Experimental Investigation of the Emission of Diesel Engine Fuelled by N-Butanol-Diesel Blend

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Abstract: **Smoke and oxides of nitrogen are the most significant emissions of the diesel engines. Fuels, which have a high oxygen content have the potential to reduce smoke and nitrogen emissions. This paper reports the results of an experimental study on the influence of blending n-butanol, an oxygenated additive, with diesel on diesel engine emissions. N-butanol is blended with diesel in different proportions namely B5 (5% n-butanol and 95% diesel), B10, B15, B20, B25 and B30 and the effects on various emission parameters are studied. Tests were performed on a single cylinder, four stroke naturally aspirated diesel engine at a constant engine speed. Experimental test results show that the emissions of carbon monoxide, oxides of nitrogen and smoke opacity are reduced with increasing concentration of n-butanol in diesel.**

1. INTRODUCTION

The diesel engine is currently the most commonly used internal combustion engine, both for stationary and mobile applications. Air quality is seriously affected by diesel engine emissions. Main pollutants emitted by the diesel engine are carbon monoxide (CO), Oxides of Nitrogen (NO_x) and smoke. Advancing technology for diesel engines is required to reduce these emissions from diesel engines. Increasing demands of energy, limited petroleum fuel resources and stringent emission standards are driving the world to look for clean alternative resources (LPG, CNG, biodiesel and alcohols).

In terms of energy consumption, India holds sixth rank in the world and is going to advance to third position by 2020, with increasing rates of 6.8% per annum. In modern economy, economic growth of any country depends on its energy resources and their utilization. Resources which are affordable, accessible and environmentally friendly arr crucial factors that affect the economic growth. Thus, the need for suitable alternative and cleaner fuels is crucial to the sustainable growth of India. [1-2]

The primary reason that the quantity of NO*x* pollutants emitted from diesel engines is greater than that of gasoline engines is the difference in the burning process inside the cylinders. The higher compression-ignition temperature and compression ratio of diesel engines produce higher gas temperatures inside the combustion chamber and on the cylinder surface[3].

Several additives for diesel fuel have been tried in search of a cost effective additive to diesel that reduces the emissions. By adding Ethylene Glycol Monoacetate (EGM) to diesel fuel, brake specific fuel consumption (BSFC), carbon monoxide (CO) and smoke decrease while brake thermal efficiency, carbon dioxide (CO_2) and NO_x increase [4-5]. Blending of Dimethyl carbonate (DMC) or MnO_2 and MgO with diesel fuel results in a decrease in carbon monoxide and smoke while NO_x increases[5-6].

Oxygenated compounds are most widely used among various additives available, because the availability to prepare blends with C.I. and diesel engines so many additives of extra oxygen lead to better combustion and thus lowering emissions. Oxygen content of the additives and its molecular formula has an influence on soot reduction. Blending of 10-20% volume of oxygenatechemicals with diesel fuels reduces soot formation. High quantity of additives alter the chemical and physical properties such as: density, volatility, viscosity and cetane index, significantly.

Alcohols have an additional oxygen atom in their molecular structure. So, they are considered as oxygenated compounds. These oxygenated compounds after blending with diesel oil improve the performance via the increase of thermal energy output and combustion products alteration.

Butanol or n-butyl alcohol or n-butanol is an alcohol having four carbons in its one molecule. Its chemical formula is C_4H_9OH. Isomers of butanol include isobutanol, 2-butanol and tert-butanol. Butanol is a member of "fusel alcohols" (German word for bad liquor) group, alcohols which have good solubility in water and have more than two carbon atoms. It is present in many foods and beverages and naturally occurs as a minor product of the fermentation of sugars and carbohydrates. It is used in fruit, rum, whisky, cream, butter, ices, ice cream, baked goods and cordials. It is also used as artificial flavoring in the United states. It is also used in a wide range of consumer products. Figure 1 shows the structure of n- butanol

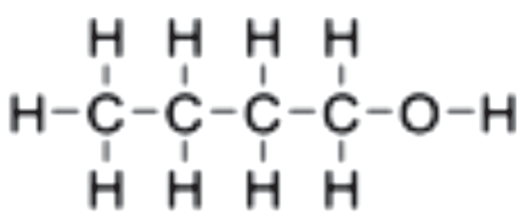

Fig.1 Structure of n-Butanol

There are some properties which are essential to check before use of additives with diesel fuel in the internal combustion engines. Table 1 gives the comparison between physical and chemical properties of n-butanol and diesel.

