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Effects of Diesel Injection Timing on Dual Fuel Diesel Engine with DME Port-Injection

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Abstract

The objective of this experimental study is to explore the possibility to optimize diesel engine operated in dual fuel mode using DME addition (Port-injection) to obtain the merit of HCCI operation. Different diesel injection timing of 16 BTDC (Standard), 18 BTDC (Advanced 2 ºCA), 15 BTDC (Retarded 1 ºCA) and 14 BTDC (Retarded 2 ºCA) of standard injection timing were investigated. DME fuel was injected in the intake manifold at 10%, 20% and 30% by mass of diesel fuel replaced. The engine test was carried out under constant engine speed (1500 rpm). The results found that using 10% DME with -2 ºCA for diesel injection timing was the optimal condition for this experiment. The low DME concentration addition are required retard ignition for simultaneous reduction of NOx-Soot while HC was increased at acceptable level. The result at optimal condition also illustrated a satisfied thermal efficiency that allow researchers to develop better understanding about HCCI operation using DME as secondary fuel by port-injection approach.

Keywords: Di-Methyl Ether (DME), Dual Fuel Operation, Port-Injection, Alternative Fuel
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1. Introduction

Di-Methyl Ether or DME is a promising candidate as an alternative fuel for diesel engines due to many advantages over conventional neat diesel fuel. For instance, soot-less combustion due to the absence of C-C bond, and high cetane number lead to promotes complete combustion in compression ignition (CI) mode, low boiling point which enhances good air-mixing, ease of transportation due to physical properties similar to LPG and DME could be produced by various feedstocks. [1]

DME can be used as main fuel in order to replace neat diesel fuel by mean of direct-injection to the combustion chamber. On the other hand, DME can be injected into the intake port as secondary fuel in dual-fuel mode. [2] According to previous works [2-4], thedirect multiple injection will benefit more from high cetane number and oxygenate component of DME. However, gaseous DME employs low viscosity and is corrosive toward elastic polymer compound which causes leakage problem in the fuel pump for a long term operation. [5]

Port-injection is another interesting method to utilize DME in a conventional diesel engine with minimal modification. [6] The small concentration of gaseous secondary fuel may be injected while primary fuel (e.g. diesel) injection is consequently reduced. [7] This resulted in homogeneous intake charge which combustion process became more homogeneous combustion. In the other word, a homogeneous charge compression ignition (HCCI) was formed. [6]

Introduction of homogeneous charge in conventional diesel engine in dual fuel mode results in simultaneous reduction of NOx and particulate matter (PM) emissions as in HCCI engines. However, diesel engine that operates in dual fuel mode is capable of operating at low load and high load better than HCCI engine. This is due mainly to better control ignition timing and combustion duration by mean of direct-injection (DI) of diesel fuel to initiate the combustion. Whereas, only autoignition initiated by high temperature from compression in HCCI engine which is very difficult to control and operating range is limited to part load condition. [8-9]

The high cetane of DME lead to the combustion phasing toward advanced combustion when high reactivity fuel such as DME is introduced as premixed charge. [10,11] Therefore, it is suggested that diesel injection timing should be retarded to accommodate advance-shifted in-cylinder pressure profile in order to obtain optimum engine performance.

This paper presents the effects of injection timing on performances of diesel engine operated in dual fuel mode using port-injection DME.

2. Experiment apparatus and procedures

Test engine

The experiment was carried out on a Yanmar L100N single cylinder direct-injection diesel engine. The test engine was mounted to a Hofmann D3210 ELZE 1 eddy-current dynamometer as shown in fig.1.

The constant engine speed of 1500±10 rpm was maintained throughout the study with engine load 25%, 50% and 75% of maximum engine output.

A Kistler 6056A pressure transducer was installed at the cylinder head using with Kistler 5018A charge amplifier to record the in-cylinder pressure profiles with in-house customed software.

