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Experimental investigation on combustion and emission of CI engine fueled with gasoline-biodiesel blends in early injection HCCI mode

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Abstract

The experimental investigation of combustion and emission of CI engines fueled with gasoline and biodiesel blends was conducted in this study. The study was conducted using a single-cylinder direct-injection diesel engine fueled with 5% biodiesel proportion in gasoline fuel blends compared with 100% neat diesel fuel. A HCCI with early direct injection was applied in this study. Some initial control parameters such as intake temperature, EGR rate and intake pressure were also adjusted to investigate their influences on combustion and emissions of this CI engine. It is found that gasoline-biodiesel blends with HCCI combustion mode and initial engine parameters especially intake boosting rate takes effect on the improvement of combustion characteristics which is closely tied to HC, CO and NOx emissions, respectively.

Keywords: HCCI, Emission, Gasoline, Biodiesel, EGR

1. Introduction

Compression ignition (CI) engines have higher thermal efficiency compared to SI engines. One of the advantages of CI engines over SI engines is that CI engine do not suffer from knocking at high loads. Therefore, CI engines can have higher ratios compared to spark ignition (SI) engine. In CI engines only air is compressed, rather than a mixture of fuel and air, which brings the performance closer to the ideal cycle efficiency. However, CI engines fueled with diesel engine usually produce high emissions, especially nitrogen oxide (NOx) and soot/smoke/particulate matter, which are difficult to control through subsequent treatments.

The higher interest on CI engines than SI engines due to its higher efficiency lead to the unbalance supply and demand between diesel and gasoline fuel in several countries. Furthermore, the more strict limitations of vehicle emission regulation especially for CI engines with diesel fuel stimulate many researchers to explore the utilization of low volatile fuels, such as gasoline and alternative biofuels for CI engines which can obtain high efficiency, but produce lower emissions or so called low temperature combustion (LTC).

Recently, several studies have shown that gasoline and some other fuels with low cetane number and higher volatility are potentially advantages for low temperature combustion(Kalghatgi 2014)(Kalghatgi et al. 2006). Blending gasoline fuel with certain percent of biodiesel is the one way to obtain the good combustion and emissions results. Biodiesel, which is made from various renewable resources, is known to be very suitable as a sustainable alternative fuel for CI engines(Bae & Kim 2017)(Tesfa et al. 2013). Furthermore, biodiesel has proven to have high advantages in reducing engine soot emissions(Cordiner et al. 2016)(Rakopoulos et al. 2008), because the presence of oxygen in the biodiesel plays a significant role in reducing soot formation during combustion(Wang et al. 2016).

Previous studies have presented detailed analysis and discussion of the combustion and emission characteristics fueled with gasoline biodiesel blends using direct injection gasoline compression ignition (GCI) concept(Putrasari & Lim 2017)(Adams et al. 2013). However, the combustion and emission characteristics of CI engines are also influenced by various other factors, such as fuel injection strategy and its combustion modes. The HCCI engine mode is promising method to obtain an appropriate technology with its own characteristics of the low emissions of the SI engine and the high efficiency of the CI engine (Yao et al. 2009). The HCCI engine is one of methods that potentially to achieve an advanced LTC, which possible to produce low particulate matter (PM) and nitrogen oxides (NOx) emissions to replace conventional diesel engine combustion(Krishnan et al. 2016).

The objective of this study was to determine the effects of early injection HCCI mode on the combustion and emissions of a CI engine fueled with gasoline-biodiesel blends. The analysis of the combustion characteristics of cylinder pressure and emission characteristics are discussed in this study.

