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INVESTIGATION ON EFFECT OF MAGNETITE NANOFLUID ON PERFORMANCE AND EMISSION PATTERNS OF METHYL ESTERS OF BIO DIESEL

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Abstract. The objective of this work is to reduce viscosity and other related problems associated with biodiesel by adding non polluting additives. Magnetite is chosen as an additive in this work. Significant reason for using magnetite as an additive is that the magnetic nano particles (magnetite) can be collected from exhaust using magnetic billets in the tail pipe. Performance and emission test is carried out in single cylinder compression ignition engine using base and modified fuel and is compared to diesel. Modified fuel consists of 98.5% base fuel (Rice bran oil methyl ester), 1.3% additives (magnetite) and 0.2% surfactant (tri methyl ammonium hydroxide) by volume. The experimental work confirmed that by adding magnetite to methyl esters of rice bran oil enhances the brake thermal efficiency by 4.27% with 5.17% reduction in SFC. In addition, 10.8%, 9.1% and 8.49% reduction in HC, CO and NOx emissions is observed respectively.

Keywords: air-fuel ratio, delay period, ignition, performance.

Introduction

Vegetable oil is found to be a potential alternative fuel owing to its properties very similar to Diesel. Vegetable oil is used as an alternative fuel due to its inbuilt advantages. The significant aspects of considering vegetable oil as a potential alternative fuel is that, it can be used in modern diesel engines with no modifications. Vegetable oils are used as direct fuel or blended with diesel fuel in diesel engine. It also emits a lesser amount of carbon monoxide and hydrocarbon emissions. In spite of numerous advantages, it also emits higher percentage of nitric oxide (NOx) emission (Aydin, Bayindir 2010; Ramadhas *et al.* 2005). The possible reason reported is due to loss in engine power as it increases NOx emissions (Ryu 2010; Karabektas 2009). NOx emissions in diesel engine fuelled with biodiesel are reduced by adding nano particles in liquid form. Nano particles in liquid form reduce the NO_X emissions as it acts as a catalyst and enhances the rate of combustion (Choi, Oh 2006). NO_X emissions are significantly related to the temperature in the combustion chamber. It has been experimentally found that by adding nano particles in liquid state lowers the thermal loading, heat flux and combustion chamber surface temperature (Galfetti *et al.* 2007). Further, it has been experimentally found that the brake thermal efficiency of biodiesel is improved significantly with addition of nanofluid. Chemical compositions of fuel are altered with inclusion of nanofluid (Jung *et al.* 2005). In addition nano fluid releases energy when diffused into higher temperature. Enhancement in oxidation reaction will take place with addition of nanofluid in the methyl ester (Selim, Elfeky 2001). Performance characteristics of methyl ester are improved due to its natural increase in density impulse of nanofluid when exposed to higher temperature in combustion chamber. Radiative heat transfer and mass diffusivity of methyl ester is improved by adding nanofluid to biodiesel (De Luca *et al.* 2005; Galfetti *et al.* 2007). Performance parameters of diesel engine fuelled with biodiesel is considerably increased with addition of nanofluid as it has high ratio of surface area to volume (Prasher *et al.* 2006). It is reported that the ignition probability of methyl ester is improved by incorporating nanofluid which results in increase in efficiency and reduction in NO_X emissions (Krishnamurthy *et al.* 2006).

In recent times, adding nano particles to liquid fuel is subjected to a lot of investigation. Arul Mozhi Selvan *et al.* (2014) studied the impact of cerium oxide nano particles of size 32 nm with a dosing level of 25 ppm using diesterol in diesel engine. They found a significant reduction in NO_X emissions. Shafii *et al.* (2011) investigated the effect of water based ferrofluid with a size of 10 nm and a concentration of

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0%, 0.4%, and 0.8% by volume in diesel fuel to views its effects on performance and emissions characteristics. It was found that the magnetic particles improves the combustion characteristics and reduce NOX emissions. Further, magnetic nano particles increase in chaotic movements and reducing in settling velocity of the particles which aids combustions. However, the impact on addition of ferrofluid to rice bran oil methyl ester has never been experimented. The present experimental study is aimed to examine the effect of ferrofluid on the various properties of methyl esters of rice bran oil and also its influence on performance and emissions characteristics. Experiments were carried out with RBOME and RBOMEF and are compared with petroleum diesel. RBOMEF was prepared comprising 98.5% biodiesel (Rice bran oil methyl ester), 1.3% magnetite based ferrofluid and 0.2% surfactant by volume was used in a CI engine.

