Performance and emission characteristics of fumigated butanol on a duel fuel mode hcci engine

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Abstract: To meet energy demand as well as emission regulations of today's world moved the researchers towards the use of alternative fuels such as alcohols, biofuels in CI engine. Present work is to examine the performance and emission characteristics of fumigated butanol on a duel fuel mode HCCI engine. Experiments were performed for n-butanol fumigation (nBF) at constant speed 1500rpm with fixed mass flow rate under varying engine loads at compression ratio 17.5:1 and injection pressure 210 bar. Obtained test results showed that the mechanical efficiency increased by 7-8%, brake thermal efficiency increased by 7-13%, specific fuel consumption decreased by 4-10%. Emissions like smoke**,** oxides of nitrogen decreased significantly however carbon monoxide & hydrocarbons increased compared to diesel fuel. Finally, it is concluded that nBF method is best suitable for CI engines at medium engine loads for better engine efficiency and less smoke and NO_x emissions.
Keywords: n-butanol fumigation, Duel fuel HCCI engine, Alternative fuels, Performance, Gaseous emissions.

1. Introduction:

Diesel vehicles are major sources for harmful emissions causing environmental pollution and badly effecting human health. Because of rapid increase in urbanization and industrialization supply of fossil fuel reserves are depleting and increasing price. This forced the need for searching alternative fuels with low emissions and to meet rising energy demand with safe emission range. Compared to SI engine, CI engine has less fuel consumption, maintenance, durability etc. but it emits more NO_x and soot emissions. Various studies were conducted on alternative fuels in CI Engine, by four different methods including (1) blending (2) fumigation (3) duel fuel (4) direct usage. Among these blending & fumigation are preferred for optimum results. For blending technique alcohol fuels (like ethanol, methanol, butanol etc.) and biofuels are mostly chosen. But because of low cetane number and heterogeneous mixing with diesel, additives are employed.Fumigation of fuels is another method, used for alternative fuels in CI engine. Where, with help of a carburetor alcohol fuel is added to the intake air during suction stroke, with a slight modification at the air intake system of the engine.

Nicholas C. Surawski et al. [1] and D.K. Jamuwa et al. [3] conducted experiment using fumigated technique with vaporized ethanol and found emissions like oxides of nitrogen, particulate matter were lessen while carbon monoxide & hydrocarbon emissions were raised and η_{bth} improved at high engine loads compared to diesel fuel. Z.H. Zhang et al. [2, 7] tested using fumigated methanol

with DOC (Diesel Oxidation Catalyst) and without DOC, Results showed that without DOC emissions like oxides of nitrogen (NO_x), smoke opacity, particulate mass concentration were reduced but carbon monoxide, hydrocarbon and NO_2 emissions were greater than before. And with DOC, significant reduction in all pollutants observed. Quangang wang et al. [4] observed at

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low, medium engine loads methanol substitution percentage increases and gradually decreases at high engine loads. Z. Sahin et al [5] conducted experiment using Gasoline Fumigation and found engine efficiency increased and brake specific fuel consumption reduces upto 5%. And 5% reduction in fuel cost. Ganesh R.Gawalemass, G. Naga Srinivasulu et al. [6] experimented using ethanol with diesel and ethanol with biodiesel with varying engine loads with different mass flow rates and observed that combustion process was enhanced with better engine efficiency. And NO_X emissions and smoke were minimized but with considerable rise in carbon monoxide & hydrocarbon emissions. G. Jamuna Rani et al. [8] conducted experiment using hydrogen and blend of esterified Mahua biodiesel (M25) and test results showed that η_{bth} is increased, specific fuel consumption decreased. Emissions like carbon monoxide, hydrocarbon reduced and NO_x emissions increased. A. Imran et al. [9] in alcohol fumigation BSFC increase at all engine loads and η_{bth} decrease at initial load and then increases from mid load to full engine load. R. Vallinayagam et al [10] investigated using fumigated pine oil and diesel fuel can be replaced by pine oil from 55-65% at full load, 30-40% at low engine load conditions. Almost every emission except NO_x reduced at full load condition.

It is concluded that n-butanol has greater advantages than other alcohol fuels with greater cetane number and flashpoint, lesser volatility, more viscosity, good lubricity and also no additives are required with no serious phase separation compared to methanol and ethanol. In present work, experiment was conducted using fumigated n-butanol and attained results are equated with diesel fuel.

Experimental setup and methodology:

In this work, a single cylinder, naturally aspirated VCR diesel engine with a constant speed of 1500 RPM, 3.5 KW rated power, fixed compression ratio 17.5:1, injection pressure 210 bar has been used for all experiments. System added to eddy current dynamometer (50kg) to load the engine.

