ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013

Characterization and Potential of Dimethyl Ether (DME) as Dual Fuel Combustion in a Compression Ignition Engine

Somkid Khunaphan[1], Unalome Wetwatana Hartley[2], Kampanart Theinnoi[3,*]
[1]Automotive Engineering Department, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, Thailand.
[2]Chemical and Process Engineering Department, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, Thailand.
[3]Combustion Technology and Alternative Energy Research Centre (CTAE), College of Industrial Technology,
King Mongkut's University of Technology North Bangkok, Bangkok, 11120 Thailand.

***Abstract—* In the present work, the dual fuelling with in-cylinder ultra low sulfur diesel (ULSD) fuel and with inlet port injected dimethyl ether (DME) or liquefied petroleum gas (LPG) on engine performance and emissions were investigated. The presence of DME and LPG can substantially improve the thermal efficiency compared with diesel fuel. The engine out emission such as the hydrocarbon and smoke emission were reduced however increased the NOx and carbon monoxide. The improvement in the engine emissions and thermal efficiency were magnified when the engine was run with in-port injected DME and in-cylinder injected ULSD compared to the engine operation only diesel and LPG additions at the inlet port. The positive effect on engine performance was indicated when DME is used as dual fuel in unmodified diesel engine and therefore offers fuel economy benefit.**

Index Terms— **Dual Fuel, Ultra low sulfur diesel, Dimethyl ether, Liquefied petroleum gas, In-port injection.**

I. INTRODUCTION

A. Background of the study

The environmental concerns become a serious issue in the present. The higher amount of vehicle has grown considerably within last few decades. Compression ignition engine that is known as diesel engine is being interested recently in order to exhibit more beneficial in term of viable technology in the future [1]. Diesel engine is generally known for its excellent durability, reliability, fuel economy, and hence low carbon dioxide (CO_2) emissions produced. However, it associated with combustion noise, engine vibration, and nitrogen oxides (NO_x)-particulate matter (PM) trade-off emissions. Thus, the simultaneous reduction of NO_X and PM emissions from diesel engine remains one of the major challenges of compression ignition engine development. Several successful technologies for clean diesel engine could be divided into four strategies: fuel technology, in-cylinder technology, lubricant oil development, and emission control device. This can be help the engines were met the stringent emission standards (i.e. Euro emission standard, US emission standard).

B. Characterization and potential of dimethyl ether (DME)

DME, known as methoxy methane is the organic compound with the chemical formula CH_3OCH_3 or C_2H_6O. DME fuel specification is the ether gas group. Esters are oxygenates organic compounds that can be used in diesel engine because some of their key properties are comparable to those of diesel fuel. The properties of DME are given in Table 1. Currently, DME are applied in different applications as a spray gas because it was proved in low exhaust gas emission. DME gas can be store under low-pressure containers storage, which is very similar to those LPG. The storage, handling, distribution and safety aspects of DME are very similar to those of LPG, in order to the similarity in physical properties of these substances. One of DME's most important characteristics is its low ignition temperature, which is similar to that of diesel fuel [2-3]. The DME can be used as pure or blended with fossil diesel fuel hence; it is the respective substitution alternative fuels for conventional diesel fossil fuel.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013

Table 1-Physical and Chemical Property of DME with Other Fuels

Property	Fuel			
	DME	Diesel	LPG	
			Propane	Butane
Formula	CH_3OCH_3 or C_2H_6O	C_8 to C_{25}	C_3H_8	C_4H_{10}
Mole weight	46.07	≈200	44.11	58.13
Boiling temperature, °C	-25	≈150-380	-42	-0.5
Vapor pressure @20 °C, bar	5.1	-	8.4	2.1
Liquid viscosity @25 °C, kg/ms	0.12-0.15	2-4	0.2	0.18
Liquid density @20 °C, kg/m^3	660	800-840	490	610
Gas specific gravity (vs air)	1.59	-	1.52	2.01
Lower heating value, kJ/kg	28430	42500	46360	45740
Explosion limit in air, vol %	3.4-17	0.6-6.5	2.1-9.4	1.9-8.4
Cetane number	55-60	40-55	5	-
Auto ignition temperature@ 1 atm, °C	235	206	470	365
Stoichiometric A/F, kg/kg	9.0	14.6	15.7	14.8
Latent heat of evaporation, kJ/kg	410	250	426	390