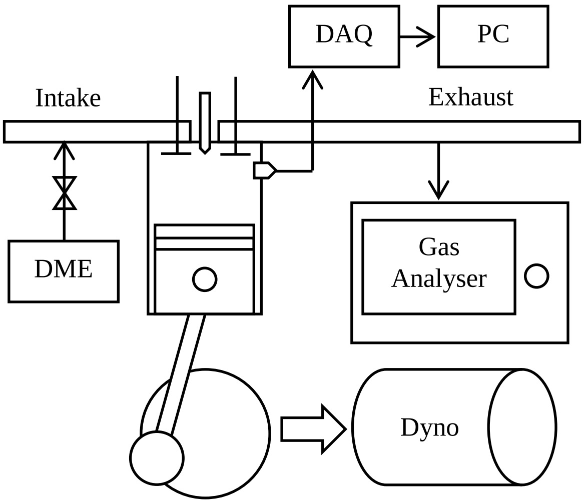

Fig.1 Experiment setup

Fuel system

Diesel was used as primary fuel in dual-fuel mode operation. Diesel injection timing could be adjusted by changing injector pump shim thickness. Injection timing of 16 BTDC (standard injection timing: STD), 18 BTDC (Advanced 2 °CA: +2 °CA), 15 BTDC (Retarded 1 °CA: -1 °CA) and 14 BTDC (Retarded 2 °CA: -2 °CA) were experimented. Fuel specification is presented in table 1.

Table 1 Fuel specifications

Properties	Diesel	DME
Low heat Value (kJ/kg)	46,800	27,600
Cetane number	40-55	≥55
Density in atmosphere (kg/m^3)	836.8	1.97
Boiling point (°C)	180-360	-24.9
Auto ignition temp (°C)	250	235
Enthalpy of evaporisation (kJ/kg)	290	460 @-20(°C)
Modulus of compressibility (N/m^2)	14.86x10^8	6.37x10^8
% wt Oxygen	0	34.8
% wt Carbon	86	52.2
% wt Hydrogen	14	13
Chemical formula	-	CH_3OCH_3

DME was used as secondary fuel. A gas nozzle was installed at approx. 30 cm upstream the intake valve in order to ensure well homogeneous charge between DME and fresh air intake. DME was continuously fed with various flow rate measured by a rotameter. The gas feed system was able to supply up to 30% of DME mass to replace mass of diesel fuel. Brake specific energy consumption (BSEC) was used to compare engine performances in term of energy when different ratio of DME employed. BSEC could be calculated using equation 1.

$$BSEC = \frac{\left[(\dot{m}_{diesel} \times QHV_{diesel}) + (\dot{m}_{DME} \times QHV_{DME}) \right]}{\dot{W}_B} \quad (1)$$

Where,

$\dot{m}_{diesel}$ = diesel mass flow rate (kg/h)
QHV_{diesel} = heating value of diesel (MJ/kg)
$\dot{m}_{DME}$ = DME mass flow rate (kg/h)
QHV_{DME} = heating value of DME (MJ/kg)
W_B = Output work of the engine (kW)

Emission analysers

Partial flow of exhaust gas from the test engine was continuously analysed by a Horiba Mexa 584L which concentration of NO, CO_2, HC and O_2 were monitored. The claimed range and accuracy of exhaust gas analyser is presented in table 2.

Table 2 Claimed range and accuracy of gas analyser

Sensor	Range	Accuracy
NO	0-5,000 ppm vol	25 ppm vol
HC	0-10,000 ppm vol (Hexane equivalent)	3.3 ppm vol
CO	0-10% vol	0.01% vol
CO2	0-20% vol	0.17% vol
O2	0-25% vol	0.01% vol

Engine smoke was measured using a Zexel 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 Smoke Number (SN).

