Reduction of NOx and Smoke Emission with the effect of Biodiesel-Water Emulsion Mixture Fuel in a Diesel Engine

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Abstract

Biodiesel fuels derived from vegetable oils are quite promising alternative fuels for diesel engines, because of their low environmental impact and has potential as an alternative fuel for diesel engine without any modification on the engine. The present investigation focuses on the study on simultaneous reduction of NOx and smoke emissions by water emulsion of Cotton seed oil methyl ester (CSME) in a single cylinder, direct injection diesel engine. The quantity of water was varied from 10 % to 30 % (by vol.) in steps of 10%. Water-emulsified diesel fuel has been proven to reduce nitrogen oxides (NOx) and smoke simultaneously at relatively low cost compared to other emission control methods. From the results, it is observed that 30% water emulsion with biodiesel results in a substantial reduction of NOx by 30 % and smoke emissions by 32 % with a marginal decrease in brake thermal efficiency compared to diesel fuel at full load conditions without emulsion.

Keyword: Diesel engine, CSME, Emulsion, BTE, brake power, Emission, Transesterification

I. INTRODUCTION

Diesel engines are dominant in the field of transportation, heavy industries and agricultural sectors due to their better fuel to power conversion efficiency. It is one of the major pollution contributors to present time. Due to stringent emission regulations, researchers have investigated alternative fuels for diesel engines. In earlier days efforts have been taken to use straight vegetable oils as fuel in diesel engines. The vegetable oil could not be used directly in diesel engine due their high viscosity [1, 2]. So the vegetable oils can be converted into biodiesel using transesterification process in the presence of catalyst. Biodiesel is a promising substitute fuel for diesel engine which gives better performance, reduced emissions and does not require any engine hardware modifications [3]. Several researchers have investigated the properties of a bio-diesel from vegetable oils in diesel engines and found that particulate matter (PM), CO, and soot emissions were decreased, while NOx emissions were increased [4-6]. Emissions like NOx can be reduced either by retarding the injection timing or by including the exhaust gas recirculation (EGR) system. Rajan and Senthil Kumar [7] have studied the effect of exhaust gas recirculation on the performance and emission characteristics of a twin cylinder diesel engine with sunflower oil methyl ester. They reported that NOx and smoke emissions were decreased with slight increase in CO and HC emission for 15% EGR at full load compared with diesel fuel.

Water emulsified fuels are most preferably used in diesel engine due to the simultaneous reduction of NOx and smoke emissions. In the case of water emulsion diesel/biodiesel, water is mixed homogeneously with the base diesel fuel on volume basis in the presence of an appropriate surfactant, which helps to produce stable emulsion fuel. Water emulsion diesel is a convenient renewable fuel option as the existing engine does not require any modification of the engine The emulsified diesel/biodiesel can lead to other advantages, such as; additional momentum in jet behavior which may assist better mixing of fuel and air. Moreover, the presence of tiny water particles may lead to micro explosion, which also enhance further fuel atomization [8-12]. Armas et al [13] have studied the performance and exhaust gas emission of a diesel engine with the effect of 13% v/ v basis water emulsion diesel on public buses and reported higher specific fuel consumption, improvement in smoke and slight reduction in oxides of nitrogen (NOx) emission.

Kandasamy and Marappan [14] have studied the performance of a diesel engine with biodiesel with water emulsion in the ratios of 5%, 10%,15% and 20% in a direct injection diesel engine. They reported that slight improvement in brake thermal efficiency accompanied by the drastic reduction in NOx emission. It is also found that found that 15% water emulsified fuel showed the best performance and less emission than the other combinations. Yasimoto and Tamaki [15] the performance and the emission characteristics of Diesel engine using emulsified biodiesel as fuel with water in the ratios of 5, 10, 15, and 20%. Balusamy and Marappan [16] have studied the effect of emulsified biodiesel in diesel engine with different blends with water. They reported that the emulsified biodiesel improved the trade-off relation between NO_X and smoke emissions over that of diesel emulsion. In this investigation, the emulsifying agent, called surfactant Span 80 of 0.5% by volume is added with water and biodiesel and it is stirred at constant speed of 5000 rpm to make the required stable emulsion. Then the specified quantity of water was added and the stirring was continued at 2500 rpm. Using these emulsions, the diesel engine performance, emission and characteristics were studied.