2. Methodology

A single-cylinder, water-cooled, naturally aspirated, 4-stroke diesel engine with 498 cm^3 of displacement and 4-valve SOHC was used to carry out the engine tests. The engine specification data is given in Table 1. The engine was coupled with a 57 kW Dynamometer Elin AVL Puma engine test system (MCA325MO2. An Autonics E40S8-1800-3-T-24 encoder and Kistler 6056A pressure transducer combined with a Kistler 5018 amplifier were installed on the engine and connected to a Dewetron DEWE-800-CA combustion analyzer. A Bosch 7-hole injector was used to deliver the fuel into the engine combustion chamber. The injector was controlled using a Zenobalti multi-stage injection engine controller (ZB-8035) combined with a common rail solenoid injector peak and hold driver (ZB-5100) and encoder interfacing box (ZB-100) to adjust the injection timing and duration. A schematic diagram of the test engine and measurement setup is presented in Figure 1.

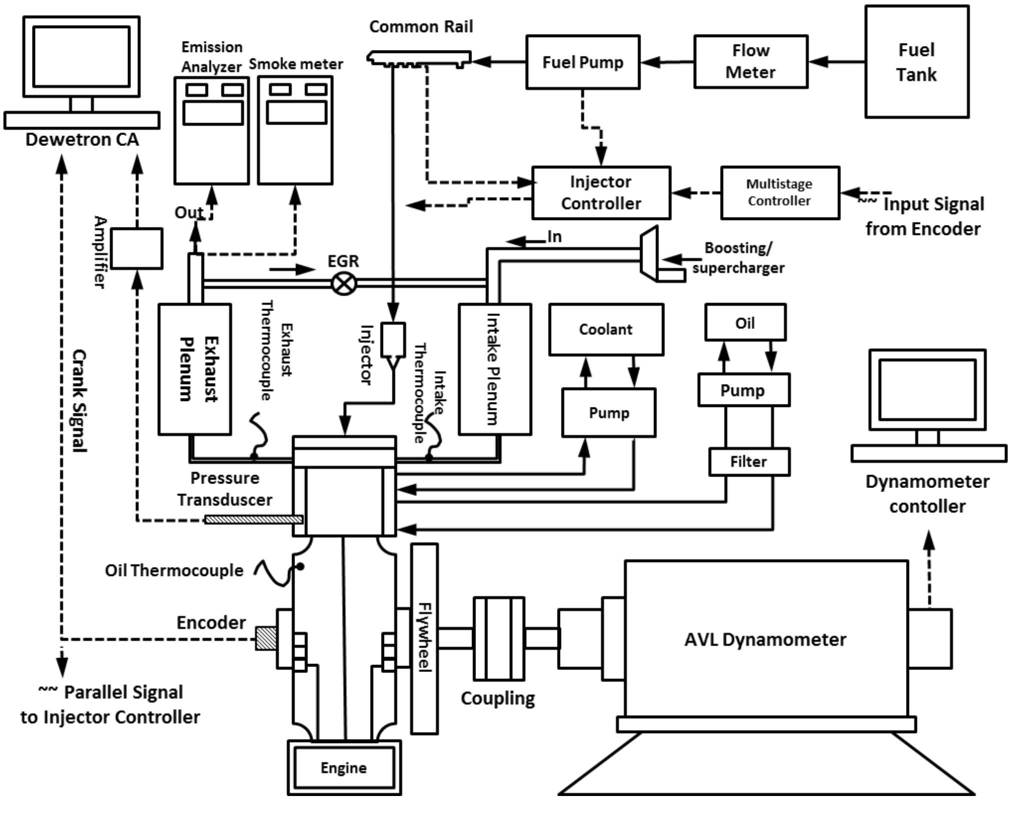

Fig. 1: Schematic diagram of test engine

The fuels utilized in this study were commercial gasoline (GB00) and diesel (D100) and pure soya bean biodiesel (B100). Biodiesel and gasoline were then mixed to make a gasoline-biodiesel blend. The concentration of biodiesel in the blend was 5% by volume, and the blend was referred to as GB05. The gasoline-biodiesel blend was prepared through a mixing/shaking process for approximately 2 to 10 minutes to obtain homogeneity. The fuel blending process in this study was performed immediately before the experiment was conducted to minimize the fuel separation stratification phenomenon. The physical properties of gasoline, diesel, biodiesel, and GB05 from laboratory tests based on international standards are presented in Table 2[30].

