ID: 2016-ISFT-155

Performance and Emissions Characteristics of Dual Fuel Engine using CNG and MOME

Parvesh Kumar[1], Vartika Shivaji[2]

[1,2]Research Scholar, Delhi Technological University, New Delhi
pkkhatkar12@gmail.com

Abstract: *In a developing economy like India, crude petroleum serves as a major source for meeting energy needs. Escalating prices of petroleum fuels coupled with environmental degradation has led to growing interest in alternative fuels like vegetable oils, alcohols, CNG, LPG, Producer gas and biogas. Transesterified vegetable oil has properties quite similar to that of diesel fuel. Although there are several advantages of using vegetable oil derivative (biodiesel) as a diesel engine fuel, there are some disadvantages in its utilization such as increase in oxides of nitrogen and deposits in combustion chamber. This problem can be alleviated to a great extent by using biodiesel in a dual mode operation along with CNG which is a cleaner fuel and has the potential to meet stringent emission norms. In the present study, biodiesel from Mahua oil was prepared and pilot injection of this fuel was carried. In the present scenario of energy scarcity, there is greater need of cleaner fuels.*

In the present investigation, it is proposed that a small (<15% of fuel energy) pilot injection of Mahua oil Methyl Ester, injected during the compression stroke, with high volatility and low auto ignition temperature will act to initiate combustion of a CNG charge which was fed to the engine along with intake air through the inlet manifold during suction stroke of the engine, in a stationary, constant RPM, air cooled CI engine. The effect of the pilot charge on various performance, emission and combustion characteristics was investigated, as well as the extension of the load range of the engine. The results show that there is an increase in brake thermal efficiency of the engine and drastic reduction in various emissions such as CO, NOx, CO_2, HC etc when CNG is used as a duel fuel in the operation of CI engine with Mahua oil methyl ester.

Keywords: *biodiesel, dual fuel, Mahua oil, pilot injection, air cooled engine, brake thermal efficiency*

1. INTRODUCTION

Diesel engines play an important role in heavy duty applications due to its high efficiency and power. Moreover, it has low emissions of unburned hydrocarbons (UHCs), Carbon monoxides (CO) and carbon dioxides (CO_2) when compared with gasoline (SI) engine [1, 2]. However, diesel engines are emitters of harmful pollutants like oxides of nitrogen (NOx) and particulate matter (PM) which adversely affect human health and also the environment [3]. Diesel engines operate on high compression ratio, thereby allowing it to use low energy alternative fuels such as biofuels. Petroleum derived fuels such as diesel are non-renewable in nature and hence suffer from volatile prices in the international market. In wake of rising environmental concerns regarding fossil fuels, exhaustive research is carried out round the world to find various alternatives to mineral diesel [4-7].

Diesel – CNG dual fuel engines have emerged as a very promising alternative in reducing harmful emissions of diesel engines [8-10]. The main source of energy is the gaseous fuel (known as primary fuel) and a liquid fuel in small quantities having low self-ignition temperature (known as pilot fuel and used as an ignition source) [3]. Existing diesel engines can be easily converted into dual fuel system operated on CNG with same compression ratio. The efficiency is found to be similar to diesel engines with significantly reduced emissions such as NOx (oxides of nitrogen), smoke and particulate matter (PM) [11].

However, some critical problems are experienced when a diesel engine is operated on dual fuel mode. At low load, dual fuel engines are fueled with lean mixture which is difficult to ignite and burns slowly which results in high level of unburned hydrocarbons (UHCs) and carbon monoxides (CO) [12, 13]. But with increasing load, the quantity of unburned hydrocarbon and carbon monoxide decreases gradually although NOx (oxides of nitrogen) increase due to increased temperature of the combustion chamber [11, 14]. Significant reduction in NOx emission level was achieved by employing relatively advanced pilot injection timings [55–60^0 before top dead center (BTDC)] but with some penalty in UHCs emissions and engine stability [15, 16]. On addition of gaseous fuel, it was found that the ignition delay increased initially in comparison to diesel fuel. However, with further gas addition, the ignition delay reduced gradually [3, 17].