II. MATERIALS AND METHODS

1. PREPARATION OF BIO-DIESEL

Cotton seed oil was selected for this study and it is converted into its methyl ester by the transesterification process. In transesterification reaction, 8 gram of KOH catalyst per litre of oil was mixed with 200 ml of methyl alcohol to produce methoxide. The methoxide and the Cottonseed oil mixture were heated at 65°C with constant stirring. The reaction was allowed for one hour and the final products were allowed to settle in the separating funnel for 8 hrs and then the settled glycerin layer was drained off. After decantation of glycerol, the methyl ester was washed with distilled water to remove excess methanol. The properties of cotton seed oil methyl esters were found out and compared with that of diesel. The comparison shows that the methyl ester properties have relatively closer to properties of diesel fuel. The properties of diesel, cotton seed oil and its methyl ester are listed in Table.1. Water was added in the ratios of 10%, 20% and 30% with biodiesel by volume and emulsified.

TABLE 1 Properties of Diesel, Cotton seed oil and its methyl ester

PROPERTIES	DIESEL	COTTONSEED OIL	CSME
Density (kg/m^3)	840	910	880
Viscosity(mm^2/s)	3.8	55.6	5.37
C.V (MJ/kg)	42.5	38	38.45
Flash Point (^{o} C)	50	207	200
Fire Point (^{o} C)	60	230	220
Cetane Number	47	42	52

2. EXPERIMENTAL SET UP

A Kirloskar Diesel engine of AV1 model, four stroke, direct injection, water cooled diesel engine was used to investigate this study. The schematic of experimental set-up is shown in Fig. 1. The engine was coupled with an eddy current dynamometer. Fuel flow rates are obtained with calibrated burette. The cylinder pressure was measured by a piezoelectric sensor (Make: Kistler and model 6056A). The pressure signals were amplified with a charge amplifier (Make: Kistler and model 5011B) and analyzed with a combustion analyzer to obtain the heat release rate. A crank angle encoder was employed for crank-angle signal acquisition. The exhaust gas emissions like CO, HC, and NO were measured with the help of AVL-444 five gas analyzer and the smoke emissions were measured by Bosch smoke meter. Inlet and outlet water temperatures and exhaust gas temperatures were measured by using *K* type thermocouples. The engine specifications are listed in Table.1. The experiments were conducted in different loads like 25, 50, 75% and 100% load with emulsified biodiesel. Similar experiments were done with diesel fuel, biodiesel fuel so as to make comparisons.

TABLE 2 Test Engine specifications

Engine	Kirloskar, AV-I,
Power(kW)	**3.67**
Bore (mm)	**80**
Stroke(mm)	**110**
Compression ratio	**16.5:1**
Speed (rpm)	**1500**
Number of cylinders	**1**

(1) – Diesel engine, (2) – Electrical dynamometer, (3) – Dynamometer controls, (4) – Air box, (5) – U-tube manometer, (6) – Fuel tank, (7) – Fuel measurement, (8) – Pressure transducer, (9) – TDC position sensor, (10) – Charge amplifier, (11) – TDC amplifier circuit, (12) – Analog to digital card, (13) – Personal computer, (14) – Exhaust gas analyzer, (15) Bosch *smoke meter*

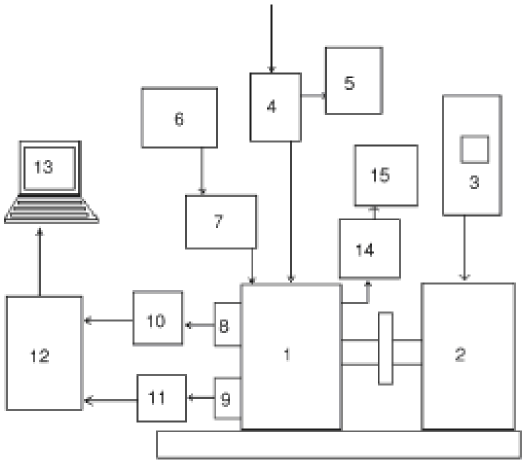

Figure 1. Experimental setup

III. RESULTS AND DISCUSSIONS

1 .PERFORMANCE CHARACTERISTICS

The variations of brake thermal efficiency (BTE) with brake power for all test fuels shown in Fig. 2. The brake thermal efficiency increases with the increase in load for all test fuels. The BTE of biodiesel is lower than that of diesel fuel due to its lower calorific value and volatility. The BTE of biodiesel with water emulsified fuel gives slightly higher BTE at full loads compared to biodiesel. This may be due to the micro explosion phenomenon and volatility difference between water and fuels, which enhances the air fuel mixing during higher engine loads and hence the improvement in combustion efficiency. This could be the possible reason for higher BTE even though the calorific values of the emulsions are less than that of biodiesel. The BTE of 20% emulsified biodiesel is 7% higher than that of biodiesel fuel at full load, and 10% and 30% emulsified biodiesel shows an increase of 3.23% and 6.67% respectively at full load.

