The Investigation of CNG Dual-Biodiesel fuel Approach to Address the Performance - Emission Assisted Multipurpose Diesel Engine

Wacharaphun Sidthiphong[1], Thanit Swasdisevi[2], Sumol Sae-heng Pisitsungkakarn[3] and Kampanart Theinnoi[3*]

Abstract

Diesel engines can operate on a variety of the different fuels such as diesel fuel derived from crude oil, natural gas and biodiesel. Nowadays, the price of compress natural gas (CNG) and biodiesel is cheaper than diesel fuel since it is a potential advantage to use a combined CNG and biodiesel for multipurpose diesel engine. The aims of this work were to investigate the efficiency and emission from the multipurpose diesel engine. In the experiments, the fuel used in a combustion chamber was diesel, biodiesel derived from waste cooking oil (B100) and combined B100 and CNG. Effect of the various ratios of CNG (10, 20 and 30%), engine load (25, 50 and 75%) and exhaust gas recirculation (EGR: 0, 10 and 20%) were also investigated. Based on these experiments, the brake thermal efficiency decreased with an increase in CNG ratio. However, the brake thermal efficiency increased with an increase in the engine load. When the CNG ratio in a combustion chamber increased, the hydrocarbon concentration and Smoke number (SN) increased whereas the nitrogen oxide decreased. In term of exhaust gas recirculation (EGR), the use of EGR was not significant effect to brake thermal efficiency for various fuels. However, the increasing of EGR and CNG ratio led to an increase in hydrocarbon, carbon monoxide and Bosch smoke number. It should be noted that the nitrogen oxide decreased with an increase in EGR and CNG ratio.

Keywords : Biodiesel, Compressed Natural Gas, Emission, Multipurpose diesel engine

---

[1] Energy Management Technology, School of Energy, Environment and Materials – SEEM, King Mongkut's University of Technology Thonburi.

[2] Thermal Technology, School of Energy, Environment and Materials – SEEM, King Mongkut's University of Technology Thonburi.

[3] Combustion Technology and Alternative Energy Research Centre – CTAE, Department of Power Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok.

[*] Corresponding author, E-mail: ktn@kmutnb.ac.th, kampanart.t@cit.kmutnb.ac.th Received 18 February 2015, Accepted 19 May 2015

1. Introduction

Energy crisis is an important problem for several countries. In Thailand, the agricultural industry is essential because the main population in upcountry is still the farmer. In recent years, the price of fuel for agricultural machinery is higher due to the depleting sources of petroleum. Since the higher price of fuel, the alternative fuels from renewable resources that are cheaper and environmentally are challenge. Biodiesel is one of the alternative fuels for replacing the diesel fuel. It is derived from the transesterification of fat, oil and used cooking oil. The biodiesel properties are similar to diesel produced from crude oil and can be used directly to run existing diesel engines. The advantages of biodiesel are following: it assists to reduce carbon dioxide, carbon monoxide (CO), total hydrocarbon (THC) and particulate matter (PM) emission [1-6]. Compressed natural gas (CNG) is one of the best alternative fuels for Internal Combustion Engines (ICE). It may be derived from oil deposits or waste water treatment plants where it is known as biogas. The main component of CNG is methane and it can be used in place of diesel fuel, gasoline and LPG. The use of CNG in IC engines will significantly contribute to reduce environmental pollution [7-9]. It can improve the brake thermal efficiency and reduce the noise and vibration of engines. The combustion of CNG produces fewer undesirable gases than other fuels. Moreover, the CNG is safer than LPG because CNG is lighter than air and disperses quickly when released. However, the CNG composition is highly variable and strongly dependent on the supply source.

From the advantages of biodiesel and CNG as mentioned above, the aims of this work are to investigate the combustion characteristics, engine efficiency and engine emissions of multipurpose diesel engine using a combined biodiesel and CNG as the fuel. The biodiesel and CNG with various ratios are injected into the combustion chamber for examining the suitable engine efficiency and specific fuel consumption. In terms of engine emissions, the carbon dioxide, carbon monoxide, hydrocarbon, nitrogen oxide and smoke opacity are also investigated at various engine speeds and engine loads. Furthermore, the effect of exhaust gas recirculation was also examined.