1. Experimental material & methods

1.1. Materials and reagents

1.1.1. Rice bran oil

Rice bran oil is best suitable for high-temperature cooking methods such as stir frying and deep frying. It is accepted as cooking oil in several Asian countries. It has a low-cost feed stock with high value added by- products. In addition, the chemical properties of rice bran are closer to that of petroleum diesel. The properties of transesterifed methyl esters of rice bran oil fall well within the acceptable limit of ASTM standards. Rice bran is obtained as a by-product during polishing of rice from its kernel. Rice bran is dried to remove the water present in it. It is then fed to oil extractor which extracts oil by crushing. The oil obtained is classified as defatted and crude rice bran oil. Defatted rice bran oil with 16–20% of protein content is used for edible purpose. Crude rice bran oil with 23–24% free fatty acid is used as the main source of biodiesel production process. Crude rice bran oil is converted into its methyl esters of rice bran oil by conventional transesterification process. The present work utilized refined Rice bran oil. The alcohol used in this work was methanol and KOH was used as catalyst for transesterifications.

1.1.2. Ferrofluid

Ferrofluid (Fe_3O_4) is prepared using the following Eq. (1).

$$FeCl_2 + 2FeCl_3 + 8NH_3 + 4H_2O \rightarrow Fe_3O_4 + 8NH_4Cl. \quad (1)$$

Diameter of ferrofluid was in the order of 10nm (Berger *et al.* 1999). Aqueous tri methyl ammonium hydroxide ((CH3)3NOH) solution is used as a surfactant to improve the bonding between ferrofluid to methyl ester. The most significant reason for using ferrofluid is that the magnetic nano particles can be collected from exhaust using magnetic billets. Furthermore, it can be easily diluted to biodiesel and as a result it can collect the benefits of water- biodiesel emulsions.

1.2. Apparatus & procedure

1.2.1. Base fuel preparation procedure

Batch transesterification process is followed during conventional transesterification. Molar ratio of vegetable oil and alcohol is 5.9:1. 0.51% of catalysts (wt/wt) to rice bran oil were used. Temperature is maintained at 60 °C during transesterification process. Vegetable oil, methanol and catalysts are then mixed and stirred at 280 rpm for 75 minutes. Further, the mixture is then allowed to cool. The top layer from the mixture is separated, washed and dried for further investigation. The ester obtained by conventional transesterification is used as a base fuel. Table 1 shows the fatty acids compositions of rice bran oil using Gas-liquid chromatography technique.

Table 1. Fatty acids compositions of rice bran oil

Fatty acids	Percentage
Myristic acid	0.9%
Palmitic acid	21.5%
Stearic acid	2.6%
Oleic acid	37.7%
Linoleic acid	35%
α-Linolenic acid	2.3%

1.2.2. Modified base fuel preparations procedure (RBOMEF)

0.3% of aqueous tri methyl ammonium hydroxide and 1% of magnetite by volume is used in the study. Surfactant, magnetite and methyl esters of rice bran oil are mixed using ultrasonic agitator. Stability test were performed to view its phase change quality. Test results in homogeneity of magnetite in methyl esters of rice bran oil and found stable. The ester achieved by adding magnetite is referred as RBOMEF.

1.3. Base and modified fuel properties

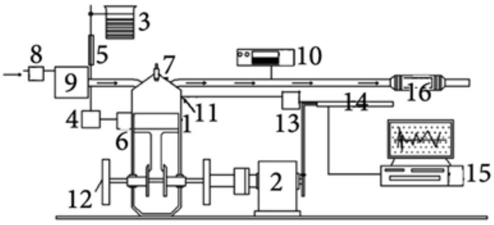
Fuel properties of methyl esters and Diesel are shown in Table 2. There is a significant change in all the properties with addition of ferrofluid. 3.15% enhancement in Kinematic viscosity is observed by adding magnetite to methyl esters of rice bran oil. This is caused by increase in resistance among fuel layer. 2 °C increase in flash point is observed by adding magnetite to methyl esters of rice bran oil. Higher flash point is beneficial for safety measures. 0.02% increase in water content was found by adding magnetite to methyl esters of rice bran oil. This is due to presence of water content in ferrofluid. Higher water content will reduce the NO_X emissions. Other property such as, density and calorific value of RBOMEF is enhanced by 2.96% and 2.61% respectively. This is due to positive effects of ferrofluid.

