Investigation of Dual Injection of Ethanol Fuel in Downsized Spark Ignition Engine

By

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Nizar F. O. Al-Muhsen

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List of Publications

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Conference Proceedings:

1. Nizar F. O. Al-Muhsen, Guang Hong "Effects of EDI on Combustion and Emissions of Small Spark Ignition Engine at Lean Mixture Conditions," Australian Combustion Symposium, the Combustion Institute, Melbourne Australia, 2015.

2. Nizar F. O. Al-Muhsen, Guang Hong "Comparative study on Gasoline-Ethanol Dual Fuel Injection Strategies in a Small Spark Ignition Engine," Australian Combustion Symposium, the Combustion Institute, Melbourne Australia, 2015.

3. Nizar F. O. Al-Muhsen, Jianguo Wang, and Guang Hong "Investigation to Combustion and Emission Characteristics of the Dual Ethanol Injection Spark Ignition Engine," 20th Australasian Fluid Mechanics Conference, Perth Australia, 2016.

4. Nizar F. O. Al-Muhsen, Guang Hong "Effect of Spark Timing on Performance and Emissions of a Small Spark Ignition Engine with Dual Ethanol Fuel Injection," SAE paper, 2017-01-2230, 2017.

5. Nizar F. O. Al-Muhsen, Guang Hong "Engine Performance Affected by Direct Injection Timing in a Dual Ethanol Injection SI Engine," 11th Asia-Pacific Conference on Combustion, Sydney Australia, 2017.

6. Nizar F. O. Al-Muhsen, Guang Hong "A Novel Dual Injection Strategy to Improve the Performance of Ethanol Small Spark Ignition Engine," The 3rd International Scientific Conference for Renewable Energy (ISCRE'2018), 2018, Basrah, IRAQ.

Abstract

Ethanol fuel, as a bioproduct has become a common option to address the issue of energy sustainability. However, the current method of blending ethanol with gasoline does not take the full advantages of ethanol fuel such as its high octane number and great latent heat which potentially allow the increase of the compression ratio and improvement of engine efficiency. Dual injection of ethanol fuel is currently in development and has aimed to make more effective and efficient use of ethanol fuel in SI engines. Experiments were performed on a small single-cylinder four-stroke SI engine equipped with two dual fuel injection systems to investigate both dual injection of ethanol fuel (DualEI) and ethanol port injection plus gasoline direct injection (EPI+GDI).The effect of EPI+GDI on knock mitigation was also investigated.

In the investigation of DualEI, the effects of the ratio of the directly injected (DI) ethanol fuel, spark timing, and DI timing on engine performance, combustion and emissions were analysed. The results demonstrated that the indicated mean effective pressure (IMEP) was improved over all the DI ratios in DualEI engine compared to the original engine with gasoline port injection (GPI) only. This improvement was mainly due to the enhanced combustion quality. However, at higher DI percentages, the over-cooling effect and poor mixture quality adversely affected the combustion performance. The indicated specific nitric oxide emission (ISNO) was reduced by the cooling effect enhanced by ethanol fuel and the DI strategy, but the indicated specific hydrocarbon emission (ISHC) and the indicated specific carbon monoxide emission (ISCO) were raised with the increased DI percentage. As shown by the results for the effect of spark timing, the greatest IMEP and thermal efficiency occurred at spark timing around 30 CAD bTDC at the light load and 23 CAD bTDC at the medium load, which was identified to be the MBT spark timing. The IMEP was increased and the combustion duration was shortened when the spark timing was advanced from 15 CAD bTDC to the MBT timings.

The effect of DI timing associated with spark timing was also investigated. Results showed that the early DI timing enhanced the DualEI engine performance. The variation of IMEP with DI timing was not significant either with early DI timing or in most of the tested conditions with late DI timing. However, the results showed different effects of early and late DI timings associated with the spark timing on engine emissions. With late

DI timing, the engine emissions of ISCO and ISNO increased with the advance of late DI timing and spark timing. With early DI timing, the engine emissions increased with the advance of spark timing. However, the variation of engine emissions with early DI timing was greater than that with late DI timing, showing more unstable combustion.

