissions.*

Keywords*-Emulsion fuel, Biodiesel, Emission, Water Concentration, Diesel engine.*

I. INTRODUCTION

Diesel engines are widely utilized in many applications, such as transportation, mining equipment, and agriculture machinery due to their high-energy conversion and economic power source [1]. However, diesel engines contribute to environmental pollution, with hydrocarbon (HC), CO, NOx and particulate (PM) because the main pollutants from the combustion process [2–4]. Increased concerns over environmental issues and traditional resource depletion have heightened the motivation to use clean and alternative fuels. Biodiesel may be a prospective clean diesel fuel, and is defined because the mono alkyl esters of long-chain fatty acids derived from renewable lipid feedstocks, like vegetable oil and animal fats [5,6]. Biodiesel features a lower heating value, but has a higher cetane number and oxygen content than fossil diesel [7–9]. In terms of engine emissions, biodiesel emits lower HC, CO and PM, whereas NOx emission is higher compared thereto of conventional diesel [10–12]. the upper NOx formation is thanks to the elevated oxygen content in biodiesel, also as high combustion temperatures [13–15]. Attempts are made to scale back the combustion temperature. for instance, the introduction of water into the combustion chamber, whether through direct injection as a steam-into-intake air system or as fuel emulsion of a diesel engine is an efficient technique to extend thermal efficiency and reduce combustion temperature and engine emissions [16–18].

Emulsion fuel has positive effects on diesel engines in terms of engine performance and emissions. The experiment conducted by Senthil et al. [19] investigated diesel engine emissions and performance, using a fuel with an emulsion blend of 20% biodiesel and diesel, with various percentages of water content. Their investigation concluded that the emulsion fuel resulted in slightly lower BTE. HC, NOx and smoke opacity were also lower compared to that obtained from B20 and diesel. Scarpete [20] studied emission reduction of a diesel engine fueled by emulsified diesel, and found a significant reduction in NOx and PM emission when the diesel engine ran on emulsion fuel. Using 1% Span 80 with two different water content levels, Hasannuddin et al. [21] prepared emulsified diesel to investigate diesel engine emissions, and observed that the NOx and PM emissions were reduced, while the CO emission increased compared to diesel at a low load. Yang et al. [22] tested diesel engine performance fueled with emulsion fuel with nanoorganic additives, during which they obtained higher BTE compared to neat diesel. Ogunkoya et al. [23] operated a diesel engine with three different types of emulsion fuel to analyze engine performance. They observed that using three types of emulsion fuel resulted in a reduction of output and mechanical efficiency, with a slight increase in BTE and BSFC compared to their base fuels. Baskar and Senthil Kumar [24] conducted an investigation on diesel engine performance fueled with emulsified diesel while supplying oxygen into the intake air system, and they reported higher BTE for all loads compared to that obtained from conventional diesel.

Hence it is decided to do an experimental investigation on a diesel engine test rig and have a comparative study about the performance and emission characteristics of the diesel engine by running it by fueling it with pure diesel, diesel biodiesel blends and diesel biodiesel water emulsion to find out the substitute of the diesel fuel as it is a nonrenewable source and have control emission is also the main outcome of our research work for that the testing of the fuel sample is done by varying the load conditions on the diesel engine to check the performance of fuel sample on the diesel engine on varying condition to attain actual real time results.

II. EXPERIMENTAL SETUP

A. Biodiesel production

Running diesel engines with 100% vegetable oil or animal fats as a fuel resulted in several operational issues, such as incomplete combustion, engine deposits, and an increase in lubricant viscosity due to the high viscosity of those oils. Therefore, attempts have been made to reduce the oil viscosity using four different approaches: Pyrolysis, dilution, micro-emulsification, and transesterification [25,26]. Transesterification is simply a chemical reaction of oil and alcohol with the help of a catalyst, which accelerates the reaction to produce biodiesel [27]. Among the mentioned methods of reducing oil viscosity, transesterification has advantages of effortlessness and comparatively low cost [28]. Via the transesterification method, Vegetable oil (Cotton seed) was used with methanol and sodium hydroxide to produce biodiesel, the by-products of which were glycerine and fatty acids.