Table 2. Properties of test fuels

Properties	RBOMEF	RBOME	Diesel
Kinematic Viscosity [cst]	6.56	6.31	4.2
Flash point [°C]	143	137	50
Water content [%]	0.152	0.131	Nil
Density [gm/cc]	0.911	0.881	0.821
Calorific Value [kJ/kg]	39243	38223	42957
Cetane Index	54	52	45

1.4. Experimental set-up & testing procedure

Air cooled compression ignition engine is used for experimentation. Technical specification of engine is illustrated in Table 3. Engine exhaust pipe is linked to AVL444 di gas analyzer having a maximum response time of 8 sec for monitoring the engine emissions. The probe that is used to the exhaust gas analyzer was placed inside the exhaust pipe in which emissions such as HC, CO and NOx are measured. Exhaust gas temperature was measured using K-type thermocouple made of Chrome-alumel with digital indicating unit. U-tube manometer having one end connected to tank and other end left free to ambient is used to measure the air flow rate. Pressure inside the cylinder was measured with the help of an AVL pressure transducer with sensitivity of 16.04pc/bar, linearity of <± 0.3% and the crank angle were inferred using a TDC encoder. Both the pressure transducer and TDC encoder were linked to a computer for monitoring and recording the combustion parameters through AVL 617 indimeter of software version V2.00. Details of gas analyzer are shown in Table 4. Figure 1 shows the layout of engine and instrumentation set up.



1. Kirloskar TV1 engine
2. Eddy current dynamometer
3. Fuel tank
4. Fuel filter
5. Fuel measurement setup
6. Fuel pump
7. Fuel injector
8. Air filter
9. Air stabilizing tank
10. Smoke meter and flue gas analyzer
11. Pressure transducer
12. TDC encoder
13. Charge amplifier
14. Indimeter
15. Monitor
16. Exhaust silencer

Fig. 1. Layout of experimental setup

Table 3. Specifications of the engine

Make	Kirloskar
Stroke	4
Number of Cylinders	1
Power rated	4.45 kW
Speed rated	1500 rpm
Bore diameter(D)	87.5 mm
Stroke length(L)	110mm
Compression ratio	17.5:1

Table 4. Details of gas analyzer

Parameters	Make	Accuracy	Relative Uncertainty
CO	AVL gas analyzer	0.01	±3%
HC		± 10 ppm	±2%
NOx		± 10 ppm	±2.5%

1.5. Error analysis

The error analysis for HC emission are calculated using the Equation (2)

$$\sigma_{HC} = \left[\frac{\sum_{i=1}^{n} \left((HC)_i - \left(\overline{HC} \right) \right)^2}{n-1} \right]^{\frac{1}{2}}. \tag{2}$$

The uncertainty in $\Delta(HC)$ in hydrocarbons is calculated by Equation (3)

$$\frac{\sigma_{HC}}{\sqrt{n}}, \tag{3}$$

where n = number of HC measurements,
$\overline{HC}$ = mean value of HC measurements,
σ_{HC} = unbiased standard deviation for HC measurements.

By adapting the above equation, the error analysis of other emissions such as CO, NOx and smoke were analysed.

2. Results and discussion

2.1. Effect of magnetite on emission parameters

2.1.1. Hydrocarbon emissions

Figure 2 shows the change in HC emissions for all the test fuels with respect to load. Average HC emission from diesel, RBOME and RBOMEF is 46.5 ppm, 44.7 ppm and 38.0 ppm at all loads respectively. Significant reduction in HC emissions were observed for RBOME and RBOMEF when compared to diesel. RBOME and RBOMEF have inbuilt oxygen content which helps in improved combustion and lesser HC emissions. Puhan *et al.* (2005) found that reduction in HC emission was about 63% for methyl ester compared with Diesel. Alam *et al.* (2004) observed significance reduction in HC emission for methyl ester comparing diesel citing ample availability of oxygen as the reason. By adding magnetite to RBOME, 9.1% reductions in HC emissions were found. Activation temperature of carbon combustion is lowered by adding magnetite which performs as oxidation catalysts. Similar trend was mentioned on the experimental work by (Sajith *et al.* 2010; Kannan *et al.* 2011).