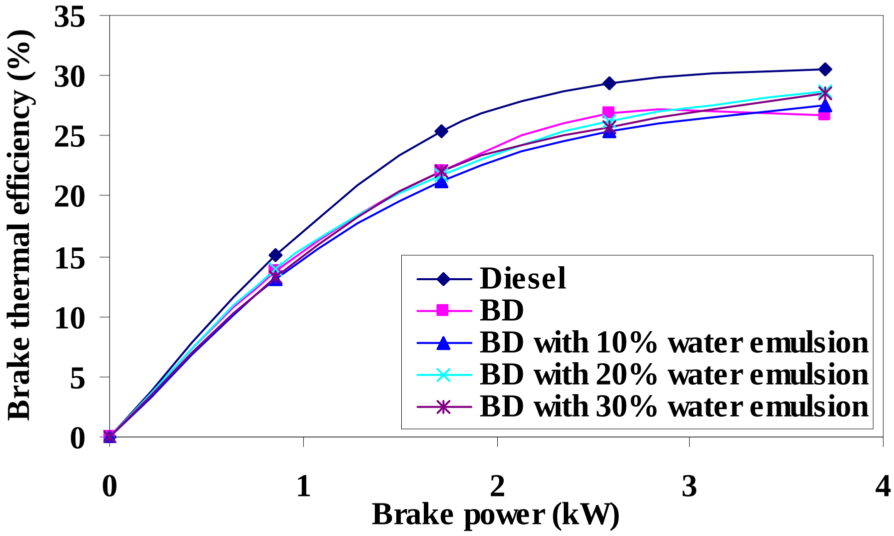

Fig. 2. Variations of brake thermal efficiency with BP

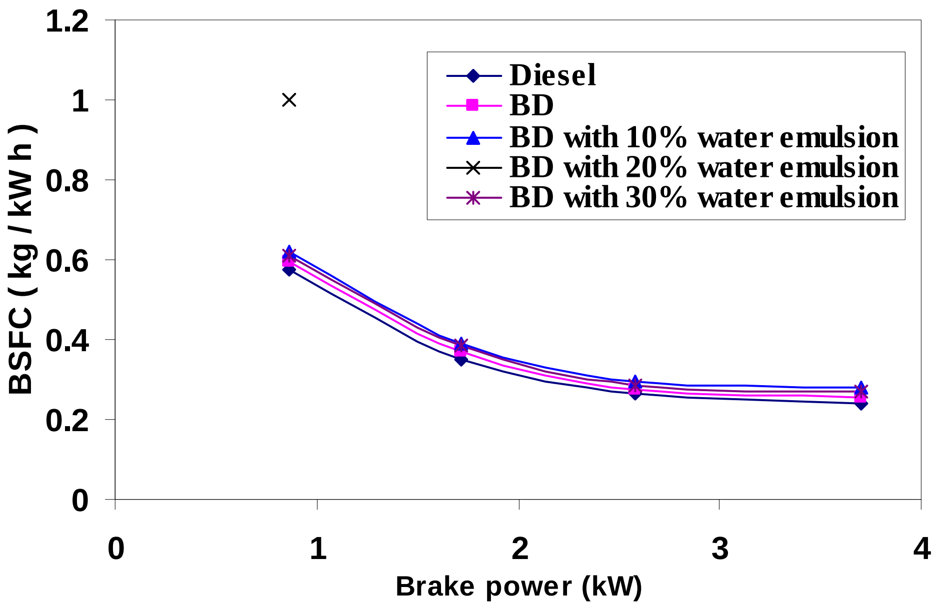

Fig. 3. Variations of brake specific fuel consumption with BP

Figure 3 shows the variation of brake specific fuel consumption (BSFC) with brake power for all the test fuels. The BSFC of all the test fuels are decreases with increase in load. It is observed that the 10% water emulsion of biodiesel has higher specific fuel consumption as compared to diesel and biodiesel fuel. The BSFC of diesel fuel and biodiesel fuel are fuel is 0.242 kg/kW-h and 0.257 kg/kW-h where as for 10% water emulsion biodiesel is 0.278 kg/kW-h at full load. This is due to lower energy content of biodiesel which has resulted in more fuel consumptions for all the emulsified biodiesels.

