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Experimental Investigation of Engine Performance and Emission Characteristics of a Diesel Engine Using Blends Containing Microalgae Biodiesel, n-butanol and Diesel Fuel

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Abstract. An experimental research was conducted to evaluate the effects of n-butanol (normal butanol) addition to conventional diesel fuel and microalgae biodiesel (MB) blends on the performance and exhaust emissions of a diesel engine. Engine performance parameters and exhaust gas emissions such as nitrogen oxides, carbon monoxide were measured. It is revealed that; although n-butanol addition caused a slight reduction in torque and brake power values, the emission values of the engine were improved. Measured physical properties of n-butanol, MB and diesel blend (D70B20But10) satisfy EN 14214 standards. Therefore, n-butanol can be used as a very promising additive to diesel-microalgae biodiesel blends.

Keywords: Microalgae, n-butanol, biodiesel, fuel properties, engine performance.

1. Introduction

Energy supply has vital importance for economic growth, social development, human welfare and improving the quality of life. With increasing trend of modernization and industrialization, the World energy demand is also growing at faster rate. Since their exploration, the fossil fuels continued as the major conventional energy source [1]. However, environmental concerns and depletion of fossil fuels and their non-renewable nature has led to a world-wide search for renewable and greener alternatives for internal combustion engines [2]. In the recent years, serious efforts have been made by several researchers to use different sources of energy as fuel in existing diesel engines [3]-[6].

Bio-fuels made from agricultural products (oxygenated by nature) reduce the world's dependence on oil imports, support local agricultural industries, and enhance farming incomes. Moreover, they offer benefits in terms of reduced smokiness or particulate matter from diesel engines. Among those, vegetable oils or their derived bio-diesels (methyl or ethyl esters) are considered as very promising [7]. Biodiesel is the most used renewable fuel in compression ignition (CI) engines. The advantages of bio-diesel as diesel fuel are the minimal sulphur and aromatic content, and the higher flash point, lubricity and cetane number. Their disadvantages include the higher viscosity (though much lower than the vegetable oils one), the higher pour point, the lower calorific value and volatility, the hygroscopic tendency, and the lower oxidation stability [8]. The majority of the literature agrees that particulate matter (PM), unburnt total hydrocarbons (THC) and carbon monoxide (CO) emissions from biodiesel are lower than from conventional diesel fuel [9]. The global biodiesel market has increased dramatically over the past 20 years with increasing annual production in order to cater for increasing demand, especially from Europe and the United States which have high levels of biodiesel use. According to a report from market research reports database, Axis Research Mind, the market value of biodiesel is expected to increase 26% reaching $62 million (€43.4 million) by 2015 [10]. Most governments are encouraging use of renewable fuels to decrease fuel imports and boost energy security [11].

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The objective of this study is to evaluate performance characteristics and emissions of a diesel engine which uses microalgae biodiesel, n-butanol and diesel blends as fuel. Some of the physical properties such as density, viscosity were also determined since they have a significant impact on these characteristics.

2. Materials and Methods

2.1. Test Fuels

Two blends were prepared in order to evaluate n-butanol addition effect on microalgae biodiesel (MB) and diesel mixtures, namely D70B20But10 (70% diesel, 20% microalgae biodiesel, 10% n-butanol) and D80B20 (80% diesel and 20% microalgae biodiesel). 100% diesel fuel was also used as a reference.

The tested fuels were commercial diesel, n-butanol and microalgae biodiesel. Microalgae oil used in biodiesel production was purchased from Soley Biotechnology Institute/ISTANBUL and n-butanol was provided by Merck. During the microalgae biodiesel production, the necessary amount of catalyst (NaOH) for the transesterification reaction (0.4% by weight of the oil) was dissolved in methanol and added to the reactor after heating the microalgae oil to 65^{o}C; the reaction was performed at 60–61^{o}C and the mixture was stirred by the help of a magnetic stirrer at about 600 rpm during 1 h. After completion of the transesterification reaction, the mixture was cooled to room temperature and then transferred to a separatory funnel and separation of the ester and glycerin phases was performed by letting them stand for 8 hours in the separatory funnel. The crude ester phase was washed 3 times with hot water at 1/5 water to ester phase ratio. After washing process, the mixture was waited in seperatory funnel during 30 minutes and by this way water is separated from methyl ester. Since purity level has strong effects on fuel properties, in order to provide water content to be less than 0.1, drying process was conducted by heating the biodiesel to 105^{o}C during 1 h until bright colour occurred. Finally, filtering process was done in order to ensure that the end product is of excellent quality.

