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Utilization of Oxygenate with CNSO Diesel Blends (B20) in a CI Engine using Dual Fuel Technology

Ashok Kumar*[1], K. Rajan*, and M. Rajaram Narayan*

Abstract – In today's world, as the technology is progressing day by day, the availability of oil-based fuel resource is getting depleted. The demand for an alternative fuel resource to sustain and advance the technological development is linearly increasing. To meet this challenge, experiments have been conducted with suitable engine modifications in a 4-stroke single cylinder water-cooled direct injection (DI) diesel engine at 1500 rpm and 3.78 KW power. The aim of this experimental investigation is to use oxygenate of ethanol and isobutanol along with B20 in a diesel engine via the DF combustion mode. In this experiment, the pilot fuel of B20 and the port fuel of oxygenate were injected at different flow rates of 10%, 20% and 30% by volume. The results of different flow rates were analyzed. This B20 blend improves the emission characteristics of the engine with an insignificant reduction in the engine performance. The result indicates, substantial emission reductions in carbon dioxide (CO_2), oxides of nitrogen (NO_X) and smoke opacity with a marginal reduction in Brake thermal efficiency (BTE) in comparison to B20 without the oxygenate under similar load conditions.

Keywords – CI engine, CNSO, dual fuel, ethanol and isobutanol.

1. INTRODUCTION

To make the world emergent, optimum use of an engine in all aspects is essential. With the continuous use of fossil fuel and coal-based power plants, the consequence has been climate changes and rise in sea level. Diesel engine is one among the best to use the fossil fuel but the operational requirement of the engine is different from the normal thermodynamic cycle. The basic advantage of diesel engine being high compression ratio, it allows using low energy alternative fuel like alcohol. Continuous uses of fossil fuel, increases the global temperature due to its vicious life cycle in various applications. The mere number of engine based applications, makes it alarming. Higher CO_2 emission being the main source for greenhouse effect, its exponential release is of great concern for the researchers since the advent of the century. Hoeven *et al.* [1] has stated that 43% of CO_2 emission is produced from combustion of coal, 36% from oil and 20% from gas. Basically, alcohol as a fuel is used in a spark ignition (SI) engine as it has high volatility and Octane number. But, when alcohol fuel is used in a single mode compression ignition (CI) engine, the difficulty is that the higher % of alcohol cannot mix with diesel fuel that leads instability. In the 1970s, a single fuel blended with the diesel was used to run an engine. Presently, the concept of DF combustion mode is implemented by using the mix of 2 bio-fuels or injecting diesel fuel blends in a tested engine. Zhu *et al.* [2] has stated that the oxygenate have high Octane number and as a renewable feed stock and its' utilization is a promising alternating fuel. Alasfour *et al.* [3] reported that alcohols like ethanol, isobutanol give cold start whereby, the performance is significantly reduced when the engine is operated in cold weather. To overcome the cold start while using oxygenates, the engine is initially warmed up using only diesel. Ethanol and isobutanol are an oxygenated fuel that is burnt in a lean pre-mixed mode. Kowalewicz *et al.* [4] revealed that the DF combustion mode is a better option for the modern high speed CI engine than either the Diesel or Otto cycle. At the present situation, enough warnings are in place to use proper cycle for superlative and efficient results. For this experimental test, the DF combustion mode has an edge over the normal test mode as in the dual cycle the heat supplied are at constant volume and constant pressure. But in case of diesel engine, the heat is supplied only at constant pressure [5]. The emissions and engine performance of a diesel engine run-on bio-diesel has been examined by many investigators. The bio-diesel used in the experiments is subjected to trial for evaluating its performance. The different vegetable oils such as sunflower, rapeseed, soybean, karanja, and rubber seed oil, etc. have been used [6]. In the case of fossil fuel, there exists well known and documented data. But for edible or non-edible fuel, which has different composition and properties, separate results have to be obtained by various experimental methods. Still most of the countries largely depend on fossil fuel that leads to global warming and various emission environmental issues. To use an alternate fuel with different oxygenates will control these ill-effects. In the past and present research work, it has been proposed for a different technique to improve the combustion process and reduce the exhaust emission without any modification to the diesel engine. Papagiannakis *et al.* [7] reported that various research studies of DF combustion mode for low and intermediate loads have poor utilization of gaseous fuel, poor performance along with higher emission concentrations of carbon monoxide

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(CO) and hydrocarbon (HC). However at higher loads, fuel efficiency and performance slightly improves.

