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Performance & Emission Characteristics of a Diesel Engine Fuelled with Pyrolysed Cashew Nut Shell Liquid (CNSL) Along with Oxygenates

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***Abstract*— The total fuel consumption in automobile may lead to increase in cost of the fuel, emission rate and great demand for fossil fuel. This lead to development in automobile by using alternative fuels which may includes gaseous fuel, biodiesel and vegetable oil etc. Biomass in the form of cashew nut shell represents a new energy source for the production of an alternative fuels. The oil from the cashew nut shell liquid can be extracted by the method of pyrolysis .In this work, the pyrolysed cashew nut shell liquid (CNSL) along with Oxygenates such as Dimethyl Carbonate (DMC) and Diphenyl ether (DPE) are used to run the diesel engine (CI). The experiments were conducted on the four stroke single cylinder diesel engine with various blends such as 5 % and 10 % of Oxygenates over CNSL oil in diesel engine. Their effects on exhaust emission characteristic were investigated. Their results are compared with neat diesel operation. The engine performance is improved 18% along with reduction in CO, HC and NO_X by adding DPE & DMC as oxygenates. The brake thermal efficiency, mechanical efficiency & specific fuel consumption were also increased by blending DPE & DMC with CNSL at 5% and 10% in order to improve its combustion.**

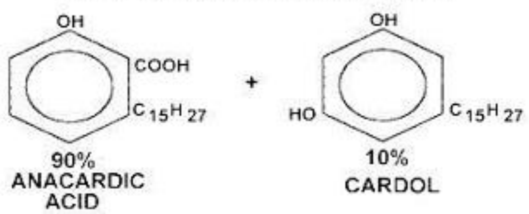
Keywords—Bio-fuel; oxygenates; Dimethyl carbonate; diphenyl ether; cashew nut shell liquid.

I. INTRODUCTION

In this century it is believed that crude oil and petroleum products will become very scarce and costly. However enormous rise in the number of vehicles and its consumption, leads to the demand of fossil fuels. With increases in usage and depletion of fossil fuels, alternative fuel technology will become more common in the coming decades [1]. In today's world, the majority of automotive and transportation vehicles are powered by CI engine. It is important for an alternative diesel fuel to be technically acceptable, economically competitive, environmentally acceptable and easily available [2]. Diesel engine dominates the field of transportation and agricultural machinery on account of its superior efficiency, the consumption of diesel in India is several times higher than that of petroleum consumption. Rough estimation of petrol and diesel consumption is 30% and 70% respectively[5].An Indian product oil seed like groundnut, coconut, sunflower, rapeseed, mustard, karanja, jatropa, neem, rubber seed, rice bran & cashew nut shell liquid etc. Because of its reproducibility, non-toxicity, sulphur-free property, a considerable amount of recent research has focused on use of biodiesel on diesel engine [2]. All most all the CI engine use diesel as fuel, but diesel is one of the largest contributions to environmental pollution problem [3]. Cetane number was determined to be the most important fuel variable associated with emission of HC, CO, NO_X whereas fuel aromatic significantly affected PM emission. Oxygen content in the fuel was important for estimating PM [10].

Cashew nut shell liquid (CNSL) is a versatile by-product of the cashew industry. The nut has a shell of about 1/8 inch thickness inside which is a soft honey comb structure containing a dark reddish brown viscous liquid which is a cashew nut shell liquid (CNSL) [4]. CNSL has innumerable applications such as friction lining, paints, varnishes, laminating resins, polymers, surfactants & intermediates for chemical industry [4]. Cashew (anacardium occidentale) is one of the well known species of the anacardiceae family. India has a comparative advantage in the production & processing of cashew nuts on account of its skilled labor [6]. CNSL constitute anacardic acid 90% & cardol 10% [11].With the resemblance of CNSL to diesel in structure (C_{11}-C_{20}) its calorific value is expect to be high as diesel [11].

CHEMICAL STRUCTURE OF C.N.S.L.



The most applied technique is the extraction of oil in India consists of immersion of the cashew nut in a bath of CNSL at 185-190°C. This method recovers about 50% of CNSL and the hot extraction produces a different from the natural, obtained by cold extraction. Due to the heat, the anacardic acid undergoes decarboxylation and it is converted to cardanol [7]. Extraction of CNSL may involve various method such as open pan roasting, drum roasting, hot oil roasting, cold extrusion and solvent extraction [7]. Pyrolysis is done in a reactor at vacuum pressure of 5kPa and at various maximum temperatures between 400 - 600°C. The decarboxylated cardanol is termed as CNSL [9].