B. Biodiesel blending

The prepared biodiesel is then mix with pure diesel in proportion of 5% which is known as B5 and 20% which is known as B20 to prepare their blends with diesel. These two sample were taken for experimentation as they are the most popular blends used.

C. Emulsion preparation

Emulsified fuel was prepared using the external force method. In total, 3 emulsion fuels were prepared. Firstly, a blend of Span 80 and Tween 80 was stabilized at HLB 8.25, which showed best results for diesel emulsion in terms of emulsion stability, and was added to the fuel in a volumetric percent of 2 [40,44]. The fuels used were diesel and biodiesel-diesel blends, namely B5 and B20. Two different levels of water concentration in emulsion were investigated (5% and 15%) the fuel composition is as shown in the table 1. Secondly, using the magnetic stirrer at a speed of 2000 rpm for 25 min, the water was added to the fuel, after which the emulsifiers were added slowly at a rate of 1.25 ml/mi. The result was milky emulsified fuel.
Table 1.

Table 1. Fuel Composition

Surfactant %	Biodiesel %	Water %	Diesel %
7.5	17.5	5	70
7.5	17.5	15	60

D. Engine Setup

A water cooled, Single cylinder, 4-stroke light duty (Kirloskar) diesel engine with a direct fuel injection system was used, and its specifications are shown in Table 1. A schematic diagram for the diesel engine is outlined in Figure 1.

Table 2. Engine specification

Sr.no	Parameter	Specification
1	Make	Kirloskar
2	Model	AV1
3	Type	Single-Cylinder, Four Stroke, Direct Ignition Water cooled CI Engine
4	Rated Power	3.7 KW @1500 rpm
5	Bore & Stroke	80*110mm
6	Swept Volume	0.5531
7	Governing Class	B1 as per IS:10000
8	Compression ratio	16.5:1 range 13.5-20
9	Dynamometer	Electrical AC Alternator
10	Orifice Diameter	20mm

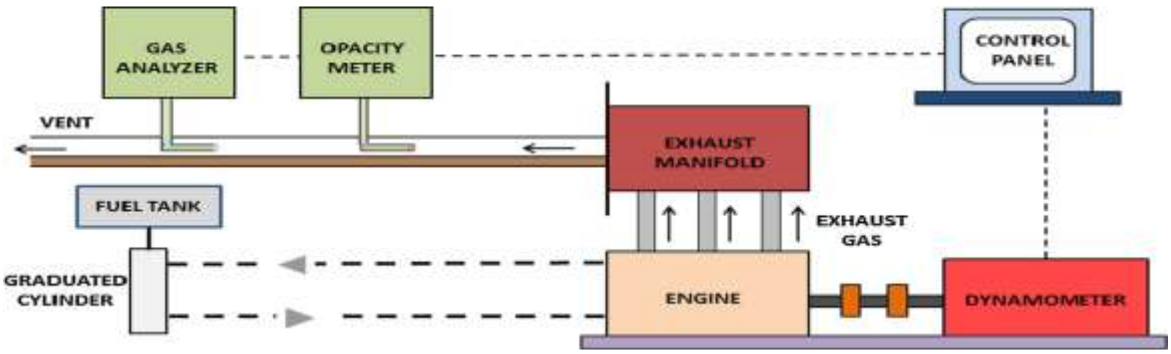

Figure 1. Schematic diagram of diesel engine

III. RESULTS AND DISCUSSION

3.1 Engine performance

3.1.1 Brake-specific fuel consumption

Figure 2. indicates BSFC of different fuels and emulsions at various engine loads at the speed of 1500 rpm. At low load, the BSFCs of B0&B20 fuels were 0.63&0.423 respectively. Emulsion fuels consisting of 15% water content showed higher BSFC than those with 5% water content, with their base fuels at constant operating conditions. This is due to less heat content of emulsion fuels that have higher water content. As shown in the figure, the BSFCs for all fuel types decrease with the increase in engine load, which signifies higher burning efficiency [29]. The higher the biodiesel content in the emulsion, the higher the BSFC is, because there is a lower heat content of these fuels than the base and lower biodiesel content fuels.

