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EFFECTS OF ENHANCING CETANE NUMBER OF ETHANOL FUMIGATION ON DIESEL ENGINE PERFORMANCE AND EMISSIONS

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ABSTRACT

This study investigated the impact of fumigating different percentages of anhydrous ethanol (E) and cetane number enhancer (CNE) on the combustion, performance as well as exhaust pollutants of DI diesel engine. The addition of this mixture (ECNE) exhibited higher premixed combustion peaks, faster combustion process, and higher coefficient of variation of indicated mean effective pressure (IMEP) and reduced maximum in-cylinder temperature, in comparison with neat diesel (D). The total combustion duration as well as the ignition delay prolonged when ECNE fumigated compared to that of diesel fuel only. The combustion characteristics of ECNE ratios at high load could be recovered to diesel fuel by introducing CN enhancer, but a large difference occurs at lower load. Neither Ethanol only nor ECNE presented better thermal efficiency (BTE) and brake specific fuel consumption (BSFC) than the baseline diesel fuel. Engine performance with ECNE fumigation is highly susceptible to operating conditions; therefore, it is necessary to optimize the specific thermal conditions for implementing a fumigation approach. ECNE increased total hydrocarbons (THC) and carbon monoxide (CO), reduced particulate matter (PM) and nitrogen oxides (NOx) in comparison with pure diesel fuel. However, the amount of this reduction was markedly affected by engine operating mode. The DECNE (85% diesel+10% ethanol+ 5%Cetane enhancer) showed the best trade-off between the engine performance, combustion and emissions characteristics (PM vs NOx + THC) among the ECNE ratios.

Keywords: cetane enhancer, ethanol, diesel and fumigation.

INTRODUCTION

Biomass-produced fuels such as alcohol, bio-diesel, biomass-to-fluid, and hydro treated vegetable oils, are used as partial replacements of standard diesel fuel. Specifically, alcohol are desirable because: they are easily combined or inserted to the engine, they can be created through fermentation techniques from a top number of non-edible plant and organic waste resources, and most of all they have a higher share of oxygen, which includes he capacity to lessen particulate matter (PM) and NOx pollutants[1],[2] and [3]. For using alcohol in diesel-powered engines typically the most popular methods are alcohol fumigation in the intake port and diesel blends [4] [5].

Researchers [6] [7] stressed some concerns that undesirably affect the use of diesohol blend in the compression ignition engine. Among these issues: Cetane number of this blend becomes lower compared to diesel fuel, i.e. the addition of 10% by volume of ethanol decreases cetane number by approximately 30%. Moreover, ethanol is not completely miscible in regular diesel fuel where a very small proportion of ethanol, less than 5% by volume, shows complete miscibility in diesel fuel [8]. Minor variations in the fuel delivery system are required while using diesohol as fuel [9]. The density, viscosity, lubricity, energy content and the flash point of the fuel blend are affected [8]. When adding ethanol to diesel, the blend viscosity becomes lower. The addition of 10% by volume of bioethanol decreases viscosity approximately by 10-25% [10]. Some mechanical issues are unavoidable particularly those concerning Bosch type fuel pump by jamming their valves stems.

An excellent option to avoid these issues is alcohol fumigation, which includes the following edges: (1) large versatility on diesel fuel replacement [11]; (2) the quantity of alcohol fumigated may be corrected to coincide with the specific engine condition [12], (3) hydrous alcohols may be employed [13], (4) coincident decrease in NOx and PM pollutants in most instances [14], while the particle number concentration (PNC) falls, the geometric mean size is not changed and (6) evaporation losses are lower when compared to alcohol-diesel mixtures. Nevertheless, this method encounters some disadvantages: (1) probability of established knock under high-load conditions[15], because of the lower cetane number of the alcohol, restricts the volume of diesel replacement [16]; (2) the high temperature of evaporation of alcohol could cause key problems and large aldehyde emissions at cold-start, warmup and low-load processes [17]; (3) although it is verified to decrease PM and NOx, it is ,on the other side, improves the formation of CO, THC and NO_2 pollutants (4) requires other fuel-injection system and fuel-tank modification[18]. Based on above-mentioned facts, the primary objective of this study is to assess the influence of cetane number enhancer (CNE) on combustion, performance and emission of fumigating different mixtures of ethanol CNE ratios into a compression ignition DI diesel engine.

