PERFORMANCE AND EMISSION CHARACTERISTICS OF B20 CARDANOL BIOFUEL WITH METHANOL AS ADDITIVE IN SINGLE CYLINDER DIESEL ENGINE

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Abstract— **This study investigated the performance and emission characteristics of diesel engine operated with different blends of cardanol, which is obtained from cashew nut shell oil and methanol used as an additive to blend. Experiments have been conducted on a single cylinder four-stroke constant speed, water-cooled direct injection diesel engine. The engine was fuelled with the diesel and B20 blends of cardanol without methanol and B20 with methanol at different load condition and injection timing of 27.5 deg btdc. From the experimental results it was found that for the blend B20 with methanol has positive effect over the performance and emission because of methanol's higher latent heat of vaporization. Increase in the brake thermal efficiency of B20 with methanol by 2.08% as compared to B20 without methanol. Decrease in the emission of B20 with methanol, NOx reduced by 23.2%, UBHC reduced by 2.1% and CO reduced by 8% as compared to B20 without methanol. Hence, Methanol can be used as additive to improve performance and emission characteristics of single cylinder diesel engine for B20 cardanol blend.**

Keywords: Cardanol, Methanol, UBHC, NOx, Injection timing, btdc, biofuel, CNSL

1.Introduction

Biodiesel is one of the most promising alternative to the fosile fuel. It is renewable, biodegradable, non toxic and has almost very close property to that of diesel fuel [1]. The advantages of biodiesel over diesel fuel are higher combustion efficiency, lower sulfur and aromatic content, higher cetane number and higher biodegradability. The main disadvantages of biodiesel over diesel fuel are its higher viscosity, lower energy content, higher cloud point and pour point, and higher nitrogen oxide (NOx) emission. Biodiesel offers safety benefits over diesel fuel because it is much less combustible, with a flash point greater than 423 K compared to 350 K for petroleum based diesel fuel [2].

Several studies have been extensively investigated concerning biodiesel like sunflower oil, Pongamia oil, palm oil, Jatropha oil etc. Among all the biodiesel in this investigation cardanol has been taken to study, since studies related to cardanol are scanty, hence an attempt has been made to investigate the effect of cardanol as biofuel source material on CI engines. Cashew nut shell liquid (CNSL) is a unique natural source for unsaturated long- chain phenols, Obtained during the processing of cashew nuts [3]. CNSL is extracted by various methods like roasting nuts and collecting expelled liquids, extraction with hot CNSL without charring the kernels, superheated steam treatment method, solvent extraction method and pyrolysis [4]. DR-CNSL-Double Refined Cashew nut Shell Liquid is the cashew nut shell Liquid (CNSL) obtained by pyrolysis. It mainly consists of two naturally produced phenolic compounds: Anacardic acid 90% Cardol or cardanol 10% [5].

So for additives used for biodiesel was ethanol, cyclo-alkanes, dimethyl carbonate and diethyl carbonate. In this work methanol is used as an additive in the cardanol based biofuel due to methanol has high latant heat of vaporization. It has been identified that the usage of biodiesel fuel reduces carbon monoxide, hydrocarbon and particulate matter emissions but nitric oxide emissions are increased compared to diesel fuel operation. Several techniques like retarded fuel injection timing, recycled exhaust gas and after treatment devices are employed for reducing nitric oxide emissions from an engine. It is observed that these techniques while reducing nitric oxide from the exhaust of an unmodified engine suffer from one or more disadvantages because of the inherent trade-off with respect to particulate matter or cost. Addition of methanol to biodiesel has been considered as an option to reduce nitric oxide formed during biodiesel or its blends operation with diesel in compression ignition engine because methanol burns cleaner when it is blended with diesel and produces lesser carbon monoxide, HC and oxides of nitrogen, since it has higher heat of vaporization which results in cooler intake process, therefore it reduces the peak temperature inside the combustion chamber leading to lower NOx emissions and increased engine power [6].

2. Objective

The main objectives of the present investigation are:
1. To find the properties of Cardanol as per ASTM conditions.

2. To study the properties of Cardanol-Diesel-Methanol blends at various proportions.
3. Compare the results of Cardanol biofuel blends with additives and without additive to diesel.
4. To examine the potential of Cardanol as an alternative fuel for CI engine at different blending conditions.
5. To determine the effect of oxygenated additives added to Cardanol blends on the performance and emission characteristics.