Significant number of studies has been carried out using CNG as main fuel and diesel as pilot fuel in dual fuel combustion engines. Recent developments in the field of alternative fuels have mandated the study of biodiesel as a pilot fuel in dual fuel engines. Biodiesel has great potential as an alternative fuel for compression ignition engines. One of the many advantages of using biodiesel is the similarity in properties between biodiesel and diesel [18, 19]. Diesel can be easily substituted by biodiesel as it is ecofriendly in nature; because it produces less smoke in comparison to diesel due to increased oxygen content in it. Mahua oil methyl ester has higher specific gravity and kinematic viscosity than petroleum diesel. Mahua oil methyl ester has higher Cetane number than diesel which decreases the ignition delay at low load and also lowers the NOx level (oxides of nitrogen) in the initial phase of combustion. Mahua oil methyl ester gives lower exhaust emissions such as hydrocarbons, carbon monoxides, particulate matter, polycyclic aromatic hydrocarbons, SO2, and smoke as compared to diesel.

In this study, a biodiesel–CNG dual fuel combustion system is studied as a low-temperature combustion technology for the simultaneous reduction of particulate matter (PM) and oxides of nitrogen (NOx) from diesel engines. Biodiesel fuel is used as a pilot injection fuel to ignite the compressed natural gas which is the main fuel of the dual fuel combustion system in this study. The results are then compared with that of single fuel diesel combustion system and Dual Fuel Diesel CNG combustion system.

2. EXPERIMENTAL SETUP

The engine chosen for current research was Kirloskar (CAF8) 8hp air cooled, four stroke, single cylinder, compression ignition engine with rated output 5.9(8) KW (hp). Main engine specifications are given in table 1. CNG is induced into the combustion chamber by installing a CNG gas kit (including a CNG cylinder, a reducer along- with a battery, lambda controller) along-with a venturi in the intake manifold just after the air filter. It assures proper mixing of the air and CNG and hence results in the formation of a homogenous mixture before combustion. A reducer is used to expand the CNG from the CNG cylinder pressure to the pressure (8-10 bars) at which it is to be injected into the combustion cylinder, a lambda controller which governs the amount of CNG to be injected. However, during all range of experiments the CNG used was of similar quality.

An exhaustive investigation of air cooled engine was done in different operating conditions Diesel, Diesel + CNG and Mahua Methyl Esters + CNG. All the tests were conducted according to Indian testing standard IS: 10,000 and loaded by an eddy current dynamometer coupled with the engine by a rigid coupling. All the experiments were conducted three times and average of them was taken into account. And the accuracy and uncertainty of the equipments used in the current investigation is given in appendix.

TABLE 1*:* Technical Specification of the engine

No. of Cylinders:	1
Bore * Stroke	87. 5*110 mm
Cubic Capacity	0. 661 litre
Compression Ratio	17. 5 : 1
Rated Output	5. 9 (8) KW(hp)
Rated Speed	1500 rpm
Crank Shaft Height	203 mm
Specific Fuel Capacity (SFC)	202 +5%(gm/hp-h)
Lube Oil Consumption	1% of SFC max
Lube Oil Sump Capacity	3 (Litre) at higher level mark on dipstick
Fuel Tank Capacity	6.5 litre
Physical dimensions of bare engine	531*546*856 mm (Length* Width* Height)
Engine Weight (dry)	163 (kg)
Rotation while looking at the Flywheel	Clockwise
Power Take –off	Flywheel end
Starting	Hand Start
Governing	Class" A2/ B1"
Combustion System	Direct Injection

A governor is used to regulate the amount of diesel and biodiesel entering the combustion chamber as it ensures the passage of just enough mixture of CNG and air to start the combustion process when the engine is run on dual fuel combustion mode. The ratio of pilot fuel to CNG injected is kept around 0.22 using the governor and the lambda controller.