2. Experimental setup

A schematic of a multipurpose diesel engine and its relevant accessories shows in Fig. 1. The steady state engine tests were performed using an unmodified Yanmar model L100 diesel engine to examine the effect of CNG concentration addition with biodiesel and diesel on engine performance and exhaust gas emissions. This engine consists of a single cylinder with direct injection to the combustion chamber and it is equipped with the external cooled EGR system. The standard injection timing was set at 20 Crank Angle Degree (CAD) before top dead centre (BTDC) by the manufacturer. Table1 shows the detail of multipurpose diesel engine using in this work. The DC electric dynamometer was used to measure power of engine. An orifice plate equipped with monometer was used to measure the intake air flow rate into the engine. A nozzle of gas fuel (CNG) was also installed at the intake air pipe (between an orifice and air filter). Liquid fuels (diesel or biodiesel) from tanks flow via a multiple valve used to switching the fuel type and it is injected into the diesel engine.

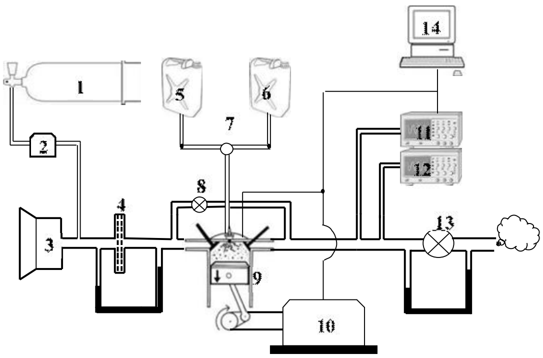

Fig. 1. A Schematic diagram of a multipurpose diesel engine and its relevant accessories; (1)CNG tank; (2) Pressure regulator; (3) Air filter; (4) Orifice; (5) Diesel tank; (6) Biodiesel tank; (7) Multiple valve; (8) EGR valve; (9) diesel engine; (10) Dynamometer; (11) Exhaust analyzer; (12) Bosch smoke meter; (13) Back pressure valve; (14) Personal computer

2.1 Measurement of exhaust emissions

A Horiba MEXA-584L exhaust gas analyzer was used to monitor exhaust emissions from engine. The exhaust gas analysis included the measurement of carbon dioxide, carbon monoxide and unburned hydrocarbons (NIDR-non-dispersive infrared), oxygen (magneto pneumatic sensor), and NO_x (CLD-chemiluminescence detection). In addition, Smoke opacity (soot) was measured by a Bosch smoke meter and was shown in terms of smoke number (SN). In this work, the exhaust gas in each operating condition was measured and reported.

Table 1 Detail of a multipurpose diesel engine

Name of the engine	Yanmar L100
Engine type	4 stroke, Air cooled
No. of Cylinder	1
Bore x Stroke (mm)	86 x 75
Displacement (cc)	435
Compression ratio	21.2 : 1
Continuous rated output	6.2 kW/3,600 rpm
Combustion type	Direct Injection
Injection Timing	20° BTDC

2.2 Fuels

The fuels used in these experiments were conventional diesel fuel, biodiesel from treated waste cooking oil (B100) and compressed natural gas (CNG).

Table 2 The Compositions of CNG [10]

Components	**CNG**
Methane - CH_4	74.1-77%
Ethane - C_2H_6	6.4-6.0%
Nitrogen - N_2	2-2.2%
Carbondioxide-CO_2	12.7-14.4%
Sulfur-S	<16 ppm
Wobber index-WI	41.9-44 (MJ/m^3)
Methane number-MN	76-82
(Stoichiometric Air/Fuel Ratio)	11.6-12

The compress natural gas composition are shown in Table 2. Before feed compressed natural gas into the engine, it must be heating up and reducing pressure by pressure regulator. Rotameter was used to measure the flow rate of CNG before entering the engine. The properties of fuels (diesel, biodiesel and CNG) were shown in Table 3.