3. Results and discussions

Effects of different DME concentrations addition

The first aspect of this study was to observe the effects on engine performances when different DME portions were introduced. The diesel injection timing was kept under standard value of 16 °CA BTDC. The in-cylinder pressure profile and heat release rate (HRR) in figure 2 reveals that the presence of DME homogeneous charge would lead to a drop of HRR and a slightly shift toward advanced combustion. This was due mainly to autoignition of homogeneous charge in the late compression stroke that accelerated overall combustion process. In this case, DME is considered as reactive agent which advanced combustion was expected.

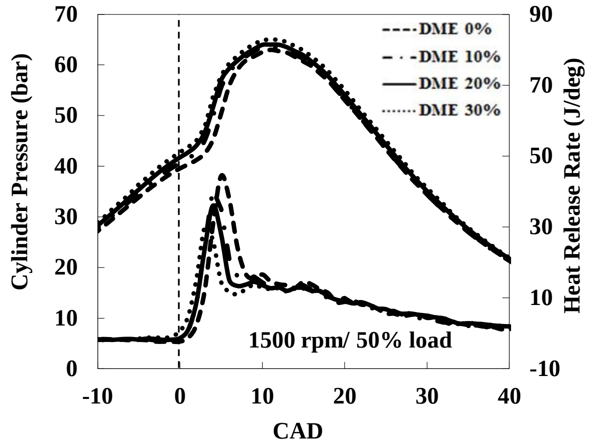

Fig.2 Effects of different DME addition on In-cylinder pressure and HRR profiles

The HRR of all engine conditions with DME injection illustrated a slight shift of the rising curve toward advanced combustion in order to the DME is more reactive intake charge as mentioned in previous work [8]. As DME is fuel with high cetane number which promotes autoignition.

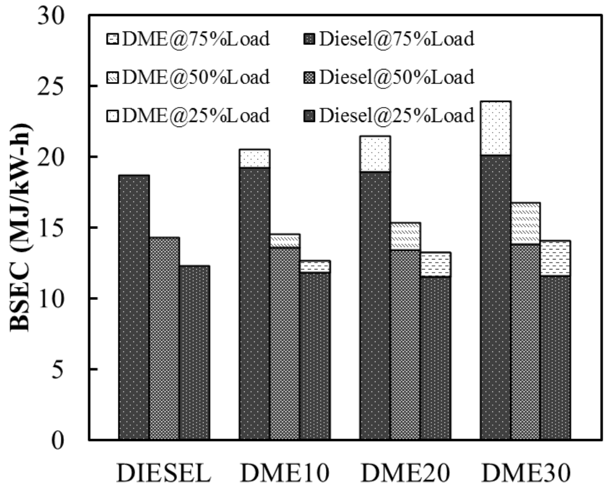

Fig.3 Effects of different DME additions on brake specific energy consumption

The increase of DME injection led to further decrease of HRR which resulted in the increase of brake specific energy consumption (BSEC) as shown in figure 3. In the other word, increasing DME flow rate led to the decrease of thermal efficiency for all engine conditions as shown in figure 4. This might be explained by the increasing of in-cylinder pressure above piston before reaching top dead center which caused more negative work. Thus, reduction of thermal efficiency when DME was the result.

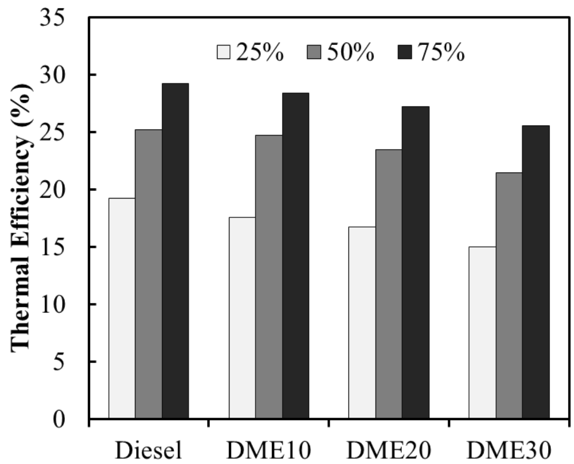

Fig.4 Effects of different DME additions on thermal efficiency

Homogeneous charge by 10% by mass of DME port-injection was able to significantly reduce soot concentration at the entire engine load range as shown in figure 5. As much as 71.25% reduction was realized at medium engine load. This was due mainly to the lowering air-fuel rich region caused by well mixed intake charge. In addition, oxygen content in DME also helped to promote complete combustion which contributed to the decrease of smoke number.

