American Journal of Applied Sciences 10 (10): 1201-1213, 2013
ISSN: 1546-9239

doi:10.3844/ajassp.2013.1201.1213 Published Online 10 (10) 2013 (http://www.thescipub.com/ajas.toc)

Effect of Metalloid Compound and Bio-Solution Additives on Biodiesel Engine Performance and Exhaust Emissions

[1,2]Karoon Fangsuwannarak and [1]Kittichai Triratanasirichai

[1]Department of Mechanical Engineering,
Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand
[2]Institute of Engineering, School of Mechanical Engineering,
Suranaree University of Technology, Nakhon Ratchasima, Thailand

Received 2013-05-07, Revised 2013-08-22; Accepted 2013-08-29

ABSTRACT

The purpose of this study is to perform comparative analysis of the effect of the different fuel additives as polymer based-bio-solution, natural organic based-bio-solution and nano-titanium metalloid (TiO_2) compound on the performance parameters and exhuast emissions of a pickup Diesel engine, operating on commercial Diesel fuel (D) and B5 palm biodiesel (95 D+5% palm oil). The basic properties of the fuel blended with TiO_2 metalloid compound and bio-solution based additives were measured according to ASTM standard. Engine performance of a pickup diesel engine was investigated by testing on a chassis dynamometer with the simulation of road load condition. It was found that TiO_2 based-additive is more effective for improving engine power than pure Diesel and B5 fuels by 7.78 and 1.36%, respectively. Meanwhile, with using TiO_2 additive, the maximum engine torque on average increased by 1.01 and 1.53% in the wide range between 1,700 and 3,000 rpm as compared with Diesel and B5 fuels, respectively. The TiO_2 and natural organic additives is significantly effective on Diesel fuel for reducing brake specific fuel consumption reached by 13.22 and 10.01%, respectively as compared with pure Diesel. Moreover, the exhaust emissions (NO_x, CO and CO_2) decreased from the engine using the TiO_2 additive in Diesel fuel and natural organic additive in Diesel fuel.

Keywords: Diesel Engine, Performance, Bio-Solution Additives, Titanium Oxide Additive, Exhaust Emissions

1. INTRODUCTION

Nowadays, Diesel fuel is increasingly used in trucks and pick-ups cars in term of vehicle fuel usage in Thailand. Utilization of pick-up cars is not only for transportation sector but also for personal purpose. This cause leads to more requirement of Diesel fuel on average increased by 20% between 2000 and 2010, according to the annual report of Energy Policy and Planning Office (EPPO). In the fact that, typical characteristic of commercial diesel has low combustion efficiency and high carbon contents which causes air pollution as compared with biodiesel (Duarte *et al*., 2007). Biodiesel, in particular palm oil as an alternative fuel source, is playing an important role on the bioenergy development due to without modifying diesel engines, a massive energy plantation in Thailand and the benefit of the environment and local population. Moreover, biodiesel predominantly produced from biomass is becoming cost competitive with fossil fuels due to the widespread availability of biomass resource (Duarte *et al*., 2007). In the present, palm oil is a trade commodity to cause direct competition between using palm oil for biodiesel production and using for food, which leads to an increase in the price for both uses. Nevertheless, biodiesel is emerging as one of the promising environmentally friendly renewable energy options, as the major conventional energy sources are gradually depleted.

Corresponding Author: Karoon Fangsuwannarak, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand

Some studies have noted that a decrease in engine power relates to an increase in content of biodiesel (Basha *et al*., 2009; Aydin and Bayindir, 2010; Hazar, 2009; Ozsezen *et al*., 2009). Nonetheless, many researches have widely investigated and improved the properties of various kinds of biodiesel such as viscosity, density and flash point in order to be similar to those of diesel fuels (Qi *et al*., 2010; Fazal *et al*., 2010; Chastek, 2011). In previous research, biodiesel degrades through antioxidants, moisture absorption as a result of high oxygen content in the range of 10% to 45% in biodiesel, whereas petroleum has essentially none (Demirbas, 2008). The biodiesel properties differing from diesel such as it has lower Cetane number, higher viscosity, a bit higher density and extremely higher flash point. The reduction of Cetane number affects the decrease of particulate at high load of automobile (Xue *et al*., 2011). Moreover, higher density and viscosity of bio-fuel can affect the volatisation and poorer atomization of the fuel spray and, subsequently, less accurate operation of the fuel injectors. Finally, the combustion suddenly deteriorates in chamber (Xue *et al*., 2011). That is cause to make many researchers have focused on improvement of biodiesel properties by using alternative additives in the optimal fraction of biodiesel in diesel oil (Kannan *et al*., 2011; Varatharajan *et al*., 2011; Qi *et al*., 2011; Guru *et al*., 2009; Chotwichien *et al*., 2009). Adding additive in diesel fuel is found to be able to significantly improve the operating time of the oil filter by decreasing the rate of clogging and enhancing the turbidity removal (Lin *et al*., 2008). In the present, typical additive compositions can be catalogued as metalloid compound based and bio-solution based. However, we observe that the chemical composition of fuel additive, its optimized fraction of amount of biodiesel and effective reaction of additive with diesel fuel are the crucial factors to influence on fuel consumption and exhaust emission of diesel engine.

Several works have looked at synthesis of additive formulations based on bio-solution for appropriate bio-oil blends, for example, mixing 4-Nonyl phenoxy acetic acid (NPAA: $C_{17}H_{27}O_3$) (Kalam and Masjuki, 2008). ethers based (ETBE: $C_6H_{14}O$ and TAEE: $C_7H_{16}O$) (Weber *et al*., 2006), ethanol based (C_2H_5OH) (Hernandez *et al*., 2011) or glycerol based ($C_3H_8O_3$) (Chen *et al*., 2010) in palm biodiesel. In addition, the commercial multi-functional fuel additives have been claimed that they can enhance the combustion performance and also reduce exhaust gas after being dosed in commercial biodiesel fuel. Several works involved metal based fuel additives have been studied about several metals such as manganese, ferric chloride, barium, iron, copper, cerium, calcium and platinum (Guru *et al*., 2009). However, Titanium oxide metalloid based fuel additives behaving as a good catalyst has not study extensively in order to achieve the improvement of fuel quality. On the other hand, utilization of bio-solution of natural organic as a fuel additive has become attractive to provide less Particulate Matter (PM) and more energy saving than both of premium diesel fuel and biodiesel without additive. Nevertheless, the comparison of effectiveness of multi-functional fuel additives has been studied insufficiently when they are dosed in biodiesel fuel. Thus, the aim of this work is to verify the comparative engine performance of Direct Injection (DI) pickup automobile which was tested by mixing commercial Titanium oxide metalloid based and bio-solution additives in biodiesel fuel. At the same time, exhaust emission from the tested engine is studied.

