Isı Bilimi ve Tekniği Dergisi, 33, 2, 83-88, 2013
J. of Thermal Science and Technology

ISSN 1300-3615

DIESEL ENGINE EMISSIONS IMPROVEMENTS BY THE USE OF SUN FLOWER METHYL ESTER /DIESEL BLENDS

Cenk SAYIN
Department of Mechanical Engineering, Marmara University, 34722, Istanbul-Turkey

(Geliş Tarihi: 03. 05. 2012, Kabul Tarihi: 13. 06. 2012)

Abstract: The study focuses on the influence of blending sun flower methyl ester (SOME) to conventional diesel. In order to determine the emission characteristics of SOME/diesel blends, the engine was performed at five different engine speed under full load condition. With addition of SOME resulted in a combined increase in smoke opacity, CO_2 and NO_X emissions and decrease in CO and HC emissions. Also, BSFC of SOME is close to the values obtained from diesel fuel. Hence, it has been seen that blend of SOME and diesel fuel can be used as alternative fuel successfully in a diesel engine without any modification and also it is an environmental friendly fuel in terms of emission parameters.
Keywords: Diesel engine, Sun flowermethyl ester, Specificfuelconsumption, Exhaustemissions.

AYÇİÇEK YAĞI METİL ESTERİ DİZEL KARIŞIMLARI KULLANILARAK DİZEL MOTOR EMİSYONLARININ İYİLEŞTİRİLMESİ

Özet: Bu çalışmada, konvansionel dizel yakıtı ve ayçiçeği metil ester karışımlarının etkileri üzerinde durulmuştur. Emisyon karakteristiklerini belirlemek için bir dizel motoru beş farklı hız ve tam yük testlerine tabi tutulmuştur. Ayçiçek yağı metil esteri katkısı ile is emisyonu, CO_2 ve NO_xemisyonlarında artma, CO ve HC emisyonlarında ise gözlenmiştir. Aynı zamanda, ayçiçeği metil esteri karışımlarının BSFC değerlerinin saf dizel yakıtından elde edilen değerlere yakın olduğu görülmektedir. Sonuç olarak, ayçiçeği yağı metil esteri karışımları alternatif yakıt olarak dizel motorlarda herhangi bir modifikasyon değişikliğine gerek duyulmadan kullanılabilecektir. Ayçiçek yağı metil esterinin emisyon parametreleri açısından çevre dostu bir yakıt olduğu söylenebilir.
Anahtar Kelimeler: Dizel motor, Ayçiçek yağı metil esteri, Özgül yakıt tüketimi, Egzoz emisyonları.

INTRODUCTION

The discriminate usage of petroleum products resulted in depletion and global warming of environment. These problems led to necessitiy of alternative fuels, especially automobiles in transport sector, power sector and agricultural sector etc. Vegetable oils can be used as neat oils having high viscosity and low volatility. Different methods are being used to reduce the viscosity and make them usable in engine applications. Among different methods, transesterification proved to be precise to chemically modify the oils to make clean biodiesel. So, chemical modification of oils is needed to improve the properties. Transesterified vegetable oils usually called biodiesel proved to be a promising alternative diesel fuel (Barsic and Humke, 1981; Nwafor, 2003; Carmen et al., 2007; Ma, 1999).

Exhaust emissions from diesel vehicles are very complex mixtures containing many types of air pollutants, which are distributed among particulate, semi volatile and gaseous phases. Due to the growing concern over possible adverse health effects caused by diesel emissions, the pollutants including hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM) have been regulated by law in many developed countries. However, HC and PM in the exhaust can contain many different types of compounds with varying toxicity level. Unregulated emissions, such as polycyclic aromatic hydrocarbons and aldehydes, are recently receiving huge attention because of their potent mutagenic activity and carcinogenicity (Enya et al., 1997; Johansen et al., 1997; Kuchenmeister et al., 1998).

Biodiesel has received, and continues to receive, considerable attention for its potential use as an augmenting fuel to petroleum diesel. Its advantages include decreased net carbon dioxide (CO_2), HC, CO, and PM emissions, and fuel properties similar to petroleum diesel for ease of use in diesel engines. Biodiesel can be produced from feedstock’s that are generally considered to be renewable. The vegetable oil ester based biodiesel has long been used as fuel for diesel engines. Many studies about the use of biodiesel fuels in diesel engines have been done and some of them have been reviewed (Sun et al., 2010; Gill et al., 2012).