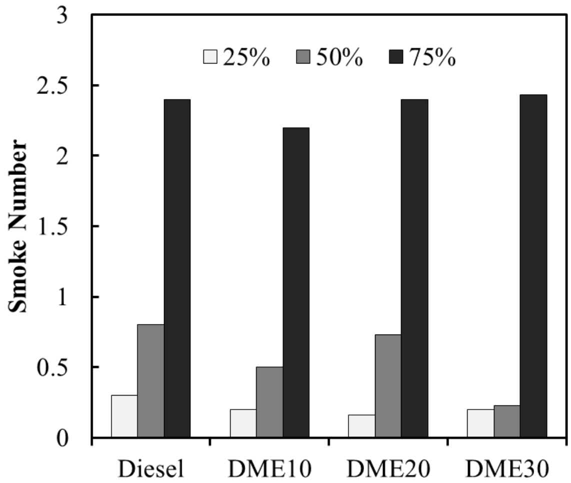

Fig.5 Effects of different DME additions on smoke number

On the other hand, higher portion of DME addition was unable to improve soot reduction at high engine load, but soot concentrations seemed to remain the same level as standard engine operated on pure diesel fuel. As higher DME addition was introduced lead to the HRR began to drop and explained that less rate of heat released and thus, lower the temperature of the combustion process.

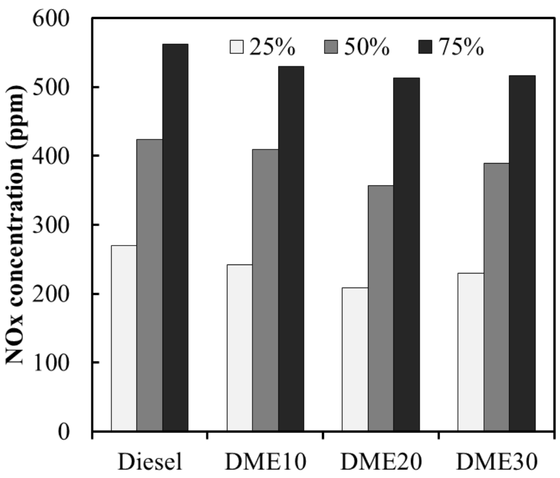

Fig.6 Effects of different DME additions on NO concentration

NO concentration was a function to the HRR as shown in figure 6. Increasing DME flow rate caused NO to drop by absorbing heat from compressed air. Thus, temperature in the combustion chamber are reduced. DME addition up to 20% was able to effectively reduce NO. However, further increase DME concentration has no significant effect to further reduce NO emission.

Meanwhile, HC was directly related to DME addition as shown in figure 7. The trend of HC increase with higher DME additions which are linear and uniform for entire conditions. The majority of unburnt HC was caused by local lean DME-air mixture which was extremely lean and unable to ignition.

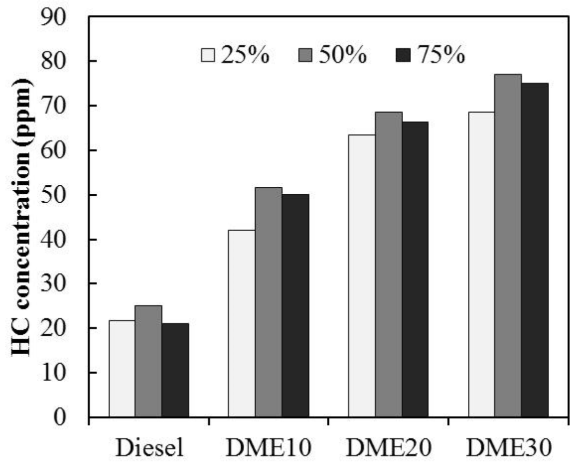

Fig.7 Effects of different DME additions on HC concentration

Overall, engine operation in dual-fuel mode using standard injection timing with 10% DME addition is the optimised operating condition considering thermal efficiency, BSEC and emission levels.