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MATERIALS AND TEST PROCEDURE

Cetane number used in this study was a mixture of straight-chain n-propyl ester 30% and methyl esters 70% by volume (>99% purity) (Table1). The top levels of materials that should be obtained for the purpose of this study were further purified by distillation through an effective 40-lightbulb device. Esters are not easy to keep up in state of high purity because they are readily hydrolyze on boiling and very hygroscopic. Anhydrous ethanol with an analysis-grade of 99.8% purity was utilized (Table1).

The engine operated in this research has a combustion chamber of bowel type, a direct injection diesel type, single-cylinder, four strokes (4cycles) and normally (naturally) aspirated engine Figure-1. Table-2 displays the specification of the engine used. A higher precision flow meter was utilized to assess the fuel flow per 1-5 s. Engine combustion features are quantified using data-acquisition (DAQ) program provided by TFX Executive, United States.

Table-1. Main properties of selected fuels.

Fuel properties	Cetane number enhancer	Ethanol	Diesel
Density (1 g/cm3)	0.677	0.785	0.84
Latent heat of evaporation (LHE) (kJ /kg)	330	840	250
Kinematic viscosity	-	1.2	3.11
Cetane number (CN)	-	5-8	46
Flash point (°C)	-35	13.5	78
Stoichiotric air-fuel	-	9.0	14.5
Self-ignition	320	420	250
Boiling point (°C)	31.6	78	180-330
Lower calorific value (LHV)(kJ kg^{-1})	34560	26800	42500
Carbon content (C) (wt%)	64.9	52.18	87
Hydrogen content (H_2)(wt%)	13.5	13.04	13
Oxygen content (O_2) (wt%)	18.6	34.8	0
Molecular weight	74.12	46.07	170

It contains LCS data logger, magnetic-type crank position sensor, detector software, transport cable and cylinder pressure sensor. For emitted emission measures, KANE mobile gas analyzer from model KANE900 PLUS was utilized for instant records.

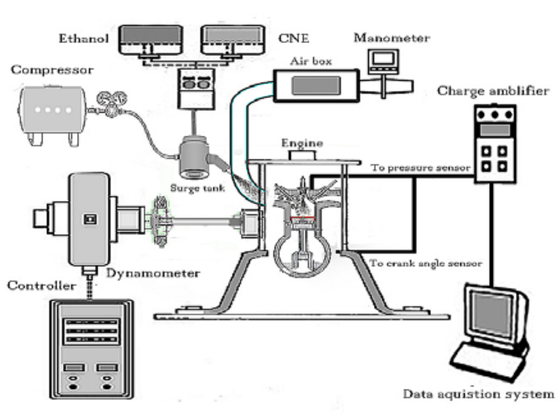

Figure-1. Scheme of the testing bench.

Table-2. Specification of test diesel engine.

Injection timing, deg.	BTDC 17.7
Bore X stroke, mm	92x96
Displacement, lit.	0.638
Rated continuous output, hp / rpm (kW)	10.5/2400(7.8)
At 1-tir. rated output, hp / rpm (kW)	12.0 /2400 (9.0)
Maximum torque, kgf.m / rpm	4.42 / 1800
Compression ratio	17.1

In all test runs, the engine was allowed to warm up to attain balance. This is established by tracking the coolant and exhaust temperature. As it had been determined to measure the result of substituting ethanol for diesel fuel while retaining the overall fuel power the same, it was initially necessary to observe the overall fuel energy provided for every operating point in the evaluation matrix employed. Operating the engine at every test condition to the base-line fuel achieved this. Fractional power rates of 20 and 50% were selected. For fumigating the ECNE, a nozzle was mounted to the surge tank by a couple made principally to guarantee the continuous supply of added ECNE at selected pressure rates. A special wheel with controlled speed driven by the engine pulley installed to interrupt the continuity of fumigated ECNE in accordance to the required stoichiometric condition of the dual fuel and TDC angle.