Dia et al. (2009) investigated regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cookingoil. Experiments were conducted on a 4-cylinder direct-injection diesel engine under five engine loads at an engine speed of 1800 rpm. Blended fuels containing 19.6%, 39.4%, 59.4% and 79.6% by volume of biodiesel, corresponding to 2%, 4%, 6% and 8% by mass of oxygen in the blended fuel, were used. Results indicated that the brake specific fuel consumption (BSFC) and the brake thermal efficiency (BTE) increase. The HC and CO emissions decrease while NO_x and NO_2 emissions increase. The smoke opacity and PM concentrations were reduced significantly at high engine load.

Dorado et al. (2003) researched that the exhaust emissions of a Diesel direct injection Perkins engine fueled with waste olive oil methyl ester were studied at several steady state operating conditions. Emissions were characterized with neat biodiesel from used olive oil and conventional Diesel fuel. Results revealed that the use of biodiesel resulted in lower emissions of CO (up to 58.9%), CO_2 (up to 8.6%, excepting a case which presented a 7.4% increase), nitrogen oxide (up to 37.5%), and sulphur dioxide (up to 57.7%), with increase in emissions of nitrogen dioxide (up to 81%, excepting a case which presented a slight reduction). Biodiesel also presented a slight increase in BSFC (lower than 8.5%) that may be tolerated due to the exhaust emission benefits.
As mentioned above, the fuel properties of biodiesel depend on the feedstock source and they may present different combustion behaviors at the different engine designs. Biodiesel is also an important alternative fuel for the countries; especially if their energy depends on foreign sources such as Turkey. For these reasons, a DI diesel engine, which is widely used in the Turkey's highways, was selected to test two different biodiesels. The properties of the biodiesels have been investigated and their effects on the emissions have been discussed.

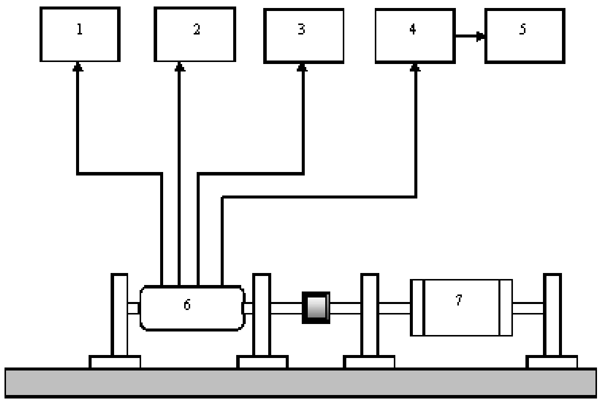
MATERIAL AND METHODS

The fuel tests were carried out with a 2500 cc, three cylinder, four-stroke, water-cooled, 18.5:1 compression ratio, DI diesel engine Perkins AD 3-152. The maximum torque is 162.8 Nm at 1300 rpm, and the maximum engine power is 34 kW at 2250 rpm. The engine was not new but reconditioned to original specification. With the purpose of measure the emissions such as CO, HC, smoke opacity, NO_x, and BSFC during operation, the actual driving conditions on the road were created on dynamometer. The engine was tested at full load and various speeds. The engine was loaded at five various speeds ranging from 1000 to 2200 rpm with 300 rpm period.

In another study, a blend of 50% sesame oil and 50% diesel fuel was used as an alternative fuel in a direct injection diesel engine. The engine was tested at full load and six various speeds ranging from 1800 to 3300 rpm with 300 rpm period. Engine performance and exhaust emissions were investigated and compared with the ordinary diesel fuel in a diesel engine. The experimental results show that the engine power and torque of the mixture of sesame oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel (Altun et al., 2008).

Ilkilic et al. (2011) studiedbiodiesel from safflower oil and its application in a diesel engine. The produced biodiesel was blended with diesel fuel by 5% (B5), 20% (B20) and 50% (B50) volumetrically. Some of important physical and chemical fuel properties of blend fuels, pure biodiesel and diesel fuel were determined. Performance and emission tests were carried out on a single cylinder diesel engine to compare biodiesel blends with petroleum diesel fuel. Average performance reductions were found as 2.2%, 6.3% and 11.2% for B5, B20 and B50 fuels, respectively, in comparison to diesel fuel.