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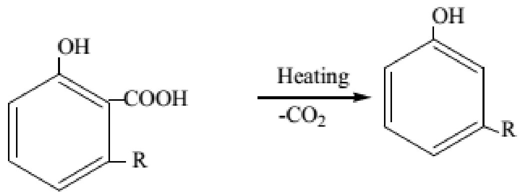
According to investigation [14] viscosity was reduced to half its normal value mainly due to dilution with methanol by the method of transesterification where the NaOH is uses as a catalyst. Investigation [15] says about the isolation of cardanol & cardol by dissolving CNSL with methanol (320ml) and ammonium hydroxide (200ml) along with adding hexane (4x25ml) on the upper layer of the mixture in order to obtain pure cardanol. Whereas in investigation [14] deals with the physiochemical properties of CNSL (anacardium-1 occidentale) in which the methanol is used as an reagent for transesterification process because of its low cost & obtained viscosity of 49.62 cSt. Investigation [17] concludes that the decarboxylation of raw CNSL involves loss of carbon dioxide molecules from anacardic acid.



Decarboxylation of raw CNSL

Oxygenates are oxygen rich compounds which, when they are added to motor vehicles fuels, make them burn clearly, thereby significantly reducing toxicity tailpipe exhaust. Investigation [8] says about oxygenates as supplementary to the diesel fuel in order to improve the combustion characteristics and emission parameters from the engine by comparing various kind of oxygenates like DMC, MTBE, Diglyme, Ethanol fumigation over blending with diesel fuel.

II. MATERIALS & METHODOLOGY

A. *Preparation of CNSL*

In this work, the cashew nut shell liquid which undergoes the pyrolysis process is used as an alternative fuel. Pyrolysis is a thermo-chemical decomposition of organic matter which is heated in the absence of oxygen. Technically, the raw CNSL is extracted by heating cashew nut shell in a heating drum which is surrounded by the bricks which are heated at the range 190 -210ºC. During this process anacardic acid is converted to cardanol by the process of decarboxylation. The CNSL oil is collected through the hose connected to the heating drum where the burnt residues are settled at the bottom tray connected to the drum. The polymeric material present in cardanol can be increased if proper temperature is not maintained. The CNSL oil obtained will have a polymeric content will lead to increases the viscosity of the oil which is practically difficult to used directly in the CI engine. Typically the composition of technical CNSL is approximately 52% cardanol, 10% cardol and 30% polymeric material with remaining substance. CNSL is further processed to distillation where their composition is 78% cardanol, 8% cardol and 2% of polymer material. In order to improve its viscosity of CNSL the post-pyrolysis method has been selected instead of transesterification process .The obtained raw CNSL is then once again pyrolysed by heating the fuel in the oil furnace where the oil steam obtained are collected through an converging steel pipe in order to increase its pressure. The constant temperature has to be maintained inside the furnace at the range of 170-200ºC. The steel pipe outlet is connected to the rubber tube which acts as a passage to the condenser. The steam CNSL oil is then condensed by a water tub passing through the sides of the rubber tube which acts as a condenser. The outlet of the rubber tube is used to collect the condensed CNSL steam into oil where the polymeric content in the oil can be reduced with improved in its viscosity. The obtained condensed oil are said to be the pyrolysed CNSL. Thus by the method of post-pyrolysis about one –third of viscosity of the CNSL is reduced.

B. *Test Fuels*

In this research work, the pyrolysed cashew nut shell liquid (CNSL) is used with oxygenates as Diphenyl ether (DPE) and Dimethyl carbonate (DMC). The pyrolysed CNSL and oxygenates are mixed with the help of stirrer. The mixture is kept under investigation for a day in order to find its stabilization and it's clear that there is no separation of fuel. The oxygenates are blended with the CNSL oil are mixed at the proportion of 5% and 10% by its volume which are said to be CNSL 95% + DPE 5% , CNSL 90% + DPE 10% , CNSL 95% + DMC 5% and CNSL 90% + DMC 10%. The blending of oxygenates to CNSL will have effect on the physiochemical properties of the fuel. By adding oxygenates kinematic viscosity, density, lower heating value of the blends decreases. Oxygenates help in improving the combustion of fuel by increasing the oxygen content necessary for combustion. The main purpose of adding oxygenates with cashew nut shell oil as an additives is to reduce the emission parameter which are high in CNSL oil. The properties of Pyrolysed-CNSL, Diesel, Raw CNSL, Diphenyl ether (DPE), and Dimethyl carbonate (DMC) are presented in table 1

Table 1: Properties of Fuel.