Renovation and increase in the number of automobiles worldwide, has enormously increased the consumption of diesel and gasoline. Fossil fuel being a non-renewable energy source and simultaneous rapid depletion of its reserves warrants the need to search for alternative fuels for automobiles [8]-[10]. Thus, the growing trend toward the usage of diesel engine has caused an increase in experimenting with alternate fuel sources that are renewable in nature. This paper studies the possibility of CNSO as an alternative fuel for a diesel engine in a DF combustion mode. Gerpen *et al.* [11] conducted experiments with CNSO diesel blends to obtain the performance and emission characteristics in the presence of ethanol and isobutanol at different flow rates using DF combustion mode. Padla *et al.* [12] investigated the variations in engine efficiency and emissions. The result showed that the unburnt HC and CO emission increases, combustion efficiency marginally decreases with increase in % of ethanol. Again, during the next stage, utilization of isobutanol has advantages over ethanol due to higher cetane number (15), lower heat of vaporization and higher heating value. The DF technology was first developed to utilize natural gas in a diesel engine because of availability. During DF combustion mode, limited mix of natural gas and diesel fuel resulted in better performance and emission. Also, the experimental investigation of alcohol fuels of ethanol and isobutanol showed similar trends. The major advantage of DF combustion mode is that the emission of CO_2, NO_X and smoke reduces. There are several fuels that can be used in a DF combustion mode. Nwafor *et al.* [13] reported that in his experiment, ethanol and isobutanol were selected as an induction fuel (port injection fuel) and B20 as a pilot fuel. During the experiment, alcoholic fuels were supplied into the intake manifold using a conventional port-fuel injector while the diesel fuel is injected directly using a common rail injection system. In this DF concept, induction fuel is injected into the intake manifold that gets ignited by injecting B20 fuel into the cylinder near the top dead center (TDC). This concept could be a true alternative for on-off road heavy duty vehicles without any energy density and fuel distribution complications. Popuri *et al.* [14] reported that ethanol and isobutanol have higher Octane numbers and oxygen content. But, isobutanol has high production cost having limited use in a food industry. Combustion of alcohol in SI engine has better results compared to gasoline. Nielsen *et al.* [15] reported that it has some practical difficulties in the ignition of the air fuel mixture in a CI engine due to high ignition temperature, low Cetane number, and high latent heat of evaporation. In order to overcome the above difficulties in a CI engine, the DF combustion mode has been followed. Karim *et al.* [16] analyzed and compared isobutanol and ethanol. Performance and emission characteristics of isobutanol produced better result. Isobutanol has high net heating value, latent heat of vaporization, which allows it to easily mix with diesel fuel. Its stoichiometric air fuel ratio is very close to that of diesel fuel. As its oxygen content is approximately 22%, direct replacement of diesel is difficult. The thermal efficiency of dual cycle may increased by increasing the heat supplied during constant volume (v=c) and decrease the heat supplied during constant pressure (p=c) while keeping the total heat supplied constant. Hence, the efficiency of dual cycle can be increased by increasing the pressure ratio (P2/P1). The cycle of operation is shown in Figure 1. On comparison, between Otto, Diesel and dual cycle, the heat rejection rate is less in an Otto cycle and more in diesel. Dual cycle heat rejection rate is lesser than that of diesel cycle. Thereby, dual cycle engine efficiency is higher than Diesel engine. The objective of this experimental investigation is to use oxygenate of ethanol and isobutanol along with B20 in a diesel engine via the DF combustion mode. The pilot fuel of B20 and the port fuel of oxygenate were injected at different flow rates of 10%, 20% and 30% by volume. The results of different flow rates were analysed.

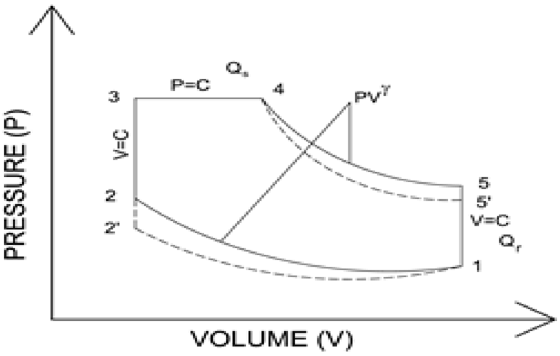

Fig. 1. P–V diagram for the air standard dual cycle.

2. TEST FUEL AND PROPERTIES

CNSO is a resourceful by-product of the cashew industry. The nut has a shell of 3 cm thickness whose inside is a soft honey comb structure, which has a dark reddish brown viscous liquid. Inside the shell is the kernel wrapped in a thin skin known as the testa. The cross-sectional view of CNSO is shown in Figure 2. The researchers found that the constituents of cashew nut are kernel 20-25%, kernel liquid 20-25%, testa 2% with the rest being shell [17]. The raw material for the manufacture of CNSO is the cashew nut shell. Thus, the name cashew nuts shell oil, which is the pericarp fluid of the cashew nut. It is often considered as the better and cheaper material for unsaturated phenols [18]. CNSO has innumerable applications in polymer based industries such as in friction lining, paint, varnish, laminating resin, rubber compounding resin, cashew cement, surfactant, epoxy resin, foundry chemicals and also as intermediates for chemical industry. The composition of CNSO is approximately 52% cardanol, 10% cardol and 30% polymeric material. The production potential for the product is very high [19]. The total production of raw cashew nut in India is approximately 2 lakh tonnes and at 10% recovery by weight, the production potential for CNSO is about 20,000 tonnes. Cashew cultivation now covers a total area of 0.70 million Hectares of land. Pyrolysis is generally used to describe a process in which the preferred product~~s~~ are oil. Pyrolysis is one of the thermo-chemical conversions in absence or limited supply of air. Risfaheri *et al.* explains the pyrolysis procedure of CNSO, which is done in a reactor at a vacuum of 5kPa and temperature maximum of 400-600°C in steps of 50°C. The volatiles removed on pyrolysis are gradually condensed in a pre-weighed condensation from atmospheric to ice bath of 5-7°C [20].

The decarboxylase cardanol is termed as CNSO biodiesel. The biodiesel obtained from CNSO does not require for further processing like transesterification. Comparatively, it has moderate viscosity, easily combustible and high miscibility with diesel. The tested properties of diesel, CNSO, ethanol, isobutanol and B20 are presented in Table 1.

Fig. 2. Cross-secional view of CNSO.

Table 1. Properties of tested fuels.

Properties	Diesel	CNSO	Ethanol	Isobutanol	B20
Density (kg/m³)	820	943	790	810	845
Kinematic Viscosity (cSt)	3.2	30.24	0.983	0.97	5.6
Cetane number	47	50	7	15	48
Calorific value (MJ/kg)	43.2	38.53	27	33.3	42.8
Flash Point (°C)	62	198	26	28	179
Auto ignition temperature (°C)	210	206	385	415	207

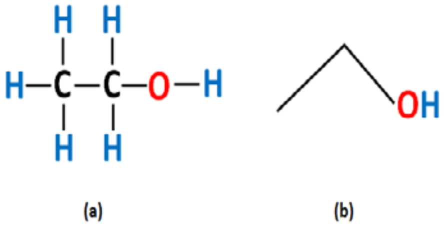

Fig. 3. (a) Molecular structure of ethanol (b) Skeleton formula of ethanol.