Table 1 Comparison of physical and chemical properties between n-Butanol and Diesel

Properties	n-butanol	Diesel
Chemical Formula	$C_4H_{10}O$	$C_{10}H_{20}$-$C_{15}H_{28}$
Molecular Weight (g/mole)	74	170
Density (kg/m^3) (15°C)	0.811	0.820-0.845
Boiling Point (°C)	117	180-370
Flash Point (°C)	35	55-85
Auto-ignition temperature (°C)	385	>250
Lubricity (µm)	590	310
Lower heating value (MJ/kg)	34.366	43.4
Latent heat of vaporization (kJ/kg)	0.581	0.27
Cetane Number	<25	40-55
Viscosity (40°C) cSt	2.5	2-3.5
Oxygen Content (wt %)	21.6	0
Carbon Content (wt %)	64.8	84-87
Hydrogen Content (wt %)	13.5	16-13
Sulphur Content (PPM)	0	<50

n-Butanol is a renewable biofuel, as it is less hydrophilic. Butanol has a high cetane number, higher energy content, higher viscosity, lower vapor pressure, higher miscibility, higher flash point than ethanol, so it is more preferable in blending with diesel.

Ethers –Diethyl ether (DEE) or dimethyl ether (DME) - show the tendency to decrease emissions of internal combustion engine. They mainly reduce the smoke and oxides of nitrogen when mixed with diesel fuel [7-9].

Alcohol fuels have a better tendency to decrease emissions of internal combustion engine, due to their lower carbon and sulphur content and high oxygen content than diesel fuel. Alcohol fuels have a high octane number than traditional fossil fuel used as an octane booster for gasoline fuels[10-16].

The alcohols, Methanol and ethanol, which have a high oxygen content, are high-quality alternative fuels for the diesel engine. If blended, the combustion process of diesel engine would be improved and the particulate matter would be reduced effectively. However, with the increasing of methanol and ethanol blending ratio, the cetane number of methanol and ethanol would decrease a lot, causing the problem of poorer self-ignitability [3,17,18,10].

Butanol is one of the primary alcohols. It is better than ethanol and methanol as an alternative fuel for internal combustion engines. Various fuel properties of butanol are closer to fossil fuels. It has a lower auto-ignition temperature than methanol and ethanol, so it can be ignited easily when burned in diesel engine. It releases more energy per unit mass and is less evaporative than ethanol and methanol. It has a higher cetane number than ethanol and methanol.

From the above discussion, it is concluded that blending of n-butanol with diesel will be the best alternative for securing reduction in NOx. This study therefore focuses on the n-butanol-diesel blends to experimentally verify this conclusion from the review of literature.

The objective of this study is to find out the effect of n-butanol-diesel fuel blends on diesel engine performance and emissions. For this, n-butanol is blended with diesel in different ratios in 5% steps namely B5 (5% n-butanol and 95% diesel), B10, B15, B20, B25 and B30 and the effects on BSFC and various emission parameters are studied.

2 THE EXPERIMENT

Blend Prepration:

Different blends of n-butanol and diesel were prepared in 5% increment of n-butanol proportion. The lowest blending proportion is 5% of n-butanol and 95% of diesel, named B5. Other blends uprepared as B10, B15, B20, B25 and B30. Higher blends were not considered as the cost of the blended fuel is not considered economical beyong 30% blending of n-butanol.

Experimental Set-up

A single cylinder, four stroke, direct injection, water-cooled, vertical type, and naturally aspirated variable compression ratio engine is used for research study. The engine can start in both ways- by hand or by self start provided by centrifugal speed governor. The engine's compression ratio can be changed by changing the position of cylinder head up and down.

The engine test rig is shown in Fig.2. It consists of an engine coupled with eddy current dynamometer, smoke meter, exhaust gas analyzer, control panel, computer system, thermocouples and various sensors to measure temperature at different parts of the engine.