These reductions are low and can be compensated by a slight increase in BSFC. For blends, BSFCs were increased by 2.8%, 3.9% and 7.8% as average for B5, B20 and B50, respectively. Considerable reductions were recorded in PM and smoke emissions with the use of biodiesel. CO emissions also decreased for biodiesel blends while NO_x and HC emissions increased.



1.Exhaust gas analyzer 2.Fuel tank 3.Control panel
4. Data acquisition unit 5. PC unit 6.Engine
7. Dynamometer
Figure 1. Schematic layout of the engine test system.

As seen in the Figure 1, the engine was coupled to a Neftren brand hydraulic dynamometer to provide brake load. In the tests, ordinary diesel fuel was sold commercially and sun flower methyl ester (SOME) manufactured from crude sunflower oil was blended with diesel fuel volumetrically 10% SOME and 90% diesel fuel, 50% SOME and 50% diesel fuel, and 100% SOME. Physical properties of SOME and diesel fuel are given in Table 1.

Table 1. Physical properties of SOME and diesel fuel.

Properties	SOME	Diesel fuel
Density (g/cm^3) at 26 ^{o}C	0.89	0.84
Viscosity (mm^2/s) at 26 ^{o}C	4.5	3.2
Flash point (^{o}C)	85	59
Lower heating value (MJ/kg)	40.5	42.98
Cetane number	74	56
Acid value	0.13	0.22

Fuel consumption was measured by weighing fuel used for a period time on an electronic scale. An MRU Brand 95/3 CD model gas analyzer was used for measuring exhaust emissions. Before taking the measurements, the gas analyzer instruments were calibrated and its probe was inserted to the exit of the exhaust pipe, which is 1.5 m away from the exhaust manifold.

RESULT AND DISCUSSION

Carbon Monoxide (CO) Emissions

CO gas is a toxic byproduct of all hydrocarbon combustion that is also reduced by increasing the oxygen content of the fuel. More complete oxidation of the fuel results in more complete combustion to CO_2 rather than leading to the formation of CO. Figure 2 shows the plots of CO emissions of the diesel fuel, the SOME and their blends operation at the full load at various speed conditions. The CO emissions are found to be decreasing with the increase in speed. When hydroxyl (OH) radical, which transforms CO to CO_2, decreases below 1500 K, burning deteriorates and, consequently, the amount of CO increases due to lower temperature. Since turbulence occurs in the combustion chamber at higher engine speeds, burning improves and due to increase of temperature of the mixture, CO emission decreases (Kirkpatrick and Ferguson, 2000; Challen and Baranescu, 1999).

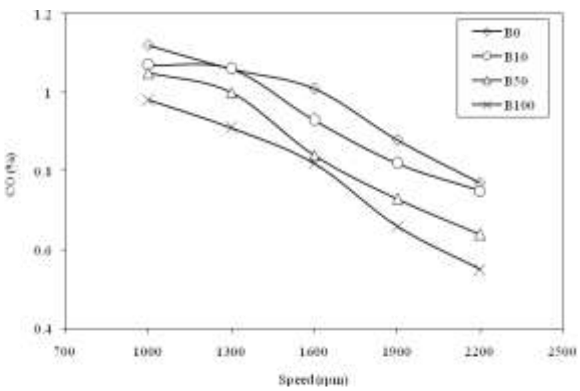


Figure 2. Variation of CO emissions with respect to engine speed.

The comparative analysis of CO is shown in Figure 2. For SOME mixtures CO emission was lower than that of diesel fuel, because SOME mixtures contain some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to CO_2. As a result, minimum CO emission was obtained with 0.55% for B100 at 2200 rpm.

Hydrocarbon (HC) Emissions

HC emissions consist of fuel that is completely unburned or only partially burned. HC emissions result from the problems of fuel and air mixing, and they are largely unaffected by the overall air-fuel equivalence ratio (Lapuerta et al., 2005). Figure 3 indicates the changing in HC emissions versus SOME percentage and engine speeds. As the engine speed increases, the level of HC emission decreases because greater turbulence intensity promotes better combustion and decreases the quench zone.

The HC emission level was decreased with the proportion of SOME in the fuel blend. Biodiesel in the fuel blend improves the cetane value of the mixture; this situation shortens the ignition delay and promotes reaction timing of the blends and reduces the level of unburned HC emission. In addition, by increasing oxygen content in the fuel, the combustion efficiency is significantly improved. Thus, when the test engine was fueled with SOME, the HC amount reduced compared with diesel fuel due to the high oxygen content of SOME. Thus, maximum HC emission was observed with 6 ppm for B100 at 2200 rpm.