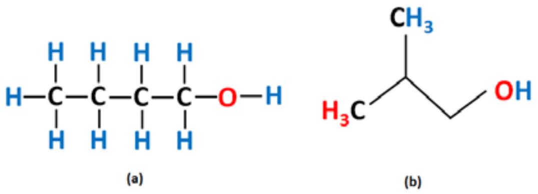

Fig. 4. (a) Molecular structure of isobutanol (b) Skeletal formula of isobutanol.

2.1 *Ethanol*

It is a bio-mass based renewable energy source. This can be produced from crops like corn, vegetables and fermentation of sugar by yeast at relatively low cost. Ethanol, also commonly called as ethyl alcohol, drinking alcohol~~,~~ or simply alcohol is the principal type of alcohol found in alcoholic infusion. Having high Octane number, ethanol is considered as the best fuel for SI engine. It is also considered as a fuel for a CI engine. It is a neurotoxic psychoactive drug being one of the oldest recreational drugs used by human. It can cause intoxication when consumed in sufficient quantity. Ethanol is used as a solvent, antiseptic, fuel and the active fluid in a modern (post-mercury) thermometer having a low freezing point. It is a volatile, flammable, colourless liquid with a strong odour [21]. Its molecular and skeleton structures are shown in Figures 3 (a) and (b). The chemical formula is CH_3CH_2OH.

2.2 *Isobutanol*

Isobutanol is produced naturally during the fermentation of carbohydrates and may also be a by-product of the decay process of organic matter. It's molecular and skeleton structures are shown in Figures 4 (a) and (b). The chemical formula is $CH_3\ (CH_2)_3OH$. The biosynthetic pathway used to produce isobutanol was first discovered in species of bacteria from the genus Clostridium. This pathway has been genetically engineered into several species of micro-organisms, which are more easily manipulated by current scientific methods than micro-organisms of the genus Clostridium [22]. Although these engineered organisms are capable of producing isobutanol, it is small in quantities unsuitable for commercial use. These organisms are being moved toward commercialization through genetic modifications, which allows higher yields of isobutanol. Cyanobacteria is a phylum of photosynthetic bacteria. Cyanobacteria is used for isobutanol synthesis, when genetically engineered to produce isobutanol. Isobutanol producing species of Cyanobacteria offer several advantages as biofuel synthesizer. Cyanobacteria grow faster than plants and also absorb sun light more efficiently than plant. Hence, Cyanobacteria can be replenished at a faster rate than the plant matter used for other biofuel synthesis. Cyanobacteria can be grown on non-arable land [23]. This eliminates competition between food and fuel sources. The supplements necessary for the growth of Cyanobacteria are CO_2, H_2O and sunlight. CO_2 is derived from the atmosphere ensuing in bioremediation. Cyanobacteria do not need plant matter to synthesize isobutanol. Since plant matter is not used by this method of isobutanol production, the necessity to source plant matter from food sources and create a food-fuel price relationship is avoided

2.3 Material and Environmental Conditions of Cashew Nut tree

The cashew tree is evergreen that grows up to 12 meters high with a spread of 25 meters. Its extensive root system allows it to tolerate a range of moisture levels and soil types. Commercial production is advisable only in well-drained, sandy or red soils. Annual rainfall needs to be at least 889 mm (35 inches) and maximum of 3048 mm (120 inches). Cashew trees are most frequently found in coastal areas. The main commercial product of the cashew tree is the nut. The major producing regions are East Africa and India. In Brazil, the cashew apple is used to prepare Jam, soft and alcoholic drinks. The cashew apple is an edible fruit, which is attached to the externally grown nut by a stem. The cashew apple is shown in Figure 5. In its raw state, the shell of the nut is leathery. It contains the thick vesicant oil, CNSO within a sponge like interior. A thin testa skin surrounds the kernel and keeps it separated from the inside of the shell. The processing methodology CNSO is shown in Figure 6.

Fig. 5. Cashew apple.

2.4 Biodiesel

Biodiesel is an alternative fuel made from renewable biodiesel source such as vegetable oils (edible and non-edible) and animal fat. Nabi *et al.* [24] describes vegetable oil is usually esters of glycol with different chain length and degree of saturation. It may be seen that vegetable oil contains a substantial amount of oxygen in their molecules. Practically the high viscosity of vegetable oil of 30-40 centistokes as compared to that of Diesel having 3.8-6.4 centistokes leads to unfavourable pumping, inefficient mixing of fuel with air that contributes to incomplete combustion, high flash point results in increased carbon deposit formation and inferior coking. Due to these problems, vegetable oil needs to be modified to bring the combustion related properties closer to those of diesel oil. The fuel modification is mainly aimed at reducing the viscosity and increasing the volatility. All countries are at present heavily dependent on petroleum for transportation and agricultural machinery.

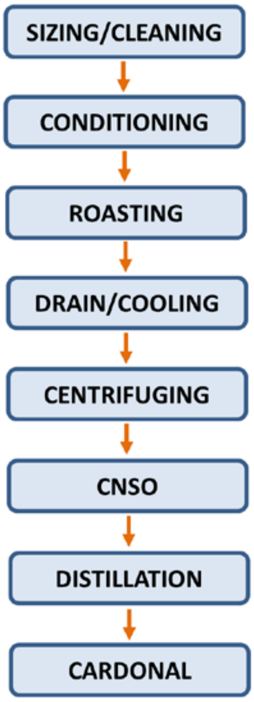

Fig. 6. CNSO processing methodology.