In this study, three different fuel additives based on Paraffin with polymer compound, bio-solution and nano-TiO_2 materials, respectively were considered as catalysts in the fuel blend. The detail of additive compositions is shown in **Table 1**. The physical properties of the blended fuel tested in this study including viscosity, specific gravity, flash point, fire point and carbon residue were evaluated under ASTM standard. Moreover, a DI pick-up diesel engine was tested on FPS 2700 chassis dynamometer. All tests were performed without any modifying engine. The influence of using 3 different kinds of commercial additives in a 4-cylinder, 4-stroke DI diesel engine is examined at full load condition. In order to measure NO_x, CO and CO_2 emissions and exhaust gas temperature, exhaust emissions and its temperature were verified by Testo 350 gas analyzer.

2. MATERIALS AND METHODS

2.1. Physical Properties Testing of Fuel Dosed by Additives

The physical characteristics of the premium diesel and B5 Palm Bio-Diesel (B5-POB) dosed by various additive compounds were measured in this study including viscosity, specific gravity, flash point and carbon residue. The influences of the additives on the physical properties were investigated using standard test methods. Each measurement was repeated 3 times in order to calculate the average data used for the analysis. Kinematic viscosity was measured at 40°C according to ASTM D445 using a capillary tube viscometer.

Table 1. Fuel compositions

Tested Fuels	Fuel blended (%vol.)
D (commercial diesel)	98% pure diesel fuel+2% palm oil
B5-POB	95% commercial diesel fuel+5% palm oil
D + Additive A	99.85% commercial diesel fuel+0.15% Paraffin-Xylene-acetone and polymer based additive
D + Additive B	100% commercial diesel fuel+0.2 g (pellet) natural organic based additive
D + Additive C	99.80% commercial diesel fuel+0.20% TiO_2 based additive
B5 + Additive A	99.85% B5+0.15% Paraffin-Xylene-acetone and polymer based additive
B5 + Additive B	100% B5+0.2 g (pellet) natural organic based additive
B5 + Additive C	99.80% B5+0.20% TiO_2 based additive

Table 2. Test engine specification

Items	Specifications
Engine type	4-Stroke, 4-Cylinder, compression ignition
Displacement volume	2982 cm^3
Number of cylinder	4
Cylinder arrangement	Vertical in-line
Bore/stroke	96 mm/103 mm
Method of charging	VN Turbocharged
Compression ratio	17.9:1
Maximum power (new engine)	120 kW (163 hp.) at 3400 rpm
Maximum torque (new engine)	343 Nm at 3200 rpm
Injection type	Direct injection common-rail
Cooling type	water

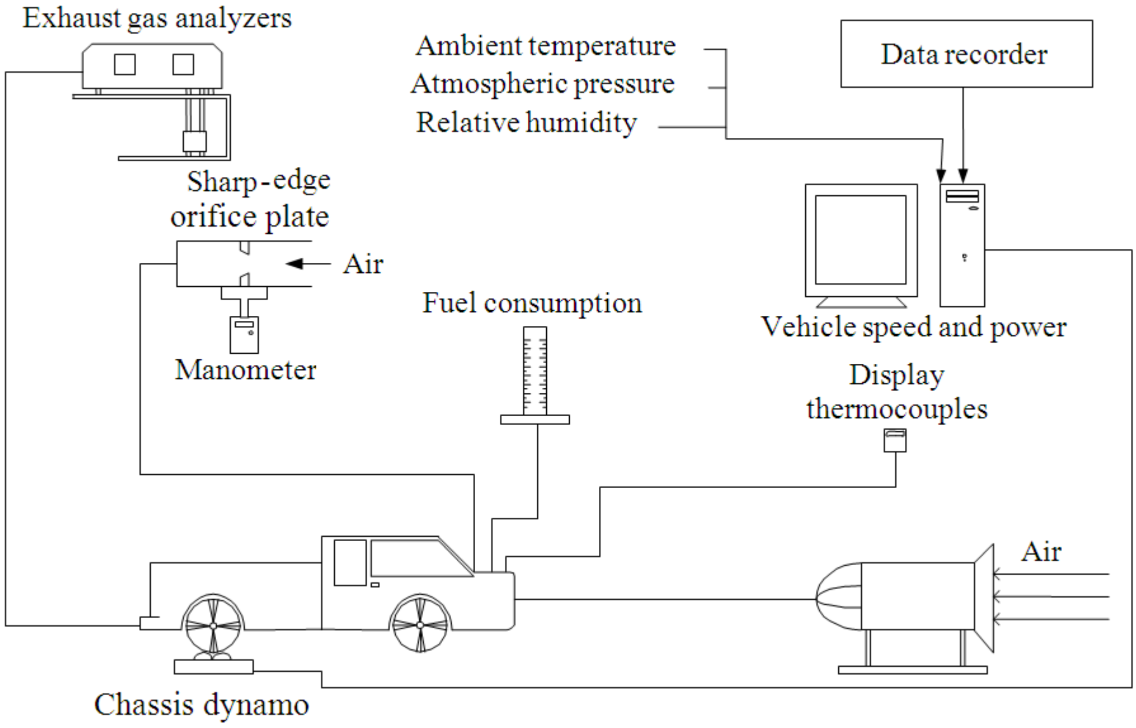

Fig. 1. The schematic of experiment setup

Specific gravity was determined following ASTM D1298 using the calibrated glass API gravity hydrometers. Flash point was tested as according ASTM D93 using a Pensky-Martens. A Rambottom carbon residue tester was used for measuring Carbon residue under ASTM D189.

The composition of fuel blends studied in this study is detailed in **Table 1**. The mixture ratios of additives were used at the recommended concentrations from their producers. The required quantity of the additives was measured by using a precision electronic balance. Each required additive was mixed with in the tested fuel by means of an ultrasonic shaker for 15 min in order to produce the uniform suspension. Experimental data on the basic properties of premium diesel fuel and B5 POB without additives and with additives are presented in **Table 2**.