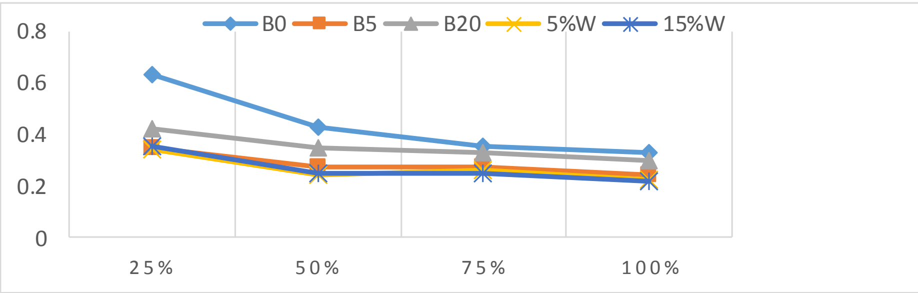

Figure 2. Engine BSFC for different fuel consumption

3.1.2 Brake thermal efficiency

Figure 3. illustrates BTE of different fuels and their emulsions at various engine loads. BTE rises with increased engine load. Although biodiesel-diesel blends have a lower heating value than pure diesel, oxygen content in biodiesel promotes burning efficiency. Therefore, biodiesel-diesel blends have slightly higher BTE compared to diesel at all engine conditions. Correspondingly, emulsion fuels significantly improved the engine's BTE, which increased with the additional water and biodiesel content in emulsion. This is due to the fact that micro-explosion of emulsion fuel and water evaporation during combustion enhances air fuel mixing, hence leading to improved combustion efficiency. The BTE of 15%W increased by 5.85% and 6.75% compared to B20 and B0 respectively, at high load condition. Similar results were obtained from the study conducted by Lin and Wang [30], which investigated the engine performance using different water concentration levels in the emulsion. In general, 15% water concentration in the emulsions of diesel and biodiesel-diesel blends could substitute neat diesel fuel for improved BTE in diesel engines.

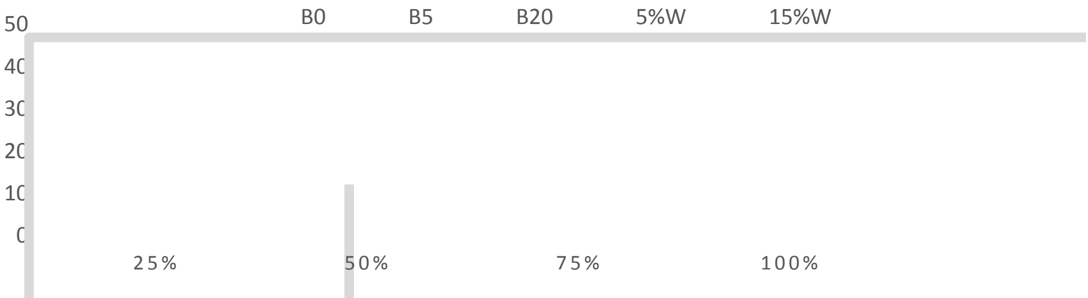

Figure 3. Engine BTE for different fuel consumption

3.1.3 Exhaust gas temperature

Figure 4. shows the exhaust gas temperature variation with the engine load and speed of 1500 rpm for B0, B5, B20 and emulsions of two different levels of water content (5% and 15%). It was observed that EGT increases with the increase in engine speed and load. Higher water concentration reduced the EGT of all emulsion fuels; however, there was no significant change in EGT with higher percentage of biodiesel in the blends. Mainly, the water content in emulsion fuel resulted in absorption of the combustion heat, which led to a drop in the peak flame temperature.