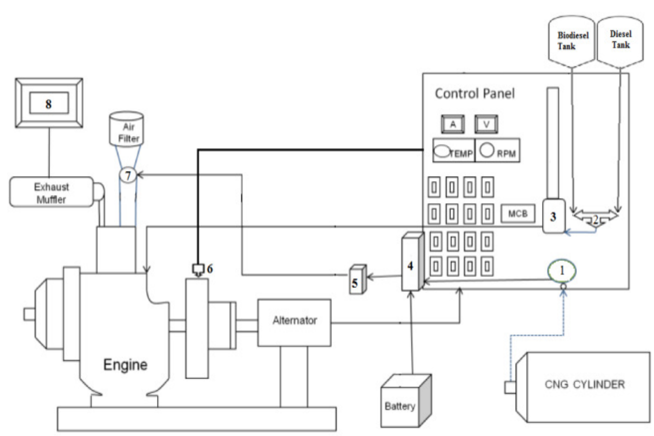

Fig. 1. Engine setup layout

Footnote: 1. CNG pressure valve, 2. Two way valve, 3. Liquid measure burette, 4. CNG reducer, 5. CNG controller valve, 6. Speed measurement, 7. Venturi and 8. Di-gas analyzer

The primary measurements for this study include the air mass flow rate using U-tube manometer and intake temperature. The pilot fuel consumption is measured with the help of fuel consumption measuring unit via a burette.

The exhaust temperature is measured with the help of a thermocouple installed in the exhaust system. Various electric bulbs of 500W and 200W ratings were used for controlling the load on the running engine. The voltage and current are measured with the help of installed voltmeter and ammeter. The engine has been run under pure diesel engine conditions, direct diesel pilot injection assisted compressed natural gas dual fuel mode conditions and direct Mahua oil methyl ester pilot injection assisted compressed natural gas dual fuel mode conditions. The major exhaust emissions such as NOX, HC, CO2, CO and smoke were measured with AVL 4000 di-gas analyzer whose s specifications are given in table 2.

Data points were recorded at steady state operating conditions. Engine speed for the tests was held constant at 1500 RPM. Data sets were taken at different loads of 20%, 40%, 60%, 80%, 100% (full load i.e. 5.9kW) and no load conditions. Each data set contained the below mentioned characteristics of the test fuel.

TABLE 2. Specification of Di-Gas analyzer.

S No.	Parameters	Range	Resolution	Technique
1	CO	0-10 (% vol.)	0.01 (% vol.)	Non dispersive infra-red sensor
2	CO2	0.1 (% vol.)	0.1 (% vol.)	Non dispersive infra-red sensor
3	HC	0-20000 (ppm)	1 (ppm)	Flame ionization detector-FID
4	NOx	0-10000 (ppm)	1 (ppm)	Chemi-luminescence principle, electro-chemical sensor

Voltage and current was measured along-with each reading to measure the brake power (BP). The data sets were first taken without CNG induction i.e. engine operating fully on diesel fuel and then repeated with CNG fuel along with pilot diesel injection and CNG fuel along with pilot Mahua oil methyl ester injection as dual fuel mode. The three modes were respectively referred to as neat diesel mode, pilot diesel assisted CNG-dual fuel mode and pilot Mahua oil methyl ester assisted CNG dual fuel mode.

3. RESULTS AND DISCUSSION

In this section, experimental results concerning the effect of use of Mahua oil methyl ester and diesel as a pilot fuel in dual fuel engine for the performance and pollutant emissions are presented and discussed.