The fact that a few nations together produce the bulk of petroleum has led to high price fluctuation and uncertainties in supply for the consuming nations. This has led to look for an alternative fuel that they themselves can produce. Among the alternative being considered are methanol, ethanol, biogas and vegetable oil. Vegetable oil has certain features that make them attractive as substitute for Diesel fuel. Suggestions and research have been made to produce biodiesel by using alternative or greener oil resource like non-edible oil. The non-edible vegetable oil such as Madhuca indica Jatropha curcas, CNSO and Pongamia pinnata are found to be suitable for biodiesel production that are in experimental stage.

2.5 Parametric Study of Dual fuel

The parameter study in this section serves as a guideline for the interpretation of results. Three important ratios for DF operation are defined. B20 as pilot fuel with ethanol and isobutanol as port injection fuel are chosen. Output parameters are thermal efficiency and air-excess ratio. A substantial portion of the inlet air is displaced by B20. The effect of DF operation of B20 with ethanol and isobutanol is difficult to predict the thermal efficiency from first principles, since it is governed by a complex combined combustion process. In this work, overall thermal efficiency is obtained from experimental data [25].

3. EXPERIMENTAL PROCEDURE

Before measurement is taken, the engine is run by diesel fuel for 10 minutes to heat up the engine. Thereafter, B20 as pilot fuel is fed at constant flow rate and in the 1st stage, ethanol as port fuel is supplied approximately at 10%, 20% and 30% by volume. During the 2nd stage, isobutanol is supplied at same proportion by volume.

3.1 Experimental Setup and Engine Specification

The experimental setup used for this study was carried out on a vertical, 4-stroke naturally aspirated water-cooled single cylinder direct injection (DI) compression ignition engine. The parameters are as follows; bore 80 mm, a stroke length of 110 mm, a displacement volume of 553 cm^3 and compression ratio of 17.5:1. The rated maximum power was 3.78 kW and running at constant speed of 1500 rpm. The detailed and dimensions specifications of the test engine are summarized in Table 2. The engine was connected to a rope brake dynamometer. The intake system of the test engine was modified for a duel fuel mode. The photographic view of experimental setup of engine is shown in Figure 7.

3.2 Gas Analyzer

The engine exhaust of CO, HC, CO_2, O_2, NO_X were measured with AVL-44 Di gas analyzer. The exhaust gas analyzer specifications are shown in Table 3. The smoke opacity was measured with a filter smoke number (FSN) after reducing the pressure and temperature in the expansion chamber. The performance and emission characteristics were evaluated for 3 trials and average were taken for analysis.

Left- side View of Setup **Right-side View of Setup**

1. Orifice tank **2.** Air inlet to carburettor **3**. B20 fuel tank **4**. Burette for B20 fuel **4'**. Burette for alcoholic fuel 5'. U-tube manometer for Carburettor **5**. U-tube manometer for engine. **6**. Temperature indicator **7**. Carburettor **8.** Inlet manifold for alcoholic fuel **9**. Air inlet to engine **10**. Alcoholic fuel tank. **11**. Test Engine **12**.Loading device (Rope brake dynamometer)

Fig. 7. Experimental setup.

Table 2. Engine specifications.

Parameters	Description
Engine type	4- stroke Single Cylinder DI Compression ignition engine
Make	Kirloskar oil Engine Ltd., India
Cooling type	Water- cooled
Number of cylinder	One
Bore Diameter, D	80 mm
Stroke, L and Displacement volume	110 mm and 553 cm^3
Injector opening pressure	20 MPa
Injector opening angle	23^o b TDC
Orifice diameter	13.6 mm
Compression ratio	17.5:1
Rated power	3.78 kW
Speed	1500 rpm

Table 3. Exhaust gas analyzer specification.

Measured quantity	Measuring range	Accuracy
CO	0…10 % Volume / 0.01% Volume	±0.03 % Volume
HC	0…20000 PPM / 1 PPM / 10 PPM	±0.4 % Volume
CO_2	0…20% Volume / 0.1% Volume	±10 PPM
O_2	0…22 % Volume / 0.01 % Volume	±0.1 % Volume
NOx	0…5000 PPM / 1 PPM	±50 PPM

4. RESULT AND DISCUSSION

4.1 Performance Characteristics Measurement

Engine control and monitoring were performed using an objective based on rapid-system with electronic sensors and actuators installed beside the engine. The engine performance measurements were calculated and recorded using personal computer (PC), which is connected to the engine via data transfer unit.

4.1.1 Effect of DF Operation on Brake Specific Fuel Consumption (BSFC)

The variation of BSFC in DF combustion mode for B20 and at various flow rates of ethanol and isobutanol are shown in Figures 8 and 9, respectively. BSFC is defined as the ratio of mass fuel consumption to the brake power. At low engine load of 25% and 50%, the BSFC for DF combustion mode for both the fuels was higher than single fuel combustion. It was seen that at higher engine loads, BSFC significantly decreases. In comparison to isobutanol, BSFC of ethanol is marginally high. At full load, the BSFC values of diesel, B20, B20+E10, B20+E20, B20+E30 are 0.23, 0.34, 0.37, 0.39, 0.43kg/kw-hr. Isobutanol BSFC values for B20+Ibu10, B20+Ibu20, B20+Ibu30 are 0.36, 0.37, 0.39 kg/kw-hr respectively. During the experiment, ethanol and isobutanol had little fuel leakage from the fuel system due to low fuel viscosity. This may causes significantly increase in BSFC.

4.1.2 Effect of DF Operation on Brake Thermal Efficiency (BTE)

The variation of BTE in DF combustion mode for B20 and at various flow rates of ethanol and isobutanol are shown in Figures 10 and 11, respectively. In all cases, BTE increased with increase in load. This is due to reduction in heat losses and increase in brake power with increase in load. Using alcohol, BTE decreases at lower engine load condition while it increases at higher load condition. So, at low engine loads, the mixture could be too lean to support combustion. As alcohol has lower Cetane number, the energy is released in a very short time. The values of BTE of diesel, B20, B20+E10, B20+E20, B20+E30 are 26.42, 28.54, 27.63, 26.76, 26.12% respectively. Whereas isobutanol BTE values for B20+Ibu10, B20+Ibu20, B20+ Ibu30 are 27.97, 27.28 and 26.36% respectively at full load condition. The BTE with ethanol addition slightly decreases and is close to diesel, but the maximum BTE is in B20. In case of isobutanol, the trend is same as ethanol, but BTE marginally increases for isobutanol. Experimental result also showed that BTE of B20+Ibu10 is very close to the B20.