2.1.2. Carbon monoxide emissions

Figure 3 shows the change in CO emissions for all the test fuels with respect to load. An average CO emission from diesel, RBOME and RBOMEF is 0.07425, 0.06875 and 0.066% volume correspondingly. CO emissions for RBOME and RBOMEF are significantly lower than diesel. This is due to enhanced oxidation reaction during combustion owing to higher content of oxygen of RBOME and RBOMEF. Puhan *et al.* (2005) found 70% reduction in CO emissions when fuelled with Maua oil methyl ester. For all the fuels, CO emission increases with increase in load. This is due necessity of rich mixture with increase in load to sustain steady power output. Ulusoy *et al.* (2009) found increase in CO emission with increase in load citing decrease in air fuel ratio at higher loads as the cause. By adding magnetite to RBOME, 6.34% reductions in HC emissions were observed. This is due to increased surface area to volume ratio of magnetite which improves the mixing rate of air and fuel as cited by Lenin *et al.* (2013). Further, RBOMEF has a lesser delay period due to the presence of magnetite which results in complete oxidation. The obtained result is justified with of similar work done by Selvan *et al.* (2004), Kim, Choi (2010).

2.1.3. Nitrogen oxide emissions

Figure 4 shows the change in NO_X emissions for all the test fuels with respect to load. Average NO_X emission from diesel, RBOME and RBOMEF is 149, 175 and 197 ppm correspondingly. NOX emissions for RBOME and RBOMEF are higher than diesel by 23.5% and 18.74%. Since the peak pressure of RBOME and RBOMEF is higher than diesel, higher NO_X emissions are obvious. By adding magnetite to RBOME, 8.49% reductions in NO_X emissions were observed. The possible reason is due to shorter ignition delay period for RBOMEF. By adding magnetite to methyl ester of rice bran oil the combustion rate is improved. Further, the water present in magnetite reduces the peak combustion temperature thereby reducing NO_X emissions for RBOMEF. Similar results were citied on the experimental work done by Shafii *et al.* (2011).

2.2. Effect of magnetite on performance parameters

2.2.1. Brake thermal efficiency

Figure 5 shows Brake thermal efficiency of RBOME, RBOMEF with respect to load. It is inferred that BTE for diesel is higher than RBOME and RBOMEF. This is attributed to higher viscosity of methyl esters when compared to diesel. It was reported from the past information that BTE decreases with the increase in cottonseed oil methyl ester in the blends comparing diesel due to its higher viscosity and lower heating value (Aydin, Bayindir 2010). Moreover the calorific value of diesel is higher as compared to RBOME and RBOMEF. Higher calorific value leads to lesser requirement of fuel for delivering any given rated power. BTE for RBOMEF is higher than RBOME by 4.27%. Since the density of RBOMEF is 2.97% higher than

