Cycle-by-Cycle Variations of DME Homogeneous Charge Compression Ignition Engine

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Abstract

In this paper, the combustion cycle-by-cycle variation of using Di-methyl ether (DME) in an in-house developed homogeneous charge compression ignition (HCCI) engine was investigated. The DME HCCI combustion test was performed at constant speed steady state Wide-Open-Throttle (WOT) at 1200, 1300 and 1400 rpm. In-cylinder-pressures of 120 consecutive combustion cycles for constant speed testing with different settings of control constant equivalence ratio were recorded. Consequently, cycle-by-cycle variations of the DME HCCI combustion were analyzed, and the interdependency between the mixture equivalence ratio and performance parameters were also examined. The results reveal the cycle-by-cycle variations of indicated mean effective pressure (IMEP) are very small the cyclic variations improve with the increase of the DME equivalence ratio and load. The knowledge of cycle-by-cycle of DME-HCCI engine combustion obtained in this research can be used to develop a high stability DME-HCCI engine in a near future.

Keywords: DME, Small Diesel Engine, HCCI Engine, Mass Fraction Burn

1. Introduction

Since the present trend to use alternative fuel for internal combustion engines are increased. The Di-methyl ether (DME), having high Cetane number, low boiling point and low auto ignition temperature, is considered as one of alternative fuels for either compression ignition (CI) engine or homogeneous charge compression ignition engine (HCCI). In order to increase engine's fuel conversion efficiency and lower soot emissions, the HCCI engine must operates with DME-air leaner mixture. The leaner the DME-air mixture, the higher the engine's combustion cyclic variation, that is the main causes of engine unstable operation. Thus this research is aimed to investigate engine combustion's cycle-by-cycle variation of using DME at different setting of control equivalence ratios in an in-house developed HCCI engine. The coefficient of variation in indicated mean effective pressure is used to determine appropriate mixture control for HCCI's engine stable operation.

2. Combustion of DME fuel in HCCI Engine

The combustion characteristic of DME in HCCI engine can be separated into two phases; LTR (low temperature reactions) and HTR (high temperature reactions). The LTR and HTR are found to be associated with formation of formaldehyde and formation of CO and CO_2 respectively [1], [2]. LTR can be considered as a delay period that has some small amount of the energy released. Then, after a period of delay time, HTR (high temperature reaction) is considered as a main combustion in HCCI combustion chamber. Most of combustion's energy is released during HTR period as show in Fig. 1 [1].

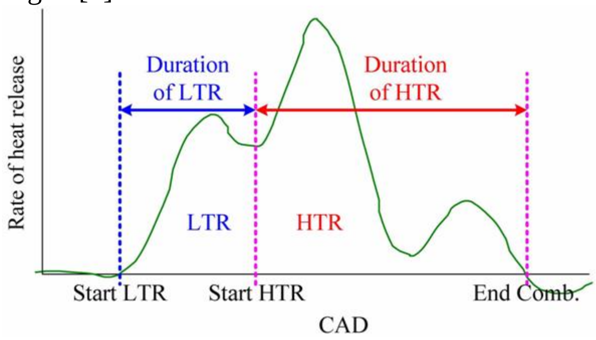

Fig 1. Definitions of LTR and HTR. [1]

3. The properties of DME fuel

DME is an ether gas. Its chemical formula is C_2H_6O or CH_3OCH_3. The DME has oxygen as a bonding component that holds a pairs of single bond with two carbon atoms. The physical properties are similar to LPG (Liquefied Petroleum Gas). The combustion of DME fuel in air has a blue flame. Because the DME fuel has higher Cetane number than diesel fuel, it is suitable to be used as fuel in HCCI engine. The combustion of DME is clean and has less soot than the combustion of petroleum diesel. The Physical and chemical properties of DME are shown in Table. 1. [3], [4]

Table. 1 The Physical and chemical properties of DME [3], [4].