Table 3 The properties of fuels

Fuel Type	Diesel	B100	CNG
Cetane number	48.70	50.02	-
Methane number	-	-	78.50
Viscosity at 40 °C (cSt)	2.70	4.88	-
Density at 40 °C (g/cc)	0.85	0.91	-
Relative density	-	-	0.765
Flash point (°C)	64	210	-184.4
High heating value (MJ/kg)	44.50	38.65	42.95

2.4 Experimental procedure

The experiments were performed at engine speed of 1500 rpm with various engine loads (25, 50 and 75 % of maximum load). These engine loads represent low, middle and high load for testing engine. The tests were carried out initially using diesel and biodiesel fuels for generating the reference data. The CNG was mixed by intake air before entering to the engine via manifold valve. A combined of biodiesel and CNG is using the fuels from CNG and biodiesel tanks with various ratios. For example, B100 + 10% CNG is using CNG of 10% by weight and B100 of 90% by weight. In this work, the various CNG concentrations (10, 20 and 30% by weight) were used for testing engine under the same conditions in order to the concentrations of CNG less than 30% by weight can be operated with engine. The objective of this study was to investigate the effect of replacing diesel or biodiesel fuels with CNG, while keeping the same engine configuration under different operating conditions. In order to this will be approached to address in agricultural industries which are required much less engine modification. The results of engine testing were reported in terms of the thermal efficiency, exhaust gas emissions and smoke number. In addition, the change of EGR (0, 10 and 20%) was investigated for reducing NO_x emission.

3. Results and discussion

3.1 Thermal efficiency

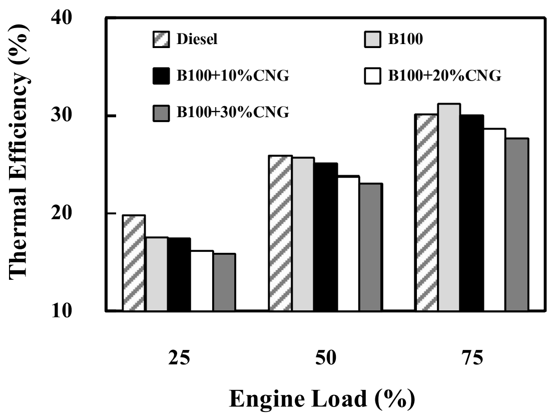

Fig. 2. Engine load and brake thermal efficiency at 1,500 rpm and 0% EGR.

Fig. 2 shows the engine load and thermal efficiency. CNG addition decreased the brake thermal efficiency for the same engine load conditions tested due to the CNG concentrations to substitute of oxygen content in air intake. To compare brake thermal efficiency between the use of diesel and biodiesel fuel, it was found that brake thermal efficiency of diesel fuel was higher than that of biodiesel fuel at low engine load due to the higher heating value of diesel fuel. When the engine load increased, the brake thermal efficiency of biodiesel fuel was higher than that of diesel. This may be because the oxygen in biodiesel fuel can enhance the combustion efficiency of engine at higher engine load [11-13].

3.2 Emissions

The engine load and hydrocarbon emission at 1500 rpm as shown in Fig.3. The hydrocarbon emission from engine using biodiesel fuel was lowest because the biodiesel had a high oxygen and cetane number led to complete combustion more than other fuels [14-16]. When the ratio of CNG increased, the hydrocarbon emission increased because the CNG was mixed with intake air hence the amount of oxygen in air entering into engine decreased led to incomplete combustion in engine [17]. Consequently, the hydrocarbon emission was high with an increase in CNG ratio. Moreover, the same tendency also occurred at all engine loads.