RESULTS AND ANALYSIS

Combustion characteristics

In this experimental work, D-E-CNE ratios with different amounts of CN enhancer (based on volume) were used in the selected engine. In-cylinder pressure records were utilized to measure the heat release rate as well as the combustion characteristics by employing the same brake mean effective pressure (BMEP).

Figure-2 represents the quantity of combustion pressure generated at the same operating conditions for both pure diesel and D-E-CNE ratios. Figures 3, 4 and 5, on the other hand, displays the effect of these fuels ratios on the heat release rate developed during the selected combustion cycles. As it can be seen from Figure-.2, the general trend of maximum cylinder pressure revealed that the ignition time reduced significantly when introducing D-E-CNE ratios without adding the cetane enhancer. However, the ignition time advanced as the cetane enhancer presented into the dual fuels.

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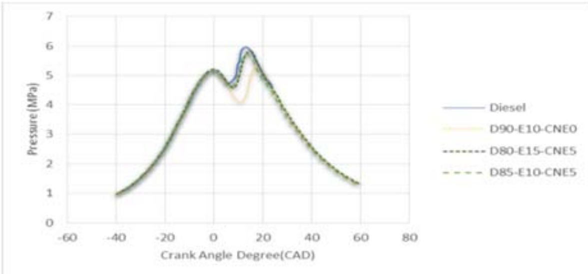

Figure-2. Combustion pressure for pure diesel and D-E-CNE ratios at BMEP =5 bar.

The premixed combustion of all D-E-CNE ratios is relatively prolonged compared to that of the neat diesel. The heat release curve demonstrates this trend when the engine kept running at a constant speed of 1800 RPM and BMEP variations. However, as the percentage of cetane number enhancer increased in the mixture, the premixed combustion dropped significantly. This might be as well be explained by the change in ignition delay period.

Figure-4 depicts the combustion pressure of the engine when fueled with pure diesel and D-E-CNE ratios at identical operating conditions. However, ethanol fuel contains a low cetane number compared to the regular diesel fuel; the addition of small amount of CNE would considerably restore the physical characteristics of the main fuel, i.e. diesel. Figure- 2, 3, 4 and 5 represent the main combustion trends obtained from the heat release rate to gain a good understanding of how D-E-CNE fumigation affects the nature of combustion.

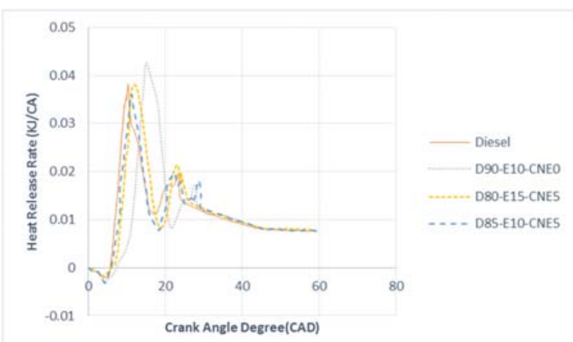

Figure-3. Heat release rate for pure diesel and D-E-CNE ratios at BMEP =5 bar.

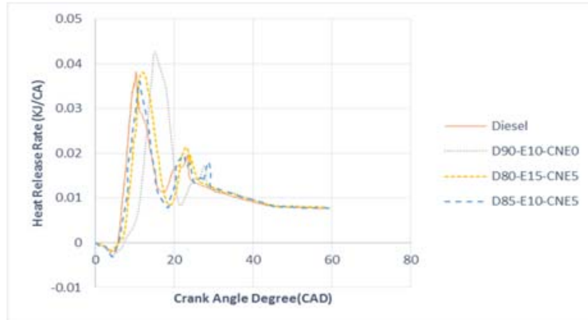

Figure-4. Heat release rate for pure diesel and D-E-CNE ratios at BMEP =3.5bar.