4.1.3 Effect of DF Operation on Exhaust Gas Temperature (EGT)

The variation of EGT in DF combustion mode for B20 and at various flow rates of ethanol and isobutanol are shown in Figures 12 and 13, respectively. The EGT is high with neat CNSO due to low heat release rate and poor combustion. As CNSO has low heat release rate, a part of the combustion extends into the exhaust stroke that leads to increase in combustion duration. Ignition delays result in a delayed combustion and higher exhaust temperature. The maximum EGT is 569^{o}C for B20 and for diesel it is 496^{o}C at full load. In this work, EGT increases linearly as the engine load is increased due to increase in total energy input, which in turn is due to higher BSFC. But EGT was found to be slightly lower in DF combustion mode compared to single-fuel combustion mode. This may attributed to the lower energy content of oxygenate. The values of EGT of diesel, B20, B20+E10, B20+E20, B20+E30 are 496, 569, 485, 483 and 482 ppm, whereas for B20+Ibu10, B20+Ibu20, B20+Ibu30 are 421,212 and 462 ppm respectively. This experimental result shows EGT of B20+Ibu20 gave better result on comparison to diesel, B20 and ethanol.

4.2 Emission Characteristics Measurement

The engine emissions were analyzed using an exhaust gas analyzer. The gas analyzer was equipped with online measuring cells for analyzing different gases of carbon monoxide (CO), carbon dioxide (CO_2) and unburnt hydrocarbons (UHC). The H_2O in the exhaust gases was separated using a draining device. The CO_2, CO and UHC contents were determined using a non-dispersive infrared (NDIR). The data processing and calculations were conducted by the analyzer systems to determine the % and/or ppm (parts per million) of examined gases in each sample.

4.2.1 Effect of DF Operation on Carbon Monoxide (CO) Emissions

The variation of CO emissions in single combustion and DF combustion modes for B20 at various flow rates of ethanol and isobutanol are shown in Figures 14 and 15, respectively. CO emission of CI engine is low in lean mixture operation as it depends on the air fuel ratio. The rate of CO formation is a function of available amount of unburnt gaseous fuel and mixture temperature, both of which control the rate of fuel decomposition and oxidation. From this graph, it is observed that CO emission has increasing trends for ethanol and isobutanol mixing at different flow rates of B20. The values of CO emission of diesel, B20, B20+E10, B20+E20, B20+E30, are 1.55, 1.18, 1.86, 2.22, and 2.36% respectively. For B20+Ibu10, B20+Ibu20, B20+Ibu30 the emission values are 1.68, 1.94, and 2.12% respectively. This is because of alcohol usually produces lower combustion temperature due to their lower heating value and O_2 content. But in comparison, isobutanol has less CO emission then ethanol as it has low water affinity and latent heat of vaporization and its specific gravity is 0.81 [26].

4.2.2 CO_2 Emissions

The variation of CO_2 emissions for single combustion and DF combustion modes for B20 at various flow rates of ethanol and isobutanol are shown in Figures 16 and 17, respectively. It shows that the variation of CO_2 with respect to load in DF combustion mode is lowest than in single fuel combustion mode~~s~~, as single fuel combustion mode~~s~~ has low C/H ratio that CO_2. The values of $C0_2$ emission of diesel, B20, B20+E10, B20+E20, B20+E30, are 7.1, 7.8, 6.2, 6.4, and 6.8% respectively. For B20+Ibu10, B20+Ibu20, B20+Ibu30, the values are 6.1, 6.2, and 6.4% respectively. From these result, CO_2 emission reduce~~s~~ in comparison to B20 and diesel fuel. Experimental result shows B20+Ibu10 gave better result when compared to diesel, B20 and ethanol.

4.2.3 Effect of DF Operation on HC Emissions

The variation of HC emissions in single combustion and DF combustion modes for B20 at various flow rates of ethanol and isobutanol are shown in Figures 18 and 19, respectively. At low and intermediate loads, the HC emission in DF combustion mode is much higher than in single mode. But at higher engine load, the HC emissions were found to be reducing. This is because of alcoholic fuel has lower oxygen content, low cetane number and high Octane number. Hence, the poor combustion result and misfire. Low cetane number causes deteriorated self-ignition characteristic and promote quenching effect. Also, lower density and viscosity of alcoholic fuel could be the reason for increase HC emissions. This causes formation of thinner size of fuel droplets. Due to thinner mixture fuel that travels to the closer section of the walls, it leads to quenching effect that causes unburnt fuel~~s~~. The values of HC emission for diesel, B20, B20+E10, B20+E20, B20+E30, are 98, 88, 192, 159, 214 ppm while for B20+Ibu10, B20+Ibu20, B20+Ibu30 are 113, 136, 202 ppm respectively. But, for isobutanol it is lower than ethanol, because it has low water affinity and latent heat of vaporization.