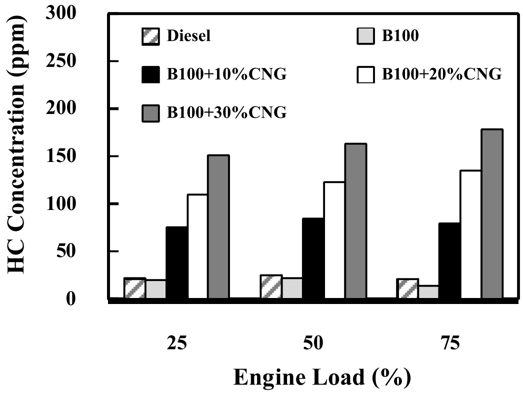

Fig. 3. Engine load and hydrocarbon concentration at 1,500 rpm and 0% EGR.

Fig. 4 shows nitrogen oxide (NO_x) emission at various engine loads and 1500 rpm. It was found that the nitrogen oxide increased with an increase in the engine load because the occurrence of NO_x was increased as a function of an increase in fuel consumption and combustion temperature [10, 18-20]. As expected, when the engine load increased, the fuel consumption and combustion temperature also increased.

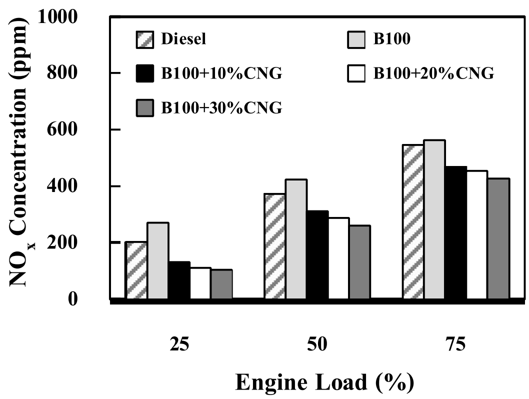

Fig.4. Engine load and nitrogen oxide concentration at 1,500 rpm and 0% EGR.

Based on these experiments, the NO_x of the use of biodiesel as fuel was higher than that of diesel because the higher cetane number enhanced cleaner and more efficient combustion [21-23]. The NO_x emission decreased with an increase in the CNG ratio because the oxygen in intake air was replaced by CNG led to the low oxygen in combustion.

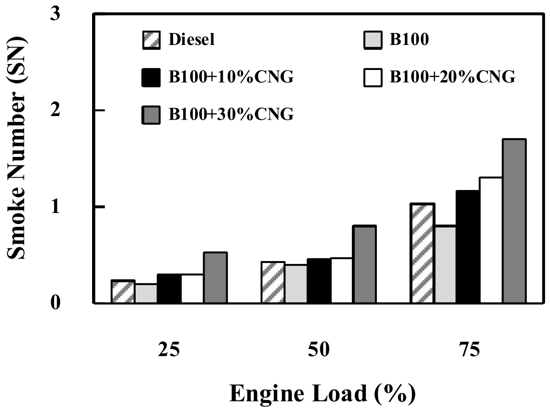

Fig. 5. Engine load and Smoke number at 1,500 rpm and 0% EGR.

The soot was indicated by SN in this work. As expected, the SN increased with an increase in engine load as shown in Fig.5. Since the fuel consumption increased, the soot formation also increased [16]. To compare the SN from biodiesel and diesel, it was found that the SN of biodiesel was lower than that of diesel because the oxygen molecule in biodiesel could assist the complete combustion in engine [11, 18-19]. Therefore, the soot formation from biodiesel was lower. For a combined CNG and biodiesel, it was observed that the SN number increased as a function of an increase in CNG ratio in biodiesel. This might be due to an incomplete combustion in engine. When the CNG ratio increased, the oxygen in an intake air was replaced by CNG hence the combustion was not complete led to an increase in the SN number.

3.2 Effect of exhaust gas recirculation

Exhaust gas recirculation (EGR) was an emission control technology used to reduce NO_x emission and has been used for gasoline and diesel fuel engines. In this work, the EGR with standard injection timing was examined at 1,500 rpm and 50% engine load. The EGR was adjusted manually for getting 0%, 10%, and 20% EGR rate. From these experiments, it was revealed that the EGR had not significant effect to the brake thermal efficiency for all fuels as show in Fig. 6.