3. Materials and Methods

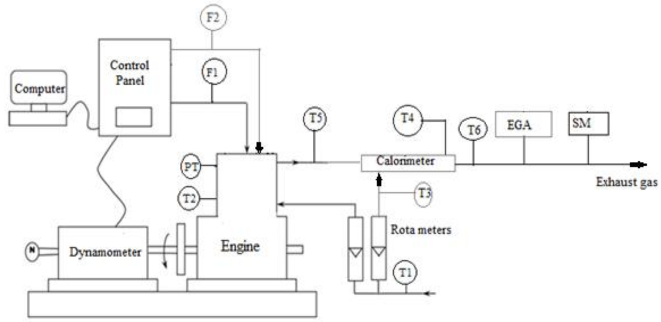
In this work, double refined cardanol is selected as biofuel with oxygenated based additives such as Methanol. Since cardanol is a phenolic compound extracted from honey comb structure (shell) of a cashew nut does not produce any glycerol during transesterfication process.Here methanol is blended with cardanol to a constant of 10%, because the flash point comes to room temperature when it is added with biofuel at higher concentrations and calorific value gets reduced. Moreover if the methanol is added more than 10% it gets separated with biofuel [8]. Hence it was decided to use 10% methanol as additive.

3.1. Engine set up and measurements

The experimental work was carried out on a computerized, single cylinder, four-stroke water cooled, and naturally aspirated, direct injection diesel engine. A schematic representation of experimental set up is shown in Fig. 1 the engine has a compression ratio of 17.5:1, 27.5 deg btdc fuel injection timing and produces BHP of 5.2kw@1500rpm.

The engine is directly coupled to a eddy current dynamometer for power measurements. The detailed specifications of the engine are given in Table 1. The air flow rate was measured by means of differential pressure unit. The signals are interfaced to computer through an analog and digital converter (ADC) card PCI-1050 which was mounted on the motherboard of the computer. Inlet temperature of exhaust gas in calorimeter is measured by temperature sensor which is connected to control panel. Thermometer is also mounted in exhaust line of Calorimeter to measure the exit temperature of exhaust gas. The computer software Engine Soft Version 2.4 will be used for recording the test parameters.

The emissions mainly carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO) were measured using an AVL DiGas 444 five gas analyzer. CO and CO_2 were determined as percentage volumes; NOx and HC were in ppm. The engine performance and emissions characteristics were recorded at different loads ranging from 0% to 100% in step of 25% at a constant speed of 1500 rpm.



1)T1 Inlet Engine water Temperature	2)T2-Outlet Engine Jacket water Temperature	3)T3-Inlet Temperature of Calorimeter
4) T5- Exhaust gas Temperature before Calorimeter	5) T6-Exhaust gas Temperature after Calorimeter	6) SM-Smoke meter
7) F2-Air Intake DP unit	8) PT-Pressure Transducer	9)N-RPM Decoder
10)T4-Outlet Calorimeter Water temperature	11) EGA-Exhaust Gas Analyzer	12) F1-Fuel Flow DP (Differential pressure unit)

Engine make	Kirloskar Tv1
Brake power	5.2 kW
Number of cylinder	1
Method of cooling	Water cooled
Bore x Stroke	87.5X 110mm
Type of ignition	CI
Compression ratio	17.5:1
Fuel injection	Direct Injection
Injection timing	27.5 deg btdc

3.2. Fuel properties analysis

Prior to conducting the experimental studies, a careful fuel analysis needs to be carried out. The fuel properties can influence the fuel droplet size, the size distribution, spray characteristics, fuel evaporation, combustion temperature and pressure as well as emissions.

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Fuel Blends	Calorific Value (MJ/Kg)	Flash Point (^{0}C)	Fire Point (^{0}C)	Kinematic Viscosity@40^{0}C (cSt)	Density@ 40^{0}C (Kg/m$^{3)}$
Diesel	42.06	74	81	3.57	826
B20	41.56	96	104	4.88	856
B20M10	39.29	48	56	4.09	849
Cardanol	39.28	224	236	6.42	910

The biofuel properties for the blends B20, B20M10, cardanol and diesel were investigated, such as kinematic viscosity, flash point, fire point, calorific value, etc. using standard instruments. Then, blend of B20 and B20M10 was selected for performance and emission investigations.