SI NO	Properties	Raw CNSL	Pyrolysed CNSL	Diesel	DPE	DMC
1	Flash Point °C	198	45	62	115	17
2	Fire Point °C	206	48	69	127	28
3	Kinematic Viscosity (cSt)	17.2	5.48	5	2.48	1.0635
4	Calorific Value (MJ/kg)	40	41.7	45	-36	15.78
5	Density (kg / m^3)	960	860	890	1070	1070

III. TEST PROCEDURES

The performance test was carried out on a Kirloskar four stroke single cylinder Diesel Engine with water cooled system. The engine was directly connected to the eddy current dynamometer. The speed of the engine is constantly maintained at 1500 rpm which are viewed through dynamometer control. The emission parameters such as Co_2, Co, HC, NO_X and EGT are measured using HORIBA Gas analyzer which works on the principle of Non Dispersive Infrared Radiation (NDIR). The Gas analyzer was calibrated with standard gases and zero gases before each test. The experiment was conducted by applying five various load at the

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engine speed of 1500 rpm. At each operating mode the experiment was carried out for Diesel fuel, CNSL, oxygenates mixture with CNSL are CNSL 95% + DPE 5% , CNSL 90% + DPE 10% , CNSL 95% + DMC 5%, CNSL 90% + DMC 10%. The modification of engine is not necessary for conducting experiments in the above study. Before conducting the experiment the engine has to be operated with fuel for 30 minutes to clean the engine wall which is affected by fuel used in previous running. The data were recorded for the corresponding fuels to be conducted in the engine. The engine specifications are given below

Type	Vertical , Water cooled , Four stroke
Model	Kirloskar AV- I
Number of Cylinder	One
Bore	87.5 mm
Stroke	110 mm
Displacement Volume	661 CC
Compression Ratio	17.5 : 1
Maximum Power	37.5 kW
Speed	1500 rpm
Dynamometer	Eddy Current Dynamometer
Injection opening Angle	23 ° b TDC
Injection opening Pressure	20 MPa

Figure 1: Experimental Setup

Calculations:

Brake power, B.P = WN / C (kW)

where W = Load Applied (N)

N = Speed of the Engine (rpm) = 1500 rpm

C = Dynamometer Constant = 9549.303

Total fuel consumption, TFC = V_f x S x 3600 / t (kg/hr)

where V_f = Volume of Fuel (gm) = 30 gm

S = Density of Fuel (kg/m^3)

t = Time taken (s)

Brake specific fuel consumption, BSFC = TFC/BP (kg/kWh)

Indicated Power, IP = BP + Friction Power (kg/kWh)

Indicated thermal efficiency = (IP x 3600)/ (TFC x CV) x 100

Mechanical Efficiency = (BP / IP) x 100

Brake Thermal Efficiency = (BP x 3600) / (TFC x CV) x 100

Brake specific energy consumption, BSEC = 100/ BTE

IV. RESULT AND DISCUSSION

In this study, the experiments are conducted on neat diesel fuel, Pyrolysed CNSL, various blend percentage of oxygenates over CNSL at the percentage of 5% and 10%. For each operated loading condition, the specific fuel consumption, engine efficiencies, brake power, exhaust emission and exhaust gas temperature were determined. Combustion, Performance and emission characteristics for the various load condition were analyzed and discussed. Based on the calculated value, the results and graph are presented.

A. Performance characteristics

1) Brake thermal efficiency:

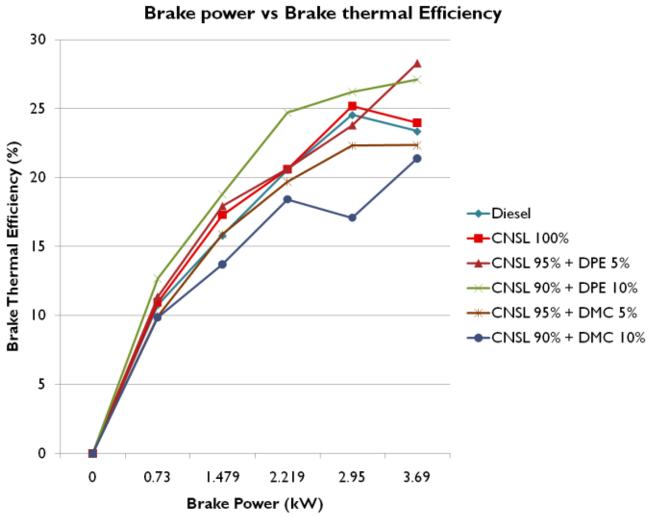

Fig 2 : Comparison of Brake Thermal Efficiency

Fig 2 shows the variation on brake thermal efficiency with respect to load conducted for the fuel to be tested. It is observed from the fig 2 that the brake thermal efficiency was 23.35% (diesel), 23.97% (CNSL), 28.3% (CNSL 95% + DPE 5%), 27.1% (CNSL 90% + DPE 10%), 22.35% (CNSL 95% + DMC 5%) and 21.39% (CNSL 90% + DMC 10%) at full load condition of 3.69 kW. Based on the value it is clear that the maximum brake thermal efficiency is obtained for blend of DPE with CNSL for 5% & 10%. Whereas the DMC with CNSL have low brake thermal efficiency compared to the Diesel and CNSL fuel. It shows the improvement in brake thermal efficiency by additing diphenyl ether as oxygenates over the CNSL which helps in enhancing the good combustion of fuel.