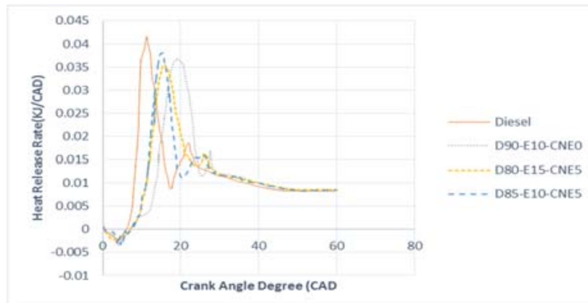

Figure-5. Heat release rate for pure diesel and D-E-CNE ratios at BMEP =2bar.

Figure-6 and 7 exhibit the complete combustion length and the ignition period for various D E CNE ratios and diesel fuel. The sum total combustion length is the period towards the end-of temperature discharge right from the start of center release. From the Figure-ures, the following discussions are drawn:

1. Compared to the diesel fuel, for a particular BMEP, the magnitudes of ignition time for all D E CNE ratios is retarded.

2. The ignition period progressively sophisticated for several ratios using the boost of the BMEP of the engine. Obviously, the ignition delay reduced using engine load variation.

3. The ignition period of DECNE could be equivalent to neat diesel fuel in particular load by cetane number enhancement, but there exists a big distinction at low loads. One justification for this can be the substantial evaporation heat, that ethanol structure contains, ends in low temperature at low loads, the in-cylinder fuel temperatures at the conclusion of compression stroke is quite reduced.

In other words, at low loads, the ignition delay of DECNE should be enhanced only by adding the CN enhancement. The connection involving the complete combustion period for different fuels at the engine-selected loads is provided in Figure-7. Clearly, the absolute combustion length of D E CNE is reduced in comparison with neat diesel fuel, and reveals an extraordinary change with CN booster inclusion. When the CN enhancement was included with the dual ethanol diesel fuel, the absolute combustion period gradually rose

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in a fashion closed to develop a particular BMEP as diesel fuel. It strictly implied that variation in ignition delay is liable to that particular behavior. While retardation was shown by the outset of heat release rate for DECNE ratios, the end of HRR stays at nearly the exact same crank angle degree irrespective of the inclusion of CN to the regular diesel fuel.

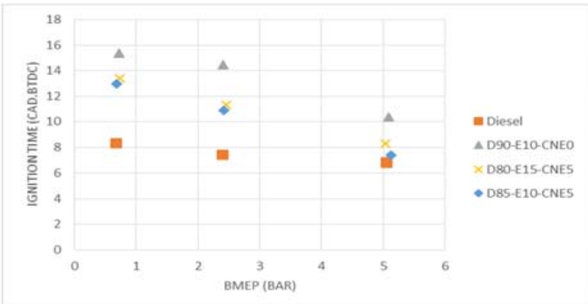

Figure-6. Ignition time for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

Performance characteristics

Figures 8 and 9 reveal the BSFC and diesel-powered equal BSFC versus BMEP for distinct DECNE ratios and regular diesel fuel. The Figures showed that as the pressure increases, the diesel-powered equal BSFC as well as BSFC lower for all fuel ratios. However, the ethanol addition increased the BSFC, the diesel-powered equal BSFC dropped concurrently by ethanol inclusion in diesel. To the same BMEP, diesel-powered equal BSFC and the BSFC display a decline with addition of CN enhancement.

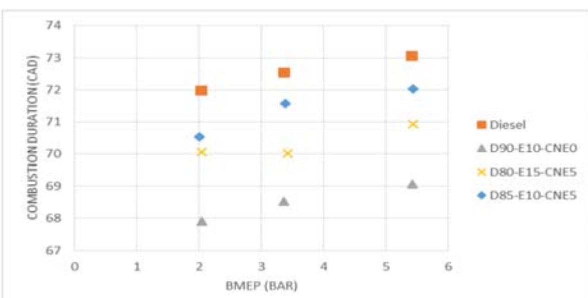

Figure-7. Combustion duration for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

These manners are acceptable considering that the engine may use more energy with DECNE ratios than with pure diesel energy to obtain the same energy output because of the decline in the low heat value of DECNE ratios. The decline of diesel-powered equal BSFC is as a result of augmentation of the combined burning stage of DECNE, and betterment of the diffusive burning stage due to oxygen enrichment. Moreover, the complete burning period reduced for DECNE ratios. According to these sorts of results, the power usage rate of DECNE demolishes. These occurrences outcomes in a reduced diesel-powered equivalent BSFC.