2.2. Engine Performance Testing

The vehicle used in this experiment was a standard pickup car with a manual gear box. The schematic of the experiment setup is shown in **Fig. 1**. The test engine specifications were listed in **Table 2**. The FPS 2700 chassis dynamometer under the simulation of road load conditions with eddy current brake was conducted in this experiment. Measuring accuracy of the chassis dynamometer is of ± 2%. The performance correction was used by following a standard of SAE J. 1349. The accuracy of wheel power of ± 3% was obtained. Fuel consumption system was arranged and coupled with the fuel pump in order to examine the amount of consumed fuel. Each engine test was repeated 3 times to ensure the average data calculation for the analysis. Owing to the different fuels tested, each engine test has a standard of the operating conditions.

2.3. Exhuast Emission Testing

Exhaust emissions and gas temperature, according to SAE J816B specifications were measured by a Testo 350 gas analyzer. Measurement resolutions for NO_x, CO and CO_2 are 0.1%, 1.0% and 0.01% ppm, respectively. Meanwhile, measurement capacity for NO_x, CO and CO_2 are in the range of 0-500 ppm, 0-10,000 ppm and 0-50% vol., respectively. Exhaust emission values were measured directly by sampling from exhaust pipe with probe of the analyzers as shown in **Fig. 1**. The test cycle were repeated three times. The software provides extraordinary data management capability and the ability to import/export data.

3. RESULTS

3.1. Comparative Physical Properties of Tested Fuels

As seen in **Table 3**, the physical characteristic results of the Diesel and B5-POB fuels to be blended with each dosing additive were compared to the Diesel and B5-POB fuels without additives, respectively. These results were obtained in the accepted levels of ASTM fuel properties. Owing to denser B5-POB fuel, slightly more viscosity, flash point and fire point were obtained as compared with Diesel fuel. These results agree with an improvement approach of fuel quality by interweaving fuel additive blends.

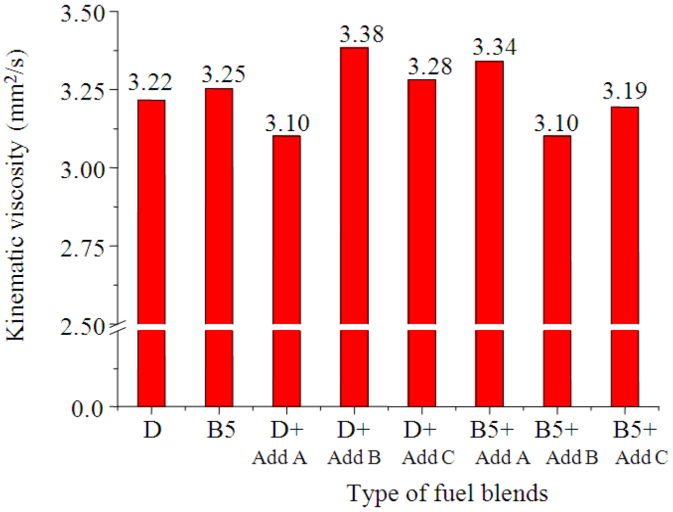

Fig. 2. Kinematic viscosity of tested fuels

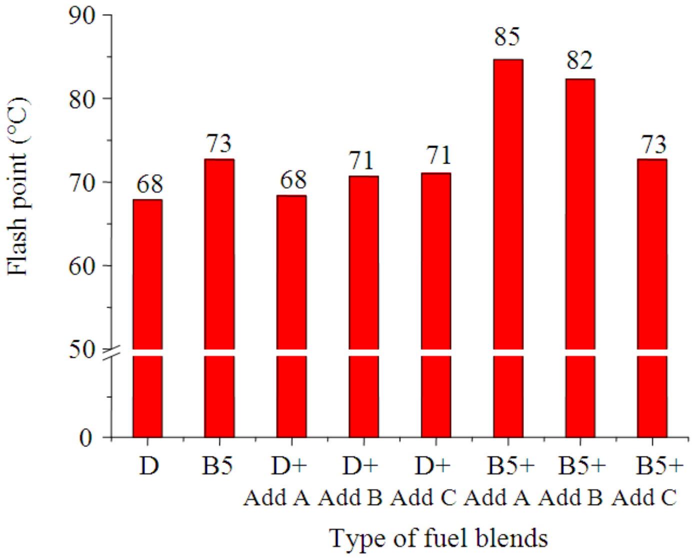

Fig. 3. Flash point of tested fuels

Table 3. Basic properties of Diesel fuel, B5-POB fuel and blends of each additive (A, B and C) with Diesel fuel and B5-POB fuel

Kinematic Properties	Viscosity at 40°C (mm^2/s)	Specific gravity at 15.6°C	Flash point (°C)	Fire point (°C)	Carbon residue (%wt.)
Test method	ASTM D445	ASTM D1298	ASTM D93	ASTM D93	ASTM D189
Thailand's regulation high speed diesel	1.8-4.1	0.81-0.87	≥52	-	≤0.05
Diesel (D)	3.21	0.823	68	98	0.0003
B5-POB	3.25	0.825	73	101	0.0005
D + Additive A	3.10	0.805	68	100	0.0004
D + Additive B	3.38	0.825	71	98	0.0002
D + Additive C	3.28	0.825	71	98	0.0004
B5 + Additive A	3.34	0.834	85	101	0.0004
B5 + Additive B	3.10	0.825	82	101	0.0002
B5 + Additive C	3.19	0.820	73	95	0.0004

In **Fig. 2**, for Diesel and B5-POB fuels blended with each dosing additive and without the additives, the results of kinematic viscosity were obtained. For Diesel fuel blended with Additive A, the viscosity value at 40°C decreases by 3.75% and associates with decreasing specific gravity as shown in **Fig. 2**. These results suggested that Additive A improved the cold-flow properties of Diesel fuel.

In addition, in our work the fuel mixture of Additive A and B5-POB fuel affect the viscosity value increased by 2.76% as compared with B5-POB without dosing additive. Thus, additive A exhibits no improvement for B5-POB fuel blend, whereas Additive B and C noticeably provided a drop in viscosity by 4.62% and 1.85%, respectively. Nevertheless, Additive B and C mixed in Diesel fuel resulted in the higher viscosity values by 4.96% and 1.86%, respectively as compared with Diesel fuel.