3.1 EFFECT OF DUAL FUEL MODE ON EXHAUST TEMPERATURE

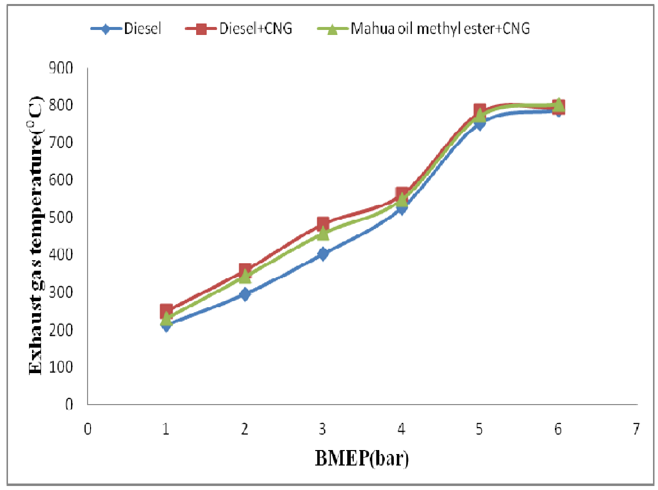

Fig. 2. Exhaust gas temperature(^{0}C) with BMEP(bar)

Fig.2 shows the variation of exhaust gas temperature with brake mean effective pressure (BMEP). It can be observed that exhaust gas temperature increases with increase in BMEP because the fuel consumption increases with increase in load and BMEP.

3.2 EFFECT OF DUAL FUEL MODE ON BRAKE THERMAL EFFICIENCY

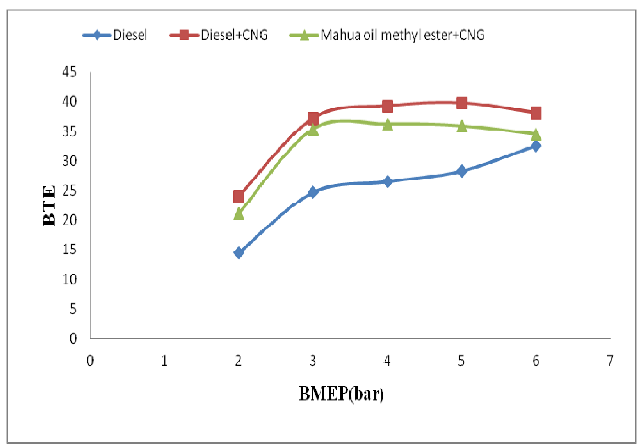

Fig. 3. Variation of BTE (%) with BMEP (bar).

Fig.3 shows relationship between brake thermal efficiency (BTE) and brake mean effective pressure (BMEP). In all the three cases BTE increases with increase in BMEP. It is found that brake thermal efficiency of the engine when run on dual fuel mode (with diesel or Mahua oil methyl ester as pilot fuel) is more than that when run on diesel alone for all loading conditions. However, the brake thermal efficiency using diesel as a pilot fuel is higher as compared to Mahua oil methyl ester as pilot fuel.

3.3 EFFECT OF DUAL FUEL MODE ON BRAKE SPECIFIC FUEL CONSUMPTION

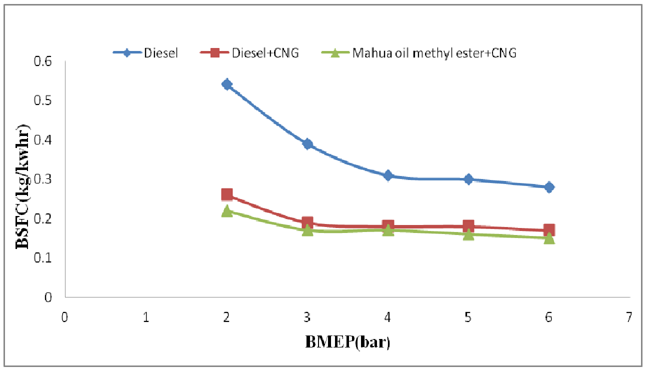

Fig.4. Variation of BSFC (kg/kW-h) with BMEP (bar).