Table 1: Engine specification

Engine Parameters	Value
Displacement	498 cm3
Bore	83 mm
Stroke	92 mm
Compression Ratio	19.5
Con. Rod Length	145.8 mm
Crank Radius	43.74 mm
Valve System	SOHC 4 valve
Fuel System	Electronic Common Rail

Table 2: Physical properties of fuels

Test item	Unit	Test method	Gasoline	GB05	B100	Diesel
Heating value	MJ/kg	ASTM D240:2009	45.86	45.32	39.79	45.93
Kinematic Viscosity (40 ºC)	mm^2/s	ISO 3104:2008	0.735	-	4.229	2.798
Lubricity	mm	ISO 12156-1:2012	548	290	189	238
Cloud Point	ºC	ISO 3015:2008	-57	-37	3	-5
Pour Point	ºC	ASTM D6749:2002	-57	-57	1	-9
Density (15 ºC)	kg/m^3	ISO 12185:2003	712.7	722.3	882.3	826.3

The engine was operated at 1200 rpm, with an injection pressure of 70 MPa and multiple injections, comprised of the pilot injection at 100 ºC A BTDC for approximately 500 µs, followed by the main injection at 20 ºC A BTDC for approximately 500 µs. The initial parameters of intake temperature, oil temperature, and coolant temperature were maintained at 85 ºC, 75 ºC, and 65 ºC, respectively. Hot EGR was applied in this study from 0% to 50% of flow rate. Boosting pressure 0.1 MPa and 0.12 MPa were also applied in the intake manifold. The engine operating parameters and injection strategies are presented in Table 3. The in-cylinder pressure data was recorded for 100 engine cycles. The emissions of unburned total hydrocarbon, carbon monoxide, and NOx were measured using a Horiba MEXA-7100DEGR.

Table 3: Engine operating parameters

Operating Parameters	D100	GB05
Speed (rpm)	1200	1200
Inj. Pressure (MPa)	70	70
Inj. Timing (ºCA BTDC)	110 and 40	110 and 40
Inj. Duration (µs)	500 and 500	500 and 500
Total Inj. Quantity (mg)	10.28	14.72
T in (ºC)	85	85
T oil (ºC)	75	75
T coolant (ºC)	65	65
EGR (%)	0, 20 and 50	0, 20 and 50
Intake pressure (MPa)	0.1 and 0.12	0.1 and 0.12

3. Results and discussion

In this study, some parameters are kept constant. The engine speed is 1200rpm and the compression ratio is 19.5. The inlet air temperature, oil temperature and coolant temperature were kept at 85 ºC, 75 ºC and 65 ºC, respectively. Pilot injection timing was set at 110 ºCA with 500 µs duration and main injection at 20 ºCA with same duration 500 µs. Variable parameters are D100 and GB05, EGR rate and boosting pressures. Commonly these variable parameters affect to the combustion and emission of HCCI engines.

a. Effects of fuels properties on engine combustion and emissions

Figure 2 shows the in-cylinder pressure of HCCI engine fueled with D100 and GB05. The same injection timing and duration between D100 and GB05 not guaranteed that the injection amount of fuel will be the same. The injection amount of D100 is 10.28 mg/cycle and GB05 is 14.72 mg/cycle. The higher injection amount of GB05 due to the lower density approximately 722.3 kg/m^3 compared to D100 approximately 826.3 kg/m^3. The higher amount of injected fuel leads to the higher in-cylinder pressure caused by the nearly similar value of heating value (LHV) of D100 and GB05 approximately 45 MJ/kg.