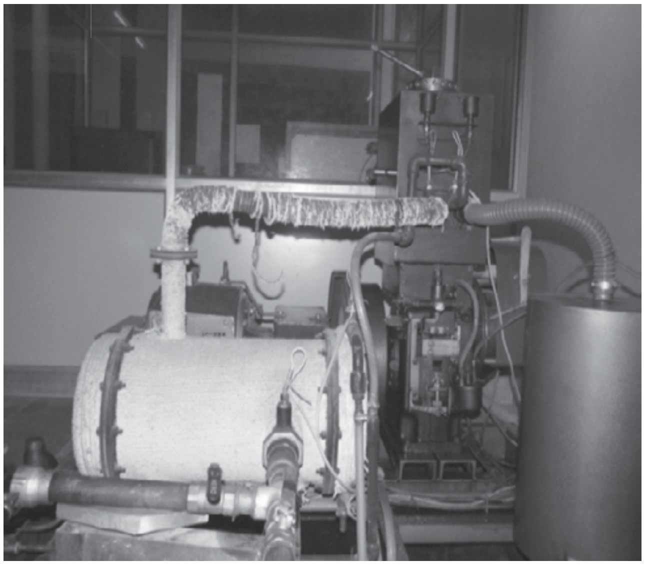

Fig 2 Engine Test Rig

The specifications of the engine are given in Table 2. The eddy current dynamometer is coupled with the engine using pipe coupling to measure the torque of the engine. The load applied on the engine is measured by using a strain gauge type load cell. The load can be varied on the engine with the help of a permanently interfaced computer and instrumentation set-up. Table 3 gives the dynamometer details.

Table 2 Test engine details

Component	Unit	Description
Make	-	TVI, Kirloskar
Type	-	Vertical/Single acting, totally enclosed, high speed compression ignition diesel engine.
No. of Cylinder	-	1
Power Rating	kW	3.67
Speed	rpm	1500
Bore	mm	80
Stroke	mm	110
Cubic Capacity	Liters	0.556
Nominal Compression	-	17.5
Type of Start	-	Self start/Crank start

Table 3. Dynamometer details

Component	Unit	Description
Make	-	Power Mag
Torque rating available	kW	5
Speed	rpm	1500
Ventilation	-	Air-cooled, self-ventilated, Drip-proof, totally enclosed, fin-cooled.
Coil voltage	V.D.C.	90

The exhaust gas has been measured by using i3sys exhaust gas analyzer, model EPM1601. It is used to measure carbon monoxide (CO) and oxides of nitrogen (NO_x) emmissions. Exhaust smoke density and opacity have been measured by using an AVL smoke meter. Table 4 gives the specifications of the exhaust gas analyzer and the smoke meter.

Table 4: Specifications of the exhaust gas analyzer and smokemeter

Equipment		Range
Exhast Gas Analyzer	CO	NDRI, Range 0-15%, Resolution .001 %
	NO_x	Electrochemical, Range 0-5000 ppm, Resolution 1 ppm
Smokemeter	Opacity %	Range 0-100, Resolution 0.1

3 RESULTS AND DISCUSSIONS

Carbon monoxide:

The graph shown in Fig.3 is drawn between carbon monoxide and engine load. With the increase in n-butanol concentration in the blended fuel, a reduction in CO emissions is observed.This can be attributed to higher oxygen content of n-butanol diesel blends that results in complete combustion of fuel.

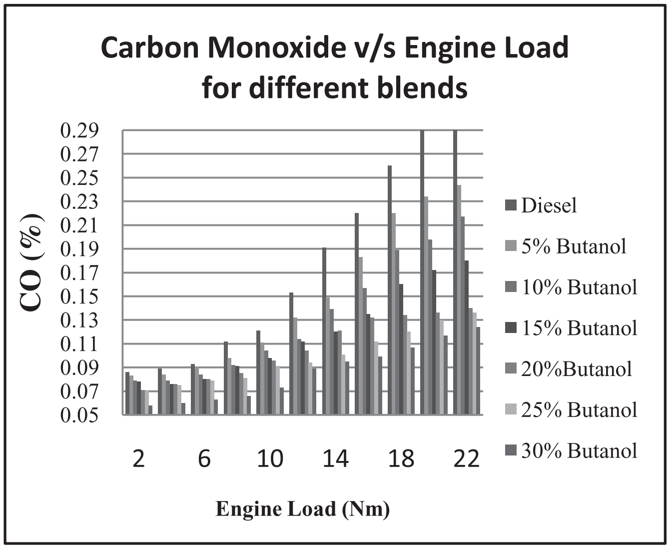

Fig. 3 Comparison of Carbon Monoxide with Engine Load for different blends of n-butanol/diesel

Oxides of Nitrogen (NOx)

The graph shown in Fig. 4 is drawn between oxides of nitrogen and engine load. At all engine loads, emissions of NOx decreased for n-butanol diesel blends with increase in proportion of n-butanol. Presence of oxygen and temperature in the cylinder have major effect on the formation of NO_x. Lower cetane number and increasing content of n-butanol diesel blends can help in the formation of NO_x. Due to lower cetane number there is a longer ignition delay which leads to higher combustion temperature in the cylinder in the premixed combustion mode, whereas there is a lower flame temperature, due to the high heat of vaporization and lower energy content. Due to these factors, there is a decrease in NO_x emissions.