Fig.4 shows the relationship between brake specific fuel consumption and brake mean effective pressure. Brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of an engine. It is also called as the power specific fuel consumption. BSFC decreases with increase in brake mean effective pressure which is a function of engine load in all the three cases as seen in the figure 4. For diesel operations, it is known that BSFC is inversely proportional to BTE. The same pattern is being followed by Diesel Dual Fuel mode and Mahua oil methyl ester Dual Fuel mode as can be seen from the Figure 4. It was found that Mahua Oil Methyl Ester Dual Fuel mode has the least BSFC as compared to baseline data.

3.4 EFFECT OF DUAL FUEL MODE ON NOX EMISSIONS

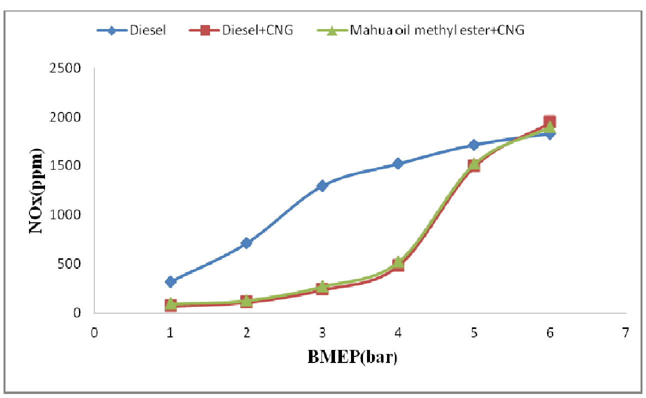

Fig.5. Variation of NOx (ppm) with BMEP (bar).

Fig.5 shows the variation of NOx emissions for conventional diesel and the two dual fuel modes at 1500 rpm engine speed in variance with the engine load. At low and moderate loads, NOx concentration of the two dual fuel modes is lower as compared to conventional diesel. However, among the two dual fuel modes, NOx in diesel as a pilot fuel is less than that of Mahua oil methyl ester as pilot fuel in dual fuel engine. It is widely recognized that the formation of thermal NOx is mainly favored by two parameters i.e., high oxygen concentration and high charge temperature. For low and moderate loading conditions, the charge temperature for all modes is almost equal. On the other hand, the higher oxygen concentration of conventional diesel leads to a significant level of NOx emission.

However, at higher loads, our results show that the NOx concentration of both the dual fuel modes becomes higher than that of conventional diesel for all engine speeds. This is primarily due to a higher charge temperature for dual fuel mode. This higher temperature is due to a more important heat release in the early premixed combustion stage, which is the result of the gaseous fuel combustion improvement at those loads. On the other hand the NOx in dual fuel engine using diesel as pilot fuel is higher than that of Mahua oil methyl ester as pilot fuel.

3.5 EFFECT OF DUAL OPERATION ON UNBURNED HYDROCARBON EMISSIONS

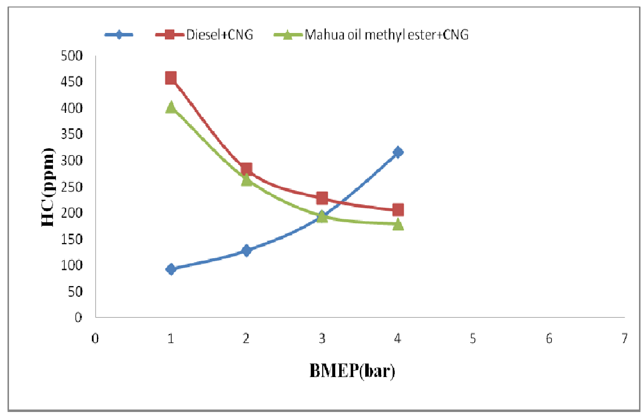

Fig. 6. Variation of HC (PPM) with BMEP (BAR).