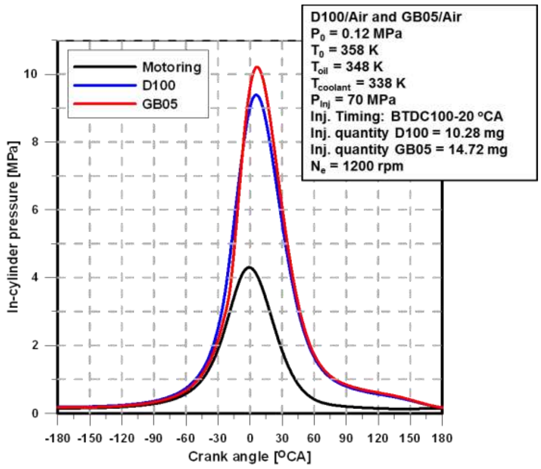

Fig. 2: Effects of fuel properties on in-cylinder pressure of HCCI engine

Figure 3 shows the THC, CO and NOx emissions of HCCI engine fueled with D100 and GB05. Meanwhile, Figure 4 shows the smoke emission of HCCI engine fueled with D100 and GB05. The lower density of GB05 leads to the higher amount of injected fuel then finally the higher emissions of THC, CO, NOx and smoke. The THC and CO emission is related to the quality of combustion inside the chamber. The higher THC and CO emission indicated the higher inefficiency of combustion. The NOx emission is related to the temperature trace of combustion inside the chamber. The NOx emission will be higher when the in-cylinder temperature more than 1800 K. However, the oxygenated fuel such as biodiesel which is contained in GB05 usually produce higher NOx emission compared to the conventional fossil fuel. The trend of smoke emission normally, is contrary to NOx emission. When the NOx emission higher the smoke emission will be lower. However, as already mentioned that the containing of higher oxygen in the fuel lead to the higher NOx and the incomplete combustion lead to the higher smoke emission. The early pilot injection timing method expected to promote the homogeneity of mixing process the resulted the improvement of complete combustion of GB05. However, D100 indicated better combustion results by lower THC, CO and NOx even smoke emission.

b. Effects of EGR rate and GB05 on engine combustion and emissions

Figure 5 shows the in-cylinder pressure of HCCI engine fueled with GB05 running with various EGR rate from 0% to 50%. The EGR20 resulted highest in-cylinder pressure. The higher EGR rate for heavy EGR rate condition (50%) the engine is almost stall indicated by the lower in-cylinder pressure which is almost similar with motoring in-cylinder pressure trace. Figure 6 shows the effects of EGR rate and GB05 on THC, CO and NOx emissions of HCCI engine. Meanwhile, Figure 7 shows the effects of EGR rate and GB05 on smoke emissions of HCCI engine. The increasing of EGR rate does not effect to the amount of THC and CO emission. However, the higher EGR rate the lower NOx emission. Contrary, the higher EGR rate the higher smoke emission.

c. Effects of intake boosting rate and GB05 on engine combustion and emissions

Figure 8 shows the in-cylinder pressure of HCCI engine fueled with GB05 running with various intakes boosting rate. The intake boosting 0.12 MPa resulted higher in-cylinder pressure. The higher boosting rate leads to the higher in-cylinder pressure. Figure 9 shows the effects of boosting rate and GB05 on THC, CO and NOx emissions of HCCI engine. Meanwhile, Figure 10 shows the effects of boosting rate and GB05 on smoke emissions of HCCI engine. The increasing of boosting rate does not effect to the amount of THC and CO emission. However, small amount of NOx reduction happened when the higher boosting rate was applied. The higher boosting rate also affected to the lower smoke emission.