Properties	DME
Chemical formular	CH_3OCH_3
Molecular weight (g/mol)	46.07
C ratio (%wt.)	52.2
H ratio (% wt.)	13
O ratio (% wt.)	34.8
Stoichiometric A/F ratio	9:1
Boiling point (C)	-24.9
Explosion limit in air (vol. %)	3.4 – 17
Auto Ignition temperature (C)	235
Liquid viscosity (cP)	0.15
Lower Heating Value (kJ/kg)	28,430
Latent heat of evaporation (Kj/kg)	460
Vapor pressure @ 20 C (MPa)	0.51
Cetane number	55-60

4. Equations

The coefficient of variation of indicated mean effective pressure, COV_{imep}, is defined as the ratio between the standard deviation of indicated mean effective pressure and the average indicated mean effective pressure, usually expressed in percent, as below. [5].

$$COV_{imep} = \frac{\sigma_{imep}}{imep_{avg}} \times 100 \qquad (1)$$

Where

COV_{imep} = the coefficient of variation in indicated mean effective pressure.

σ_{imep} = standard deviation of imep

$imep_{avg}$ = average of indicated mean effective pressure.

5. Experimental set-up and test procedure

The HCCI engine, used in this research, was developed from a small single cylinder agricultural engine, Kubota model RT140, 4-stroke direct injection diesel engine. The major modifications done were: (1) Decreasing compression ratio (CR) from 18 to 10.3 through modifying piston, (2) Modify engine in-cylinder flow to reduce swirl and promote tumble through modifying intake port and modifying piston crown, (3) fuel supply system was modified to supply homogeneous mixture using LPG regulator, needle control valve and venture mixer, (4) Engine load was controlled by using a butterfly valve. The supply upstream pressure of DME at the venture mixer inlet was set by a needle control valve. A Froude water brake dynamometer with maximum absorption power of 150 kW was used to maintain the variation of loads with respect to variation of mixture strength at different fixed engine speeds. The dynamometer was equipped with a speed sensor, the drive shaft and load scale torque measurement unit. A schematic diagram of the experimental setup is shown in Fig. 2. The HCCI engine technical specifications compared with OEM engine have been shown in Table 2 and the specifications of dynamometer is shown in Table 3 [6], [7], [8].

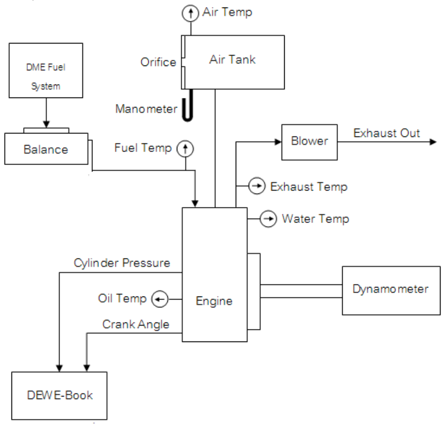

Fig 2 Schematic diagram of the experimental set-up.

Table 2 Specification of DME HCCI engine.

Engine	Kubota	DME-HCCI
Model	RT140	
Type	Single cylinder	
Combustion system	Direct Injection	Compression ignition
Bore x Stroke	94 mm. x 90 mm.	
Displacement volume	709 cc.	
CR	18 : 1	10.3:1
Fuel supply system	Injector, Injection pressure 140 kg/cm2, Piston injection pump	Venturi mixer, Regulator :FEMA model A7000U, needle control valve
Cooling system	Naturally convection radiator	

Table. 3 Specification of dynamometer [7], [8]

Dynamometer	Hydraulic Dynamometer
Manufacturer	Redman Heenan International Company, England
Model	Froude Hydraulic (DPX2)
Resolution	0.1 kg
Balance Arm (L_B)	0.3525 m
Peak Power	150/7500 CV/rpm, (1 CV ≅ 0.986 hp)

DME, in gaseous form, is supplied by a venturi mixer to ensure the well mixing of DME with air before entering to the cylinder. Engine load is controlled by a butterfly valve installed upstream the mixer. The LPG regulator is used with a needle valve to control the supply DME upstream pressure from the DME cylinder.