3.2.1. Kinematic viscosity, density and Calorific value

Viscosity is a measure of the internal fluid friction of fuel to flow, which tends to oppose any dynamic change in the fluid motion. Fuel viscosity affects injector lubrication and atomization. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, resulting in leakage or increased wear [7]. Considering the plain cardanol it has high viscosity crossing the ASTM standards but after adding 10% methanol to the prepared blend the viscosity gradually decreases which is an important property of methanol, which makes the fuel easy flow in the pipeline and results in good combustion.

The heating value or calorific value of a fuel is the magnitude of the heat of reaction at constant pressure or at constant volume for the complete combustion of unit mass of fuel. A bomb calorimeter was used to find the calorific value for various blends and with additives. Generally B20 has higher CV than B20M10 because methanol has low energy content and hence the CV of B20M10 gets reduced which can be observed from the Table2.

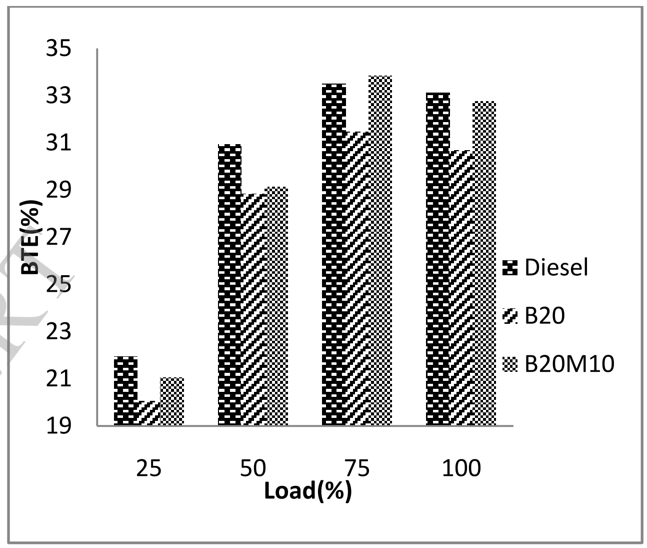
3.2.2. Flash point and fire point

It is the minimum temperature at which the fuel will gives off enough vapours to produce an inflammable mixture (fuel vapour and air) above the fuel surface, when the fuel is heated under standard test conditions. Flash point varies inversely with the fuel's volatility [7]. It can be observed from Table 2 that for B20, flash and fire point is higher than diesel Whereas, in case of B20M10, it was found to be decreasing .This is because of volatility of methanol and hence the quantity of methanol is kept to 10% since the flash and fire point of B20M10 comes to room temperature if the composition of methanol is increased.

4. Results and Discussion

4.1.Brake Thermal Efficiency:

Fig.2 shows variations of brake thermal efficiency for diesel, B20 without methanol and B20 with Methanol as additive. B20 showed less BTE compared to diesel at all loading conditions operating at 27.5 deg btdc injection timing. The BTE of B20 blend at 75% and full load is found to be 6.08% and 7.3% lesser than diesel. Then at remaining loads i.e at 25% and half load is 8.6% and 6.8% lesser than diesel.