Flash point is an ignition level at the lowest temperature of the fuel. The relation between flash point values and the tested fuels with and without dosing additives is shown in **Fig. 3**. The results suggested that the high flash point value about 82°C along with minimum viscosity value at 3.10 mm^2/s was observed. As be seen in **Fig. 3**, Diesel fuel with dosing each additive shows a slight improvement in flash point value, whereas B5-POB fuel with dosing each additive presents a considerable enhancement in flash point value in partucular Additive B. Specific gravity is the ratio of the density of fuel to the density of the water. Fuel density is an important property to indicate the diesel engine performance and to involve with heat of fuel combustion. As listed in **Table 3**, the density values for the diesel and B5-POB fuels with dosing each additive are in the range of 0.805-0.834 which is similar to the density for fuel blend without additives.

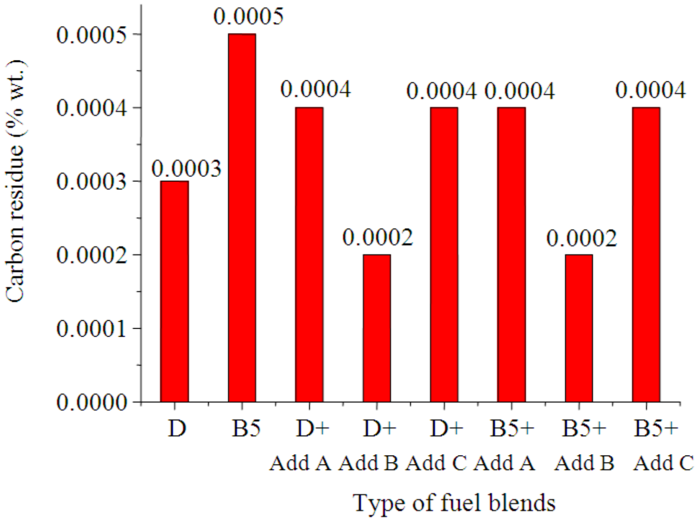

Fig. 4. Carbon residue of tested fuels

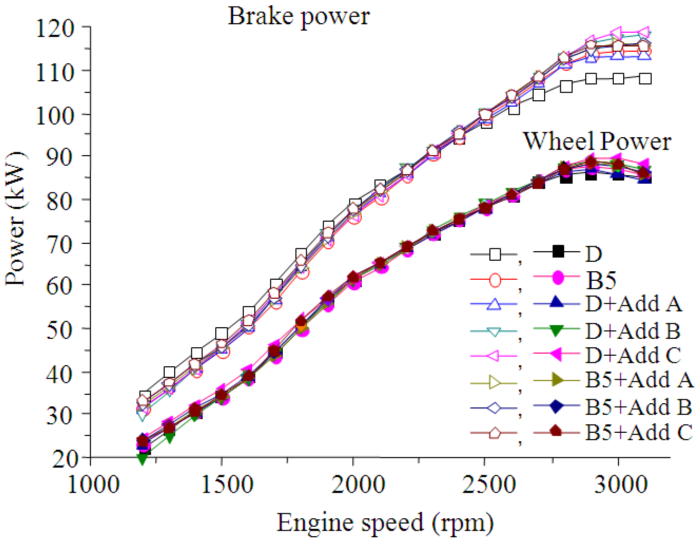

Fig. 5. Variation of brake and wheel powers with different engine speed levels

Higher specific gravity for fuel blend results in a lower heat of the combustion combustion (Sajith *et al*., 2010).

Figure 4 illustrates the minimum carbon (C) residue at 0.002 by % weight for Diesel without additives and B5-POB fuel blend with natural organic based additive (Additive B). A large amount of C-containing residue is a result of incomplete combustion in the internal engine.

3.2. Comparative Engine Performance Under Tested Fuel Conditions

The engine performances of the pickup diesel vehicle were investigated by measuring the brake engine, wheel power, engine torque and specific fuel consumption as a function of Diesel and B5-POB fuel with the different additives.

3.2.1. Brake and Wheel Powers

Figure 5 shows the increase of brake and wheel powers with increasing engine speed at full load. It was found that tested fuels with dosing additives and pure B5-POB fuel produced the higher brake power than Diesel in the range of engine speed between 2700 and 3100 rpm.