DME are produce from a vast variety of feedstock such as natural gas, coal, crude oil, residual oil, waste products and biomass. A number of experimental studies showed the attractive physical and chemical properties of DME fuel e.g. high cetane number, high oxygen content (35% by mass) and low boiling point (Table 1), enhanced engine performance and emissions [4-8].

C. Objectives of the study

The main concept of this research is investigating the effect of the use of different proportion dual fuel (DME and diesel fuel) on engine performance and emissions in association with its emission control strategies. To optimize exhaust gas emissions as well as improve engine performance and fuel economy. A prototype system will be carried on a wide range of engine operating conditions by using a single cylinder diesel engine.

II. EXPERIMENTAL SETUP AND PROCEDURE

The experimental was conducted in Combustion Technology and Alternative Energy Research Centre (CTAE) at College of Industrial Technology, King Mongkut's University of Technology North Bangkok and a schematic of the apparatus is presented in Figure 1.

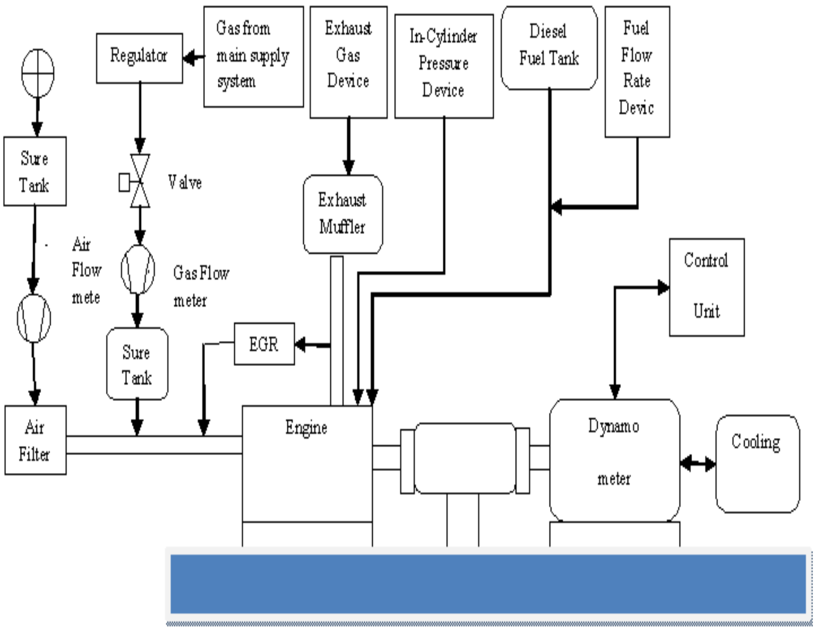

Fig 1 Schematic Diagram of Equipment and Measurement Device

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013

A. ENGINE INSTRUMENTATION - The engine used for this study was a single cylinder direct injection Yanmar model L100V diesel engine. The main engine specifications are as follows: bore 86 mm, stroke 75 mm, displacement volume 435 cm^3, compression ratio 21, standards injection timing 15.5^o maximum power 6.2 kW at 3600 rpm.

B. FUEL - The fuels used were conventional the dual fuelling with in-cylinder ultra low sulfur diesel (ULSD) fuel and with inlet port injected dimethyl ether (DME) or liquefied petroleum gas (LPG)**.** The DME stored in a low-pressure storage tank at a pressure of 4 bars was reduced to a pressure of 1 bar by a pressure regulator. A rotating gas flow meter combined was introduced to measure the gas flow rate into the intake port.