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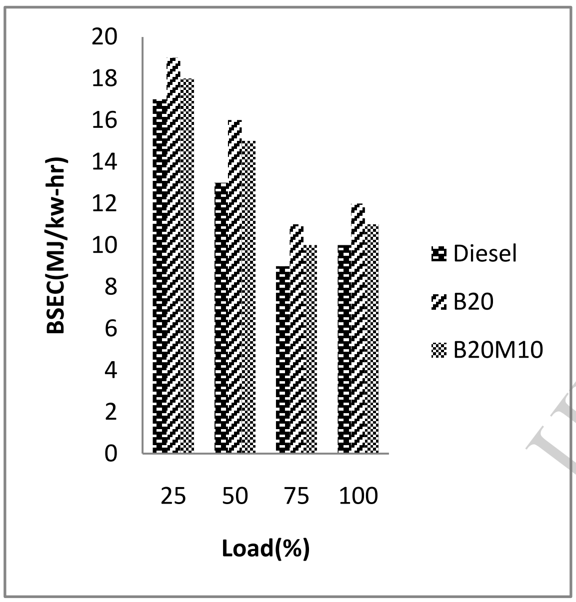
Whereas for B20M10 the BTE showed greater efficiency slightly of 1.01% than diesel at 75% load but whereas at full load the BTE showed 1.08% decrease than diesel. In case when compared with B20 the biofuel blend B20M10 showed increase in efficiency at all loads. At 75% and full load the BTE is7.5% and 6.7% higher than B20 whereas in remaining load, at 25% and half load the BTE is 5.03% and1.07% higher than B20. In all cases the brake thermal efficiency increases with increase in load. This is because, alcohol blending with various blends of biofuel improves brake thermal efficiency due to the faster burning of alcohol in the blend. The brake thermal efficiency with methanol biofuel blends was observed to be more because of better fuel properties of Methanol such as lower density, higher energy content, good atomization, vaporization and combustion that have resulted from lower viscosity and higher volatility of biofuel blended with methanol. It is expected that a wider flammability limits of methanol results in lean burn operation and contributes an increase in thermal efficiency with biodiesel-methanol blends at higher load conditions. The combined effects of higher oxygen content, higher flame speed and improved spray characteristics (lower viscosity) may result in higher burning rate of the blend over the neat biodiesel in the diffusion combustion phase dominated higher loads contributing to the observed increase in thermal efficiency [9].

4.2.Brake Specific Energy Consumption:

Figure 3 shows variation of Brake Specific Energy Consumption for B20, B20M10 blends and diesel. Here, BSEC of plain blends is compared with BSEC of diesel. Also, BSEC of blends with additives is compared to that of plain blends. All comparisons are made on percentage basis.



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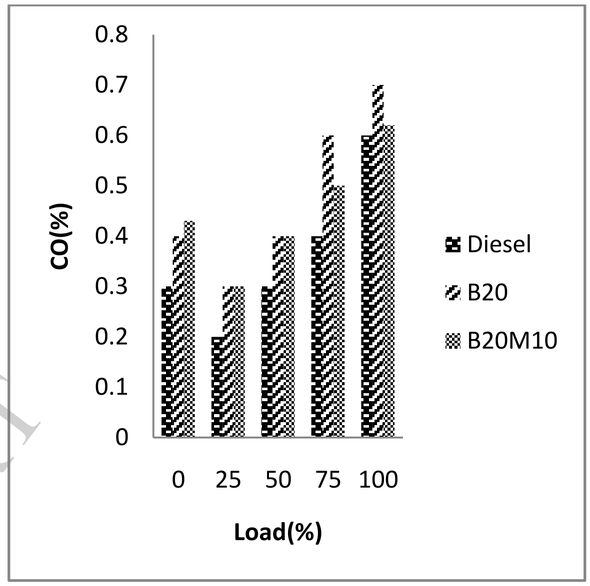
BSEC is the energy input required to develop unit brake power. BSEC values for the biofuel blends from the graph is found to lower for diesel. At 27.5 deg btdc injection timing the BSEC values showed decreasing trend with load, for test fuels. Maximum BSEC observed at 25 % load. Biofuel blend B20 showed higher BSEC compared to that of diesel at all loads. In case with additive BSEC was higher than diesel at all loads. When compared with and without additives of biofuel blends there was significant reduction in BSEC for with additives than without additives at all loads. That is for B20M10, the BSEC shows 11.11% and 10% higher than diesel at 75% and full loads. When B20M10 compared with B20 the BSEC is 9.09% and 8.3% lower at 75% and full load, whereas at 25% and half load the BSEC is 5.2% and 6.2% lower. This improvement in BSEC can be attributed to the chemical reaction of methanol when it is blended with biofuel which in turn improves the combustion of fuel.

4.3. Carbon Monoxide:

Carbon Monoxide is a product of incomplete combustion. Incomplete combustion may result due to lack of oxygen in combustion. For blends with additive, B20M10 at 75% load the CO emission is 25% higher than diesel and at full load it there is no change with diesel. In case of biofuel blends with and without methanol for blend B20M10 CO emission at 75% and full load is 16.6% and