This VCR engine changed into duel fuel mode by fixing carburetor at air inlet manifold. Separate fuel systems were used for both butanol (prime fuel) and for diesel (subsequent fuel) with separate fuel injectors. Open throttle carburetor with flow rate of 1 Kg/hr was used at air inlet manifold to supply the butanol into the cylinder with an injection pressure of 210 bar. Butanol through carburetor premixes with intake air homogeneously and enters into the combustion chamber during suction stroke. Diesel as a subsequent fuel was introduced at 23' bTDC through fuel injector. The experiments were conducted under different engine loads at constant speed of 1500 rpm and mass flow rate of 1 Kg/hr.

"Enginesoft" software was used to examine the combustion process. All the data about measurement of temperature, combustion pressure, engine load measure were computer interfaced. To change the engine load, load control knob was used. Similarly burette used to check fuel consumption, orifice meter used for air fuel ratio.Emissions like carbon monoxide & hydrocarbon, CO_2, oxides of nitrogen, O_2 measured using INDUS five gas analyzer" and smoke opacity by "NETEL Smoke meter".

Table 1: Engine specifications

parameters	*Specifications*
Model	Kirloskar VCR CI engine
Type	Four stroke, single cylinder
Displacement (cc)	661.45
Rated speed	1500 rpm
Rated Power	3.5 KW
Compression ratio	17.5:1
bore	87.5 mm
stroke	110 mm
Cooling	Water cooling
Injection pressure	210 bar

Table 2 : Properties of Diesel & n-butanol

Properties	Diesel ($C_{12}H_{23}$)	n-butanol ($C_4H_{10}O$)

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Kinematic Viscosity at 40 ˚C	3.25	3.59
calorific value (KJ/kg)	46500	33100
Density at 20(˚C Kg/m^3)	840	810
Flash and fire point	58 & 66	35 & 37

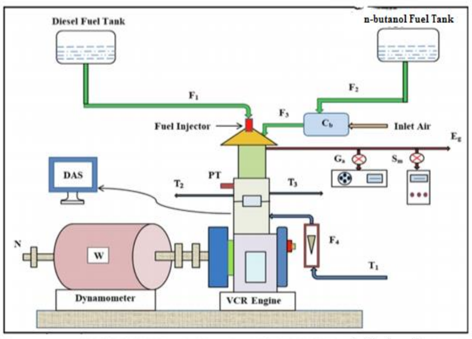

Fig. 1. Schematic diagram of butanol/diesel dual fuel HCCI engine. Where, F_1 = Fuel Line (Diesel), F_2 = fuel line (butanol) F_3 = Air-fuel mixture Line F_4 = Cooling water, N = Engine speed in rpm, W = Eddy current dynamometer, PT = Pressure transducer, DAS = Data acquisition system, T_1 = Inlet cooling wate temperature, T_2 = Outlet cooling water temperature, T_3 = Exhaust gas temperature, C_b = Carburetor, G_a = Five gas analyzer, S_m = Smoke meter, E_g = Exhaust ga flow.

Figure 1: fuel injections test system scheme.

Figure 2 : Experimental setup

Results and discussion:

Experiment was conducted by using fumigated butanol at different engine load conditions with constant mass flow rate 1 kg/hr and fixed speed 1500 RPM. Obtained results are systematically presented and compared with neat diesel fuel.

A. Performance Analysis At CR 17.5, INJ PR 210 bar:

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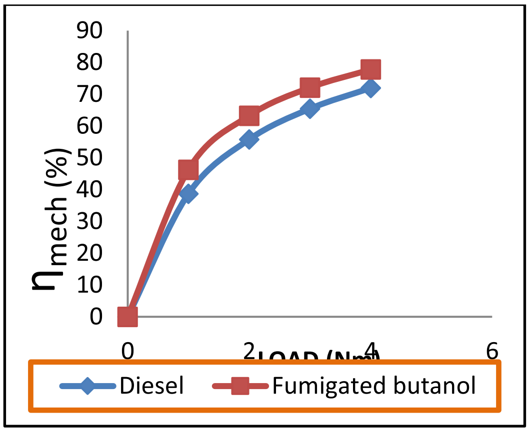