In this study, the combustion cycle-by-cycle variation of HCCI engine using DME was investigated. The DME HCCI combustion test was performed at constant speed steady state Wide-Open-Throttle (WOT) at 1200, 1300 and 1400 rpm. For each constant speed testing with different settings of control constant equivalence ratio by means of regulating needle valve opening scale, a set of parameters and engine indicating information was measured and recorded. Ambient pressure, humidity, engine speed, power output, exhaust back smoke and temperatures of intake air, DME consumption, cooling water, lubricant oil and exhaust gas were recorded five times for each point. Since the aims of this work is to determine appropriate mixture control for HCCI's engine stable operation, hence, the results of using in-cylinder-pressures of 120 consecutive combustion cycles, measured by AVL piezoelectric pressure transducer model GU12P and Kistler 2613B crank angle encoder that recorded with a high-speed data acquisition, Dewetron DEWE-BOOK5000 [9] is appropriated for the study. The cycle-by-cycle variations of the DME HCCI combustion were analyzed, and the interdependency between the mixture equivalence ratio and performance parameters were also examined. The experimental test matrix is shown in table 4.

Table.4 The experimental matrix

No.	Throttle valve (%)	DME Equivalence ratio	Needle valve openning (%)	Engine speed (RPM)
1	100	0.272	40	1200
2		0.352	50	
3		0.395	60	
4		0.333	50	1300
5		0.373	60	
6		0.415	70	
7		0.313	50	1400
8		0.344	60	
9		0.394	70	

6. Results and Discussion

The in-cylinder-pressures of 120 consecutive combustion cycles of DME HCCI combustion test at constant speed steady state WOT at 1200, 1300 and 1400 rpm are presented in Fig. 3 to Fig.5. The maximum in-cylinder pressure are 60.927 bar at the DME equivalence ratio of 0.395, 69.494 bar at the DME equivalence ratio of 0.415 and 66.201 bar at the DME equivalence ratio is 0.394 at engine speed of 1200, 1300 and 1400 rpm, respectively. The maximum indicated mean effective pressure (IMEPmax) at the engine speed of 1200 rpm is 336.561 kPa at the DME equivalence ratio is 0.395. For the engine speed of 1300 rpm the IMEPmax is 341.59 kPa at the DME equivalence ratio is 0.415 and at the engine speed of 1400 rpm. the IMEPmax is 336.561 kPa at the DME equivalence ratio is 0.394. The result of Pmax and IMEPmax are shown in Figs 3-5 and Table. 5.