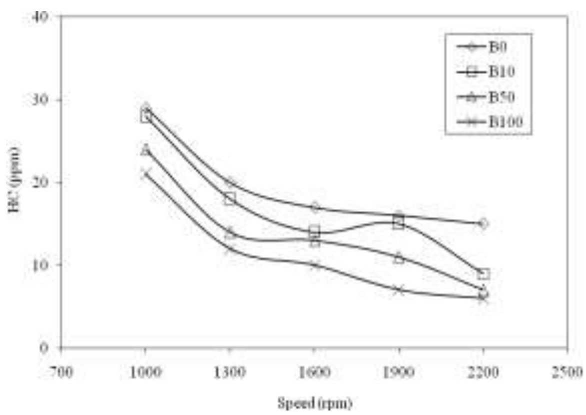


Figure 3. Variation of HC emissions with respect to engine speed.

Smoke Opacity

Smoke in diesel engine exhaust is an indication of poor combustion, resulting from an over-rich air/fuel ratio or partially evaporated fuel during cold start conditions (Gratton and Hansen, 2003; Puhan et al., 2005). Figure 4 depicts the variation of smoke opacity with respect to different fuels considered. The increasing engine speeds lead to shorter residence times of gases in the combustion chamber. Therefore, smoke opacity increased.

As shown in the figure, the smoke density decreases with the increase in SOME included in the blends and reaches a minimum value with using neat SOME as fuel. In diesel engine smoke formation generally occurs in the rich zone at high temperature, particularly within the core region of fuel spray (Nabi et al., 2009). For the reason that SOME contains a large amount of oxygen, locally over rich region decreases and formation of crucial smoke is restricted by the favorable effect of oxygen content in SOME. The best result was monitored 91% for B100 at minimum engine speed (1000 rpm).

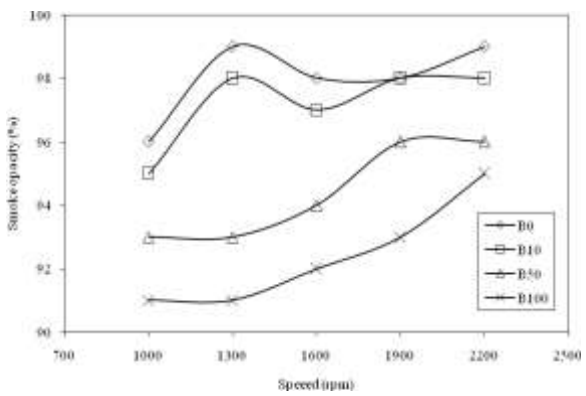


Figure 4. Variation of smoke opacity with respect to engine speed

NitrogenOxides (NO_x) Emissions

The variation of NO_x emission with regard to speed for different fuels is plotted in Figure 5. Naturally, NO_x emission increases with the increase in engine speed. It is well known that nitrogen is an inert gas, but it remains inert up to a certain temperature (1100 ^oC) and above this level it does not remain inert and participate in chemical reaction. At the end of combustion, gas temperature inside cylinder arises around 1500 ^oC. At this temperature oxidation of nitrogen takes places in presence of oxygen inside the cylinder. On the other hand, since the formation of nitrogen oxides do not attain chemical equilibrium reaction; then after the end of expansion stroke when the burned gases cool and the formation of NO_x freeze, the concentration of the formed NO_x in the exhaust gas remain unchanged. Figure 5 also shows that NO_x level was higher for SOME mixtures than conventional diesel fuel at the same engine speed. This can be explained due to the presence of extra oxygen in the molecules of SOME mixtures. This additional oxygen was responsible for extra NO_x emission (Agarwal and Das, 2001). Approximately 10% increase in NO_x emission was realized with 50% SOME mixtures.

Carbon Dioxide (CO_2) Emissions

CO_2 emission is produced by complete combustion of fuel. CO_2 is an important component in the global warming. Same researcher claimed that all of the carbon released by combustion of the biodiesel has been fixed by the plant through the process of photosynthesis (Korbitz, 1999). Indeed, fossil carbon content in the SOME needs to be considered, whereas only a portion of the carbon in SOME is fossil-free. Fig. 6 shows the effect of biodiesel percentage and engine speeds on CO_2 emissions. More amount of CO_2 in exhaust emission is an indication of the complete combustion fuel. So higher CO_2 emission of the B100 indicates effective combustion due to oxygen content of SOME, which improves combustion of the fuel. So, the maximum CO_2 emissions observed as 11.25% for B100 at maximum engine speed.