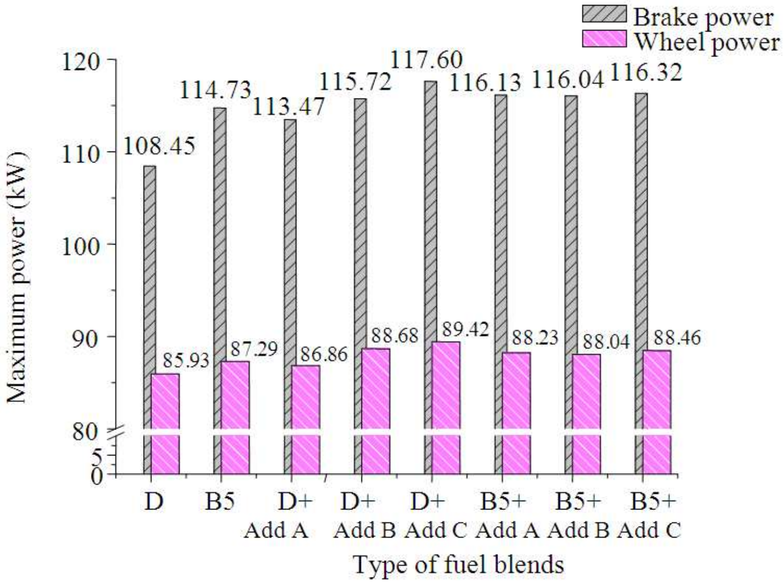

Fig. 6. Maximum brake and wheel power values of different fuel blends

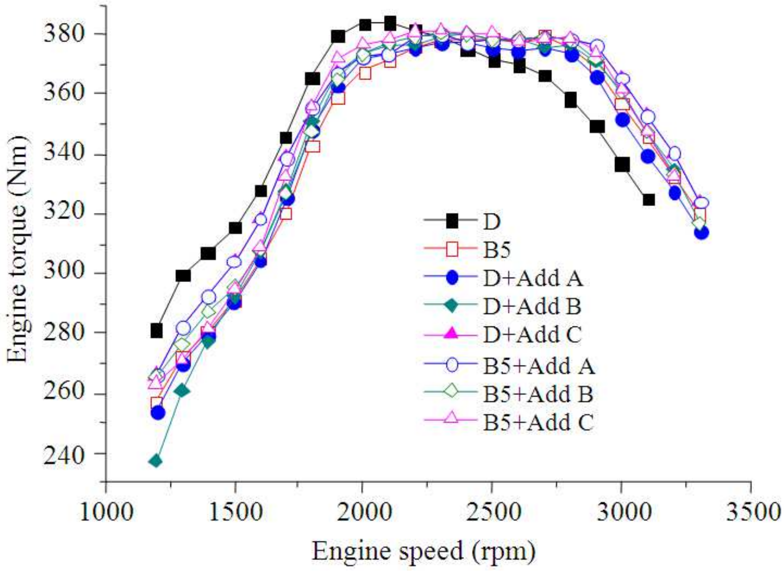

Fig. 7. Variation of engine torque depending on engine speed for the tested fuel blends

Nonetheless, there is no main effect of the tested fuels with dosing additives on the efficiency of brake and wheel power in the speed range below 2500 rpm.

Maximum brake and wheel power values were determined by calculating the average power in the speed range between 1200 rpm and 3100 rpm. By comparison with the different additives in tested fuel blends, **Fig. 6** shows the maximum brake and wheel powers. In normal behavior, the brake power as a function of speed was obtained a higher value than the wheel power due to presence of power transmission loss. Nonetheless, the curves of brake and wheel powers show the same trend.

In **Fig. 6**, it was found that all studied additives is very effective on the improvement of maximum brake and wheel power values as compared with the tested fuels without dosing additives.

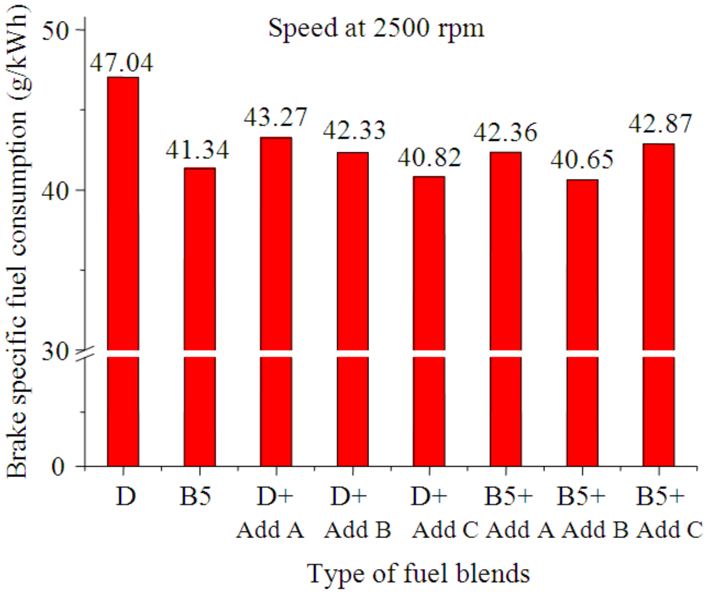

Fig. 8. Brake specific fuel consumption of test fuels

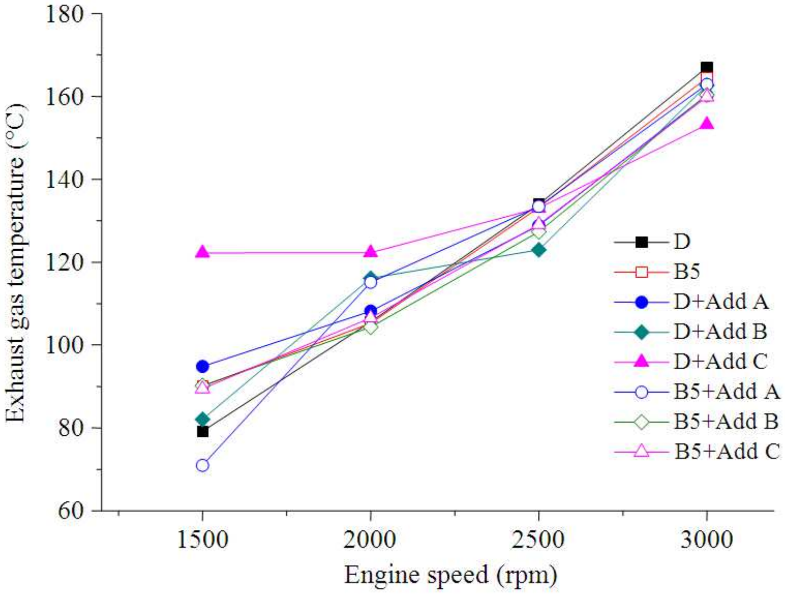

Fig. 9. Exhaust gas temperature of test fuels

TiO_2 based additive dosed in the tested fuels provided the most effective maximum brake and wheel power values of 117.60 kW and 89.42 kW, respectively. Therefore, maximum brake and wheel power values were higher than the used Diesel fuel by 7.78% and 3.907%, respectively.

For B5-POB fuel with additives, the brake and wheel powers show that the average maximum slightly increases by 1.24% and 1.06%, respectively comparing with that for B5 POB fuel.

3.2.2. Engine Torque

The variation of the engine torque with engine speed shows in **Fig. 7**. Maximum torque occurs at low engine speed in typical diesel engine. The results in **Fig. 7** show the high engine torque of all tested fuels during the wide range of engine speed between 1800 and 2700 rpm except diesel fuel. For commercial diesel fuel, it was found that the torque steeply increases with an increase in engine speed and then decreases in the speed around 2000 rpm. For other tested fuels (B5-POB fuel and blended fuels with multi-function additives), the wide-maximum range of torque has a consistent improvement in brake power at around 2700-3000 rpm. For comparison of tested fuels, the results suggested that commercial diesel fuel provided the higher engine torque at low engine speed but it delivered the engine torque decreases at high engine speed. It is noted that at 2500 rpm, an improvement in the engine torque for the B5-POB fuel, D+AddA, D+AddB, D+AddC, B5+AddA, B5+AddB and B+AddC is of 1.84, 1.06, 1.85, 1.86, 1.86, 1.75 and 2.33%, respectively comparing with that for commercial diesel fuel.