2.2. Experimental Set-up

In this study, experiments were conducted on a four stroke, four cylinder diesel engine. Specifications and the schematic diagram of the engine are presented in Table 1 and Figure 1, respectively. This engine was coupled to a hydraulic dynamometer which has torque range of 0–1700 Nm and speed range of 0–7500 rpm to measure engine torque. Before starting to the experiment, the engine was operated with the new fuel for sufficient time to clean out the remaining fuel from the previous experiment. Engine performance values were read by the help of a computer program of dynamometer control unit which can take values in two second time intervals and exhaust emissions such as CO and NO_x were obtained by the help of another computer program.

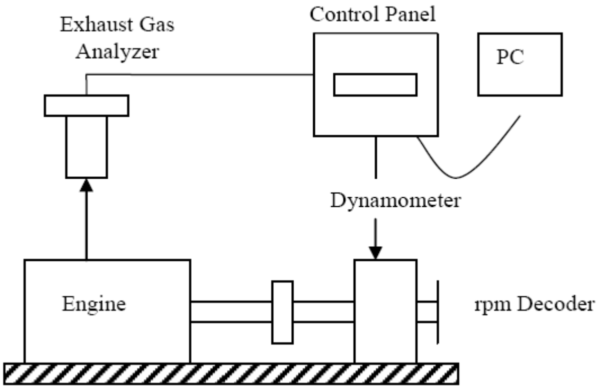

Fig. 1: Layout of experimental setup

3. Results and Discussion

3.1. Fuel Properties

The fuel properties of diesel and MB and test fuels are given in Table 2 with European Biodiesel Standards (EN 14214). The measured physical properties of microalgae biodiesel like density, viscosity, pour point and heating value are comparable with those of diesel fuel. It can also be observed from the Table 2 that except its low cetane number, all other measured properties of microalgae biodiesel are within EN 14214. Generally cetane number is an indicator of the ignition quality of a diesel fuel. If a cetane number is too high, combustion can occur before the fuel and air is properly mixed, resulting in incomplete combustion and smoke. If a cetane number is too low, incomplete combustion occur [11]. Therefore, low cetane number of MB can create problems. As it can be seen from Table 2, cetane number can be improved by mixing MB with diesel fuel and n-butanol. Although, biodiesel produced from microalgae oil was found viscous than diesel fuel this viscosity of MB not exceed EN 14214 standards. However, the high viscosity of MB was compensated by mixing it either diesel fuel or n-butanol. As it can be seen from Table 2, properties of D70B20But10 satisfy EN 14214.

3.2. Brake Power and Torque Output

The maximum torque was obtained at about 1800 rpm for all test fuels. The average torque values are decreased approximately by 5% and 2.7% compared to diesel fuel; for D70B20But10 and D80B20, respectively. The maximum brake power was obtained at about 2200 rpm for all of the test fuels. Brake power output values reduced with both microalgae biodiesel and butanol addition. A decrease in the brake torque and brake power was due to the lower cetane number compared to the diesel fuel. In addition, oxygen contents of microalgae biodiesel and n-butanol also lead to decrease brake torque and brake power when compared to diesel fuel.