Effects of different diesel injection timing

The other aspect of this study is to observe the effect of different diesel injection timing on engine performances with 10% DME addition. In figure 8 illustrated that the amount of brake specific energy consumption (BSEC) of DME was the same magnitude as DME flow rate was controlled for all engine conditions. Retarded injection timing (-1 °CA and -2 °CA) of diesel fuel led to slightly improvement of BSEC and thus, better thermal efficiency as shown in figure 9.

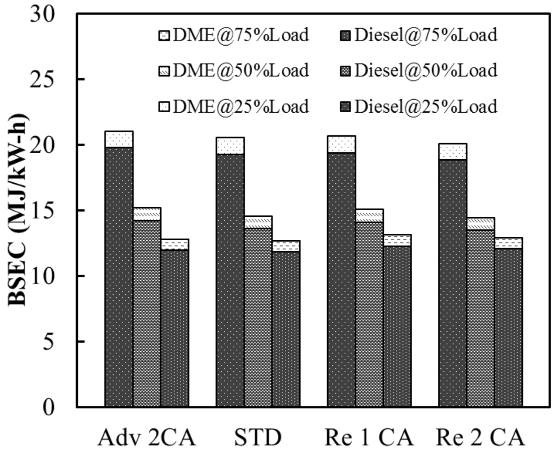

Fig.8 Effects of different injection timing on BSEC

Meanwhile, advanced injection timing (+2 °CA) also resulted in insignificant change to BSEC and thermal efficiency in comparison to standard injection timing.

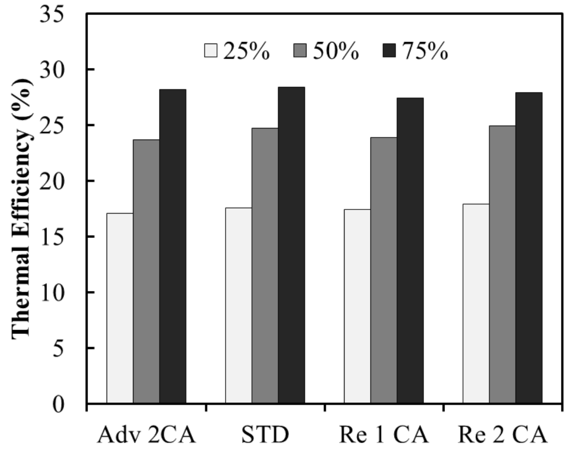

Fig.9 Effects of different injection timing on Thermal efficiency

NO concentration substantially decreased with the retarded injection timing as shown in figure 10. NO decreased as much as 44.47% at 25% load condition with -2 °CA injection timing. The results suggested that retard injection timing lowered HRR due mainly to hot gas in the cylinder had lower dP/dt which is the same as peak pressure. In additions, the piston travelled downward to BTDC and in-cylinder volume increased. The lower dP/dt means slightly rise the temperature and peak temperature within the cylinder which led to suppression of thermal NO.

On the other hand, with advanced injection timing of +2 °CA showed a significant increase of NO concentration at low and medium engine loads while NO slightly increased at high load. This was due mainly to higher rate of in-cylinder pressure built up, thus higher rate of temperature rise and higher in-cylinder temperature.