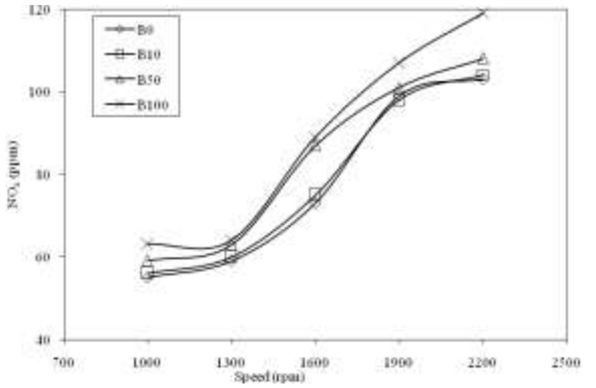


Figure 5. Variation of NO_x emissions with respect to engine speed.

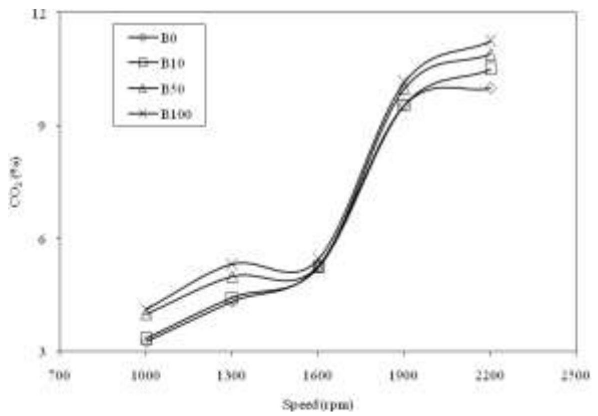


Figure 6. Variation of CO_2 emissions with respect to engine speed.

Brake Specific Fuel Consumption (BSFC)

The variation of BSFC with respect to engine speed for the diesel fuel, SOME, and the blends is presented in Fig. 7. For all of the fuels, BSFC has the tendency to decrease with respect to increasing of engine speed until it reaches a minimum value and then increases a small amount with further increase in engine speed. The BSFC initially increases slightly with the addition of SOME content in the blend until it reaches 10% value but it sharply increases with more enhancement of the SOME content owing to the LHV value and the higher viscosity of SOME. The minimum BSFC was seen as

312 g/kWh for B0 at 1300 rpm which is obtained as maximum engine volumetric efficiency.

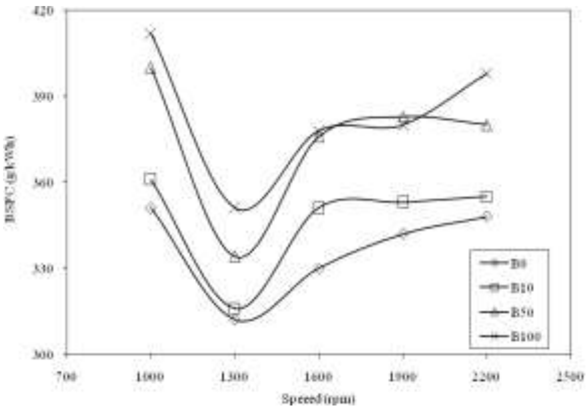


Figure 7. Variation of BSFC with respect to engine speed.

CONCLUSIONS

In this research, an experimental investigation of performance and emissions of a DI diesel engine running with SOME and its blends with diesel fuel was carried out. Based on the experimental study; the main results of performance and emission analysis are summarized as follows:

- The BSFC for biodiesel are higher than that for diesel fuel. This is resulting of lower LHV of biodiesel.
- Increasing the biodiesel mass fraction of blends results in a decrease in CO emissions. An increase in oxygen content means a decrease in the CO emissions.
- CO_2 emissions measured in the experiments with biodiesel blends were higher than diesel fuel. CO_2 emission is an emission product related to the entire combustion of the fuel. High post-combustion temperature and existence of enough oxygen for an exact burning increased the amount of CO_2.
- The presence of oxygen on the biodiesel leads to an increase in NO_xemissions because of increasing combustion temperatures.
- Increased diffusion phase temperature will promote soot oxidation. Thus, this effect increased smoke opacity.
- When the engine fueled with biodiesel or its blends, the amount of HC emissions reduced. The oxygen content of biodiesel may cause this result because the higher oxygen in the combustion region provides more complete combustion.