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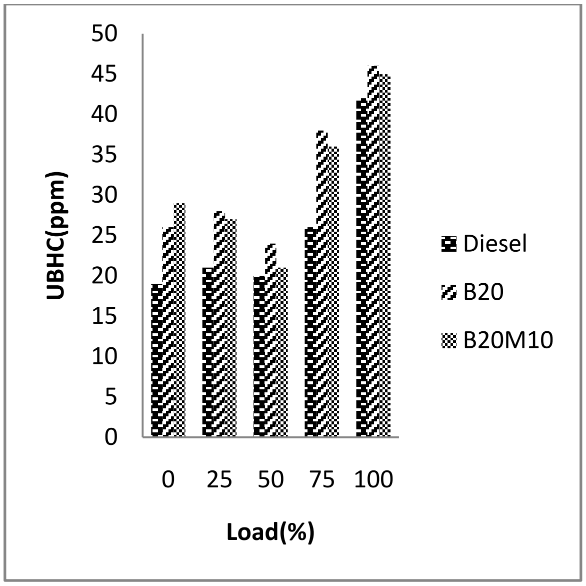
14.2% lower than B20, Whereas at 25% and half load the CO emissions are same. Carbon monoxide emissions increases with higher blends, and increases slightly more after 20% blends. The CO emissions increase as the air fuel ratio becomes greater than the stoichiometric value. CO concentration in the exhaust emission is negligibly small when a homogeneous mixture is burned at stoichiometric air–fuel ratio mixture or on the lean side stoichiometric. With increasing Cardanol percentage, CO emission level increases, also the higher emissions observed at full load condition is due to higher fuel-air equivalence ratio [10].

4.4. Unburnt Hydrocarbons (UBHC):

Comparisons of UBHC for various fuel blends with methanol are done with that of diesel and also, with that of plain blends. UBHC of plain blends are compared with UBHC of diesel. Also, UBHC of blends with additives is compared to that of plain blends.The plain B20 blends



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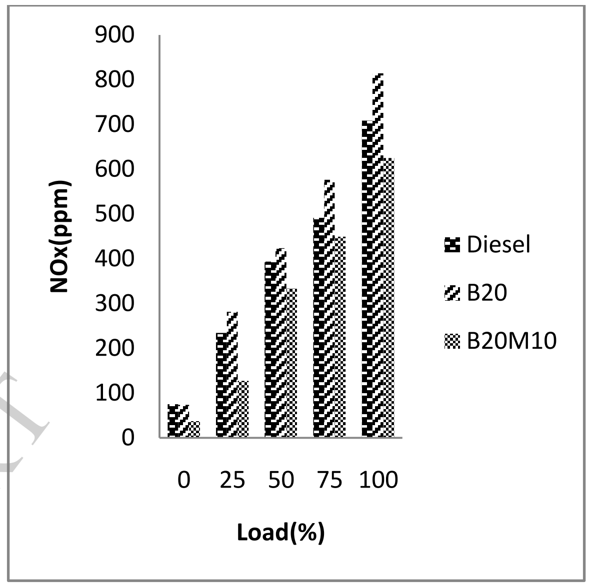
showed higher UBHC emissions when compared with diesel at all loads. At 25%,half,75% and full load the UBHC emission was 33.33%,20%,46.1% and 9.5% higher than diesel. When B20M10 compared with diesel the UBHC emission shoed increase in trend at all loads. At 75% and full load the UBHC is 38.4% and 7.1% higher than diesel. When the B20M10 blend is compared with B20 the UBHC emission showed increase in trend especially at 0 load but whereas at the remaining loads the UBHC emission showed decrease in trend. At 0 load the UBHC is 11.5% higher than B20, then at 25%, half, 75% and full load the UBHC is 3.5%, 12.5%, 5.2% and 2.1% lower than B20 respectively.

UBHC emissions decreased as the oxygen in the combustion chamber increased, with oxygenated fuels. Also, higher cetane number of biofuel reduces the combustion delay, which is related to decreases in UBHC emissions. In general, it is observed that the HC emissions are slightly higher for biodiesel-methanol blend at low load conditions and with increase in load the differences in HC emissions are insignificant between the two fuels. The higher HC emissions observed for the blend at low load conditions because the reason is that at low load conditions the quantity of fuel injected is lower resulting in a leaner mixture, the methanol addition lowers the cylinder gas temperature due to its cooling effect, the combined effect of leaner mixture and the lower gas temperature results in incomplete combustion of a significant portion of the blend leading to higher HC emissions [6].