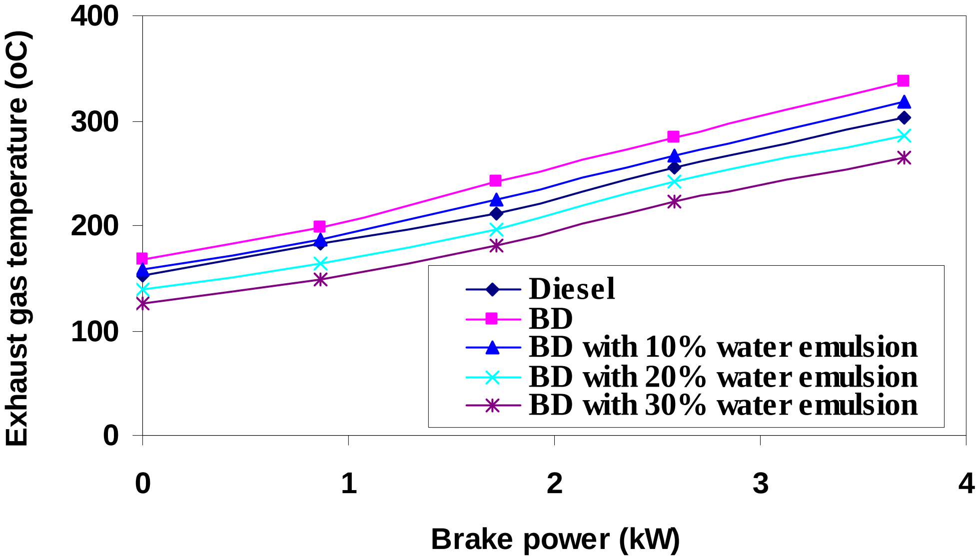

Fig. 4. Variations of exhaust gas temperature with BP

The variations of exhaust gas temperature (EGT) with brake power for all test fuels shown in Fig. 4. The exhaust gas temperature increases with increase in load because more fuel is burnt at higher loads to meet the power requirement. The EGT of biodiesel is higher than that of diesel fuel. The heavier molecules of biodiesel lead to continuous burning even during exhaust which causes higher EGT [14] and for emulsified fuels, the exhaust gas temperatures are observed to be lesser than that of biodiesel. This is because the water in the emulsion gets vaporized during the combustion process and absorbs the heat energy which decreasing the adiabatic flame temperature [8]. This leads to lower EGT than those of biodiesel fuel. The exhaust gas temperatures for diesel and biodiesel are 302^{o}C and 338^{o}C respectively, where as for 10%, 20% and 30% water emulsion of biodiesel are 318^{o}C, 286^{o}C and 265^{o}C respectively at full load. The 30% emulsified biodiesel shows 26% EGT reduction than in biodiesel, whereas 16% and 6% reduction is observed for 20% and 10% emulsified biodiesel respectively at full load.