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2) Indicated Thermal Efficiency

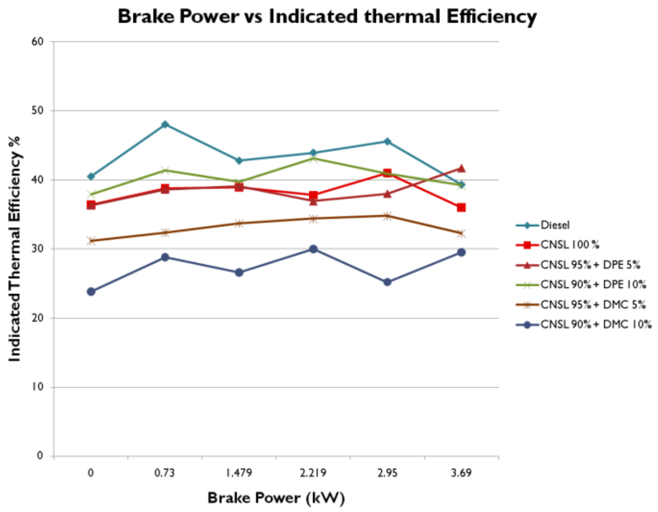

Fig 3: Comparison of Indicated Thermal Efficiency

Fig 3 shows the variation on indicated thermal efficiency for different loads conditions for the fuels to be tested. It is observed from fig 3 that the indicated thermal efficiency is 39.34% (Diesel), 35.99% (CNSL), 41.7% (CNSL 95% + DPE 5%), 39.2% (CNSL 90% + DPE 10%), 32.3% (CNSL 95% + DMC 5%), 29.5% (CNSL 90% + DMC 5%). Based on the value it is clear that the maximum brake thermal efficiency is obtained for blend of DPE over CNSL for 5% and 10%. Whereas the DMC over the CNSL have low brake thermal efficiency compared to the Diesel & CNSL operation. Improvement of indicated thermal efficiency of IC Engine is required and it is achieved by effective compression ratio.

3) Mechanical Efficiency

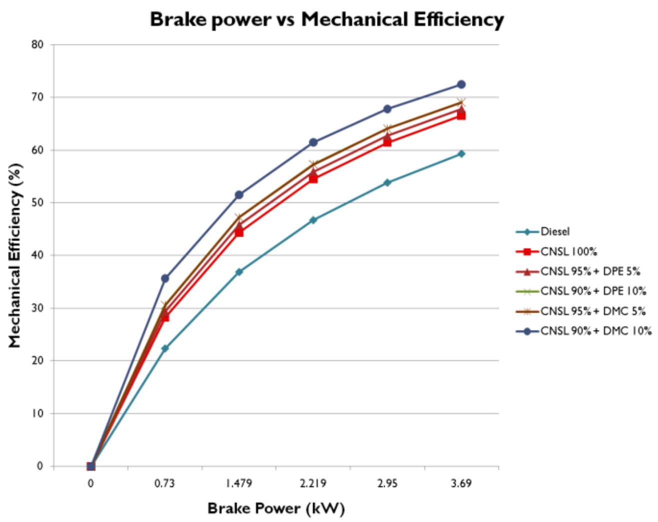

Fig 4: Comparison of Mechanical Efficiency

Fig 4 shows the variation on mechanical efficiency with respect to load conducted for the fuels to be tested. It is observed from fig 4 that the mechanical efficiency was 59.37% (diesel) , 66.6% (CNSL) , 67.8% (CNSL 95% + DPE 5%) 69.1% (CNSL 90% + DPE 10%) , 69.1% (CNSL 95% + DMC 5%) , 72.49% (CNSL 90% + DMC 10%). Based on the values obtained, it is clear that dimethyl carbonate (DMC) blended over the CNSL has more efficient than the other blends and diesel fuel has the lower mechanical efficiency. The factor which has a greater effect on mechanical efficiency is friction inside the engine. Mechanical efficiency can be improved when the engine is running at speed where maximum bhp is obtained.