The results for unburned hydrocarbon emissions, as a function of engine load, for the all the three modes of engine operation are shown in Fig.6 at 1500 rpm engine speed. At low and medium engine loads, total hydrocarbon (THC) emission for dual fuel mode is considerably higher in comparison to that of conventional diesel. At low loading conditions, the low temperature level and the high air-fuel ratio of gaseous fuel mixture induces poor and slow combustion. Hence, a significant quantity of CNG does not participate in the combustion process. Despite unfavorable conditions at lower loads, the THC emissions are lower due to small gaseous fuel participation. In the initial stage of increasing loading conditions, the emissions are found to increase. This happens due to increased gaseous fuel participation; however, the combustion quality is insufficient to lower the THC emissions.

For higher loading conditions, higher charge temperature level and richer gaseous fuel results in an improved combustion process, and as a consequence a decrease in the unburned hydrocarbon emissions occurs. It was found that the THC emissions for Diesel as a pilot fuel was higher as compared to Mahua oil methyl ester for all loading conditions.

3.6 EFFECT OF DUAL FUEL MODE ON CARBON MONOXIDE EMISSIONS

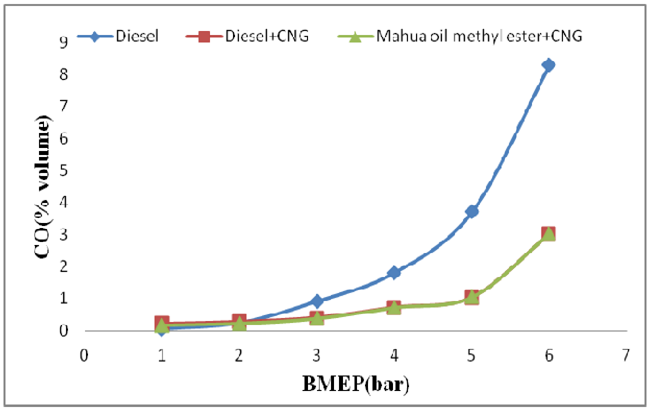

Fig.7. Variation of CO (%) with BMEP (BAR).

Fig.7 illustrates the variation of carbon monoxide (CO) emissions for the all modes of engine operation, as a function of engine load. It is known that the rate of CO formation depends on the unburned gaseous fuel availability and the temperature of the homogeneous mixture of gaseous fuel and air. As shown in Fig.7, CO emissions are higher for dual fuel mode at lower loading conditions and no load conditions. However, CO concentration for dual fuel mode decreases with the increase of engine load compared to diesel engine as a result of the improvement of gaseous fuel utilization. On the other hand, for very high loading conditions, because of very rich mixtures produced locally in conventional diesel engine operation, which result in poor combustion, the CO emissions are significantly higher.

4. CONCLUSIONS

In this paper, the effect of dual fuel operating mode on engine performance and evaluation of pollutant emissions of an existing diesel engine using natural gas as primary fuel and neat diesel and Mahua oil methyl ester as pilot fuel has been examined. For all loading conditions, the total BSFC for dual fuel mode is lower than that of conventional diesel. The increase in BSFC reveals a poor utilization of the gaseous fuel. Low BSFC increases the brake thermal efficiency (BTE) at all load conditions. It is also noticed that the BTE of dual fuel engine using Mahua oil methyl ester as pilot fuel lies between dual fuel engine using diesel as pilot fuel and conventional diesel engine.

Concerning pollutant emissions, the results show that the use of natural gas as main fuel and Mahua oil methyl ester as pilot fuel for dual fuel engine is a very efficient technique for reducing total hydrocarbon emissions at all load condition as compared to the dual fuel engine with natural gas and diesel fuel. Use of Mahua oil methyl ester as pilot fuel in place of diesel in a dual fuel engine also decreases the amount of carbon monoxides released. Moreover, the amount of oxides of nitrates and carbon dioxide increases by using Mahua oil methyl ester as pilot fuel in place of diesel in dual fuel engine using CNG as primary fuel.

REFERENCES

[1] Muller, J-O.; Su, D.S.; Jentoft, R.E.; Wild, U.; Schlögl, R. Diesel engine exhaust emission: oxidative behavior and microstructure of black smoke soot particulate. Environmental Science and Technology, 2006, 40:1231–6.