C. EXHAUST GAS COMPOSITION ANALYSIS - Horiba Mexa 584L gas analyser was used for measurement of carbon dioxide, carbon monoxide by Non-Dispersive Infrared (NDIR), oxygen by magnetopneumatic method, Nitrogen monoxide (NO) by Chemiluminescence's detection (CLD), and Hydrocarbons (HC) by flame ionization detector (FID). Engine smoke was measured using a Bosch smoke meter where a constant volume of exhaust gas was drawn through a white filter paper and the darkening of the paper was taken as a measure of the smoke density, using a scale of ascending opacity from 0 to 10 Bosch Smoke Number.

D. **COMBUSTION ANANLYSIS** - In-cylinder pressure was monitor by A KISTLER 6056A quartz pressure transducer (±0,5 % measurement accuracy), mounted flush at the cylinder head and connected via a KISTLER 5018A charge amplifier to a data acquisition board, was used to record the in-cylinder pressure. The crankshaft position was measured using a digital shaft encoder. The test-rig included other standard engine instrumentation, such as thermocouples type K to measure oil, air, inlet manifold and exhaust temperatures was monitored during the tests.

E. EXPERIMENTAL PROCEDURE - In this work are carried out by inject DME or LPG (2% by volume of air) as a dual fuel into the intake manifold of the unmodified single cylinder diesel engine. The experimental were examined under engine speed of 1500 rpm with three engine loads of 25%, 50% and 75% of maximum load. The parametric experimental study the effect of DME addition on engine load (constant engine speed) with engine performance and emissions were investigated.

III. RESULTS AND DISCUSSION

This experimental are investigated the effect of the dual fuelling with in-cylinder ultra low sulfur diesel (ULSD) fuel and with inlet port injected dimethyl ether (DME) or liquefied petroleum gas (LPG) on engine performance and emissions were investigated. The experimental were examined at one engine speed condition: 1,500 rpm engine speed with a load of 25%, 50% and 75% of the maximum load. The work presented here will enhance the current level of understanding of the differences in fuels on the brake thermal efficiency, brake specific fuel consumption, emission (CO, HC, NO_X, smoke) and in-cylinder pressure.

A. Fuel Effects on Combustion Characteristics

The in-cylinder pressure graph from the combustion of diesel with DME and LPG without EGR are illustrated in Figure 2. The fuel physical and chemical properties such as density, viscosity, cetane number, boiling point and latent heat of vaporization (Table 1) can significantly affect the combustion patterns.

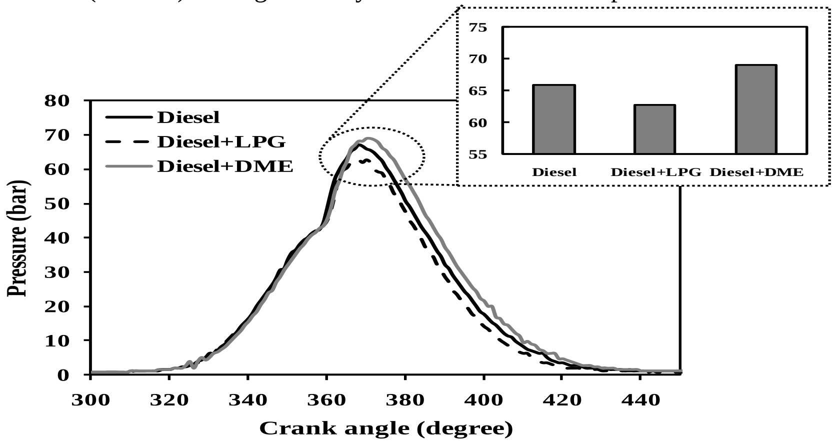

Fig 2 Cylinder pressure and for the engine fuelled with diesel, diesel with LPG and diesel with DME 75% engine load for dual fuel

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013
The in cylinder pressure of conventional diesel lie between diesel fuel with DME and diesel fuel with LPG. The advantage of DME fuel, in terms of higher cetane number compared to diesel and diesel with LPG, can improve the combustion characteristics. In additions, the peak pressure had been found in DME-operated dual fuel engine is advanced by 2^{o} compared to diesel mode due to the DME has high cetane number and low boiling point lead to the short ignition delay, low auto-ignition temperature and almost instantaneous vaporization.