4) Total Fuel Consumption

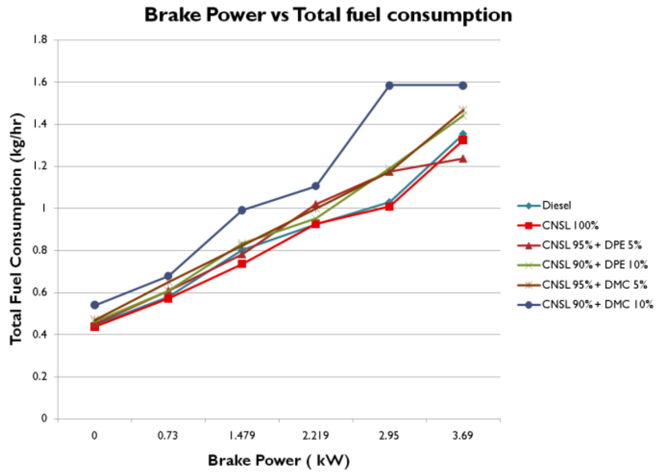

Fig 5 : Comparison of total fuel consumption

Fig 5 shows Total fuel consumption obtained for the engine based on the application of loading with various fuel blends. The total fuel consumption are said to be the amount or mass of fuel consumed for the period of time based on the loading applied to the engine. From the Fig 5 it is observed that the total fuel consumption are 1.237 kg/hr (CNSL 95% + DPE 5%), 1.326 kg/hr (CNSL), 1.354 kg/hr (Diesel), 1.411 kg/hr (CNSL 90% + DPE 10%), 1.468 kg/hr for (CNSL 95% + DMC 5%), 1.585 kg/hr (CNSL 90% + DMC 10%) at full load condition. The more fuel consumption is obtained for the CNSL blended with DMC at the range of 5% & 10% which lead to increase in the fuel cost. Thus the CNSL along with DPE at 5% consumes less fuel with increase in efficiency of the engine. At the same time pyrolysed CNSL consumes lesser fuel compared to diesel fuel but increase in fuel consumption compared to CNSL blended with DPE at 5%.

5) Specific Fuel Consumption

Fig 6 shows specific fuel consumption obtained from the engine based on the loading conditions over various fuels. The specific fuel consumption is said to be the useful energy obtained from the fuel that helps in power transmission of engine. From the fig 5 it is observed that the specific fuel consumption remains same for CNSL blended with DMC at the percentage of 5% & 10%. The specific fuel

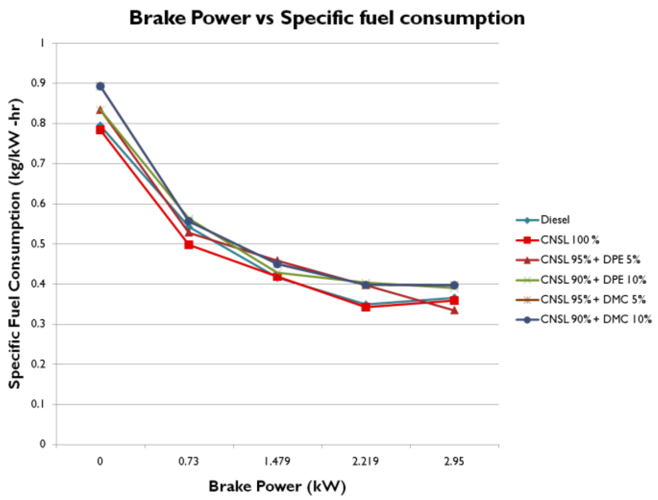

Fig 6 : Comparison of Specific Fuel Consumption

consumption obtained for full load condition are 0.397 kg/kW-hr for both 5% and 10% of DMC over the CNSL fuel, 0.39 kg/kW-hr for CNSL 90% + DPE 10% , 0.366 kg/kW-hr for diesel, 0.359 kg/kW-hr for CNSL 100% , 0.335 kg/kW-hr for CNSL 95% + DPE 5%. The higher SFC was observed in CNSL blended with DMC at the range of 5% & 10%. The variation in SFC for CNSL 95% + DPE 5% is less at full load condition possibly with increase in brake thermal efficiency of the engine.