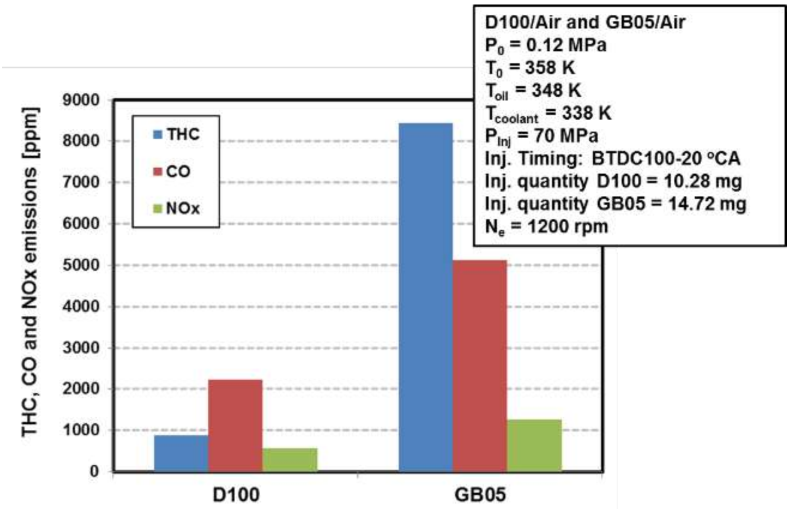

Fig. 3: Effects of fuel properties on THC, CO and NOx emissions of HCCI engine

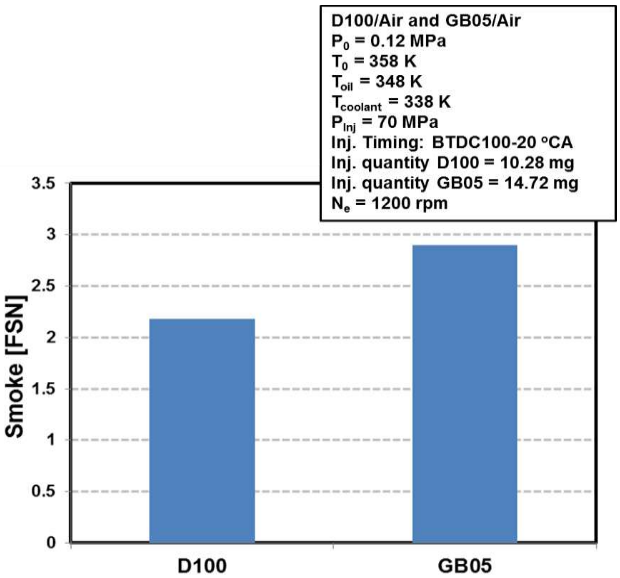

Fig. 4: Effects of fuel properties on smoke emissions of HCCI engine

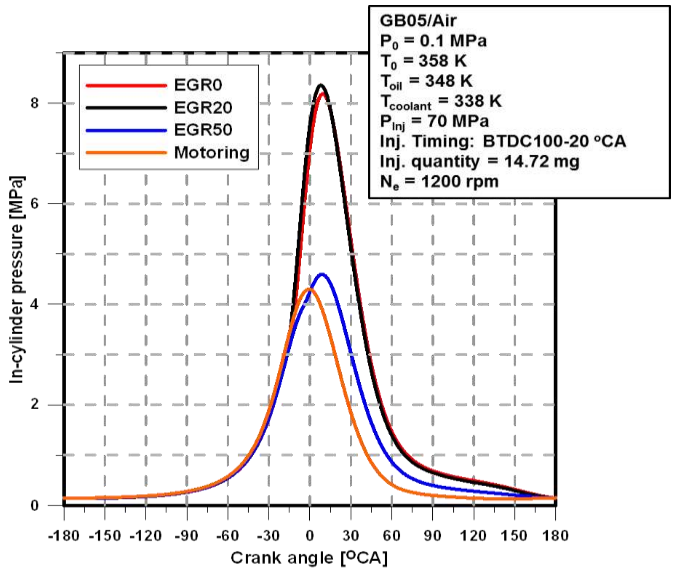

Fig. 5: In-cylinder pressure of GB05 HCCI engine running on various EGR rate