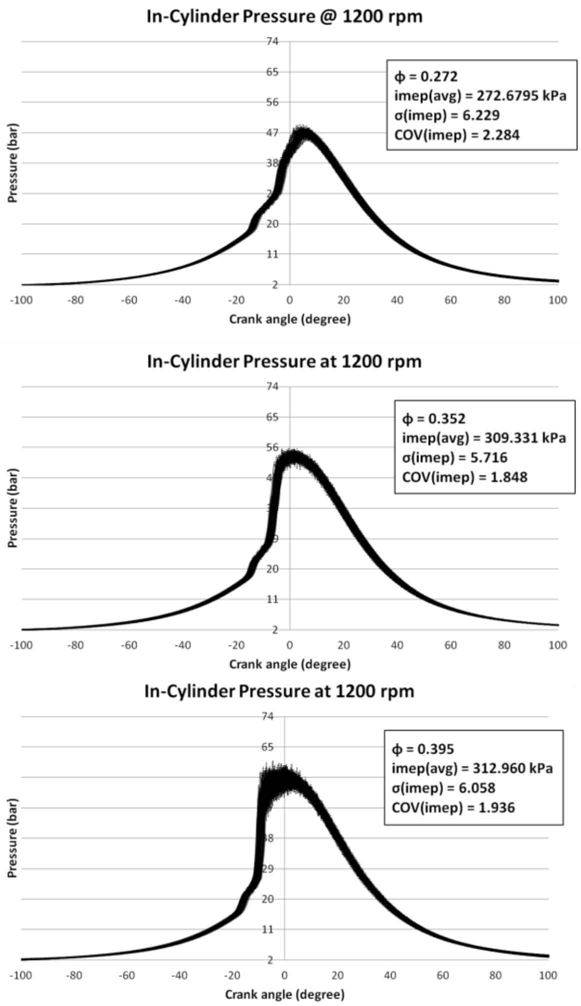

Fig 3. Comparison in in-cylinder pressure vs. crank angle of 120 Cycles at speed of 1200 rpm

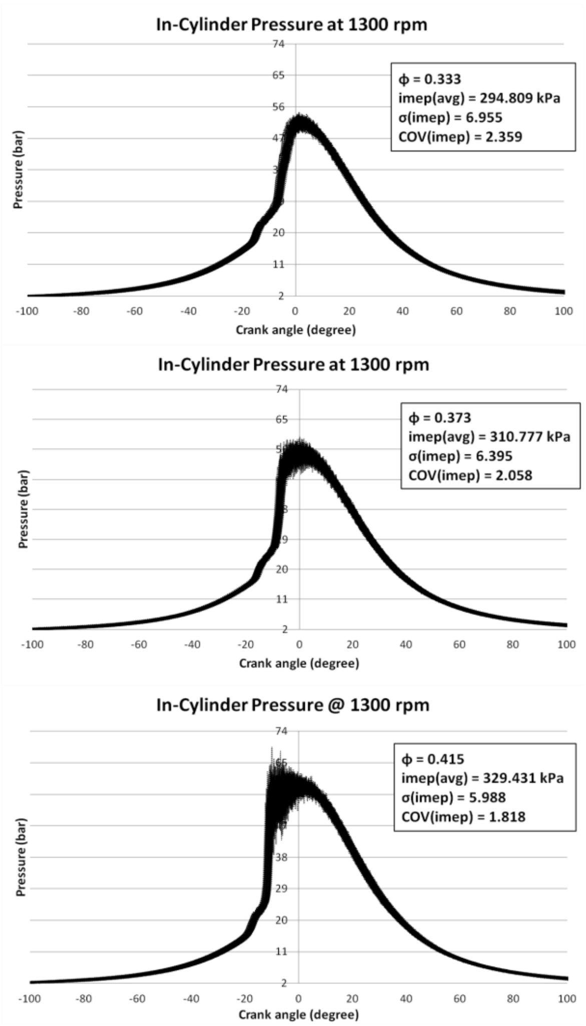

Fig 4. Comparison in in-cylinder pressure vs. crank angle of 120 Cycles at speed of 1300 rpm