3.2.3. Brake Specific Fuel Consumption

The comparison of BSFC for the tested fuel is shown in **Fig. 8**. The high BSFC is an indicator of poor engine efficiency of the engine which is supplied by the tested fuel. It is observed that the measured BSFC value for diesel oil is the highest about 47.04 g/kWh comparing with that for other tested fuels.

The DI engine was tested at full load under using the different tested fuels to ensure that the previous fuel rests in the next test. As seen in **Fig. 8**, it shows that there is not only B5-POB fuel to significantly reduce the BSFC consumption but also others mixed by the additives have a positive influence on the BSFC rate. The maximal improvement was obtained of 40.65 g/kWh from using additive B blended in B5-POB fuel.

3.3. Exhaust Gas Emissions

3.3.1. Exhaust gas Temperature

Exhaust gas temperature can indicate the amount of waste heat going with exhaust gas. The plot of exhaust gas temperature with varying engine speed is illustrated in **Fig. 9**. When the engine speed is increased, the temperature of the exhaust gas increases for all tested fuels mainly due to more heat energy produced from the amount of fuel per unit time increased. This result reveals that B5+Add B fuel is the optimum composition to reduce the exhaust gas temperature in the range of 90-160°C as compared with other tested fuels.

3.3.2. NO_x Emission

The experimental results of the NO_x emission study can be seen in **Fig. 10**. It was found that the engine operated by the commercial Diesel obtained the maximal NO_x emission and the NO_x emission became lower with increasing engine speed. However, the NO_x emission increases with the increase of the engine speed for using others (B5, B5+Add B, D+Add B and D+Add C), which is related to the increase in exhaust gas temperature as shown in **Fig. 9** due to the higher combustion temperatures.