B. Brake thermal efficiency

The effect of engine load on brake thermal efficiency is shown in Fig. 3. The presence of DME and LPG can enhance the thermal efficiency when compared to diesel fuel at increasing of engine load. At 75% of engine load found the highest brake thermal efficiency is found to be 29.2% and 28.6% that present injection of LPG and DME respectively compared to neat diesel (26.8%). The presence of LPG or DME results in shorter ignition delays and better vaporization characteristics lead to generating complete combustion at higher load conditions.

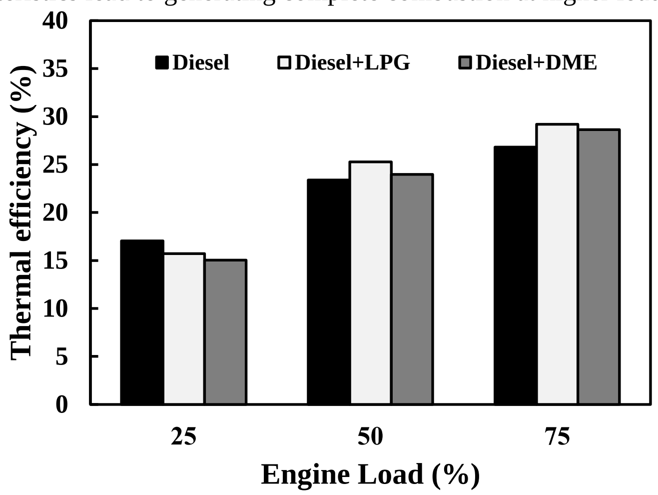

Fig 3 Effect of engine load on brake thermal efficiency for dual fuel

C. Brake specific fuel consumption (BSFC)

Figure 4 depicts the effect of engine load on brake specific fuel consumption (BSFC). The experimental showed the presence of DME and LPG can substantially reduce the brake specific fuel consumption compared to diesel fuel with higher engine load. In order to the higher oxygen content of DME and LPG contributes to improved fuel oxidation even in locally rich fuel combustion zone.

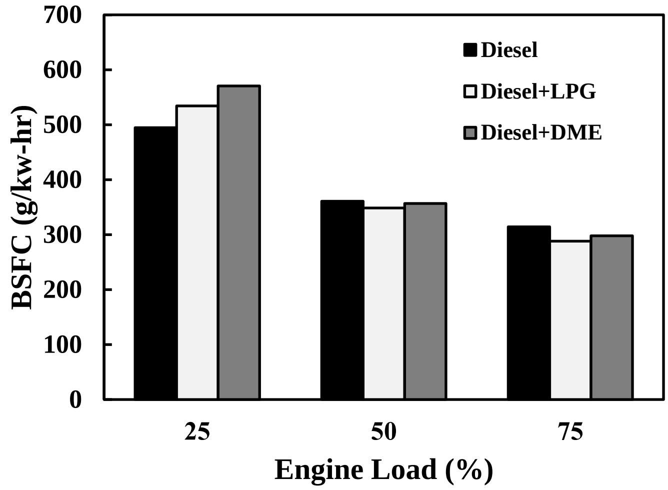

Fig 4 Effect of engine load on BSFC for dual fuel

D. Oxides of nitrogen (NO_X)

Nitrogen oxides are toxic emissions produced from diesel combustion and consist of nitric oxide (NO) and nitrogen dioxide (NO_2). The engine operates with DME and LPG injection found the higher NO_X emission than of

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013
the diesel operation as shown in Fig.5. The increase of oxides of nitrogen formation for all loads is associated with oxygen content, which influences higher adiabatic flame temperatures and hence produces more NO_X.