2 .EMISSION CHARACTERISTICS

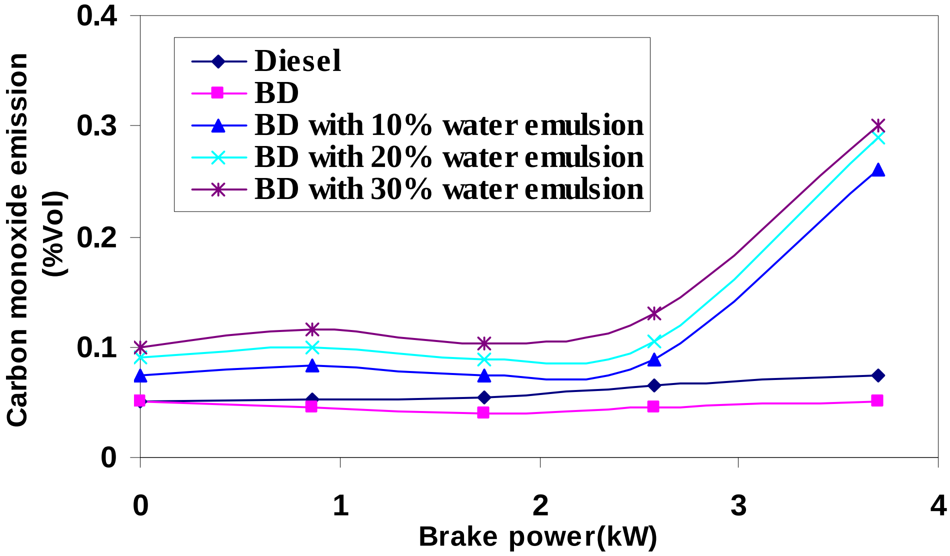

Fig.5.Variations of CO emission with brake power

Figure 5 shows the variations of carbon monoxide emission with brake power for all test fuels. The formation of CO emission depends upon mixture strength and the availability of oxygen quantity and the fuel viscosity which in turn atomization. The CO emission increases with increase in load for all the test fuels. It is observed that water emulsified biodiesel exhibits higher carbon monoxide emission as compared to diesel and biodiesel fuel. This is due to the presence of water in the emulsified fuels resulting in incomplete combustion. The carbon monoxide emission of diesel and biodiesel fuel are 0.075%Vol and 0.05 %Vol respectively, where as for 10%, 20% and 30% water emulsion of biodiesel are 0.26%, 0.29% and 0.30%Vol respectively at full load.

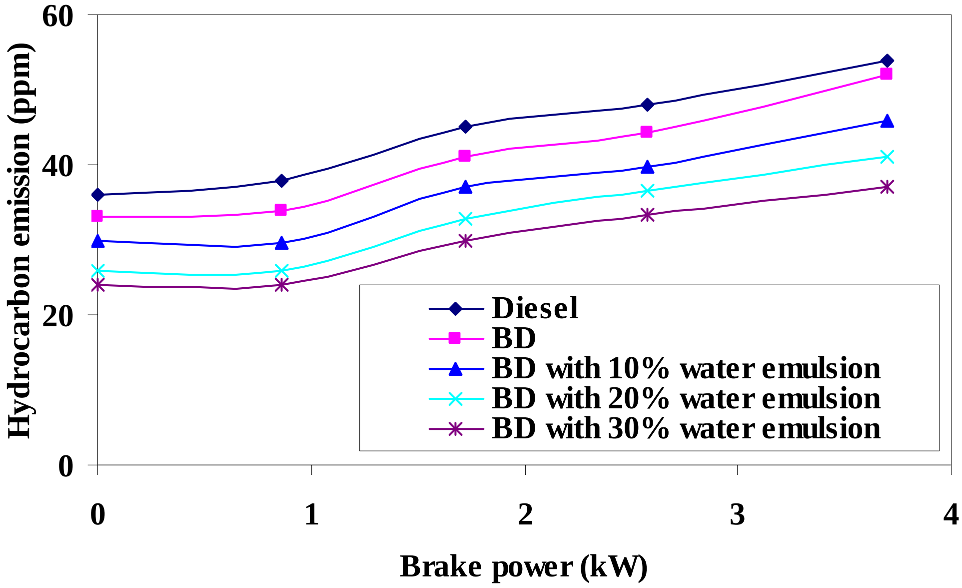

Fig.6.Variations of HC emission with BP

The variations of hydro carbon emissions (HC) with brake power for different fuels have been shown in Fig. 6. The production of HC emission depends upon mixture strength and the availability of oxygen quantity and fuel viscosity, in turn atomization. The HC emissions of water emulsified biodiesel fuels are lower than that of diesel and biodiesel. This may be due to the micro explosion phenomenon on the emulsified biodiesel, which improves the combustion process and hence the reduction of HC emissions. The hydro carbon emission of diesel and biodiesel fuel are 54ppm and 51ppm where as for 10%, 20% and 30% water emulsion of biodiesel are 46 ppm 41ppm and 37ppm respectively at full load. It is observed that 30% emulsified biodiesel showed 29% reduction in HC emission whereas 21% and 12% reduction is observed for 20% and 10% emulsified biodiesel respectively compared to biodiesel at full load.

Figure 7 depicts the variations of nitrogen oxide emission (NO) with brake power for all test fuels. The NO emissions are formed by oxidation of the atmospheric nitrogen at sufficiently high temperatures [15]. The NO emission is increases while the load is increased for all the test fuels. It is also observed that the NO emissions are increased at full load due to more oxygen molecules present in the biodiesel as compared to diesel [14]. It is observed that NO emissions of water emulsified biodiesel fuels are found decreasing than diesel and biodiesel at full load. This may be due to the lower peak combustion temperature, due to the presence of water in the emulsified fuels, reduces the formation of Nitrogen oxide emissions at full load. The NO emission of diesel and biodiesel fuel at full load is 496ppm and 538ppm respectively, where as for 10%, 20% and 30% water emulsion of biodiesel are 451ppm, 409ppm and 379 ppm respectively at full load. It is observed that 30% emulsified biodiesel showed 30% reduction in NO emission than biodiesel, whereas 24% and 16% reduction is observed for 20% and 10% emulsified biodiesel respectively at full load.