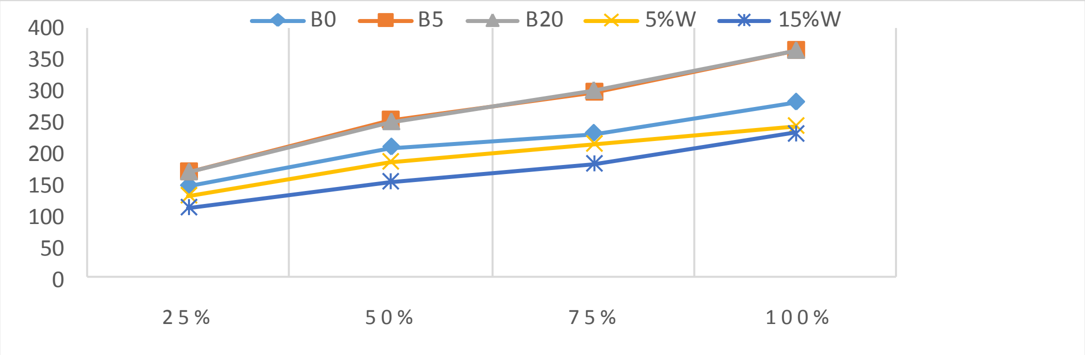

Figure 3. Engine BTE for different fuel consumption

3.2 Engine emissions

3.2.1 Oxides of nitrogen (NOx)

Figure 4. shows NOx emission of different fuels and their emulsions at various engine loads. It is clear that NOx emission rises with the increased load for all fuels investigated, since the higher combustion temperature resulting from the higher fuel supply contributed to more NOx formations. Emulsion fuels provide considerable reduction in NOx emissions, and a 15% water concentration in the emulsion presents lower NOx emissions compared to 5%water concentration. The average NOx reduction for emulsions with 15% water content is approximately 30% compared to base fuel at 1500 rpm. This is a significant reduction and 15% water content in emulsions could be a practical fuel to substitute neat diesel in diesel engines. The NOx reduction by fuel emulsion is due to the water's heat energy absorption, which leads to a reduction in peak flame temperature. No significant changes in NOx emission were observed with higher biodiesel in the blends at 1500rpm.The shorter ignition delay at the higher speed condition could be a reason for the reduction in NOx emissions. Similar results were obtained by Buyukkaya [31] and Man et al. [32]; however, an additional detailed investigation is required to study the effect of engine speed on NOx emissions.

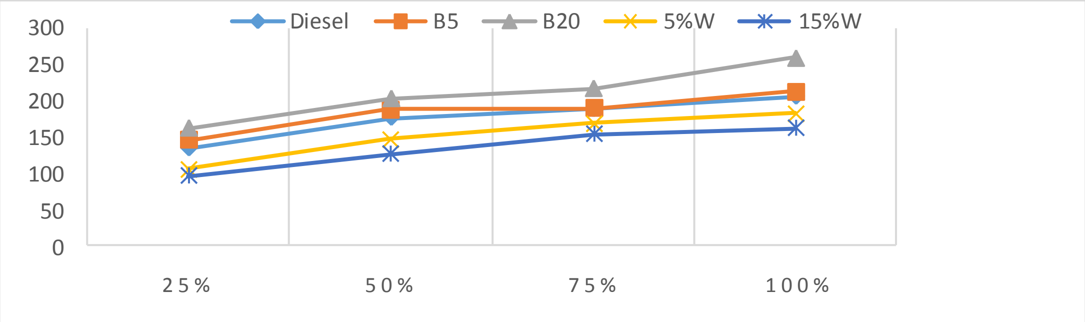

Figure 4. Engine NOx emission for different fuel

3.2.2 Carbon monoxide (CO)

Figure 5. shows CO emission of different fuels and their emulsions at various engine loads. The CO emission is mainly a product of incomplete combustion. Higher combustion efficiency and temperature help to reduce CO emission, therefore, the biodiesel-diesel blends up to 40 led to reduced CO emission compared to pure diesel at all engine conditions investigated. An increase in the load led to an adequate turbulence and high temperature environment, which resulted in additional CO reduction. Fuel emulsion attributed to an increase in CO emission, which further increased with higher water content due to the lower combustion temperature created by water content in emulsions.