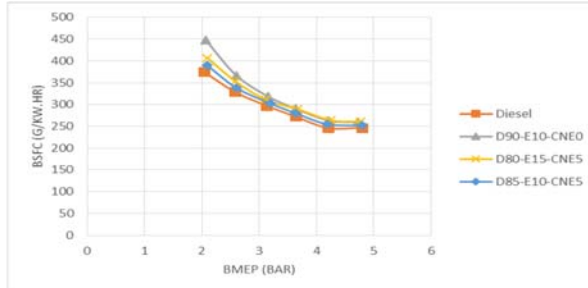

Figure-8. BSFC for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

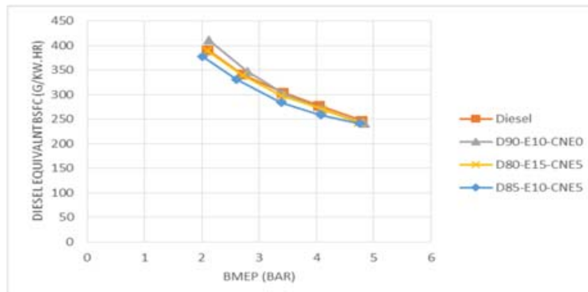

Figure-9. Diesel equal BSFC for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

Figure-10 provides the effective thermal efficiency of all the selected fuels. Like the findings of the diesel-powered equal BSFC, the thermal efficiency revealed a significant increase with ethanol inclusion; additionally, it reveals a slightly growth with CN enhancement at low loads. Moreover, the behaviour of thermal efficiency is not inconsistent with the diesel-powered equal BSFC. This suggests the thermal efficiency is a more typical expression of the fuel-consumption when working on alternate fuel ratios through the use of power consumption rate or the diesel-powered equal BSFC. The cause of enhancement of thermal efficiency that is powerful is parallel to that of the equal BSFC results obtained when the engine run with pure diesel.

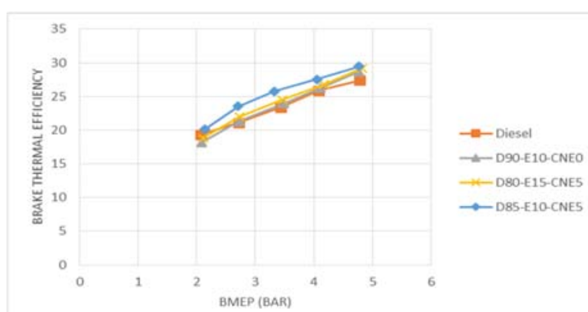

Figure-10. Brake thermal efficiency for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

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Emission characteristics

NOx emissions of the engine operated on DECNE rates and the reference diesel fuel at chosen working states are highlighted in Figure-11. Clearly, the NOx pollutants fairly drop with the rise of the designated engine speed, and reduced as the E percentages increased. With increase in the CN enhancement, the pollutants decrease up to certain engine-speed. At medium and high loads, the pollutants decrease with increase in the CN enhancement at certain engine BMEP. In-principle, high temperature period, the maximum temperature, and oxygen presence in the combination possess a dominating influence on NOx exhaust emission. It is visible from the preceding evaluation that the ignition delay of DECNE ratios increased, the premixed burning dropped, as well as their complete burning period reduced. Because of this, NOx exhaust reduced to minimum for DECNE ratios.