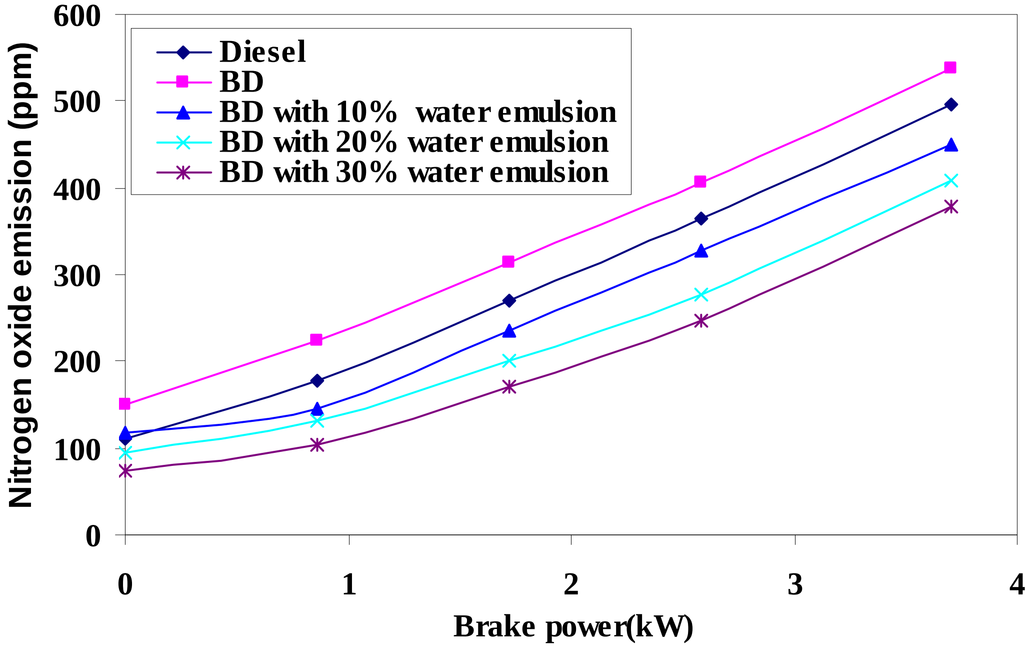

Fig.7 Variation of NO emission with BP

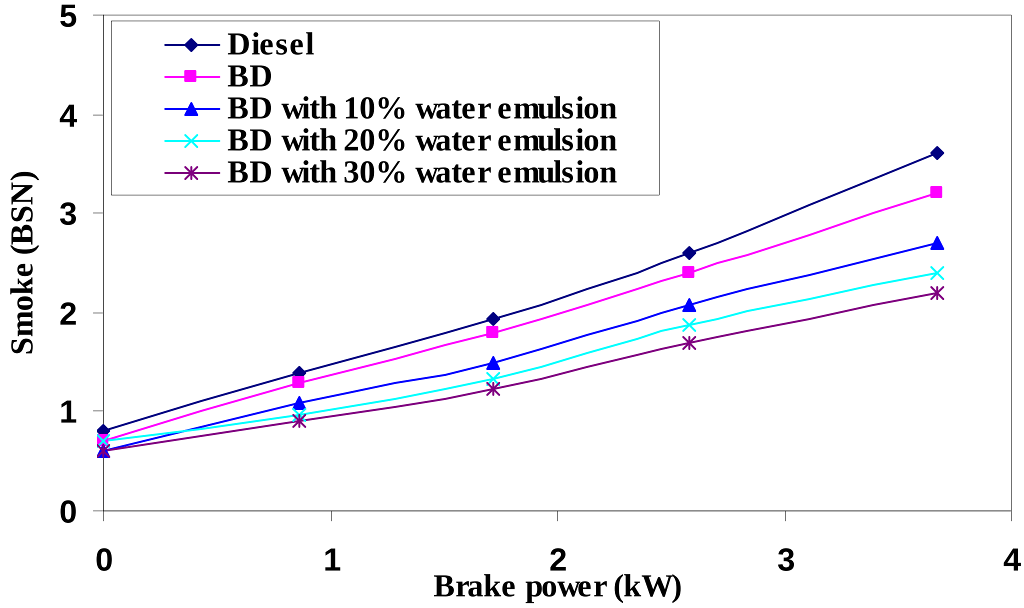

Fig 8. Variation of smoke emission with BP

The variations of smoke emission with brake power at different loads for all test fuels have been shown in Fig. 8. The smoke emission of biodiesel is lower than diesel fuel due to more oxygen molecules present in the biodiesel [14]. Water emulsified fuels show considerable reduction in smoke compared to biodiesel at full load. This may be due to water gets vaporized by absorbing the heat energy during combustion process. This increases the ignition delay period of emulsified fuels. This increase in delay period improves the mixing process which leads to faster combustion reaction and hence the reduction of smoke emission. It is observed that 30% emulsified biodiesel showed 32% smoke reduction than biodiesel, whereas 25% and 15% reduction is observed for 20% and 10% emulsified biodiesel respectively compared to biodiesel at full load.

3. COMBUSTION CHARACTERISTICS

1.Cylinder pressure and Heat release rate..