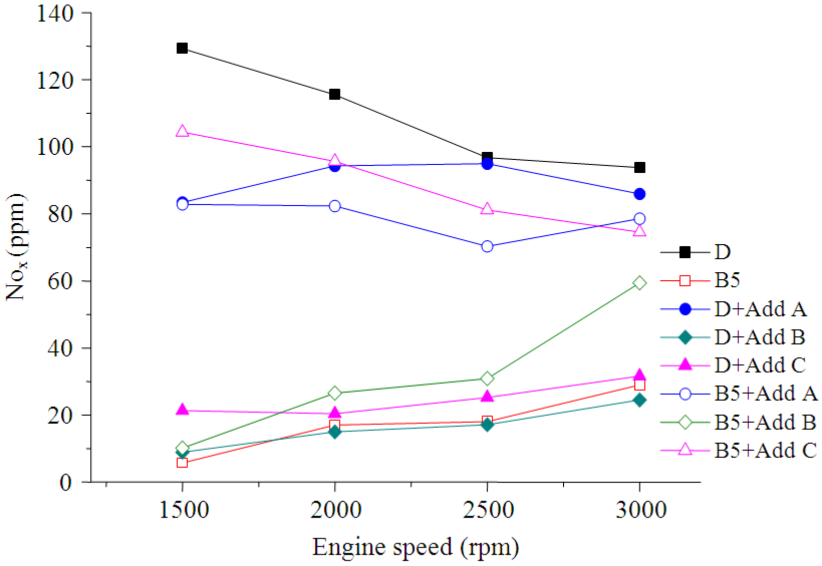

Fig. 10. NOx emissions of test fuels

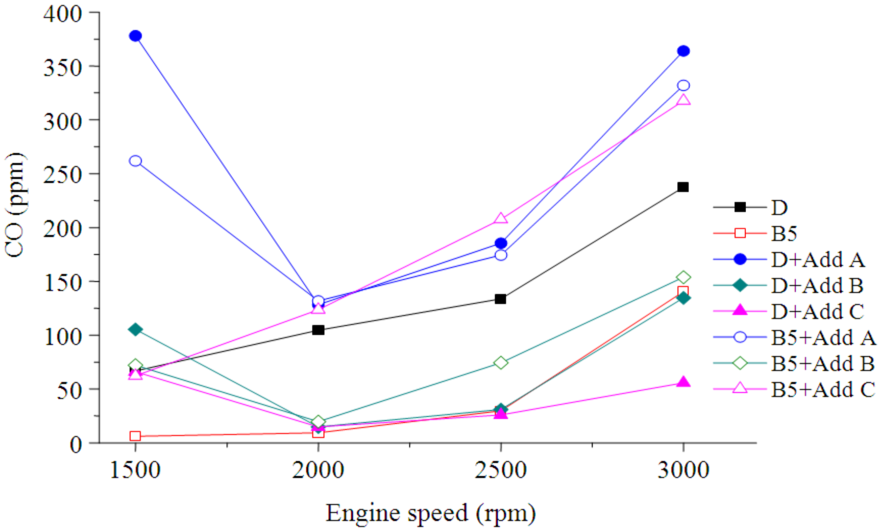

Fig. 11. CO in exhaust gas of test fuels

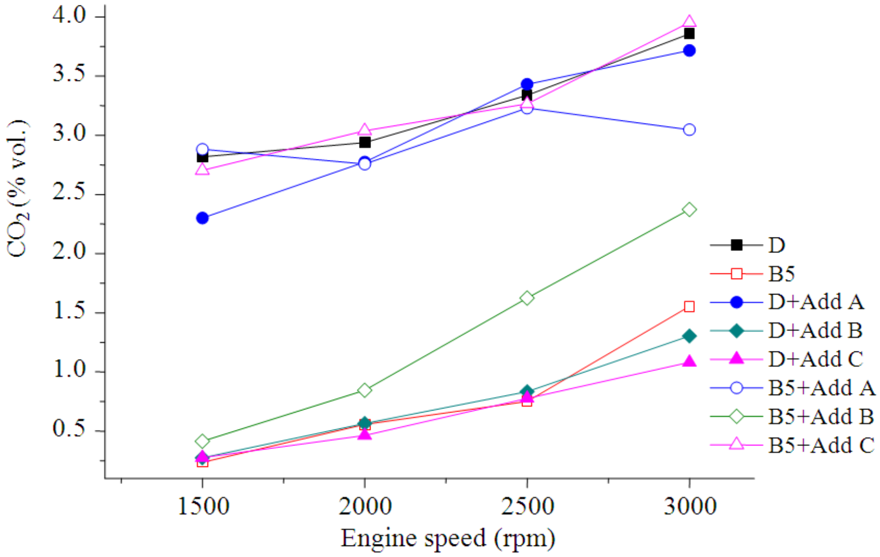

Fig. 12. CO_2 in exhaust gas of test fuels

Moreover, it is noted that the NO_x gas exhausted for B5-POB, B5+Add B, D+Add B and D+Add C fuels is effectively reduced as compared with D, D+Add A, B5+Add A and B5+Add C. In addition, D+Add B fuel is very effective on the minimal NO_x emissions obtained about 9.0 ppm at 1500 rpm, 15.0 ppm at 2000 rpm, 17.1 ppm at 2500 rpm and 24.5 ppm at 3000 rpm.

3.3.3. CO Emission

Figure 11 shows the CO emission study with the different tested fuels. At low engine speed range, the engine supplied by B5-POB fuel obtained the minimal CO emission less than 10 ppm, while it produced the increasing CO gas at high engine speed range. This is because biodiesel which contains more number of oxygen atoms results in the more complete combustion at high engine speed. In addition, at high engine speed the minimal CO emission less than 55 ppm was obtained for D+Add C. However, it is seen that the additive A mixed in Diesel fuel is not effective on the reduction of the CO emission. At low engine speed (1500 rpm) D+Add B fuel, as compared with Diesel fuel has not an effect on the reduction of the CO emission possibly due to the dominant premixed lean combustion. Chen *et al.* (2010) observed that bio-solution group for additive fuel can effectively solve the problem of Particulate Matter (PM) emissions.

Moreover, this experimental result demonstrates that the TiO_2 additive has the most influence on the Diesel fuel for reducing CO emission with the decreasing fractions by 1% at 1500, 85% at 2000 rpm, 80% at 2500 rpm and 76% at 3000 rpm, as compared with the Diesel fuel. Nonetheless, it has no an effective reduction of CO emissions for blending in B5-POB fuel.

3.3.4. CO_2 Emission

Figure 12 presents the CO_2 emission traces for different fuels at varying engine speed. The experimental results demonstrate that CO_2 emission for B5-POB fuel were obtained less than that for Diesel that is in agreement with the literatures (Ozsezen *et al*., 2009). It is known that fewer CO_2 emissions for biodiesel blends during complete combustion due to the lower carbon to hydrogen ratio. With increasing engine speed, the CO_2 emissions were increased. In this study, the additive B as natural organic based additive has the most effective reduction of CO_2 emission for Diesel fuel blend. Although the additive C blended in Diesel results in the lowest reduction, it is not suitable for mixing in B5-POB fuel because of the high release of CO_2. Therefore, for Diesel blend, D+Add B and D+Add C fuels lead to a decrease in CO and CO_2 emissions as compared with pure commercial diesel possibly due to the catalyst effect of metalloid and bio-solution additives on combustion process. The blend of TiO_2 based additive with diesel (D+Add C) does not only provide the minimum CO_2 emissions but it also leads to the minimization of fuel consumption in comparison with diesel without additive.

4. DISCUSSION

Viscosity is typically considered as an important property because the high viscosity affects the operation of fuel injection equipment. When these property values of B5-POB fuel became higher, the results can affect the injection system into the combustion chamber due to its poor ability of fuel to atomize into small droplets (Demirbas, 2008). The improvement of the cold-flow properties of Diesel fuel with adding Additive A was obtained. It is similar to Chastek (2011) to reduce the viscosity value of canola-based biodiesel by using polymeric additive. The decrease of viscosity is an improvement indicator for the formation of smaller molecules in the B5-POB. It is possibly due to the effect of an organic and TiO_2 based additives on an increase in the vapor pressure. Therefore, Additive B and C are well effective on the quality improvement for B5-POB fuel, instead of Diesel fuel. In regular rule, it is known that the viscosity value of a typical fuel decreases with decreasing flash point value. All different additives made an extremely effective flash point value for B5-POB fuel blend instead of Diesel fuel blend. It was implied the enhanced atomization of the fuel spray. In particular, natural organic based additive (Additive B) is the most effective catalyst to improve B5-POB fuel quality as a result of the minimum viscosity along with the high flash point. Meanwhile, the existence of Additive B in the fuel blend can effectively reduce carbon residue.

With using additives in fuel blends, the increasing brake power was observed that is a result from conversion efficiency increased through the complete combustion. The same increase of brake power also involved with increasing palm oil biodiesel in blends for previous report (Kalam and Masjuki, 2008). Therefore, three additive types to be added in diesel present higher improvement in brake power than adding in B5-POB fuel. Meanwhile, an improvement in the engine torque for adding additives in deisel fuel is a positive result that is able to imply a completion of the internal combustion.

Due to that nitrogen-containing fuel species are oxidized, nitrogen oxide is emitted from the combustion engine. In general, the natural nitrogen levels in both Diesel and biodiesel are very low but nitrogen-containing fuel additives which are used in high concentration can become more effectiveness. The NO_x emission from an engine is varied from depending upon numerous factors including engine type and configuration, type and quantity of fuel additive. The curve for the Diesel fuel is similar to that for B5+Add C because the rise in volumetric efficiency and gas flow motion within the engine cylinder at the higher engine speed. This effect can lead to faster mixing between fuel and air and shorter ignition delay (Kalam and Masjuki, 2008). It seems to be that the both of bio-solution and TiO_2 based additives are the preferential additive for commercial diesel in order to achieve better fuel quality with less NO_x emission.

5. CONCLUSION

In this study, it was observed that in term of basic requirement of low fuel viscosity, mixing the additive A in Diesel fuel consistently leads to an improvement in viscosity instead of additive A in B5-POB fuel. Organic based additive (Add B) is consistent with B5-POB fuel in term of viscosity improvement. Moreover, adding multi-functional additives in B5-POB and commercial Diesel fuels present a considerable enhancement in flash point value. The density of the diesel and B5-POB fuel with the additives are high enough (0.805-0.834) in the acceptable range. The multi-functional additives in the particular organic based additive significantly lead to the reduction of carbon residue.