In the investigation of EPI+GDI, the IMEP did not increase obviously with the increased ratio of EPI. However, the indicated thermal efficiency increased with the increased ratio of EPI because the total heating value of the fuels reduced with the increase of EPI. This was mainly attributed to the enhanced combustion process as the initial and major combustion durations were shortened with the increased ratio of EPI. This also explained why the coefficient of variation of the IMEP reduced with the increased ratio of EPI. As a consequence of improved combustion, the ISCO and ISHC emissions decreased with the increased ratio of EPI. However, the ISNO was increased possibly due to the average combustion temperature increased with and the oxygen added by the increased of EPI.

The EPI+GDI effectively mitigated the engine knock and permitted more advanced spark timing. Results showed that every 10% increment (by volume) of EPI permitted about 2.0 CAD advance of knock limit spark timing. When the EPI ratio was 30% and over, the engine knock was entirely suppressed. The knock intensity was decreased with the increased ratio of EPI until the engine knock was completely suppressed when EPI was increased to 30%.

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Nomenclature and Abbreviation:

Acronyms

aTDC	after top dead centre
bTDC	before top dead centre
CAD	crank angle degree
CR	engine compression ratio
DFI	direct fuel injection
DI	direct injection
DualEI	ethanol dual-injection
EDI+GPI	ethanol direct injection plus Gasoline port injection
EPI	ethanol port injection
EVO	exhaust valve opened
EVC	exhaust valve closed
GDI	gasoline direct injection
GDI+EPI	gasoline direct injection plus ethanol port injection
H/C	hydrogen to carbon ratio
HRR	heat release rate (J/CAD)
IC engines	internal combustion engines
IMEP	indicated mean effective pressure
ISCO	indicated specific carbon monoxide
ISFC	indicated specific fuel consumption
ISHC	indicated specific hydrocarbon
ISNO	indicated specific nitric oxide
IVC	intake valve closed
IVO	intake valve opened
KI	knock intensity
KLST	knock limit spark timing
MBT	the spark timing for maximum brake torque
MFB	mass fraction burnt
MPFI	multipoint port fuel injection
O/C	oxygen to carbon ratio
PFI	port fuel injection
PI	port injection

RON	research octane number
SI	spark ignition
TDC	top dead centre

Symbols

CA10-90%	the major combustion duration (CAD)
CA0-10%	the minor combustion duration (CAD)
CA50	the combustion phase when 50% of the fuel is burnt (CAD aTDC)
COV_{IMEP}	the coefficient of variation of IMEP
θ	Instantaneous crank angle degree (CAD)
θ_{Pmax}	the phase of peak pressure (CAD aTDC)
γ	specific heat capacity
λ	stoichiometric air/fuel ratio
σ_{IMEP}	the standard deviation in IMEP
t	time in msec
DIT'YY'	direct injection timing of YY CAD bTDC
E'XX'	XX% ethanol by volume e.g. E39 is 39% ethanol via port injection plus 61% gasoline via gasoline direct injection
IP	Indicated power (W, kW)
m	Mass (kg)
$\dot{m}_{air}$ *and* $\dot{m}_{air}$	air and fuel mass flow rates (kg/sec)
μ_m	Micrometer
n	polytropic index
$\eta_{Ind.}$	indicated thermal efficiency (%)
$\eta_{Vol.}$	engine volumetric efficiency (%)
ρ_{air}	air density (kg/m^3)
P	pressure (kPa, bar)
P_{θ}	the instantaneous pressure at (CAD)
P_{max}	maximum cylinder pressure (kPa, bar)

$Q_{HV,i}$	higher heating value of species (*i*) (MJ/kg)
ST'XX'	spark timing of XX (CAD bTDC)
T	Temperature (°C, K)
T_w	cylinder wall temperature (°C, K)
V	cylinder volume (m^3)
V_d	displacement volume (m^3)
V_c	clearance volume (m^3)
W_i	indicated work (J, kJ)
χ_i	the mole fraction of species