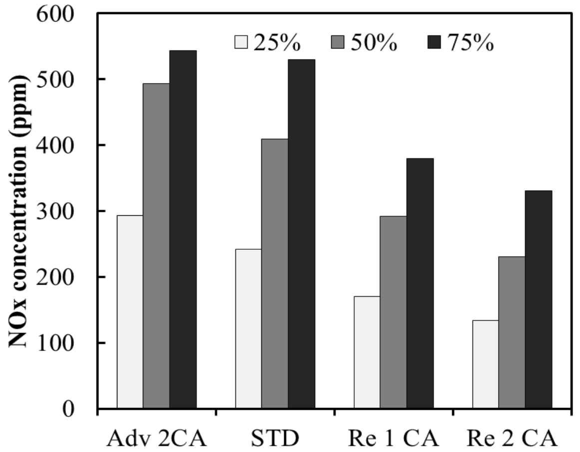

Fig.10 Effects of different injection timing on NO

On the other hand, the amount of HC seemed to be increase for all conditions under difference injection timing. The trend of HC was slightly increased when retarded injection timing for all engine loads when compared to standard injection timing. Further retard the injection timing from -1 °CA to -2 °CA led to slightly increased of HC at low (25%) and medium engine loads (50%). However, HC concentration slightly reduced at high engine load which was due mainly to high temperature and pressure in combustion chamber that promoted HC oxidation.

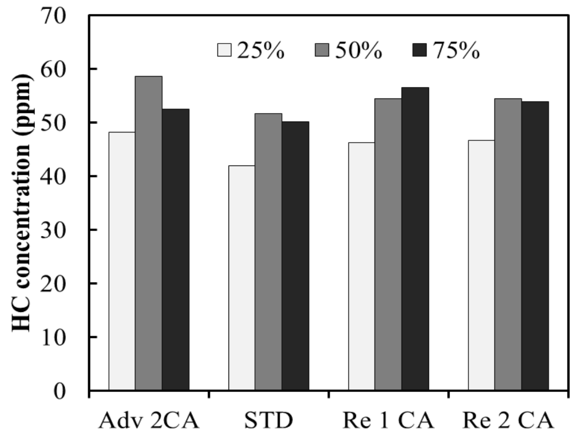

Fig.11 Effects of different injection timing on HC

Retard injection timing further to -2 °CA caused increase smoke number under low and medium load as shown in figure 12. Meanwhile, smoke number was moderately increase from average SN of 2.2 to 2.5 under high engine load with -2 °CA injection timing. This was due mainly to lowered HRR suggested by reduction of NO concentration which carbonaceous soot was unable to complete oxidation in late combustion process. This hypothesis is supported by the information of exhaust gas temperature (EGT) in figure 13 which EGT started to drop when further retard the injection timing to -2 °CA.

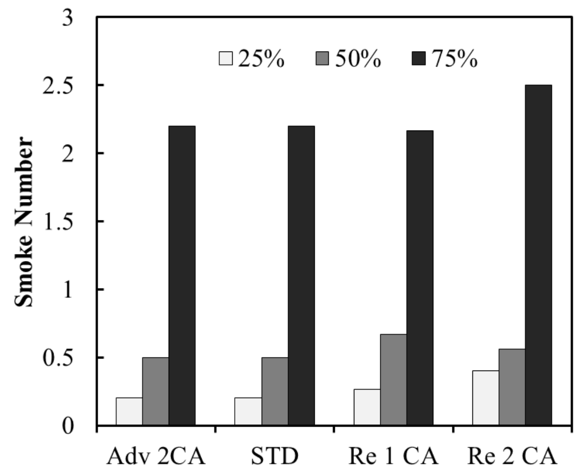

Fig.12 Effects of different injection timing on SN

In this study, smoke number could be seen as the function to exhaust gas temperature. The results suggested that carbonaceous soot was the majority reactant for oxidation process in later expansion stroke rather than hydrocarbon.