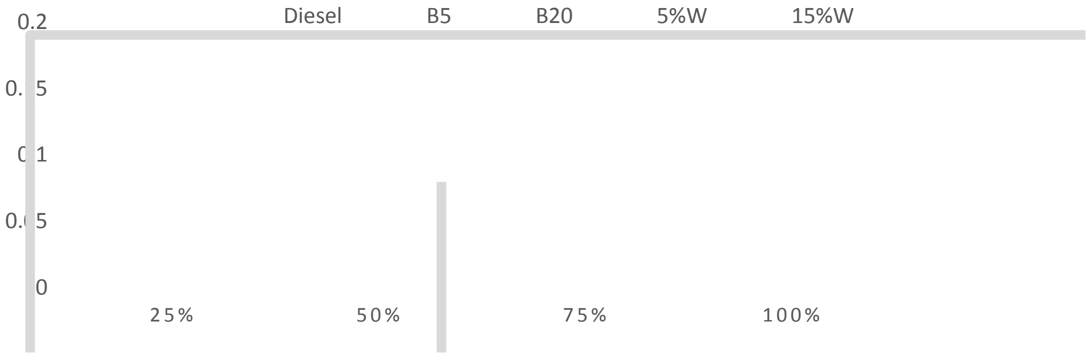

Figure 5. Engine NOx emission for different fuel

3.2.3 HC Emission

Figure 6. shows HC emission of different fuels and their emulsions at various engine loads. Biodiesel-diesel blends emit lower HC than diesel for all engine operating conditions investigated, which is attributed to improved combustion efficiency and higher oxygen content in biodiesel. Correspondingly, HC emission was observed to decline with an increase in engine load and speed. The higher combustion efficiency and in-cylinder temperature at higher speed and load is the principal reason for HC reduction. Average HC reduction of B20 and their emulsions was approximately 40% and 70% respectively, compared to the base fuel.

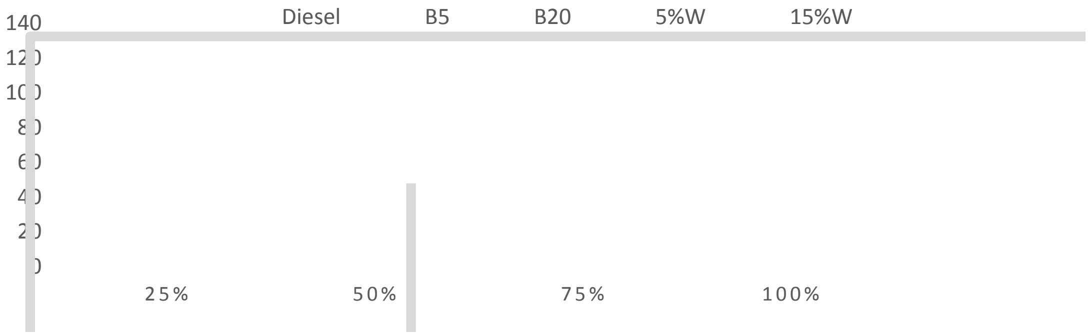

Figure 6. Engine HC emission for different fuel

3.2.4 Carbon dioxide (CO2)

The variation of CO_2 emissions with engine speed for different fuel compositions are shown in Figure 7. Increasing the engine loads increased CO_2 emissions for all the fuels. Biodiesel emulsions produced higher CO_2 emissions than B5, B20 and diesel fuel. Increasing water concentrations in biodiesel emulsions increased the CO_2 emissions. Among the emulsion fuels, W15 produced the highest CO_2 emissions (10.3%) at 1500 rpm. This result could be due to the increasing number of oxygen atoms in the fuel mixture with increasing water concentration. However, B5 and B20 produced lower CO_2 emissions than diesel fuel and biodiesel emulsions at full engine load at 1500 rpm. B5 produced less CO_2 than B20 and W5 fuels. These results confirm that the presence of water in biodiesel fuel increased the CO_2 emissions.