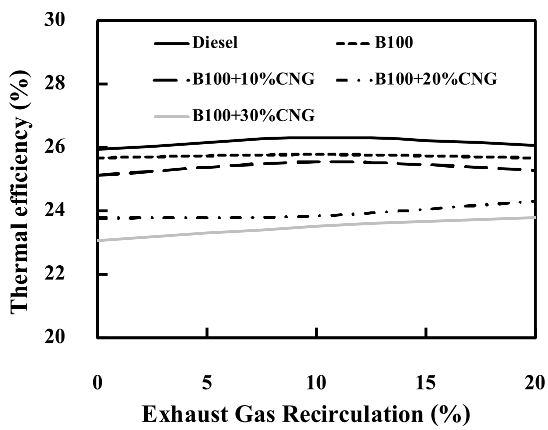

Fig. 6. EGR and brake thermal efficiency at 1,500 rpm and 50% load engine.

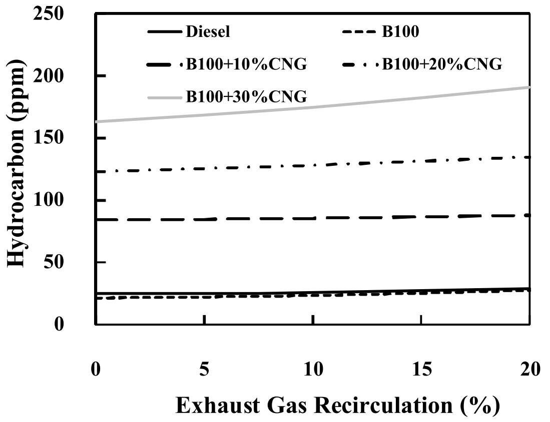

Fig. 7. EGR and hydrocarbon emission at 1,500 rpm 50% engine load.

The trend of HC increased with an increase in EGR as shown in Fig. 7. This might be due a decrease of oxygen in combustion chamber when the EGR increased [24-26]. As expected, the HC emission increased with an increase in CNG ratio in an intake air. It should be noted that the HC from diesel fuel was slightly higher than that from biodiesel fuel.

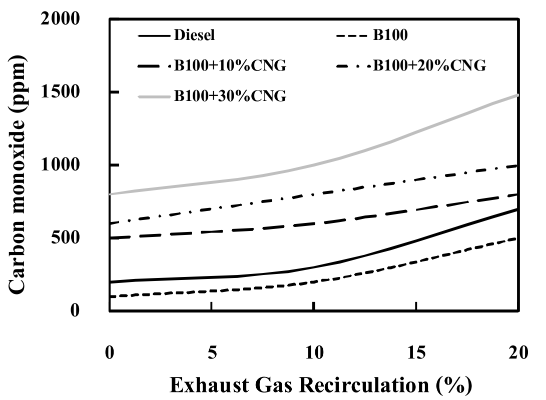

Fig. 8. EGR and carbon monoxide at 1,500 rpm 50% engine load.

For CO emission, it was found that the CO emission increased as a function of an increase in EGR as shown in Fig. 8. When the EGR increased, an intake air was replaced by exhaust gas hence the oxygen entering to combustion chamber was low and the incomplete combustion occurred led to a higher formation of CO [25-26].

In addition, the CO emission increased with an increase in the CNG ratio in biodiesel because the incomplete combustion was higher when the CNG ratio in biodiesel increased led to a higher CO formation [25-26]. Comparison between diesel and biodiesel fuel, it was observed that the CO emission from biodiesel is lower than that of diesel because the biodiesel had much molecule of oxygen led to a higher complete combustion.