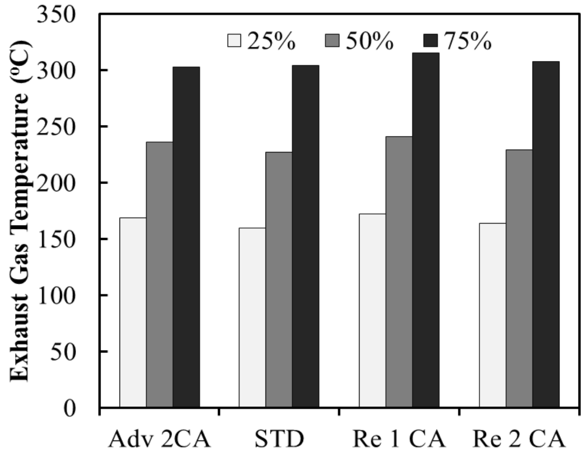

Fig.13 Effects of different injection timing on exhaust gas temperature

4. Conclusions

The effects of diesel injection timing on engine performances with port-injection DME was investigated. According to the results, 10% DME addition was the optimum amount of secondary fuel to create homogeneous charge which effectively controlled combustion characteristic. NOx and soot were improved while keeping acceptable trade-off for energy consumption and CO level. Retardation diesel injection timing to -2 °CA can be improve the NO reduction with slightly soot and HC increases. The results will enable researcher to predict input parameters for HCCI operation for the future works.

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6. References

[1] Kar, A. and Kanoria, M. (2009). Generalized thermo-visco-elastic problem of a spherical shell with three-phase-lag effect, *Applied Mathematical Modelling*, vol.33(8), August 2009, pp. 3287 – 3298.

[2] Kim, M.Y., Yoon, S.H., Ryu, B.W. and Lee, Ch.S. "Combustion and emission characteristics of DME as an alternative fuel for compression ignition engines with a high pressure injection system", Fuel 87, 2008, pp.2779–278

[3] Zhu, Z., Li, D.K., Liu, J., Wei, Y.J. and Liu, S.H. "Investigation on the regulated and unregulated emissions of a DME engine under different injection timing", Applied Thermal Engineering, 35, 2012, pp.9-14

[4] Tsuchiya, T. and Sato, Y., "Development of DME Engine for Heavy-duty Truck," SAE Technical Paper 2006-01-0052, 2006, doi:10.4271/2006-01-0052.

[5] Patil, K.R. and Thipse, S.S. "The potential of DME-Diesel blends as an alternative fuel for CI engines", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 10, October 2012, pp.35-41

[6] Charalambides, A.G. "Homogeneous Charge Compression ignition (HCCI) engines" Advances in Internal Combustion Engines and Fuel Technologies, http://dx.doi.org/10.5772/55807

[7] Ashok, B., Denis Ashok, S. and Ramesh Kumar, C. "LPG diesel dual fuel engine – A critical review", Alexandria Engineering Journal, (2015), 54, pp. 105–126

[8] Killingsworth, N.J., Aceves, S.M., Flowers, D.L., Espinosa-Loza, F. and Krstic, M. "HCCI Engine Combustion-Timing Control: Optimizing Gains and Fuel Consumption Via Extremum Seeking", IEEE Transactions On Control Systems Technology, Vol. 17, No. 6, November 2009, pp. 1350-1361

[9] Mulane, S.A. and Limaye, S.D. "Homogeneous Charge Compression Ignition (HCCI) Engine Technology-A Review", International Journal of Current Engineering and Technology, E-ISSN 2277-4106, P-ISSN 2347-5161, pp. 160-163

[10] Kakaee, A.H., Rahnama, P. and Paykani, A. "Numerical Study of Reactivity Controlled Compression Ignition (RCCI) Combustion in a Heavy-Duty Diesel Engine Using 3D-CFD coupled with Chemical Kinetics", International Journal of Automotive Engineering, Vol.4, Number 3, September, 2014, pp. 792-804

[11] Wattanavichien, K. "Development of a DME fuelled HCCI Engine", The 4th AUN/SEED-Net RC MeAe conference, 2012, January, 10th-11th, HCMUT, Vietnam