[2] Yoon, S.H.; Lee, C.S. Experimental investigation on the combustion and exhaust emission characteristics of biogas–biodiesel dual-fuel combustion in a CI engine. Fuel Process Technology, 2011, 92:992–1000.

[3] Mustafi, N.N.; Raine, R.R.; Verhelst, S. Combustion and emissions characteristics of a dual fuel engine operated on alternative gaseous fuels. Elsevier, 2013, Fuel 109, 669-678.

[4] Nabi, N.M.; Hustad, E. Influence of oxygenates on fine particle and regulated emissions from a diesel engine. Fuel, 2012;93:181–8.

[5] Hesterberg, T.W.; Long, C.M.; Bunn, W.B. et al. Health effects research and regulation of diesel exhaust: an historical overview focused on lung cancer risk. Inhal Toxicol, 2012, 24(S1):1–45.

[6] Vouitsis, E.; Ntziachristos, L.; Samaras, Z. Particulate matter mass measurements for low emitting diesel powered vehicles: what’s next? Progress Energy Combust Sci, 2003,29(6):635–72.

[7] McClellan, R.O.; Hesterberg, T.W.; Wall, J.C. Evaluation of carcinogenic hazard of diesel engine exhaust needs to consider revolutionary changes in diesel technology. Regul Toxicol Pharmacol, 2012,63:225–58.

[8] Barata, J.M.M. Performance and emissions of a dual fueled DI diesel engine. SAE paper 952364, 1995.

[9] Lin, Z.; Su, W. A study on the determination of the amount of pilot injection and rich and lean boundaries of the pre-mixed CNG/air mixture for a CNG/diesel dual-fuel engine. SAE paper 2003-01-0765, 2003.

[10] Karim, G.A. Combustion in gas fueled compression: ignition engines of the dual fuel type. ASME J Eng Gas Turb Power 2003, 125:827–36.

[11] Antonio, P.; Saracino, R.; Toto, G. Combustion and emissions control in diesel–methane dual fuel engines: The effects of methane supply method combined with variable in-cylinder charge bulk motion. Elsevier, Energy Conversion and Management 52, 2011, 3004-3017.

[12] Karim, G.A.; Liu, Z.; Jones, W. Exhaust emissions from dual fuel engines at light load. SAE paper 932822, 1993.

[13] Papagiannakis, R.G.; Hountalas, D.T. Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot diesel fuel and natural gas. Energy Convers Manage 2004, 45:2971–87.

[14] Kusaka, J.; Ito, S.; Mizushima, N.; Daisho, Y.; Saito, T. A numerical study on combustion and exhaust gas emissions characteristics of a dual fuel natural gas engine using a multi-dimensional model combined with detailed kinetics. SAE paper 2003-01-1939, 2003.

[15] Karim, G.A. Combustion in gas fueled compression ignition engines of the dual fuel type. ASME J Eng Gas Turbines Power 2003, 125:827–36.

[16] Karim, G.A. A review of combustion processes in the dual fuel engine the gas diesel engine. Prog Energy Combust Sci 1980, 6:277–85.

[17] Singh, S.; Krishnan, S.R.; Srinivasan, K.K.; Midkiff, K.C.; Bell, S.R. Effect of pilot injection timing, pilot quantity and intake charge conditions on performance and emissions for an advanced low-pilot-ignited natural gas engine. Int J Eng Res 2004, 5:329–48.

[18] Labeckas, G.; Slavinskas, S. The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions. Energy Convers Manage 2006, 47:1954–67.

[19] Kannan, D.; Pachamuthu, S.; Nabi, M.N.; Hustad, J.E.; Løvås, T. Theoretical and experimental investigation of diesel engine performance, combustion and emissions analysis fuelled with the blends of ethanol, diesel and jatropha methyl ester. Energy Convers Manage 2012, 53:322–31.