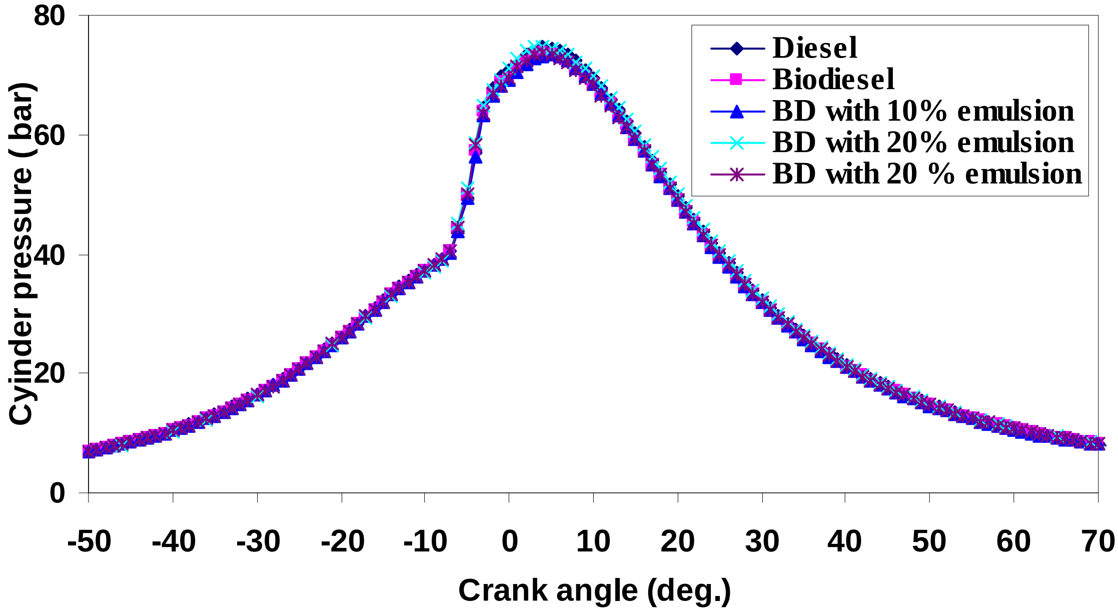

Fig.9 Variation of cylinder pressure with CA

Figure 9 shows the variations of peak pressure with crank angles at full load for all test fuels. The peak pressure for 30%, 20% and 10 % emulsified biodiesel fuels shows higher compared to diesel and biodiesel at full load. The vaporization of water in the combustion chamber created increased ignition delay period in emulsified fuels as compared to diesel and biodiesel. The higher ignition delay period increases the premixed combustion period for emulsified fuels. This leads to higher peak pressure during expansion stroke. Due to the increase in ignition delay period more amount of fuel is burned, thus increases the heat release rate in the premixed burning stage. It is observed that 30% emulsified bio diesel have more peak pressure than other two emulsified fuels. The peak pressure for diesel and biodiesel are 72 bar and 70 bar, whereas for the 10%, 20% and 30% emulsified biodiesel are 72.5 bar, 74.5 bar and 74.2 bar respectively at full load.