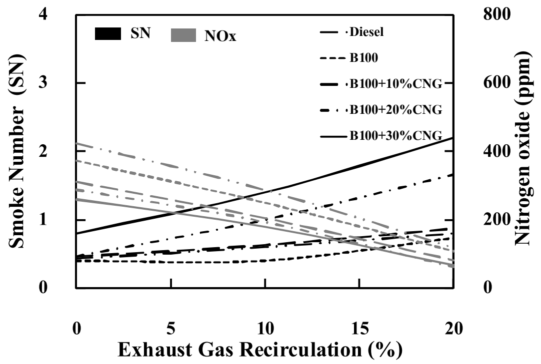

Fig. 9. Effect of EGR changed to soot and nitrogen oxide concentration at 1,500 rpm 50% load.

Fig.9. shows the effect of engine load to SN and NO_x emission. The increasing EGR ratios slightly

decreased the peak in-cylinder pressure and extended ignition delay, since the oxygen in the chamber is reduced, leading to a less clean combustion process with an increase in the smoke as shown in Fig. 9. When the temperature of mixed air and exhaust gas recirculation increased. As seen in Fig. 9, the smoke increased with an increase in CNG ratio because of an incomplete combustion occurred in engine. The NO_x emission decreased with an increase in CNG ratio.

4. Conclusion

A combined biodiesel and CNG was examined. It was found that an increase in CNG ratio caused to decrease in brake thermal efficiency whereas the HC and SN increased. In addition, the NO_x decreased with an increase in CNG ratio. The EGR system was not significantly effect to brake thermal efficiency for all fuels. The HC, CO and SN increased when the EGR and CNG ratio increased. However, the NO_x decreased with an increased in CNG ratio. Furthermore, the engine should be modified for finding a suitable operating condition in order to enhancement engine performance and decrease emissions.

5. Acknowledgement

The Authors express their sincere appreciation to the Energy Policy and Planning Office, Ministry of Energy (EPPO), Thailand (Grant No. 56101), for supporting this study financially. Krasetsart University, Thailand, is also recognized for supporting biodiesel fuels using this works.

6. References

[1] P. Chaisermtawan, S. Chuepeng and K. Theinnoi, “Load Variation Effects on Combustion Regimes in A Hydrogen-Diesel Dual Fuel Engine”, Journal of Industrial Technology 10 (3), 2014, pp.96-105.

[2] W. Wongchai, “Effects of Pyrolysis Oil-Diesel Blends on the Performances and Emissions of a Small Diesel Engine”, Journal of Industrial Technology 10 (2), 2014, pp72-84.

[3] Y. Zhang, M.A. Dube, D.D. Mclean and M. Kates, “Biodiesel production from waste cooking oil: 1. Process design and technological assessment”, Bioresource Technology 89, 2003, pp. 1-16.

[4] Z. Yaakob, M. Mohammad, M. Alherbawi, Z. Alam and K. Sopian, “Overview of the production of biodiesel from waste cooking oil”, Renewable & Sustainable Energy Reviews 18, 2013, pp. 184-93.

[5] J. Xue, “Combustion characteristics, engine performances and emissions of waste edible oil biodiesel in diesel engine”, Renewable and Sustainable Energy Reviews 23, 2013, pp. 350-365.

[6] J.M. Encinar, F.J. Gonzalez and A. Rodriguez-Reinares, “Biodiesel from used frying oil: variables affecting the yields and characteristics of the biodiesel”, Industrial and Engineering Chemistry Research 44, 2005, pp. 5491-5499.

[7] H. Murata, "Example of introducing compressed natural gas vehicles", Proceedings of 7th International Conference and Exhibition on Natural Gas Vehicles. October 17-19. Yokohama, Japan, 2000, pp. 219-223.

[8] P. Gandhidasan, A. Ertas and E.E. Anderson, "Review of methanol and compressed natural gas (CNG) as alternative for transportation fuels", Journal of Energy Resources Technology 113, 1991, pp. 101-107.

[9] F.T. Yusaf, A. Shamsuddin, Y. Ali and A.F. Ismail, "Design modification of high speed diesel engine to accommodate compressed natural gas", RERIC international Energy Journal 18 (1), 1996, pp. 19-26.