Table 1: Technical specifications of the test engine

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3907 cc
Bore	104 mm
Stroke	115 mm
Power	89 kW @ 3200 rpm
Torque	295 Nm @ 1800 rpm
Oil Cooler	Water cooled
Weight	325 kg

Table 2: Properties of test fuels

Properties	MB	Diesel	D70B20But10	D80B20	European Biodiesel Standard (EN 14214)
Density (kg/m^3) EN ISO 12185	886	833	844	843	860–900
Cetane Number ASTM D 613	48.3	56.46	52.24	54.19	>51
Viscosity (mm^2/s) ASTM D 445	4.47	2.37	3.62	2.88	3.5 - 5.0
Pour Point (^{o}C) ASTM D 2500	-12.0	-10	-9	-12	Summer<4.0 Winter< -1.0
Flash Point (^{o}C) ASTM D 93	165.5	58.5	42.5	78.5	>120

3.3. NO_x Emission

Thermal NO formation is extremely affected by higher combustion and flame temperatures which are formed via better combustion quality [12]. The variation of NO_x emission values for different test fuels is presented in Figure 2. There is an increase in NO_x value with MB addition to diesel. This trend may be caused from higher combustion temperature due to extra oxygen content of MB. However, NO_x values are decreased with n-butanol addition to the blends. This may be attributed to the engine running overall 'leaner' and the temperature lowering effect of the butanol (due to its lower calorific value and its higher heat of evaporation) having the dominant influence, against the opposing effect of the lower cetane number (and thus longer ignition delay) of the butanol leading possibly to higher temperatures during the premixed part of combustion [13].

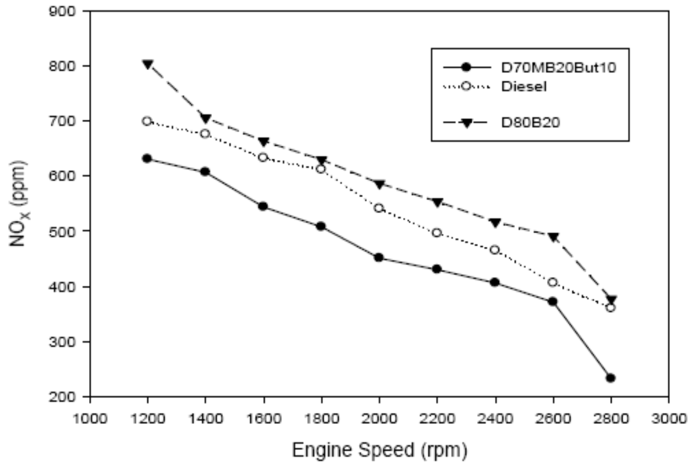

Fig. 2: Comparison of NO_x emissions for the test fuels

3.4. CO Emission

Generally a reduction in CO emission values occur when biodiesel is used instead of diesel fuel since biodiesel contains additional oxygen and this additional oxygen enhances complete combustion. CO emissions of blends are lower than diesel for as it is shown in Figure 3. This decrease is mainly due to the oxygen content of biodiesel which makes the combustion more complete [14]. In contrast to D80B20But10; n-butanol addition to MB-diesel blend further decreased CO emissions. This benefit in CO emissions using alcohols blends could be due to the lower C/H ratio of alcohols compared to MB [14].

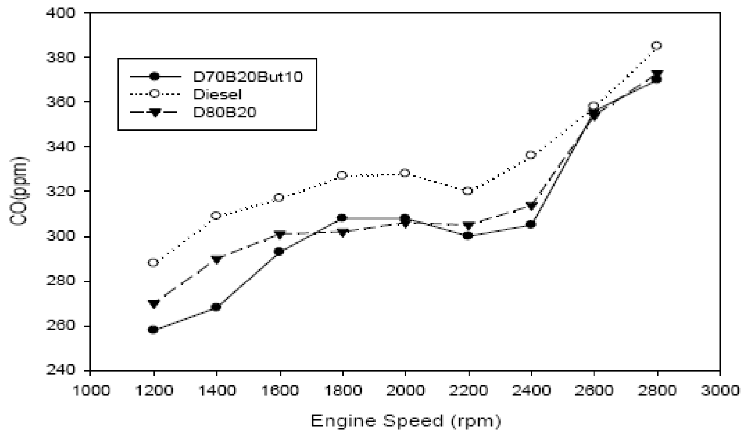

Fig. 3: Comparison of CO emissions for the test fuels

4. Conclusions

The fallowing conclusions can be drawn from the experimental results:

- Measured physical properties of n-butanol, MB and diesel blend (D70B20But10) satisfy EN 14214 standards.
- The power and torque output of engine was reduced slightly when n-butanol was added to the MB-diesel blends. However, CO and NO_X emission values improved with microalgae biodiesel usage.