The 3 different additives as multi-functional additives to be added in Diesel present the mean higher fraction of the maximum brake power and maximum power values than B5-POB fuel with the additives. The DI engine fuelled with pure B5-POB and B5-POB dosed with multi-function additives provides the maximum torque between 2000 rpm and 3000 rpm. Thus, it indicates that the maximal torque presenting in the wide range of the speed has a consistent improvement in brake power at around 2500-3000 rpm and along with low BSFC value. In the term of exhaust gas emissions, the additives are not effective on the reduction of gas emissions for B5-POB fuel blend. However, for Diesel in the term of fewer exhaust emissions (NO_x, CO and CO_2), bio-solution based additive is not only an optimum dose but it also can effectively reduce the fuel consumption in comparison with the fuel without the additives.

6. ACKNOWLEDGMENT

This study was supported by Suranaree University of Technology and Khon Kaen University.

7. REFERENCES

Aydin, H. and H. Bayindir, 2010. Perfomance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renew. Energy, 35: 588-592. DOI: 10.1016/j.renene.2009.08.009

Basha, S.A., K.R. Gopal and S. Jebaraj, 2009. A review on biodiesel production combustion emission and performance. Renew. Sustain. Energy, 13: 1628-1634. DOI: 10.1016/j.rser.2008.09.031

Chastek, T.Q., 2011. Improving cold flow properties of canola based biodiesel. Biomass Bioenergy, 35: 600-607. DOI: 10.1016/j.biombioe.2010.10.024

Chen, K.S., Y.C. Lin, L.T. Hsieh, L.F. Lin and C.C. Wu, 2010. Saving energy and reducing pollution by use of emulsified palm-biodiesel blends with bio-solution additive. Energy, 35: 2043-2048. DOI: 10.1016/j.energy.2010.01.021

Chotwichien, A., A. Luengnaruemitchai and S. Jai-In, 2009. Utilization of palm oil alkyl esters as an additive in ethanol-diesel and butanol-diesel blends. Fuel, 88: 1618-1624. DOI: 10.1016/j.fuel.2009.02.047

Demirbas, A., 2008. Biodiesel: A Realistic Fuel Alternative for Diesel Engines. 1st Edn., Springer, London, ISBN-10: 1846289947, pp: 208.

Duarte, A.R.C.D.L.M., U.H. Bezerra, M.E.L. Tostes and G.N.DR. Filho, 2007. Alternative energy sources in the amazon. IEEE Power Energy Mag., 5: 51-57. DOI: 10.1109/MPAE.2007.264870

Fazal, M.A., A.S.M.A. Haseeb and H.H. Masjuki, 2010. Comparative corrosive characteristics of petroleum diesel and palm biodiesel for automotive materials. Fuel Process. Technol., 91: 1308-1315. DOI: 10.1016/j.fuproc.2010.04.016

Guru, M., B.D. Artukoglu, A. Keskin and A. Koca, 2009. Biodiesel production from waste animal fat and improvement of its characteristics by synthesized nickel and magnesium additive. Energy Conversion Manage., 50: 498-502. DOI: 10.1016/j.enconman.2008.11.001

Hazar, H., 2009. Effects of biodiesel on a low heat loss diesel engine. Renew. Energy, 34: 1533-1537. DOI: 10.1016/j.renene.2008.11.008

Hernandez, D., J.J. Fernandez, F. Mondragon and D. Lopez, 2011. Production and utilization performance of a glycerol derived additive for diesel engines. Fuel, 92: 130-136. DOI: 10.1016/j.fuel.2011.06.073

Kalam, M.A. and H.H. Masjuki, 2008. Testing palm biodiesel and NPAA additives to control NO_x and CO while improving efficiency in diesel engines. Biomass Bioenergy, 32: 1116-1122. DOI: 10.1016/j.biombioe.2008.02.009

Kannan, G.R., R. Karvembu and R. Anand, 2011. Effect of metal based additive on performance emission and combustion characteristics of diesel engine fulled with biodiesel. Applied Energy, 88: 3694-3703. DOI: 10.1016/j.apenergy.2011.04.043

Lin, Y.C., W.J. Lee, H.R. Chao, S. Liwang and T.C. Tsou *et al*., 2008. Approach for energy saving and pollution reducing by fueling diesel engines with emulsified biosolution/biodiesel/diesel blends. Environ. Sci. Technol., 42: 3849-3855. PMID: 18546733

Ozsezen, A.N., M. Canakci, A. Turkcan and C. Sayin, 2009. Performance and combustion characteristics of a DI diesel engine fuelled with waste palm oil and canola oil methyl esters. Fuel, 88: 629-636. DOI: 10.1016/j.fuel.2008.09.023

Qi, D.H., H. Chen, L.M. Geng and Y.Z. Bian, 2011. Effect of diethyl ether and ethanol additives on the combustion and emission characteristics of biodiesel-diesel blended fuel engine. Renew. Energy, 36: 1252-1258. DOI: 10.1016/j.renene.2010.09.021

Qi, D.H., H. Chen, L.M. Geng and Y.Z.H. Bian, 2010. Experimental studies on the combustion characteristics and performance of a direct injection engine fuelled with biodiesel/diesel blends. Energy Conversion Manage, 51: 2985-2992. DOI: 10.1016/j.enconman.2010.06.042

Sajith, V., C.B. Sobhan and G.P. Peterson, 2010. Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel. Adv. Mechan. Eng., 2010: 6-6. DOI: 10.1155/2010/581407

Varatharajan, K., M. Cheralathan and R. Velraj, 2011. Mitigation of NO_x emissions from a Jatropha biodiesel fuelled DI diesel engine using antioxidant additives. Fuel, 90: 2721-2725. DOI: 10.1016/j.fuel.2011.03.047

Weber, E.W.D., R.D. Silva and R.J.C. Ortega, 2006. Effect of ethers and ether/ethanol additives on the physicochemical properties of diesel fuel and engine tests. Fuel, 85: 815-822. DOI: 10.1016/j.fuel.2005.08.027

Xue, J., T.E. Grift and A.C. Hansen, 2011. Effect of biodiesel on engine performances and emissions. Renew. Sustain. Energy Rev., 15: 1098-1116. DOI: 10.1016/j.rser.2010.11.016