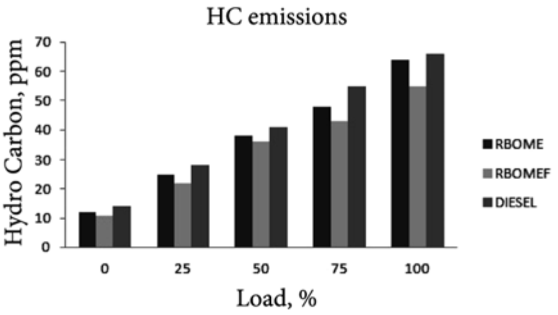


Fig. 2. Hydro carbon emissions with respect to load

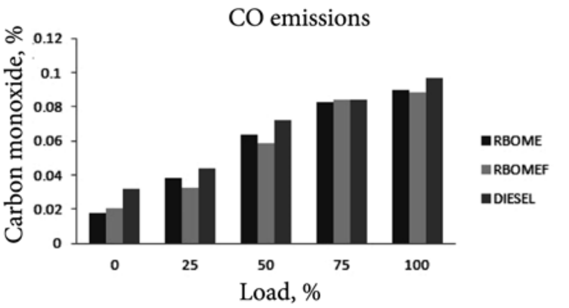


Fig. 3. Carbon monoxide emission with respect to load

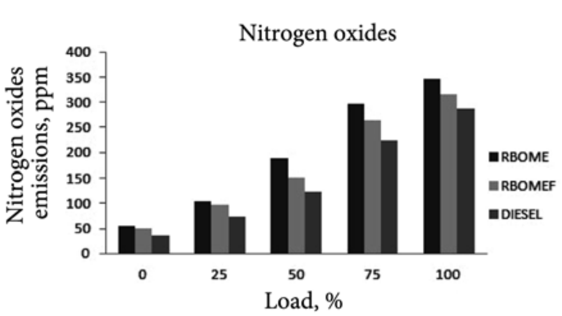


Fig. 4. NOx emission with respect to load

RBOME the mixture momentum and penetration depth in cylinder is controlled and result in shorter ignition delay and enhanced combustion. Furthermore, the fuel with higher density as in the case of RBOMEF restrains spray tip penetration, ensuring that the air fuel mixture is only created at the core region of the combustion chamber owing to improved combustion (Raheman, Phadatare 2004). The other reason is due to higher availability of oxygen which enhances air fuel mixing and increase efficiency Shafii *et al.* (2011)

2.2.2. Specific fuel consumption

SFC of RBOME, RBOMEF is shown in Figure 6. SFC for diesel is least during the trail. This is because of higher calorific value of diesel. Further, addition of ferrofluid decreases SFC. Average BSFC for RBOMEF is lesser than RBOME by 5.17%.This is due to positive effect of ferrofluid which reduces ignition delay thereby reducing fuel consumption. The other reason is due to surplus availability of oxygen in RBOMEF which promotes improved combustion and lesser consumption of fuel. Furthermore, nanosized particles can be dispersed into high-temperature zones for direct oxidation reaction leading shorter delay period thereby resulting in lesser consumption of fuel (Shafii *et al.* 2011).

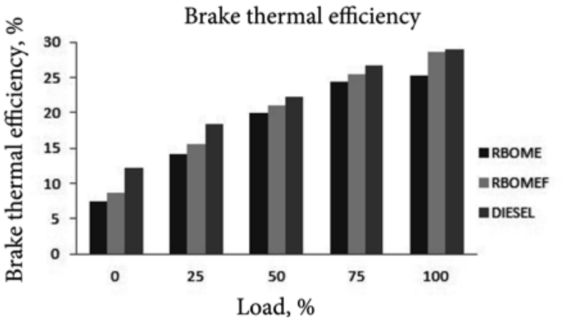


Fig. 5. Brake thermal efficiency with respect to load

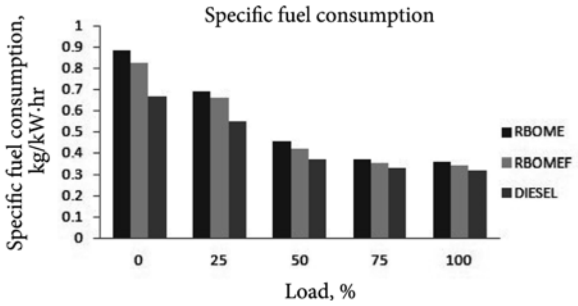


Fig. 6. Specific fuel consumption with respect to load

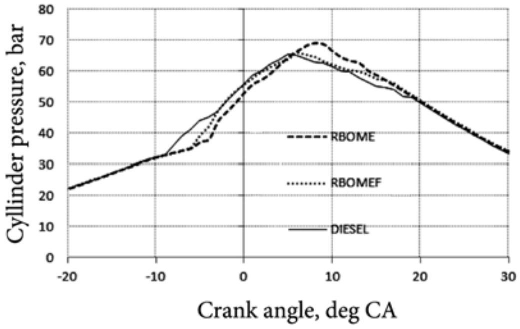


Fig. 7. Variation of pressure with crank angle

2.2.3. Pressure vs crank angle

Figure 7 shows the variation in pressure with crank angle for RBOME, RBOMEF and Diesel at full load conditions. Peak pressure of RBOME is higher than RBOMEF and Diesel by 4.18% and 5.34%.Since the viscosity of RBOME is higher by 5.94% comparing RBOMEF atomization and mixing of fuel with air is not in uniform rate causing longer breakup length, lower dispersion rate and increased ignition delay. Due to longer delay period more measure of fuel is accumulated causing rapid increase in peak pressure. Similar results were cited on the experimental work by (Buyukkaya 2010).