B. Emission Characteristics

1) Carbon Monoxide Emission

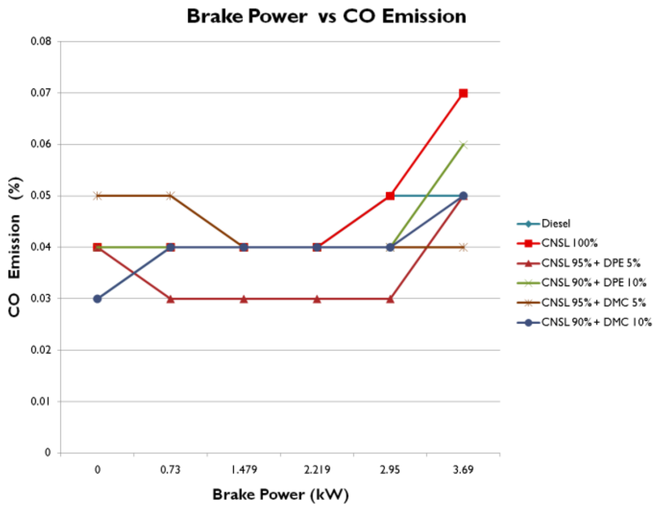

Fig 7: Comparison of carbon monoxide emission

The incomplete combustion of CNSL leads to high percentage of CO emission as discussed in Kasiraman.G et al (2013). In order to overcome this problem, the CNSL undergoes process of pyrolysis where the viscosity of the oil is reduced. The oxygenates are also used to improve the combustion of the CNSL oil. Fig 7 shows the CO emission obtained is 0.07% (CNSL) which is higher when compared to Diesel whose value is 0.05%. Thus by adding oxygenates such as DPE & DMC, the CO emissions are reduced to 0.04% (CNSL 95% + DMC 5%) and remain same as 0.05% (CNSL 90% + DMC 10%, CNSL 95% + DPE 5%) compared to diesel at full load condition. But CNSL 90% + DPE 10% have 0.06% of CO which is higher than diesel but lesser than CNSL. At the partial load of the engine, there is a reduction in CO emission due to enriched O_2 in the combustion chamber and then obtained a constant value of 0.04% except CNSL 95% + DPE 5% which are greatly reduced to 0.03% of CO in the partial loading of CI engine.

2) Unburnt Hydrocarbons Emissions

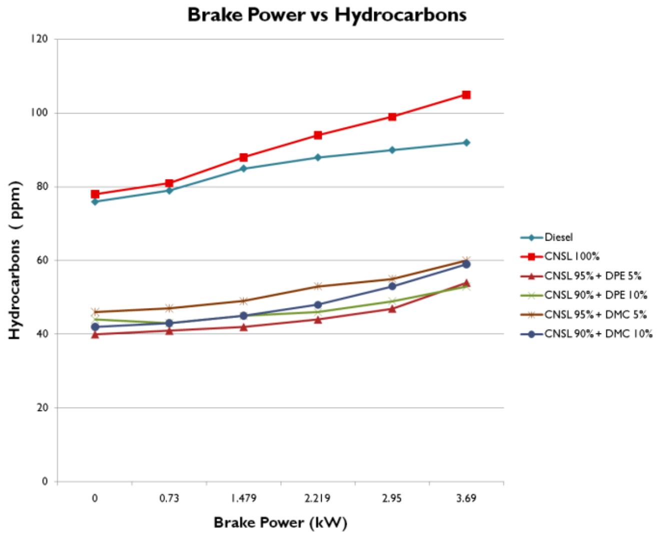

Fig 8: Comparison of Unburnt Hydrocarbon emission

Fig 8 shows the variation in unburnt hydrocarbon emission. By blending oxygenates with CNSL, the complete combustion is achieved that makes reduction in unburnt hydrocarbon. The oxygenates are highly volatile which results in better evaporation and combustion, kasiraman.G et al (2013). From Fig 8 it is observed that CNSL has 105 ppm of HC and diesel has 92 ppm of HC. In order to reduce the HC emission and improves the combustion of the engine, the oxygenates are added. The HC emission obtained by CNSL with the oxygenates are 54 ppm (CNSL 95% + DPE 5%), 53 ppm (CNSL 90% + SPE 10%), 60 ppm (CNSL 95% + DMC 5%) and 59 ppm (CNSL 90% + DMC 10%) at full load condition. It is cleared that HC emission is greatly reduced in CNSL blended with DPE at 5%.

3) Carbondioxide Emission

Fig 9 shows the variation in Carbon dioxide emission based on the load applied to the engine. The CO_2 emission can be reduced by improving the complete combustion of fuel which can be achieved by increasing the oxygen content by the help of oxygenates. From Fig 9 it is observed that CO_2 are higher in CNSL as 6.62% than diesel as 5.75%. The oxygenates helps in improving the CO_2 reduction as 3.32% (CNSL 95% + DPE 5%), 3.22% (CNSL 90% + DPE 10%), 2.96% (CNSL 95% + DMC 5%) and 3% (CNSL 90% + DMC 10%) at full load condition. The overall reduction of CO_2 on varying load is achieved in CNSL blended with DPE at the range of 5%.

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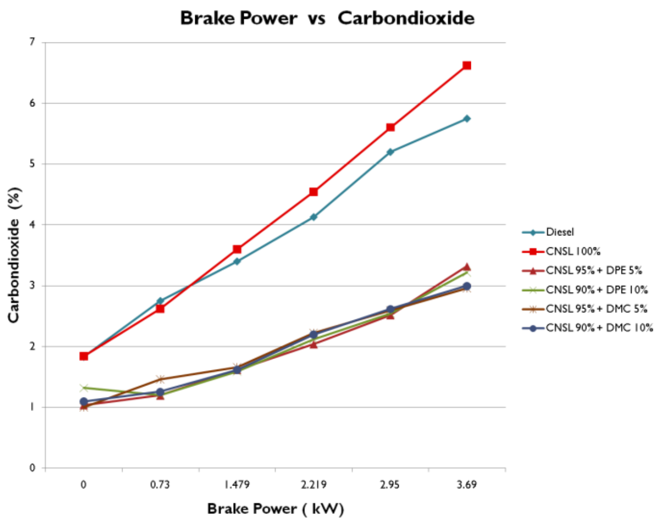