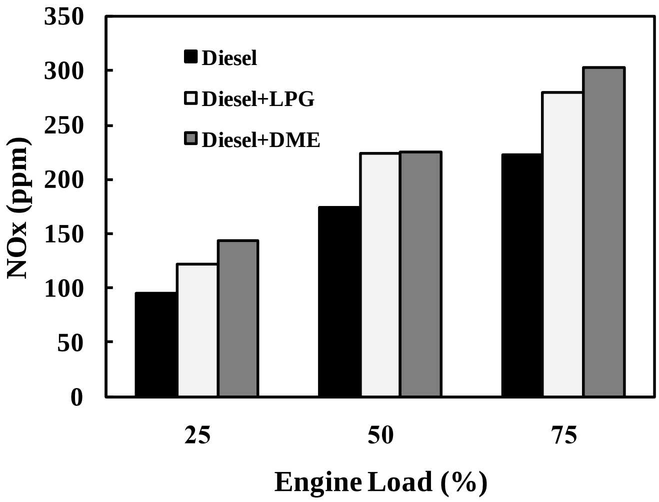

Fig 5 Effect of engine load on oxides of nitrogen for dual fuel

E. Carbon monoxide (CO)

The CO concentration of dual fuel engine is greater than diesel fuel as shown in Fig.6. Due to the engine is operated with a fuel-rich, there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned (incomplete combustion) and some carbon ends up as CO. There was an increase in concentration of DME or LPG substitution is result in higher CO concentration in order to incomplete combustion of the dual fuel system. The main causes of combustion deterioration (such as high latent heats of vaporization) could be responsible for the increased CO production [9]. The low CO concentration of DME due to significantly higher cetane number of DME fuel compared to LPG fuel leads to shorter ignition delay (defined as the time between start of injection and start of combustion), longer diffusion combustion, and reduces the premixed combustion phase (especially at low injection pressures and low in-cylinder temperatures).

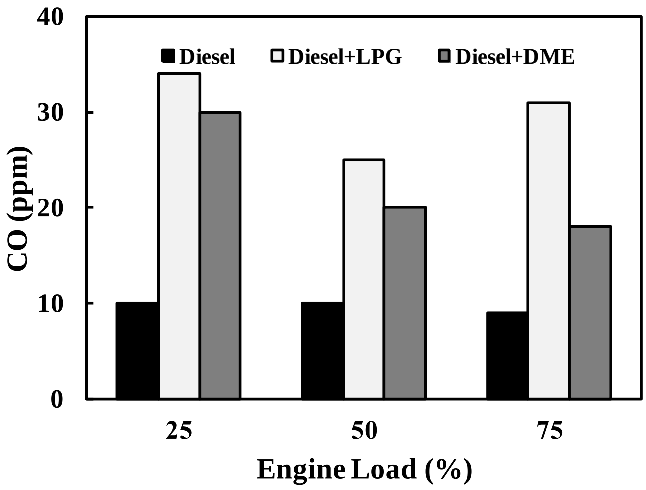

Fig 6 Effect of engine load on carbon monoxide for dual fuel

F. Hydrocarbon (HC)

Figure 7 depicts the effect of engine load on hydrocarbon emissions with engine load. The high latent heat of vaporization hence this causes signification higher HC emissions formation for dual fuel engine (DME and LPG). In addition, the flame quenching at the cylinder wall can contribute to HC formation due to the cylinder walls and crevice regions around the top of the piston edge including piston rings, having a lower temperature compared to the combustion gases. Moreover, LPG or DME additions can produce slow vaporization and mixing of fuel and air, which achieved the high HC concentrations.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013