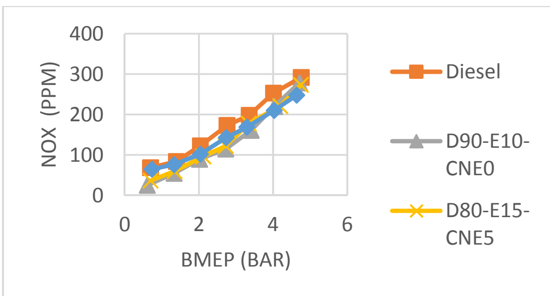

Figure-11. NOx emissions for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

Figure-12 depicts the rate of emission of CO at different BMEP. The Figure compared the effect of adding different ratios of D-E-CNE to the baseline diesel fuel. For DECNE ratios, CO and HC emitted pollutants develops unexpectedly at low and moderate loads, however, it worth reporting that the increasing level of CO emissions drops with the increase in the CN inclusion. The increase in the CO percentages is due to imperfect burning of the D-E-CNE combination. However, another explanation for the increase of CO percentages is the upsurge in ignition delay. This caused by the high latent heat of evaporation linked to D-E-CNE presence in the combustion components. The latest findings brought about a reduction in combustion heat at moderate and lower loads. Conversely, the CO emissions detected to somewhat decreased at high loads. As raising the percentage of air will encourage the additional oxidation of CO to the engine emission, this phenomenon could be justified by the supplementation of oxygen owing to inclusion of D-E-CNE.

From Figure-13, the emitted HC showed a reasonable increase for DE dual fuel with and without CN enhancement and particularly D85E10CNE5 at all engine operating conditions. Apparently, the previous trend could be attributed to the imperfect burning of D-E-CNE ratios due to the lower cetane number.

CONCLUSIONS

The primary conclusions to be drawn from the results are:

1. The results confirmed that adding CN enhancer to the combination of ethanol and diesel fuel would bring about the engine optimal combustion characteristics. However, this optimal condition is restricted to running the engine at high loads only as low loads showed contrary behavior.

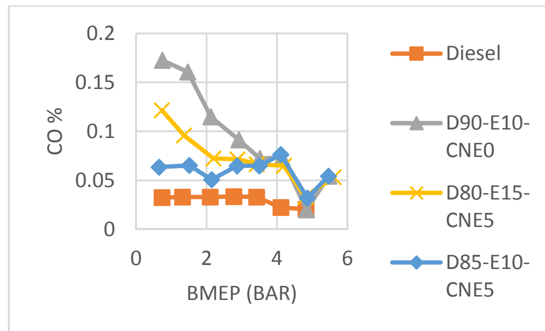

Figure-12. CO emission for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

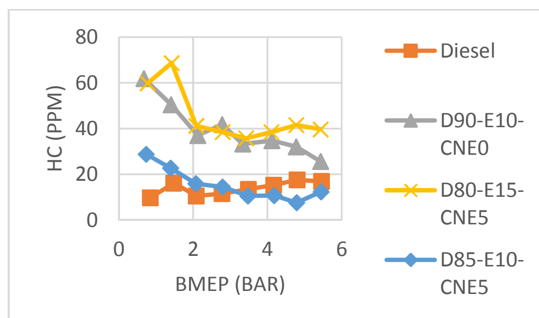

Figure-.13. HC emission for pure diesel and D-E-CNE ratios at engine speed= 1800 RPM.

2. The diesel-powered equal BSFC decreased, while thermal efficiency enhanced unexpectedly when diesel-engine fueled with D-E-CNE ratios. The CN enhancer had a good influence on energy usage and engine thermal efficiency.
3. When diesel-engine fueled with D-E-CNE ratios, smoke and NOx emissions decreased concurrently; especially, when CN enhancer was introduced to the mixtures, smoke and NOx emissions further decreased. CO exhaust pollutants improved unexpectedly at moderate and lower loads, while the trend level of HC showed a considerable reduction.

REFERENCES

[1] X. Shi, Y. Yu, H. He, S. Shuai, J. Wang, and R. Li, "Emission characteristics using methyl soyate-

ethanol-diesel fuel blends on a diesel engine," Fuel, vol. 84, no. 12-13, pp. 1543-1549, Sep. 2005.

[2] M. P. Ashok, "Effect of Dimethyl Ether in a Selected Ethanol/Diesel Emulsified Fuel Ratio and Comparing the Performance and Emission of the Same to Diesel Fuel," Energy Fuels, vol. 25, no. 8, pp. 3799–3805, Aug. 2011.

[3] "Operational and Environmental Evaluation of Diesel Engines Burning Oxygen-Enriched Intake Air or Oxygen-Enriched Fuels: A Review." [Online]. Available: http://papers.sae.org/2004-01-2924/. [Accessed: 27-Jan-2016].