Fig 9: Comparison of CO_2 Emission

4) Oxygen emmission

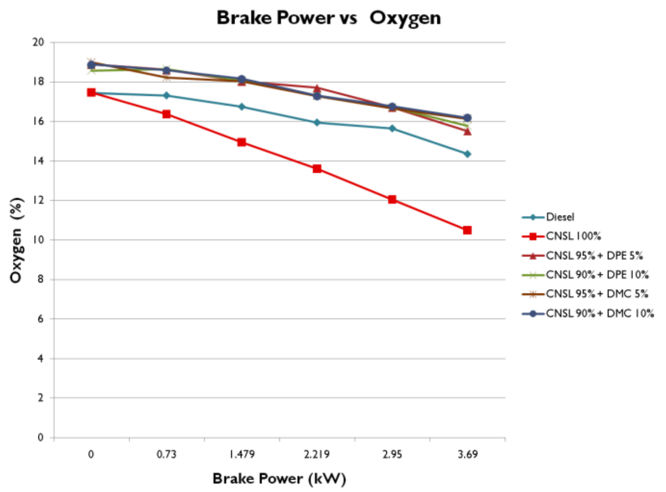

Fig 10: Comparison of Oxygen

Fig 10 shows the variation in oxygen obtained from the exhaust emission at loading conditions. Oxygen is one of the important parameter that helps in complete combustion of the fuel. The oxygen also helps in the reduction of CO_2 emission by reacting with CO to form CO_2. From Fig 10 it is observed that CNSL has insufficient amount of oxygen which causes improper combustion of fuel whose value is 10.5% when compared to diesel of 14.35%. Thus by adding oxygenates, the oxygen emission obtained from the engine increases as 15.52% and 15.77% for CNSL blended with DPE at 5% and 10%, 16.14% and 16.18% for CNSL blended with DMC at 5% & 10% at full load condition. The oxygen is excessively found on DMC compare to DPE.

5) Oxides of Nitrogen (NO_X)

Fig 11 shows the variation in oxides of nitrogen obtained from the engine exhaust for various loading condition. The inlet temperature helps in reduction of nitrous oxides. Lower heat rate and combustion temperature are the reason for less NO_X emission. From Fig 11 it is observed that NO_X emission is

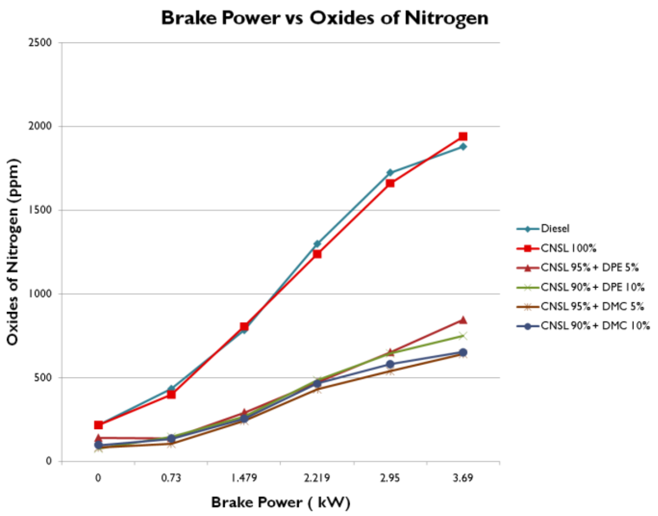

Fig 11 : Comparison of Oxides of Nitrogen (NO_X)

1942 ppm in CNSL which is more compares to diesel whose value is 1880ppm. Thus by adding oxygenates the NO_X Emission are reduced to 846 ppm (CNSL 95% + DPE 5%) , 750 ppm (CNSL 90% + DPE 10%) , 643 ppm (CNSL 95% + DMC 5%) & 654ppm (CNSL 90% + DMC 10%) at full load condition . Thus the oxides of Nitrogen are greatly reduced in CNSL blended with DMC at the range of 5% & 10%. The EGT increases with reduction in NO_X emission.