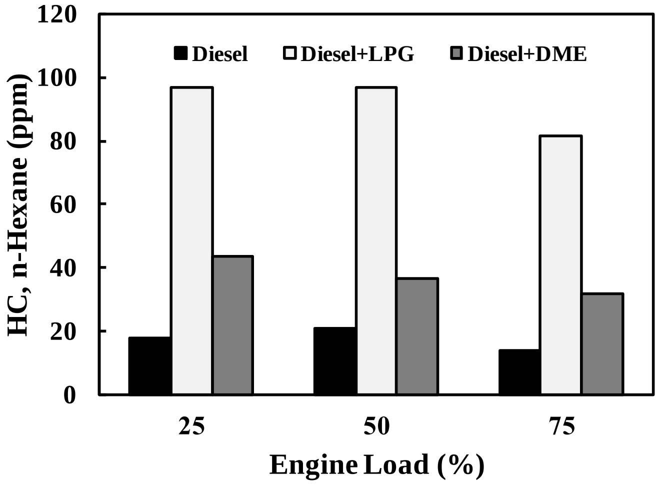

Fig 7 Effect of engine load on hydrocarbon for dual fuel

G. *Smoke emissions*

Fig. 8 shows the variation of smoke emissions under different engine load at 1500 rpm. It can be seen that the smoke emission from DME or LPG operated dual fuel engine reduces significantly than that of diesel operation. At 75% engine load in the DME-operated engine smoke is observed to be 1.6 BSN compared to LPG mode of 1.7 BSN and diesel mode of 2.1 BSN. The high oxygen content of DME fuel (35% by mass) and low carbon to hydrogen ratio (C:H) leads to high flame temperature and diffusive combustion in the combustion chamber [10]. DME fuel combustion tends to improve engine smoke.

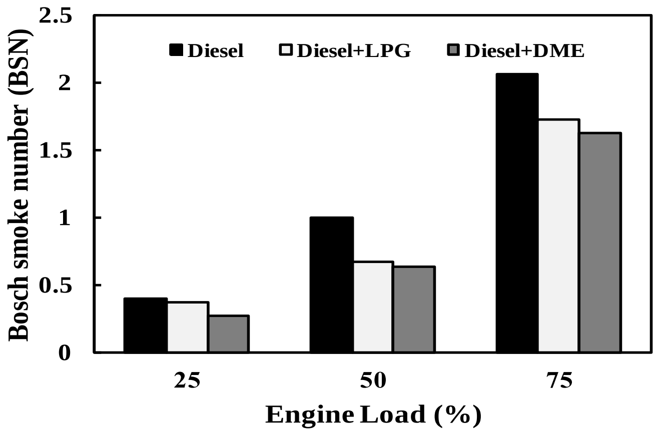

Fig 8 Effect of engine load on smoke emissions for dual fuel

IV. CONCLUSION

The combustion characteristics of dual fuelling with in-cylinder ultra low sulfur diesel (ULSD) fuel and with inlet port injected dimethyl ether (DME) or liquefied petroleum gas (LPG) on engine performances and emissions were comparatively investigated and the main findings can be summarized as follows:

- The advantage of the positive properties of DME and LPG addition led to an improvement of combustion characteristic. The brake thermal efficiency. The maximum thermal efficiency approximately 28.6% and 29.2% for DME and LPG, respectively. In additions, the engine fuel consumption was reduced by operating with DME (297.8 g/kW-hr) and LPG (288 g/kW-hr) additions compare with pure diesel fuel combustion (314.3 g/kW-hr) at 75% of maximum load.
- The presence of DME and LPG leads to reduce CO and hydrocarbon concentrations, as well as smoke emission. However the high NO_X emission has been found, as expected. All these results indicate the characterization and potential of DME + diesel operation for improve combustion in diesel engine.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 3, May 2013

ACKNOWLEDGEMENT

The authors would like to thank Siam-gas and Petrochemicals Public Company Limited THAILAND for their support DME gas in this work.