Figure 3: Load vs Mechanical Efficiency At 17.5:1 CR

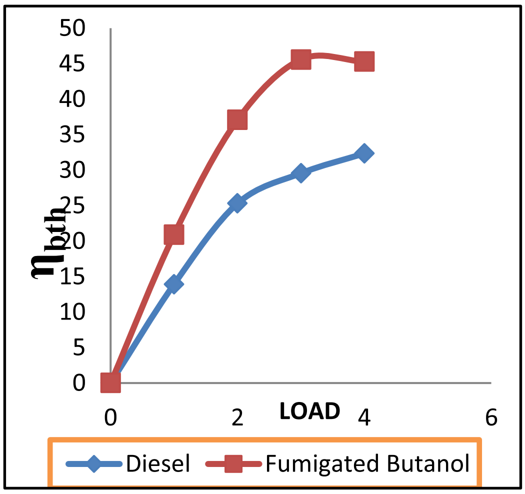

Figure 4: Load vs Brake Thermal Efficiency At 17.5:1 CR

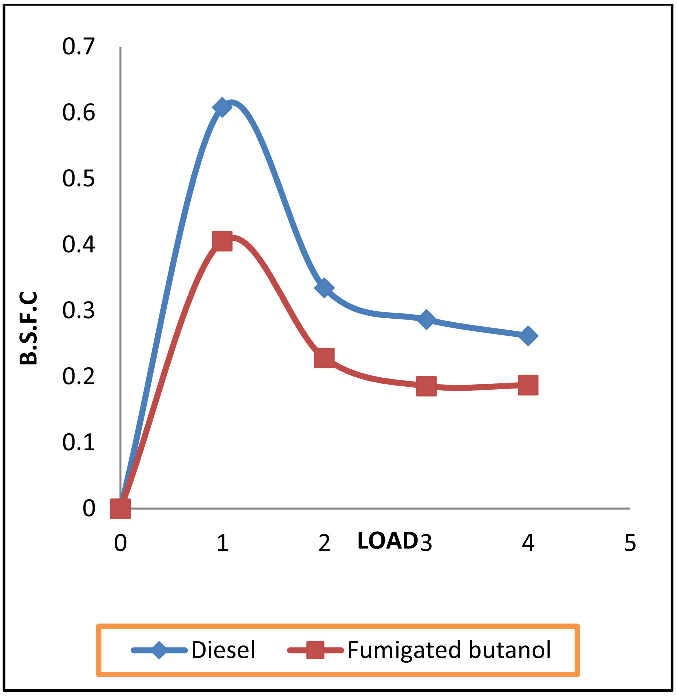

Figure 5: Load vs Specific fuel consumption At 17.5:1 CR

Mechanical efficiency : Mechanical efficiency increased by 8%, 8%, 9%, 6% at ¼ load, ½ load, ¾ load, full load in butanol fumigation process equated to diesel fuel.

Brake thermal efficiency :

Brake thermal efficiency of butanol increased by 7%, 12%, 16%, 13% from ¼ load, ½ load, ¾ load, full load equated to neat diesel fuel because of high flame speed , high diffusion & low density of butanol.

Specific fuel consumption :

Specific fuel consumption of butanol reduced by 20%, 10%, 10%, 8% compared to pure diesel because of sufficient amount oxygen present in it and observed that the rate of fuel consumption in fumigation process decreased with increasing load.