- Finally, it can be concluded that, n-butanol can be used as a very promising additive to diesel-microalgae biodiesel blends in conventional diesel engines, by this way exhaust emission values can be improved.

5. Acknowledgements

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6. References

[1] P. K. Sahoo, L. M. Das, M. K. G. Babu, S. N. Naik. Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. *Fuel.* 2007, **86:** 448–454.

[2] L. Siwale, L. Kristóf, T. Adam, A. Bereczky, M. Mbarawa, M. Penninger, A. Kolesnikov. Combustion and emission characteristics of n-butanol/diesel fuel blend in a turbo-charged compression ignition engine. *Fuel*. 2013, **107:** 409–418.

[3] J. Xue. Combustion characteristics, engine performances and emissions of waste edible oil biodiesel in diesel engine. *Renew. Sustain. Energy Rev*. 2013, **23:** 350–365.

[4] A. M. Liaquat, H. H., Liaquat, M. A. Masjuki, I. M. R. KalamFattah, M. A., Hazrat, M. Varman, M. Mofijur, and M. Shahabuddin. Effect of Coconut Biodiesel Blended Fuels on Engine Performance and Emission Characteristics. *Procedia Eng.* 2013, **56:** 583–590.

[5] G. Tüccar, K. Aydın. Evaluation of methyl ester of microalgae oil as fuel in a diesel engine. *Fuel. 2013,* **112:** 203–207.

[6] R. Behçet. (2011). Performance and emission study of waste anchovy fish biodiesel in a diesel engine. *Fuel Process. Technol.* 2011, **92**: 1187–1194.

[7] C. D. Rakopoulos, A. M. Dimaratos, E. G. Giakoumis, D. C. Rakopoulos. Study of turbocharged diesel engine operation, pollutant emissions and combustion noise radiation during starting with bio-diesel or n-butanol diesel fuel blends. *Appl. Energy.* 2011, **88:** 3905–3916.

[8] D. C. Rakopoulos, Combustion and emissions of cottonseed oil and its bio-diesel in blends with either n-butanol or diethyl ether in HSDI diesel engine. *Fuel*, 2013, **105:** 603–613.

[9] E. Sukjit, J. M. Herreros, K. D. Dearn, A. Tsolakis, K. Theinnoi. Effect of hydrogen on butanol–biodiesel blends in compression ignition engines. *Int. J. Hydrog. Energy*. 2013, **38**: 1624–1635.

[10] M. H. Mat Yasin, T. Yusaf, R. Mamat, A. Fitri Yusop. Characterization of a diesel engine operating with a small proportion of methanol as a fuel additive in biodiesel blend. *Appl. Energy* doi:10.1016/j.apenergy.2013.06.012

[11] G. Knothe, and J. Krahl, *The biodiesel handbook.* AOCS Press, 2010.

[12] A. Atmanlı, B. Yüksel, E. İleri. Experimental investigation of the effect of diesel–cotton oil–n-butanol ternary blends on phase stability, engine performance and exhaust emission parameters in a diesel engine. *Fuel.* 2013, **109:** 503–511.

[13] D.C. Rakopoulos, C.D. Rakopoulos, D.T. Hountalas, C.C. Kakaras, E.G. Giakoumis, R.G. Papagiannakis. Investigation of the performance and emissions of bus engine operating on butanol/diesel fuel blends. *Fuel.* 2010, **89:** 2781–2790.

[14] E. Sukjit, J. M. Herreros, K. D. Dearn, R. García-Contreras, A. Tsolakis The effect of the addition of individual methyl esters on the combustion and emissions of ethanol and butanol -diesel blends. *Energy*, 2012, **42:** 364–374.