4.2.4 Effect of DF Operation on NO_X Emissions

The variation of NO_X emission in single combustion and DF combustion modes for B20 at various flow rates of ethanol and isobutanol are shown in Figures 20 and 21, respectively. With increase in engine load, the NO_X emission increases. NO_X emission is caused by higher combustion temperature and O_2 concentration in the cylinder. Alcohol usually produces lower combustion temperature due to their lower heating value and O_2 content. The values of NOx emission for diesel, B20, B20+E10, B20+E20, B20+E30, are 342, 302, 281, 273, 261 ppm while for B20+Ibu10, B20+Ibu20, B20+Ibu30 are 268, 253, 242 ppm respectively. It is observed that the NOx emission reduces at different flow rates of ethanol and isobutanol than that of B20 and diesel fuel. This is because of very high value of latent of vaporization of alcoholic fuel *i.e.* 833 KJ /Kg, whereas for diesel it is 250 KJ /Kg. The higher rate of latent heat causes decreasing trend of NO_X emission. This results in lower NOx concentration in the exhaust at an average of 35% below the single mode combustion. Experimental result showed that the NO_X of B20+Ibu30 gave better result compared to diesel, B20 and ethanol.

4.2.5 Effect of DF operation on smoke emissions (FSN)

The variation of smoke opacity in DF combustion mode with respect to load for B20 at various flow rates of ethanol and isobutanol are shown in Figures 22 and 23, respectively. Smoke is nothing but solid soot particles suspended in the exhaust gas. In single mode, smoke opacity of B20 is higher than that of neat diesel. But in DF mode, the smoke opacity exhibits reduction in trend for B20 at different flow rates of ethanol and isobutanol. The values of smoke emission of diesel, B20, B20+E10, B20+E20, B20+E30, are 3.2, 2.46, 2.23, 2.19, 2.34 FSN while for B20+Ibu10, B20+Ibu20, B20+Ibu30 are 2.1, 1.94, 2.19 FSN respectively Again, comparing the smoke opacity between ethanol and isobutanol additives, isobutanol gives marginally less smoke. This is because of its auto-ignition temperature, density and higher heating value. Experimental result showed that the smoke emission of B20+Ibu20 gave better result in comparison to diesel, B20 and ethanol.

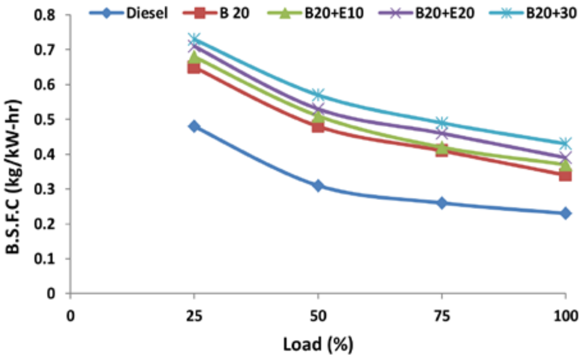

Fig. 8. Variations of BSFC with varying load conditions for different flow rate of ethanol.

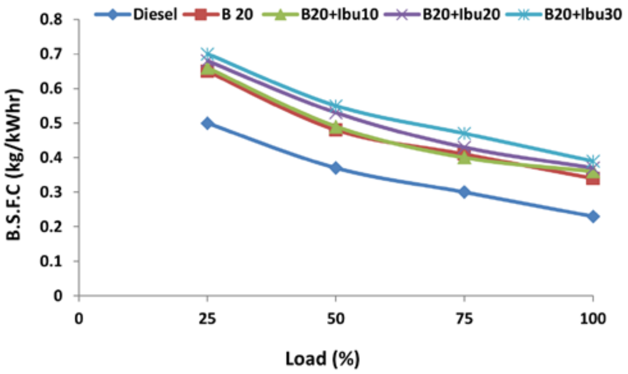

Fig. 9. Variations of BSFC with varying load conditions for different flow rate of isobutanol.

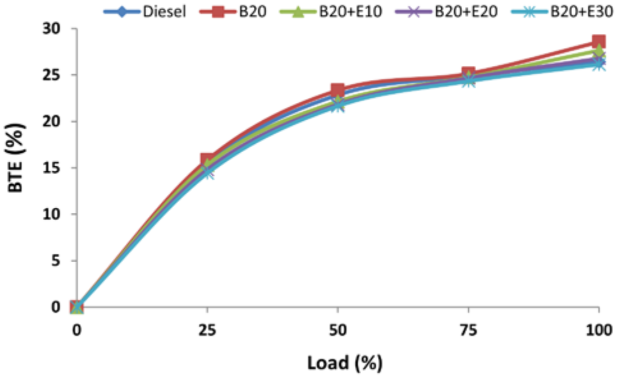

Fig. 10. Variations of BTE with varying load conditions for different flow rate of ethanol.

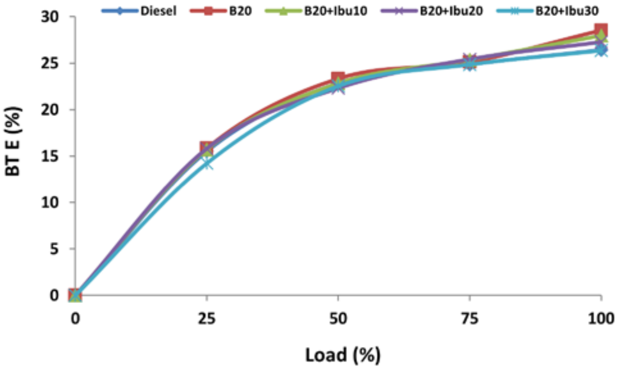

Fig. 11. Variations of BTE with varying load conditions for different flow rate of isobutanol.

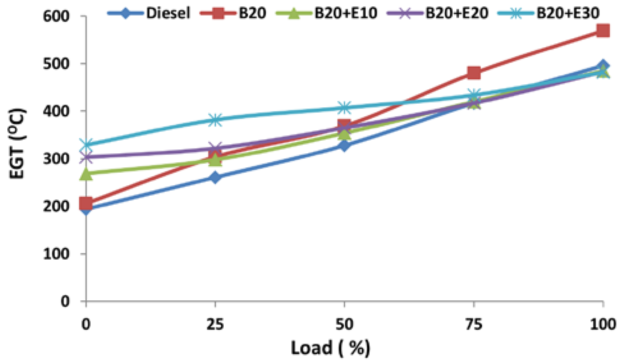

Fig. 12. Variations of EGT with varying load conditions for different flow rate of ethanol.