Figure 10 shows the variations of heat release rate with crank angles at full load for all test fuels. The heat release rate for diesel and biodiesel shows lower compared to emulsified biodiesel at full load. The vaporization of water in the combustion chamber created higher ignition delay period in emulsified fuels as compared to diesel and biodiesel. The ignition delay period affects the heat release rate. The higher ignition delay period increases the premixed combustion period for emulsified fuels. It is observed that the heat release rate is higher for 30% emulsified bio diesel than other two emulsified fuels. The heat release rate for diesel and biodiesel are 110 J/deg.CA and 105 J/deg.CA, whereas for the 10%, 20% and 30% emulsified biodiesel are 112 J/deg.CA, 114 J/deg.CA and 116 J/deg.CA respectively at full load.

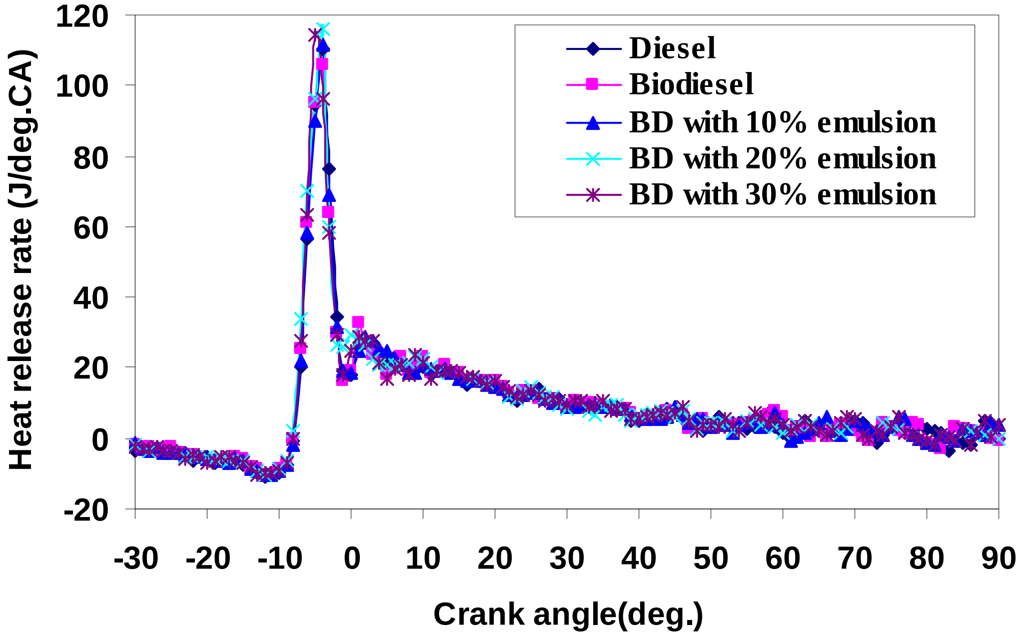

Fig.10 Variation of Heat release rate with CA

IV. CONCLUSIONS

In this study, the experiment was conducted to study the performance, combustion and emission characteristics of a diesel engine with 10%, 20% and 30% water emulsified biodiesel and the results were compared with the biodiesel fuel. From this experimental study the following conclusions were drawn.

1. The brake thermal efficiency is increased by 3.23%, 7.0% and 6.67% for 10%, 20% and 30% emulsified biodiesel compared to biodiesel at full load.

2. The exhaust gas temperature is decreased by 26% for 30% emulsified biodiesel and for 20% and 10% emulsified biodiesel is 16% and 6% is observed respectively compared to biodiesel at full load.

3. The CO emission is increased for all emulsified biodiesel due to water content present in the biodiesel, whereas the HC emission is decreased by 29% for 30% emulsified biodiesel and for 20% and 10% emulsified biodiesel it is 21% and 12% respectively compared to biodiesel at full load.

4. The NO emissions are decreased by 30% for 30% emulsified biodiesel and 24% reduction for 20% emulsified biodiesel and 16 % reduction for 10% emulsified fuel compared to biodiesel and full load.

5. The smoke emission decreased by 32% for 30% emulsified biodiesel and 25% and 15% reduction in smoke is observed for 20% and 10% emulsified biodiesel respectively compared to biodiesel at full load.

6. The higher peak pressure and heat release rate is observed for 10%, 20% and 30% water emulsified biodiesel compared to biodiesel at full load.

From the detailed study, it is observed that 20% emulsified biodiesel showed best performance and 30% emulsified biodiesel showed best emission reduction than biodiesel at full load.

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