It is also inferred that the peak pressure of Diesel is lesser than RBOME and RBOMEF. This is due to reduced fuel consumption of diesel in comparison with RBOME and RBOMESUM ensuring improved atomization and better combustion which result in shorter ignition delay and lower peak pressure. It is also inferred that by addition of ferrofluid the peak cylinder pressure is reduced by 3.35%. This is due to shorter delay period and improved ignition properties of nanoparticles which initiate the early combustion when compared to RBOME as cited by (Basha, Anand 2011). The other reason is as a result of higher cetane number of RBOMEF which initiates faster evaporation and improved combustion leading to shorter ignition delay. It is also observed that the occurrence of peak pressure is advanced with addition of ferrofluid due to shorter ignition delay. This is due to surplus oxygen in ferrofluid which promotes improved combustion. This is in agreement with similar work done by (Buyukkaya 2010).

Conclusion

The following conclusions were drawn by adding magnetite to methyl esters of rice bran oil in a constant speed diesel engine.

(1) 6.34% of CO emission is reduced by adding ferrofluid to methyl ester due to magnetite which undergoes catalytic oxidation reaction and causing complete oxidation during combustion.

(2) 9.1% of HC emission is reduced with addition of magnetite. HC oxidation reaction is improved due to the presence of ferrofluid which acts as an oxidation catalyst and lowers the carbon combustion activation temperature.

(3) 8.49% of NOX emission is achieved by doping magnetite to methyl ester. This is achieved as a result of latent heat of evaporation of water present in ferrofluid.

(4) Engine performance is enhanced by 4.27% along with 5.17% reduction in BSFC. This is due to higher availability of oxygen which enhances air fuel mixing during combustion. Ferro fluid also possesses desirable combustion characteristics such as high heats of combustion and fast energy release rates.

Adding magnetite to methyl esters of rice bran oil is promising technique to offset the drawbacks associated with it.

References

Alam, M.; Song, J.; Acharya, R.; Boehman, A.; Miller, K. 2004. Combustion and emissions performance of low sulfur, ultra low sulfur and biodiesel blends in a DI diesel engine, *SAE Technical Paper Series*. http://dx.doi.org/10.4271/2004-01-3024

Arul Mozhi Selvan, V.; Anand, R. B.; Udayakumar, M. 2014. Effect of cerium oxide nanoparticles and carbon nanotubes as fuel-borne additives in Diesterol blends on the performance, combustion and emission characteristics of a variable compression ratio engine, *Fuel* 130: 160–167. http://dx.doi.org/10.1016/j.fuel.2014.04.034

Aydin, H.; Bayindir, H. 2010. Performance and emission analysis of cottonseed oil methyl ester in a diesel engine, *Renewable Energy* 35(3): 588–592. http://dx.doi.org/10.1016/j.renene.2009.08.009

Basha, J. S.; Anand, R. B. 2011. An experimental study in a CI engine using nanoadditive blended water-diesel emulsion fuel, *International Journal of Green Energy* 8(3): 332–348. http://dx.doi.org/10.1080/15435075.2011.557844

Berger, P.; Adelman, N. B.; Beckman, K. J.; Campbell, D. J.; Ellis, A. B.; Lisensky, G. C. 1999. Preparation and properties of an aqueous ferrofluid, *Journal of Chemical Education* 76(7): 943–948. http://dx.doi.org/10.1021/ed076p943

Buyukkaya, E. 2010. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics, *Fuel* 89(10): 3099–3105. http://dx.doi.org/10.1016/j.fuel.2010.05.034

Choi, S. H.; Oh, Y. 2006. The emission effects by the use of biodiesel fuel, *International Journal of Modern Physics B* 20: 4481–4486. http://dx.doi.org/10.1142/s0217979206041550

De Luca, L. T.; Galfetti, L.; Severini, F. 2005. Burning of nanoaluminized composite rocket propellants, Combustion, *Explosion and Shock Waves* 41(6): 680–692. http://dx.doi.org/10.1007/s10573-005-0080-5

Galfetti, L.; DeLuca, L. T.; Severini, F.; Meda, L.; Marra, G. 2007. Pre and post- burning analysis of nano-aluminized solid rocket propellants, *Aerospace Science and Technology* 11(1): 26–32. http://dx.doi.org/10.1016/j.ast.2006.08.005

Jung, H.; Kittelson, D. B.; Zachariah, M. R. 2005. The influence of a cerium additive on ultrafine diesel particulate emissions and kinetics of oxidation, *Combustion and Flame* 142(3): 276–278. http://dx.doi.org/10.1016/j.combustflame.2004.11.015