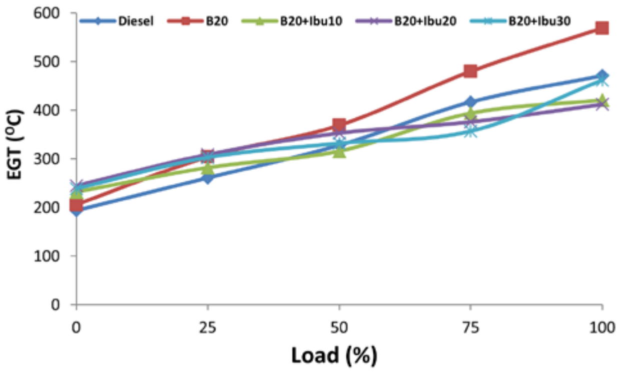

Fig. 13. Variations of EGT with varying load conditions for different flow rate of isobutanol.

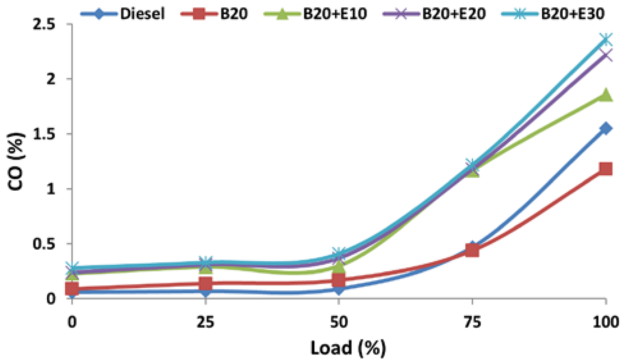

Fig. 14. Variations of CO with varying load conditions for different flow rate of ethanol.

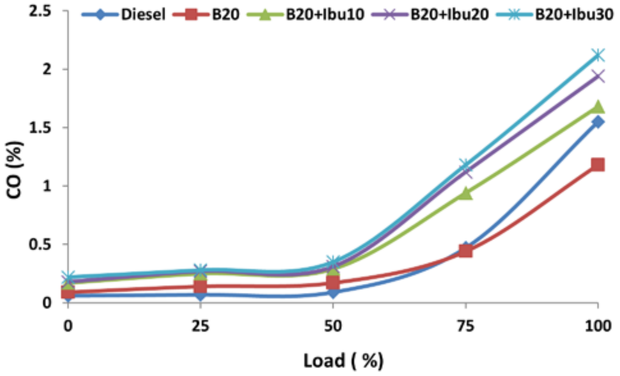

Fig. 15. Variations of CO with varying load conditions for different flow rate of isobutanol.

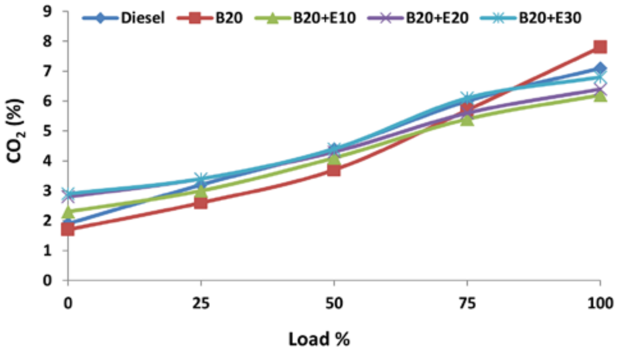

Fig. 16. Variations of CO_2 with varying load conditions for different flow rate of ethanol.

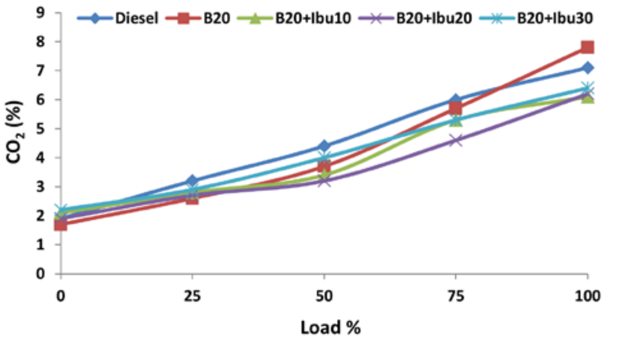

Fig. 17. Variations of CO_2 with varying load conditions for different flow rate of isobutanol.

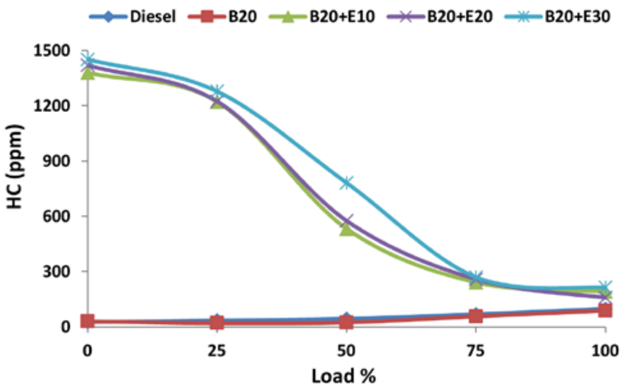

Fig. 18. Variations of HC with varying load conditions for different flow rate of ethanol.