6) Exhaust Gas Temperature

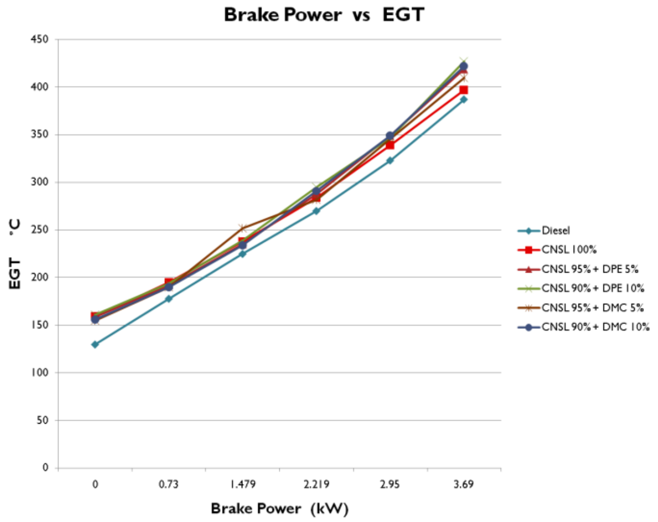

Fig 12 : Comparison of Exhaust Gas Temperature

Fig 12 shows the exhaust gas temperature obtained from engine for various kinds of fuels conducted by applying various sets of load. The variation of exhaust gas temperature with applied load with different fuel test is shown in fig 12. It is observed that diesel has less EGT compare to CNSL & its blends with oxygenates. The exhaust gas temperature of diesel is 387°C which is lesser than CNSL whose value is 397°C. The main reason may be improvement in combustion of fuel such as CNSL with DPE & DMC. Another reason is the shortened period of combustion of CNSL with oxygenates lead to increase in flame velocity as discussed in

A.Velmurugan et al (2012). The exhaust gas temperature is found to be lower for Diesel fuel at various load conditions.

CONCLUSION

Based on the result obtained, the performance & emission characteristics of diesel engine using various kinds of fuels such as Diesel , CNSL 95% + DPE 5% , CNSL 90% + DPE 10% , CNSL 95% + DMC 5% , CNSL 90 % + DMC 10% and CNSL have been identified & analyzed as follows:

- The kinematic viscosity of the CNSL has been reduced in order to improve combustion by the method of pyrolysis where the kinematic viscosity is reduced to 5.48 cSt compare to raw CNSL is 17.2 cSt.
- The oxygenates have been selected based on the emission parameter obtained from the engine which should not affect the emission characteristics. Based on the above criteria Diphenyl Ether (DPE) & Dimethyl carbonate (DMC) are selected as oxygenates which are blended with CNSL at 5% & 10%.
- Brake thermal efficiency increases with adding oxygenates over CNSL such as CNSL blended with DPE & DMC at 5% & 10%. The good brake thermal efficiency are achieved in CNSL with DPE at 5% & 10% where the efficiency increases to 28.3% (CNSL 95% + DPE 5%) & 27.1% for (CNSL 90% + DPE 10%). The brake thermal efficiency is improved to 5% at full load condition when compared to diesel.
- The mechanical efficiency is increased as 69.1% & 72.49% in CNSL blended with DMC at 5% & 10. But in CNSL with DPE at 5% & 10%, the efficiency is only about 67.8% & 69.1%, which are nearer to the efficiency of CNSL & DMC. The Mechanical efficiency of CNSL with DMC at 10% is improved to 13.12% when compared to diesel.
- Indicated thermal efficiency is greater in diesel when compared to CNSL with its blends. Here the indicated thermal efficiency is greatly reduced in CNSL with DMC at 5 & 10%. The mechanical efficiency is improved to 2.36% in (CNSL 95% + DPE 5%) compared to diesel fuel.
- Specific fuel consumption increases for CNSL with DMC & DPE. CNSL blended with DMC at 5% & 10% have greater specific fuel consumption at 0.397 kg/kW-hr. SFC is improved to 0.031 kg/kW-hr compared to diesel.
- The CO & HC emissions are increased in CNSL than diesel fuel due to incomplete combustion of fuel such as 0.07% of CO & 105 ppm. In order to reduce CO & HC emissions, the oxygenates such as DPE & DMC are added with CNSL. As a result, reduction in CO emission to 0.05% and in HC emission to 54ppm when the CNSL blended with DPE at 5%.
- Oxides of Nitrogen from CNSL are higher at 1942ppm than diesel. The NO_X were reduced by adding DPE & DMC with CNSL at 5% & 10%. Better reduction in NO_X is identified at 643 ppm, 654 ppm when CNSL blended with DMC at 5% & 10%.
- Oxygen helps in complete combustion of fuel thus by adding oxygenates the oxygen content increases. From this study it is clear that DMC have more oxygen exhaust compare to DPE.
- The exhaust gas temperature is increased for CNSL blended with DMC & DPE at 5% & 10% at all loading conditions than for conventional diesel fuel.
- On the whole CNSL blended with DPE can be used as an effective alternative fuels in conventional CI engines without any modification in its engine setup.
- Though the CNSL with DPE have lesser performance as compared to CNSL with DMC, the Brake thermal efficiency is greatly increases in former at 5% and 10%.
- The specific fuel consumption is increased for CNSL with DMC, which is a greater advantage, but at the same time total fuel consumed by engine is higher. So CNSL with DMC is not economical.
- On considering the emission parameter such as CO, HC & CO_2, they are reduced significantly in CNSL with DPE at 5% & 10% whereas the NO_X are reduced in CNSL blended with DMC.

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