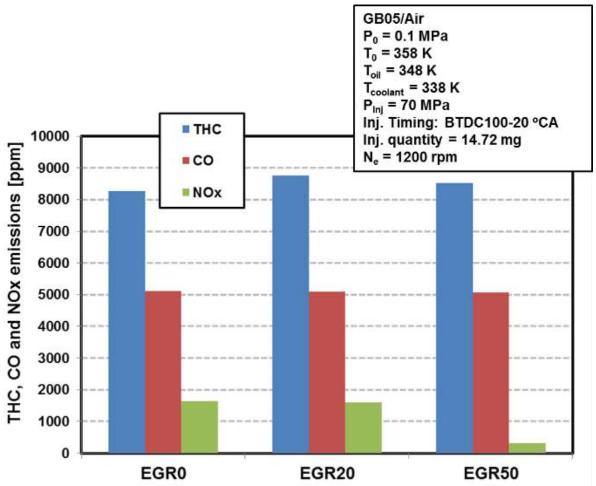

Fig. 6: Effects of EGR rate and GB05 on THC, CO and NOx emissions of HCCI engine

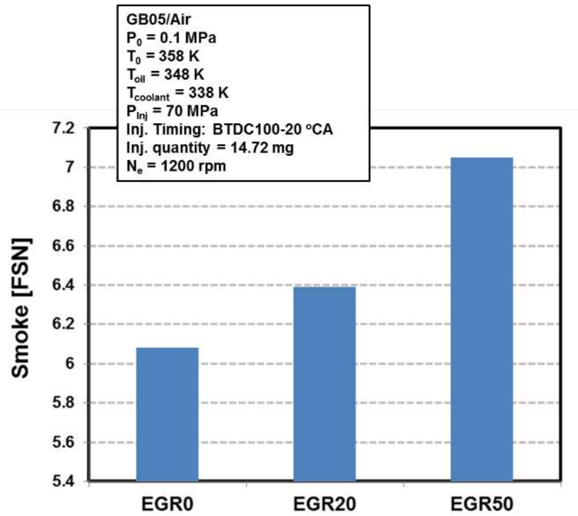

Fig. 7: Effects of EGR rate and GB05 on smoke emissions of HCCI engine

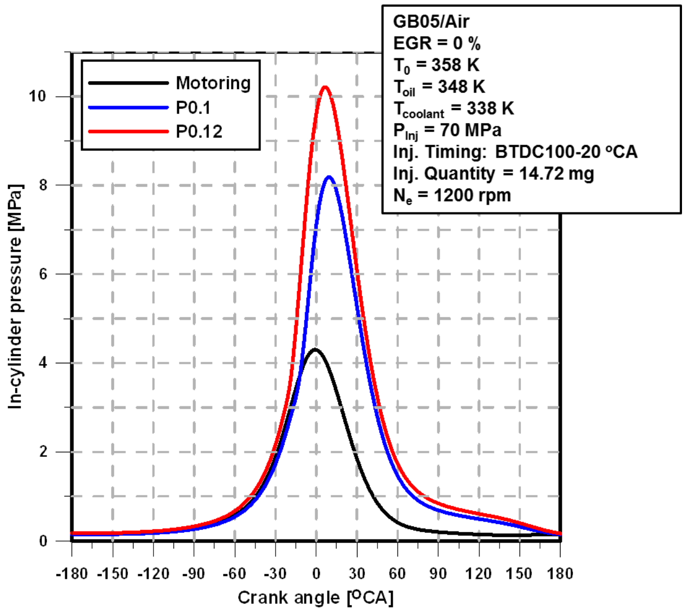

Fig. 8: In-cylinder pressure of GB05 HCCI engine running on various intakes boosting rate