4.5.Nitrogen Oxides (NO_X):

Figure 6 shows variation of NOx for B20, B20M10 blends and diesel. From the fig it is observed that at the actual injection timing the NOx emissions for diesel and blends is increasing at all loads. In case of additives blended with biofuels the emissions for B20M10 blends shows decrease in NOx emissions at all loads with diesel which is due to the application of methanol additive. B20M10 shows minimum NOx emissions than diesel at all loads. At 25%,50%,75% and full load the NOx emission emission



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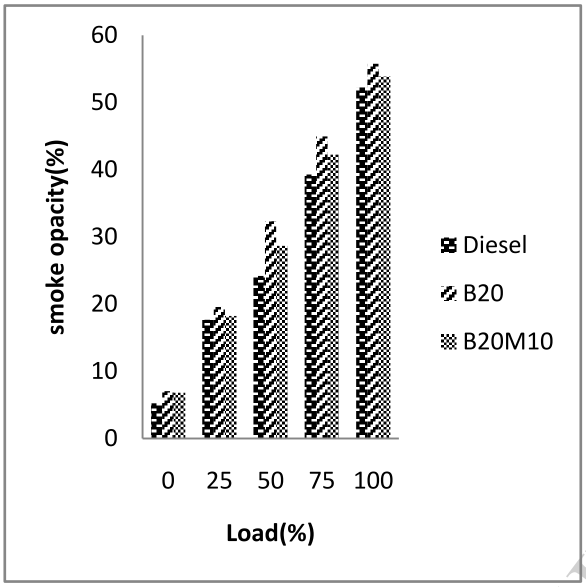
is 45.7%, 15.2%, 8.5% and 11.7% lower than diesel. Whereas when compared with B20 at 25%,50%,75% and full load the NOx emission is 54.8%, 21.2%, 22.04% and 23.2% lower than B20. The formation of NOx highly depends on in-cylinder temperatures, the oxygen concentration and residence time for the reaction to take place. Also, at full load, fuels show a small difference in NOx. This is because the cooling effect of alcohols is less influential at higher loads. At high combustion (flame) temperatures, N2 and O2 in the combustion chamber disassociate into their atomic states and participate in a series of reactions. For the alcohol blends several mechanism are involved. Firstly, the oxygen in the fuel might enhance NOx formation. Secondly, the cooling effect of alcohol, due to the higher latent heating, might lower the combustion temperature and hence reduce NOx formation. Thirdly, alcohol can lead to an increase of burned in the premixed mode because of its lower cetane number and thus an increase in the combustion temperature. This behavior is attributed to the oxygen content of methanol and cetane number which is higher than that of the other alcohols [8].

4.6. Smoke Opacity (SO):

Figure 7 shows the variation of smoke opacity (SO) for B20 blends and diesel at 27.5 deg. btdc injection timing for all load conditions. The smoke opacity for the cardanol based blends initially is higher than the diesel at all loads because the cardanol contains more number of carbon atoms than diesel since it has 15 carbon content in its chemical structure. But after adding methanol the smoke opacity for cardanol blends decreased at all loads.



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In case of B20M10 blend shows increase in SO emission at all loads with diesel, at 25%,50%, 75%, full load the SO emission is 3.2%,18.5%,7.5% and 1.9% higher than diesel, whereas when compared with B20 the SO emisssion decreased at all loads. At 25%,50%, 75% and full load the SO emission is 6.9%, 11.3%, 6% and 3.39% lower than B20 blend. The higher is the alcohol content, the higher reduction in smoke opacity. The lower smoke opacity can be explained because the presence of fuel oxygen reduces probability of rich zones formation (high local fuel–air ratio) and promotes the oxidation of soot nuclei in fuel combustion. This result indicates that the oxygen provided by methanol is more efficient than oxygen corresponding to other alcohol like ethanol because methanol contains 50 mass% oxygen and ethanol contains 34.8 mass% oxygen [8].

6. Conclusions:

The study conducted on the CI engine with diesel and cardanol blends with methanol as additive at actual injection timing leads the following conclusions:

1. Addition of 10% methanol showed changes in properties of cardanol blends.
2. For B20M10, BTE was improved by 2.08%;
3. BSEC was reduced by 8.3%.
4. In case of emissions 8%, 2.1%, 1.89% and 23.2% reductions were observed in CO, HC, SO and NOx respectively.

Hence, 10% Methanol can be used as additive to improve performance and emission characteristics of single cylinder diesel engine for B20 cardanol blend.

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