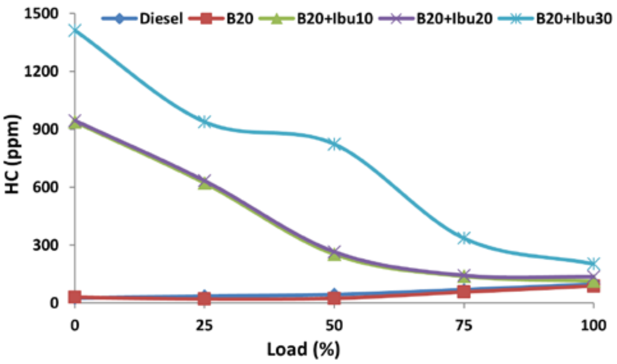

Fig. 19. Variations of HC with varying load conditions for different flow rate of isobutanol.

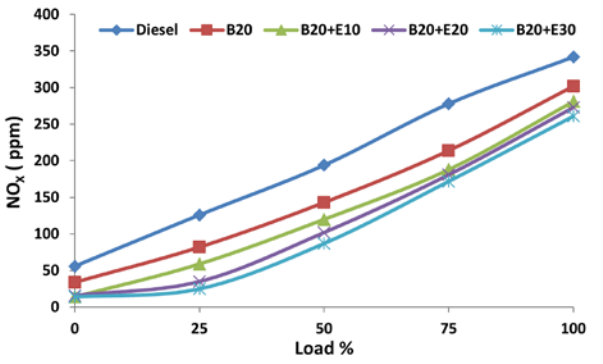

Fig. 20. Variations of NO_X with varying load conditions for different flow rate of ethanol.

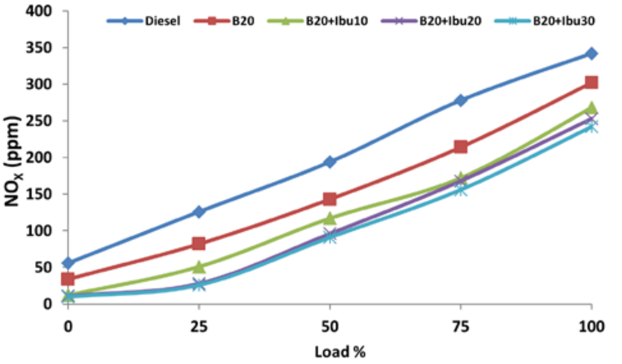

Fig. 21. Variations of NO_X with varying load conditions for different flow rate of isobutanol.

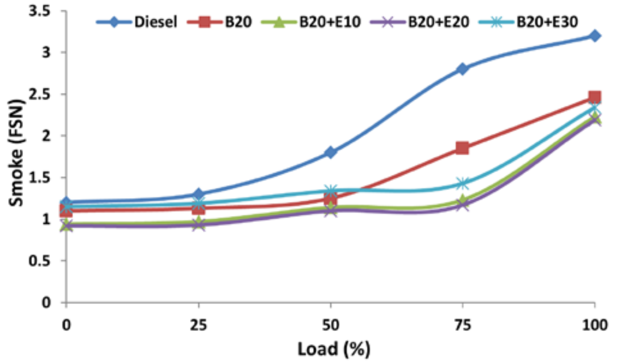

Fig. 22. Variations of smoke with varying load conditions for different flow rate of ethanol.

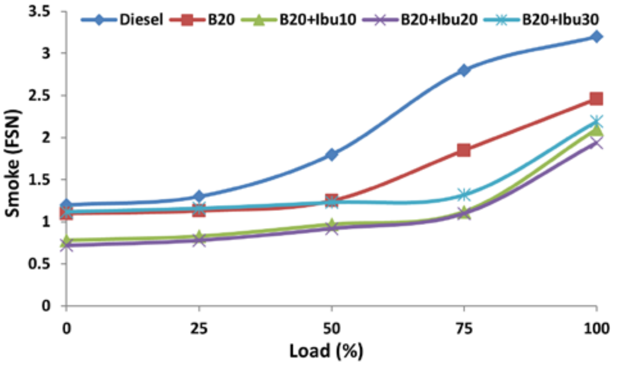

Fig. 23. Variations of smoke with varying load conditions for different flow rate of isobutanol.

5. CONCLUSIONS

The aim of this extensive experimental study is to conduct, evaluate and compare the utilization of B20 with alcoholic fuel using DF injection concept. Experiments were conducted in 4-stroke single cylinder water-cooled DI diesel engine at a constant speed of 1500 rpm and 3.78 kW power with suitable engine modifications. The engine has been properly modified to operate under DF operation while their basic configurations have been maintained. Comparisons of the effect of fuel performance and emissions characteristics in an existing diesel engine were done. In this experimental technique, B20 is injected directly into the cylinder at a constant flow rate with alcohol fuels being alternatively introduced into the intake manifold at 10%, 20% and 30% approximately by volume using port fuel injection (PFI). Concerning engine load, total BSFC increases in DF operation compared to normal diesel operation. For each of the flow rates, BTE shows marginal reduction. EGT was slightly lower for DF mode compared to the single fuel mode. About the pollutant emission, use of alcohol fuel had a positive effect on CO_2 and NO_X emissions. The level of CO_2, NO_X and smoke emissions under DF operation is lower compared to B20. Under DF operation, CO and HC emissions are higher compared to normal B20. The most important objective of the present work has been to demonstrate the possibility to using a CI engine to compare the performance and emissions for both ethanol and isobutanol.

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NOMENCLATURE

BTE	Brake thermal efficiency
B20	Diesel 80% & CNSO 20%.
BSFC	Brake specific fuel consumption
bTDC	Before top dead center
CO	Carbon monoxide
CNSO	Cashew nut shell oil
CO_2	Carbon dioxide
C.I	Compression ignition
DI	Direct injection
DF	Dual fuel
E	Ethanol
Ibu	Isobutanol
kW	Kilo watt
NOx	Oxide of nitrogen
ppm	Part per million (by volume)
PFI	Port fuel injection
S.I	Spark ignition
rpm	Revolution per minute
SFC	specific fuel consumption
UHC	Unburnt hydrocarbon

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