REFERENCES

Agarwal, A.K., Das, L.M., 2001. Biodiesel development and characterization for use as a fuel in compression ignition engines.*Journal of Engineering for Gas Turbines and Power* 123(2), 440-447.

Altun, S., Bulut, Husamettin.,Cengiz O., 2008. The comparison of engine performance and exhaust emission characteristics of sesame oil–diesel fuel mixture with diesel fuel in a direct injection diesel engine.*Renewable Energy* 33(8), 1791–1795.

Barsic, N.J., Humke, A.C., 1981.Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels.SAE Paper, 810262.

Carmen, S., Vinatoru, M., Maeda, Y., 2007.Aspects of ultrasonically assisted transesterification of various vegetable oils with methanol.*Ultrasonic Sonochemistry* 14(3), 380-386.

Challen, B., Baranescu, R., 1999.Diesel engine reference book. 2rd ed. Woburn MA: SAE and Butterworth Heinemann, USA, pp. 110-113.

Dia, Y., Cheungb, C.S., Huanga, Z., 2009. Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil. *Science of the Total Environment* 407(4), 835-846.

Dorado, M.P., Ballesteros E., Arnal, J.M., Gomez, J., Lopez, F.J., 2003. Exhaust emissions from a Diesel engine fueled with transesterified waste olive oil. *Fuel* 82(11), 1311–1315.

Enya, T., Suzuki, H., Watanabe, T., Hirayama, T., Hisamatsu.Y., 1997. 3-Nitrobenzanthrone, a powerful bacterial mutagen and suspected human carcinogen found in diesel exhaust and airborne particulates. *Environmental Science Technology* 31(10), 2772-3776.

Gill, S.S., Tsolakis, A., Herreros, J.M., York, A.P.E., 2012.Diesel emissions improvements through the use of biodiesel or oxygenated blending components.*Fuel* 95(6) 578-586.

Gratton, M.C., Hansen, A.C., 2003. Diesel engine emissions characteristics and measurement requirements of biofuels.ASAE Paper, 036032.

Ilkilic, C., Aydin, S., Behcet, R. Aydin, H., 2011.Biodiesel from safflower oil and its application in a diesel engine.*Fuel Processing Tech.* 92(3), 356-362.

Johansen, K., Gabrielsson, P., Stavnsbjerg, P., Bak, F., Andersen, E., Autrup, H., 1997.Effect of upgraded diesel fuels and oxidation catalysts on emission properties, especially PAH and genotoxicity.SAE Paper, 973001.

Kirkpatrick, A.T., Ferguson, C.R., 2000. Internal combustion engines. John Wiley& Sons, Inc., New York, pp. 285-287.

Korbitz, W. 1999.Biodiesel production in Europe and North American, an encouraging prospect.*Renewable Energy* 16(1-4), 1078-83.

Kuchenmeister, F., Schmezer, P., Engelhardt, G., 1998.Genotoxicbifunctional aldehydes produce specific images in the comet assay. *Mutation Resources* 419(1-3), 69-78.

Lapuerta, M., Martos, F.J., Cardenas, M.D., 2005.Determination of light extinction efficiency of diesel soot from smoke opacity measurement.*Measurement Science and Technology*, 16(10), 2048-2855.

Ma, F., 1999. Biodiesel production: a review. *Bioresource Technology* 70(1): 1-15.

Nabi , N.M., Rahman, M., Akhter, S. 2009. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions.*Applied Thermal Engineering* 29(11-12), 2265–2270.

Nwafor, OMI., 2003 The effect of elevated fuel inlet temperature on performance of diesel engine running on neat vegetable oil at constant speed conditions. *Renewable Energy* 28(2), 171-181.

Puhan, S., Vedaraman, N., Ram, V.B., Sankarnarayanan, G., Jeychandran, K., 2005. Mahua oil (Madhucaindica seed oil) methyl ester as biodiesel preparation and emission characteristics.*Biomass and Bioenergy* 28(1) 87–93.

Sun, J., Caton, J.A., Jacobs, T.J., 2010. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines.*Progress in Energy and Combustion Science* 36(6), 677-95.