REFERENCES

[1] Nag. Ahindra, "Biofuels Refining and Performance", McGraw-Hill**,** New York, pp 35, 2008.

[2] Bohn, L. J. M., "DME-A Promising alternative propellant in the Fluorocarbon Crisis", Aerosol Report , 18(3), pp. 70-77, 1979.

[3] Robert Bosch, Automotive Hanbook, 2^{nd} ed. Stuttgart, pp. 82, 1986.

[4] T. Murayama, T. Chikahisa, J. Guo, and M. Miyano, "A Study of a Compression Ignition Methanol Engine with Converted Dimethyl Ether as an Ignition Improver," SAE Trans 922212, vol.101, pp.1210,1992, doi:10.4271/922212.

[5] C. Arcoumanis, C. Bae, R. Crookes, E. Kinoshita, The potential of di-methyl ether (DME) as an alternative fuel for compression-ignition engines: a review Fuel 2007, pp. 1016-1017, doi: 10,1016/j.fuel.2007.06.007.

[6] TA. Semelsberger, RL. Berup, HL. Greene, "Dimethyl ether (DME) as an alternative fuel." J. Power Sources 2006; 156: pp. 497-511.

[7] AM. Namasivayarm, T. Korakianitis, RJ. Crookes, KDH. Bob-Manuel, et al. "Emulsified biodiesel and dimethyl ether as pilot fuel for natural gas fuelled engines." Appl Energy 2010; 87: pp.769-778.

[8] C. Arcoumanis, The second European Auto-Oil program (AOL II). Vol.2. European Commission. Alternative Fuels for Transportation; 2000.

[9] Willard W Pulkrabek, "Engineering Fundamentals of the Internal Combustion Engine." Prentice-hall inc**.** New Jersey, pp. 285, 1997.

[10] M. Lapuerta, F. Martos, and J.M. Herreros, "Effect of engine operating conditions on the size of primary particles composing diesel soot agglomerates". Aerosol Science, 38: pp. 455-466, 2007.

AUTHOR BIOGRAPHY

Somkid Khunaphan, Automotive Engineering Department, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS),King Mongkut's University of Technology North Bangkok, Thailand. **Email address:** somkid_17012520@hotmail.com

Assistant Professor Dr. Kampanart Theinnoi, He obtained his Ph.D from the University of Birmingham(2008) by investigating the impact of diesel fuel properties and diesel engine operation conditions on Ag/Al_2O_3 catalyst HI-SCR activity for reduced NOx emissions. Then he carried out Postdoctoral Research in automotive engineering at the University of Birmingham, Birmingham, UK, prior to returning to the King Mongkut's University of Technology North Bangkok, Thailand as a lecturer in automotive engineering (2010-2013), Assistant Professor in mechanical engineering since April 2013. He has published over 30 papers in journals and conference proceedings in the areas of fuels and fuel treatments, IC engines, combustion and emissions control technologies. His current main interests research covers both fundamentals and industrial applications are in the area of internal combustion engines, alternative fuel exhaust, environmental catalysts, gas fuel reforming and after treatment technology.

Dr. Unalome Wetwatana Hartley, she received her Ph.D. in 2009 from Imperial College London in catalytic reaction engineering. chemical engineering department. She is now a lecturer in chemical and process engineering program at Thai-German Graduate School (TGGS). TGGS is a joint institution established by RWTH Aachen University in Germany and Thai partner KMUTNB, located in Thailand, in order to transfer the RWTH Aachen Model of Graduate industry-oriented Engineering Education, Technology Innovation and Business Development to South East Asia. She has experience in researching on synthesis gas (from biomass, wastes and natural gas) via conventional steam and auto-thermal reforming using packed-bed reactor. Her expertise is recently moving towards the direction of renewable energy, CO2 utilization, photo catalytic engineering, methanol production, DME synthesis, DMC synthesis, pyrolysis and gasification.