[4] L. Wei, C. Yao, Q. Wang, W. Pan, and G. Han, "Combustion and emission characteristics of a turbocharged diesel engine using high premixed ratio of methanol and diesel fuel," Fuel, vol. 140, pp. 156-163, Jan. 2015.

[5] V. P. Ferreira, J. Martins, E. A. Torres, I. M. Pepe, and J. M. S. R. De Souza, "Performance and emissions analysis of additional ethanol injection on a diesel engine powered with A blend of diesel-biodiesel," Energy Sustain. Dev., vol. 17, no. 6, pp. 649-657, Dec. 2013.

[6] P. Satgé de Caro, Z. Mouloungui, G. Vaitilingom, and J. C. Berge, "Interest of combining an additive with diesel–ethanol blends for use in diesel engines," Fuel, vol. 80, no. 4, pp. 565-574, Mar. 2001.

[7] E. A. Ajav, B. Singh, and T. K. Bhattacharya, "Experimental study of some performance parameters of a constant speed stationary diesel engine using ethanol–diesel blends as fuel," Biomass Bioenergy, vol. 17, no. 4, pp. 357-365, Oct. 1999.

[8] L. Pidol, B. Lecointe, L. Starck, and N. Jeuland, "Ethanol–biodiesel–Diesel fuel blends: Performances and emissions in conventional Diesel and advanced Low Temperature Combustions," Fuel, vol. 93, pp. 329-338, Mar. 2012.

[9] M. Elawad and T. Yusaf, "Performance and exhaust emission of a diesel engine using crude palm oil as a fuel extender," J. Energy Environ., vol. 3, pp. 61-68, 2004.

[10] M. Zöldy, "Ethanol–Biodiesel–Diesel Blends as a Diesel Extender Option on Compression Ignition Engines," Transport, vol. 26, no. 3, pp. 303-309, Sep. 2011.

[11] M. Abu-Qudais, O. Haddad, and M. Qudaisat, "The effect of alcohol fumigation on diesel engine performance and emissions," Energy Convers. Manag. vol. 41, no. 4, pp. 389-399, Mar. 2000.

[12] Z. H. Zhang, K. S. Tsang, C. S. Cheung, T. L. Chan, and C. D. Yao, "Effect of fumigation methanol and ethanol on the gaseous and particulate emissions of a direct-injection diesel engine," Atmos. Environ., vol. 45, no. 11, pp. 2001–2008, Apr. 2011.

[13] "Aqueous Alcohol Fumigation of a Single-Cylinder DI Diesel Engine." [Online]. Available: http://papers.sae.org/811208/. [Accessed: 27-Jan-2016].

[14] A. Imran, M. Varman, H. H. Masjuki, and M. A. Kalam, "Review on alcohol fumigation on diesel engine: A viable alternative dual fuel technology for satisfactory engine performance and reduction of environment concerning emission," Renew. Sustain. Energy Rev., vol. 26, pp. 739-751, Oct. 2013.

[15] H. A. Havemann, M. R. K. Rao, A. Nataryan, and T. L. Narasimhan, "Alcohols in diesel engines," Automob. Eng., pp. 256–262, 1954.

[16] "Ethanol Fumigation of a Light Duty Automotive Diesel Engine." [Online]. Available: http://papers.sae.org/811209/. [Accessed: 27-Jan-2016].

[17] Z. H. Zhang, C. S. Cheung, T. L. Chan, and C. D. Yao, "Experimental investigation of regulated and unregulated emissions from a diesel engine fueled with Euro V diesel fuel and fumigation methanol," Atmos. Environ., vol. 44, no. 8, pp. 1054-1061, Mar. 2010.

[18] C. H. Cheng, C. S. Cheung, T. L. Chan, S. C. Lee, C. D. Yao, and K. S. Tsang, "Comparison of emissions of a direct injection diesel engine operating on biodiesel with emulsified and fumigated methanol," Fuel, vol. 87, no. 10-11, pp. 1870-1879, Aug. 2008.