Kannan, G. R.; Karvembu, R.; Anand, R. 2011. Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel, *Applied energy* 88(11): 3694–3703. http://dx.doi.org/10.1016/j.apenergy.2011.04.043

Karabektas, M. 2009. The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel, *Renewable Energy* 34(4): 989–993. http://dx.doi.org/10.1016/j.renene.2008.08.010

Kim, H.; Choi, B. 2010. 2010. The effect of biodiesel and bioethanol blended diesel fuel on nanoparticles and exhaust emissions from CRDI diesel engine, *Renewable Energy* 35(1): 157–163. http://dx.doi.org/10.1016/j.renene.2009.04.008

Krishnamurthy, S.; Bhattacharya, P.; Phelan, P. E.; Prasher, R. S. 2006. Enhanced mass transport in nanofluids, *Nano Letters* 6(3): 419–423. http://dx.doi.org/10.1021/nl0522532

Lenin, M. A.; Swaminathan, M. R.; Kumaresan, G. 2013. Performance and emission characteristics of a DI diesel engine with a nanofuel additive, *Fuel* 109: 362–365. http://dx.doi.org/10.1016/j.fuel.2013.03.042

Prasher, R.; Bhattacharya, P.; Phelan, P. E. 2006. Brownian-motion-based convective-conductive model for the effective thermal conductivity of nanofluids, *Journal of Heat Transfer* 128(6): 588–595. http://dx.doi.org/10.1115/1.2188509

Puhan, S.; Vedaraman, N.; Sankaranarayanan, G.; Ram, B. V. B. 2005. Performance and emission study of Maua oil methyl ester in a 4-stroke natural aspirated direct injection diesel engine, *Renewable Energy* 30(8): 1269–1278. http://dx.doi.org/10.1016/j.renene.2004.09.010

Raheman, H.; Phadatare, A. G. 2004. Diesel engine emissions and performance from blends of karanja methyl ester and diesel, *Biomass and Bioenergy* 27(4): 393–397. http://dx.doi.org/10.1016/j.biombioe.2004.03.002

Ramadhas, A. S.; Muraleedharan, C.; Jayaraj, S. 2005. Performance, emission evaluation of a diesel engine fuelled with methyl esters of rubber seed oil, *Renewable Energy* 30(12): 1789–1800. http://dx.doi.org/10.1016/j.renene.2005.01.009

Ryu, K. 2010. The characteristics of performance and exhaust emissions of a diesel engine using a biodiesel with antioxidants, *Bioresource Technology* 101(1): S78–82. http://dx.doi.org/10.1016/j.biortech.2009.05.034

Sajith, V.; Sobhan, C. B.; Peterson, G. P. 2010. Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel, *Advances in Mechanical Engineering* 2(0): 581407. http://dx.doi.org/10.1155/2010/581407

Selim, M. Y. E.; Elfeky, S. M. S. 2001. Effects of diesel/water emulsion on heat flow and thermal loading in a pre combustion chamber diesel engine, *Applied Thermal Engineering* 21(15): 1565–1582. http://dx.doi.org/10.1016/s1359-4311(01)00019-9

Shafii, M. B.; Daneshvar, F.; Jahani, N.; Mobini, K. 2011. Effect of ferrofluid on the performance and emission patterns of a four stroke diesel engine, *Advances in Mechanical Engineering* 3(0): 529049. http://dx.doi.org/10.1155/2011/529049

Ulusoy, Y.; Arslan, R.; Kaplan, C. 2009. Emission characteristics of sunflower oil methyl ester, *Energy Sources, Part A Recovery, Utilization, and Environmental Effects* 31(11): 906–910. http://dx.doi.org/10.1080/15567030802087528

APPENDIX

Sample calculation to find Uncertainty for HC emission

The five measurements of HC for RBOME are 25 ppm, 38 ppm, 48 ppm and 64 ppm.
The standard deviation for the measurements is

$$\sigma_{HC} = 2.75 \ .$$

The uncertainty in HC is given by

$$\Delta\ (\mathrm{HC}) = \frac{2.75}{\sqrt{5}} = 1.223\ \text{ppm} \ .$$

$$\text{Relative uncertainty} = \frac{1.223}{64} \times 100\% = 1.91 \approx 2\% \ .$$

In the same procedure, uncertainty of NO_X and CO are calculated.

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