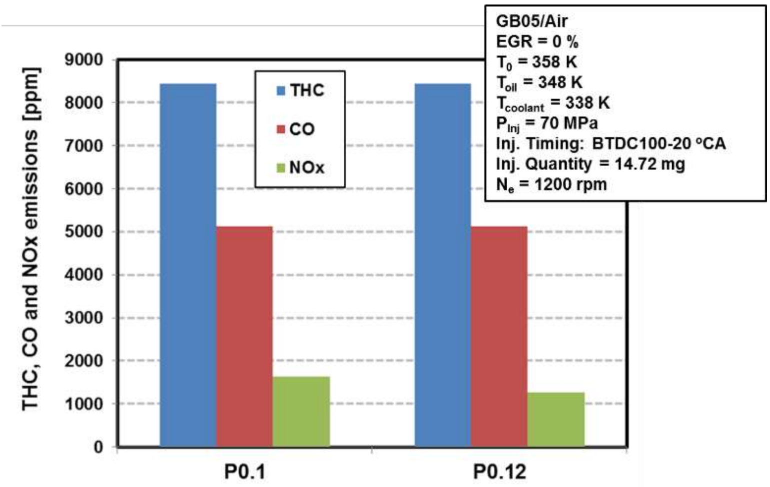

Fig. 9: Effects of intake boosting rate and GB05 on THC, CO and NOx emissions of HCCI engine

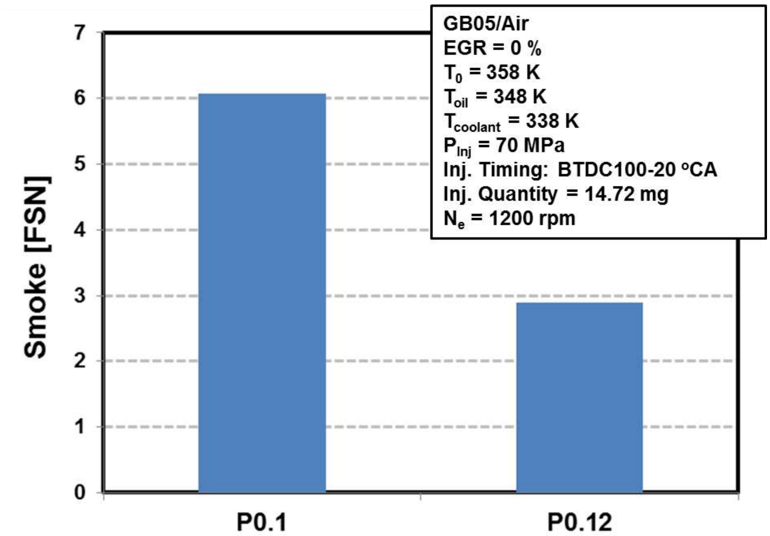

Fig. 10: Effects of intake boosting rate and GB05 on smoke emissions of HCCI engine

4. Conclusion

A study was conducted to investigate of combustion and emission of CI engines fueled with gasoline and biodiesel blends in early injection HCCI mode. Based on the results, the following general conclusions can be drawn:

- The GB05 has higher in-cylinder pressure due to the higher amount of injected fuel, which is nearly similar value of heating value (LHV) of GB05 and D100 approximately 45 MJ/kg. The trend of smoke emission normally, is contrary to NOx emission. When the NOx emission higher the smoke emission will be lower. However, as already mentioned that the containing of higher oxygen in the GB05 lead to the higher NOx and the incomplete combustion lead to the higher smoke emission.
- Heavy EGR rate condition (50%) the engine is almost stalling. The increasing of EGR rate does not effect to the amount of THC and CO emission. However, the higher EGR rate the lower NOx emission and higher smoke emission.
- Higher boosting rate leads to the higher in-cylinder pressure The increasing of boosting rate does not effect to the amount of THC and CO emission. However, small amount of NOx reduction happened when the higher boosting rate was applied. The higher boosting rate also affected to the lower smoke emission.

5. Nomenclature

B	Biodiesel
B100	100% biodiesel
BTDC	Before top dead center
CA	Crank angle

CI	Compression ignition
D100	100% diesel
EGR	Exhaust gas recirculation
G	Gasoline
GB	Gasoline-biodiesel
GB00	100% gasoline
GB05	Blend of 95% gasoline and 5% biodiesel
HCCI	Homogeneous charge compression ignition
LTC	Low temperature combustion
MPa	Mega Pascal
Ne	Engine speed
NOx	Nitrogen oxides
TDC	Top dead center
THC	Total hydrocarbons

6. Acknowledgements

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