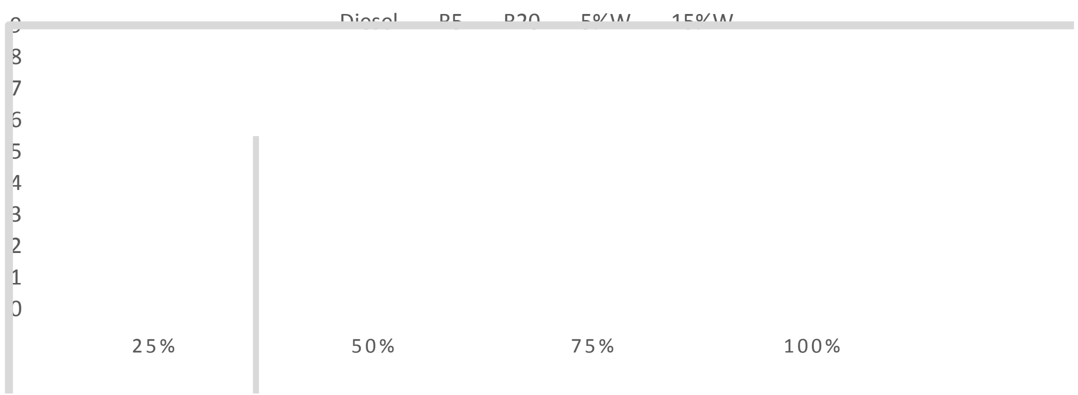

Figure 7. Engine CO2 emission for different fuel

IV. Conclusion

Diesel and biodiesel-diesel blends and their emulsions with two different levels of water concentration were investigated for their characteristics. These were used for testing engine performance and emissions at four different engine conditions of load and speed. The most significant conclusion of this research work is that 15% water concentration in emulsion fuels of diesel and biodiesel-diesel blends could realistically be used in diesel engines, which could increase BTE by approximately 6%, with a 30% reduction in NOx and smoke. In addition, HC reduction could be as high as 70% with 15% water concentration in emulsion fuels. The following are further conclusions obtained from the experimental results

1. All emulsion fuels showed higher viscosity than their bases, and the viscosity was found to increase with higher water and biodiesel content in the emulsion.
2. The emulsion fuels were found to decrease the EGT with the increase in water concentration in the emulsion.
3. The BSFC of emulsion fuels was found to increase with higher water and biodiesel concentration in the emulsion at all loads compared to their bases. Biodiesel-diesel blends have slightly higher BTE compared to diesel fuel at all engine conditions. This study found that emulsion fuels improved the engine's BTE significantly, and efficiency increased with the additional water and biodiesel content in emulsion. The highest BTE increase of approximately 7% was noticed for 15%W compared to diesel.
4. Water concentration in the emulsion resulted in NOx and smoke emission reductions, the most significant of which was at high load and high speed, whereas increased biodiesel content in the emulsion had slightly higher NOx emission compared to that of lower biodiesel content. However, 15% showed lower NOx compared to that obtained from the diesel for all engine conditions. Higher water content in the emulsion fuel resulted in lower smoke emissions, and emulsions with 15% water content showed a moderate smoke reduction.
5. The emulsion fuels investigated showed a substantial increase in CO emission with increased water content in the emulsion; this increase was found to be higher at low load and low speed engine conditions. However, the biodiesel content in the emulsion contributed to the reduction in CO emissions compared to emulsion with lower biodiesel content. Biodiesel-diesel blends showed lower HC emissions than diesel for all engine operating conditions. However, water content in the emulsion did not have a significant effect on HC emissions.

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