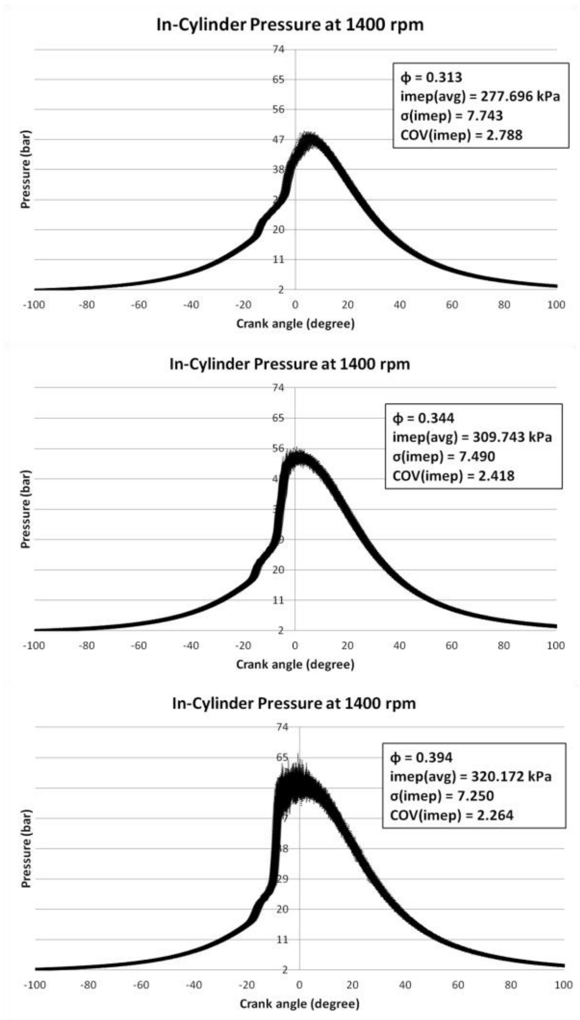

Fig 5. Comparison in in-cylinder pressure vs. crank angle of 120 Cycles at speed of 1400 rpm

Table. 5 Summary of test results

RPM	Φ	P_{max} (bar)	$IMEP_{max}$ (kPa)	COV_{imep}
1200	0.272	49.45	289.71	2.28
	0.352	55.68	321.48	1.85
	0.395	60.93	327.48	1.94
1300	0.333	54.63	310.10	2.36
	0.373	59,75	324.04	2.06
	0.415	69.49	341.59	1.82
1400	0.313	49.55	297.69	2.79
	0.344	56.64	327.11	2.42
	0.394	66.20	336.56	2.26

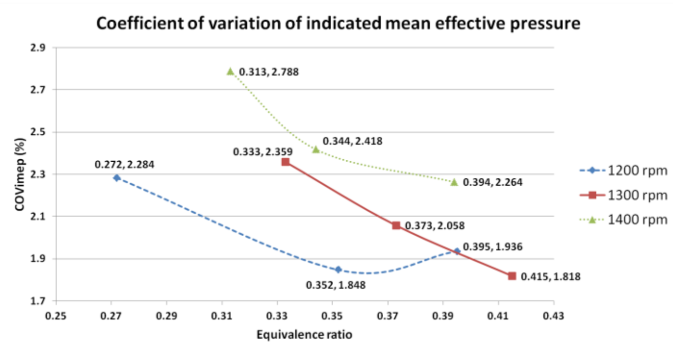

Fig.6 Comparison in COVimep vs equivalence ratio at different engine speed.

The cycle-by-cycle variations of DME HCCI combustion, shown in the form of COVimep, at various speeds as in Fig. 6 are as follows. At the engine speed of 1200 rpm, the minimum COVimep value is 1.848 when the mixture strength is set at the DME equivalence ratio 0.352. At the engine speed of 1300 rpm, the minimum COVimep is 1.818 at the DME equivalence ratio of 0.415 and at the engine speed of 1400 rpm the minimum COVimep is 2.264 at the DME equivalence ratio of 0.394.

The results were found that Pmax and IMEPmax are increased with increasing DME equivalence ratio while the COVimep is decreased at all engine speeds.

7. Conclusions

An experimental investigation of cycle-by-cycle variations of using Di-methyl ether (DME) in an in-house developed homogeneous charge compression ignition (HCCI) engine was investigated. The results reveal that

(a) The maximum in-cylinder pressure were increasing when DME-air equivalence ratio were increasing.
(b) The COV_{imep} are very small and the cyclic variations improve with the increase of the DME equivalence ratio and load.

The knowledge of cycle-by-cycle of DME-HCCI engine combustion obtained in this research can be used to develop a high stability DME-HCCI engine in a near future.

8. Acknowledgement

The authors would like to express special thanks to the Siam Kubota Industry Co., Ltd. for their test engine. Thanks are also extended to all graduate students in the internal combustion engine research laboratory for their contributions during HCCI engine development and conducting these experiments.

9. References

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