B: EMISSION ANALYSIS AT CR 17.5, INJ PR 210 bar

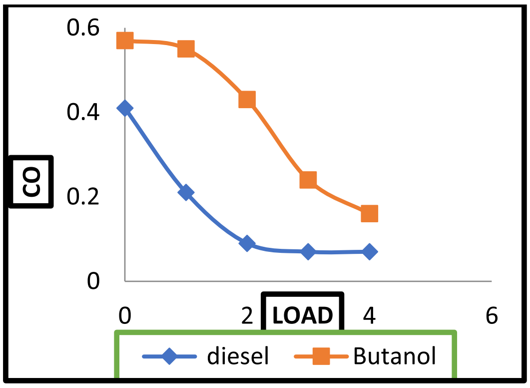

Figure 6 : variation of carbon monoxide versus to load

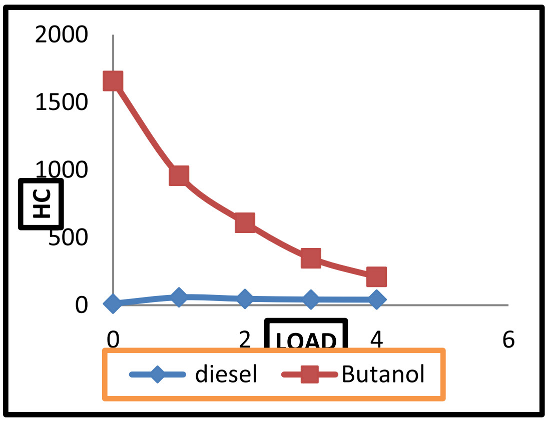

Figure 7 : variation of hydrocarbons versus to load

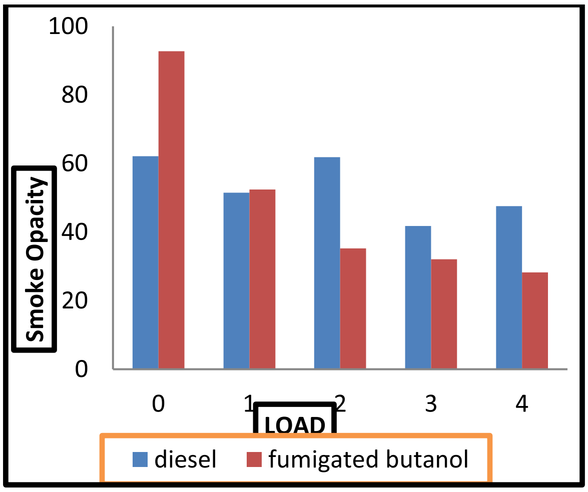

Figure 10: variant of smoke opacity through load

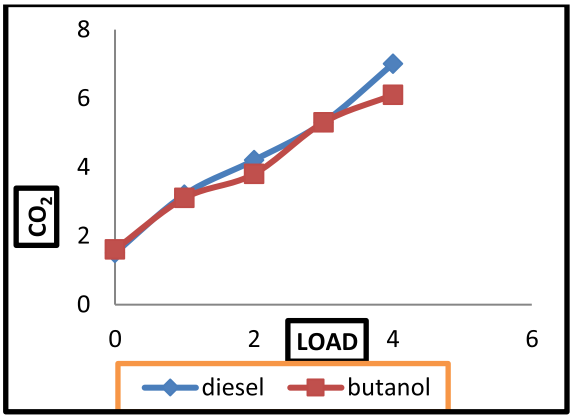

Figure 8 : variation of CO_2 versus to load

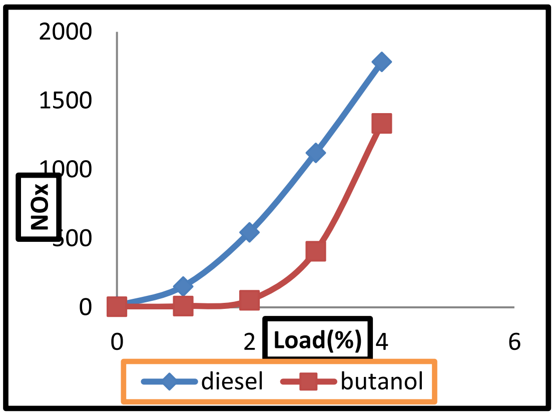

Figure 9 : variation of NO_x versus to load

Figure: INDUS Five gas analyzer

EMISSION ANALYSIS:

NOx Emissions:-

In fumigation process, butanol enters the cylinder with intake air in suction stroke and it has enough time to mix with diesel fuel before starting the combustion process. Because of this diesel fuel mixed with air butanol mixture homogenously and quickly which improved combustion process and oxides of nitrogen formation would decrease. And also in fumigation method, engine is functioning on the low temperature and cylinder temperature got reduced because of high latent heat of vaporization of butanol. Because of this the engine operating at low temperature condition, emission called oxides of nitrogen significantly reduced.

HC & CO Emissions:

CO & HC emissions take place mainly because of imperfect combustion, LTC. Related to diesel combustion process held at low temperature and a slight portion of n-butanol may perhaps leak into the low temperature quenching areas near to the CC wall, this leads to unburned hydrocarbons and CO emissions.

Smoke:

Butanol thoroughly blends with air without any additives to form homogeneous mix and would enhance combustion process. Hence smoke is reduced from ½ load to full load however increases at zero load and ¼ load.

CONCLUSION:

η_{mech} and η_{bth} increased at all engine loads in butanol fumigation process equated to diesel fuel.

Specific fuel consumption decreased from initial load to final load in fumigation mode.

From emission analysis found that NOx emissions drastically decreased from no load to half load and slightly decreased at ¾ load and full load in fumigation mode equated to diesel fuel.

Carbon monoxide and hydrocarbon emissions were increased at all engine loads however these emissions can reduce by using exhaust gas recirculation.

Smoke opacity decreased by 20-30% compared to neat diesel fuel.

Finally, viable operating range found at ¾ load at constant speed 1500 RPM with constant flow rate 1 kg/hr in butanol fumigation process where engine giving maximum η_{mech} , η_{bth} and least specific fuel consumption at CR 17.5:1 and INJ PR 210 bar.

Future Scope Of The Work:

Better engine performance can be achieved by using electrical heater to vaporize alcohol enhances the combustion process. Using diesel oxidation catalyst and exhaust gas recirculation HC & CO emissions can be reduce.

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