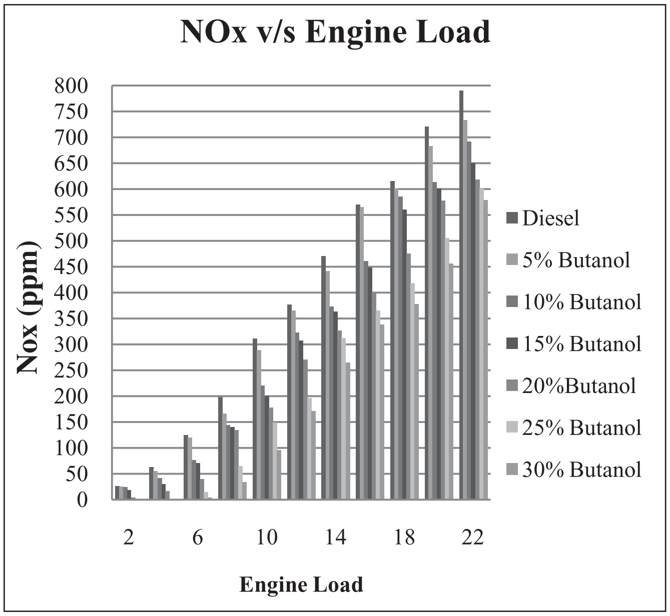

Fig. 4 Comparison of oxides of nitrogen with Engine Load for different blends of n-butanol/diesel

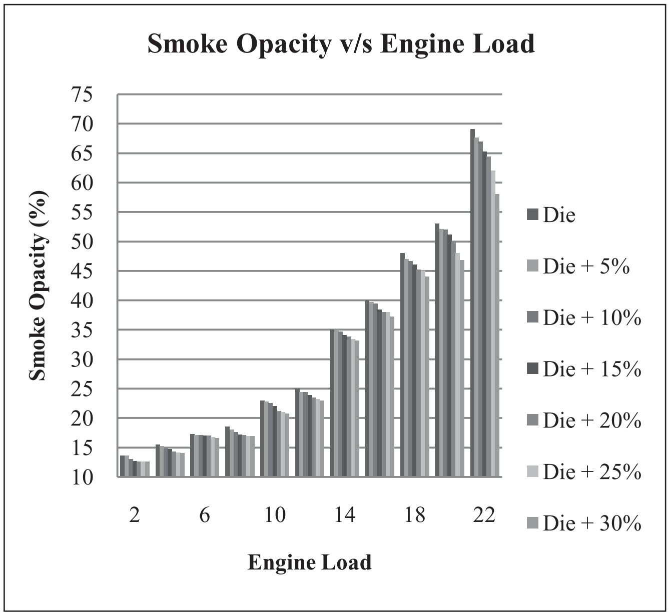

Fig. 5 Comparison of Smoke Opacity with Engine Load for different blends of n-butanol/diesel

Smoke Opacity:

The graph shown in Fig. 5 is drawn between smoke opacity and engine load. Generally emission of smoke follows the CO trend. Emission of smoke is a result of a deficiency of oxygen, they are suspended particles in the exhaust. As shown from the figure smoke opacity reduces with increase of n-butanol concentration in the blend. This is due to lower carbon and higher oxygen content of n-butanol diesel blends. So, when oxygen content increases smoke emission decreases that is why engine operating on n-butanol diesel blends emits less smoke due to lower carbon content as compared to standard diesel fuel.

4 CONCLUSION

We have discussed the various emission parameters of compression ignition engine and experimented with the use of different blends of n-butanol and diesel fuel (B5, B10, B15, B20, B25, and B30). From this research work we concluded the following result.

- The level of carbon monoxide decreases with increasing concentration of n-butanol in the blend. At higher loads decrease in CO is high as compared to lower load conditions.
- Nitrogen Oxides also decrease with increasing concentration of n-butanol in the blend and increases as load increases. More variations occur in middle load conditions. In this experiment NO_x follow the same trend which CO follows.
- Smoke opacity also decreases with increasing concentration of n-butanol in the blend. Normally, smoke opacity shows the same trend with carbon monoxide.

5. Acknowledgment

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