[10] N. Charuchinda, "NGV Policy & Roadmap," NGV seminar (Natural Gas for Vehicles) Policy direction and technological trends in 2007 "the headquarters of PTT Public Company Limited On February 26, 2007

[11] X. Meng, G. Chen and Y. Wang, "Biodiesel production from waste cooking oil via alkali catalyst and its engine test", Fuel Processing Technology 89 (5), 2008, pp. 851 – 857.

[12] Y. Di, C.S. Cheung and Z. Huang, "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 (2), 2009, pp. 835 – 846.

[13] T.F. Yusaf, D.R. Buttsworth, K.H. Saleh and F.B. Yousif, "CNG-diesel engine performance and exhaust emission analysis with the aid of artificial neural network", Applied Energy 87 (5), 2010, pp. 1661 - 1669.

[14] A.N. Ozsezena and M. Canakci, "The emission analysis of an IDI diesel engine fueled with methyl ester of waste frying palm oil and its blends", Biomass and Bioenergy 34 (12), 2010, pp. 1870 – 1878.

[15] G. Karavalakis, E. Tzirakis, S. Stournas, F. Zannikos and D. Karonis, "Biodiesel Emissions from a Diesel Vehicle Operated on a Non-legislative Driving Cycle", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 32 (4), 2009, pp. 376 – 383.

[16] S.H. Yoon and C.S. Lee, "Experimental investigation on the combustion and exhaust emission characteristics of biogas–biodiesel dual-fuel combustion in a CI engine", Fuel Processing Technology 9 (5), 2011, pp. 992 – 1000.

[17] Y. Daisho, T. Yaeo, T. Koseki, T. Saito, R. Kihara and E.N. Quiros,, "Combustion and Exhaust Emissions in a Direct-injection Diesel Engine Dual-Fueled with Natural Gas", SAE No. 950465, 1995, pp. 1 – 13.

[18] G.L.N. Rao, S. Sampath and K. Rajagopal, "Experimental Studies on the Combustion and Emission Characteristics of a Diesel Engine Fuelled with Used Cooking Oil Methyl Ester and

its Diesel Blends", International Journal of Engineering and Applied Sciences 4 (2), 2008, pp. 64 – 70.

[19] M. Lapuerta, J.M. Herrerosa, L.L. Lyonsa, R.G. Contrerasa and Y. Briceñob, "Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions", Fuel 87 (15–16), 2008, pp. 3161 – 3169.

[20] H. An, W.M. Yang, S.K. Chou and K.J. Chua, "Combustion and emissions characteristics of diesel engine fueled by biodiesel at partial load conditions", Applied Energy 99, 2012, pp. 363 – 371.

[21] M.S. Kumar, A. Ramesh and B. Nagalingam, "Experimental Investigations on a Jatropha Oil Methanol Dual Fuel Engine", New Developments in Alternative Fuels for CI Engines, SAE No. 2001-01-0153, 2001, pp. 1 – 7.

[22] A.P. Roskilly, S.K. Nanda, Y.D. Wang and J. Chirkowski, "The performance and the gaseous emissions of two small marine craft diesel engines fuelled with biodiesel", Applied Thermal Engineering 28 (8 – 9), 2008, pp. 872 – 880.

[23] Z. Utlua and M.S. Koçakb, "The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions", Renewable Energy 33 (8), 2008, pp. 1936 – 1941.

[24] A. Abu-Jrai, J.A. Yamin, A.H. Al-Muhtaseb and M.A. Hararah, "Combustion characteristics and engine emissions of a diesel engine fueled with diesel and treated waste cooking oil blends", Chemical Engineering Journal 172 (1), 2011, pp. 129 – 136.

[25] M.M. Abdelaal and A.H. Hegab, "Combustion and emission characteristics of a natural gas - fueled diesel engine with EGR", Energy Conversion and Management 64, 2012, pp. 301 – 312.

[26] V.S. Yadav, S.L. Soni and D. Sharma, "Performance and emission studies of direct injection C.I. engine in duel fuel mode (hydrogen-diesel) with EGR", International Journal of Hydrogen Energy 37 (4), 2012, pp. 3807 – 3817.