Preliminary study on the combustion and emission in a direct injection LPG spark ignition engine

July 28, 2010

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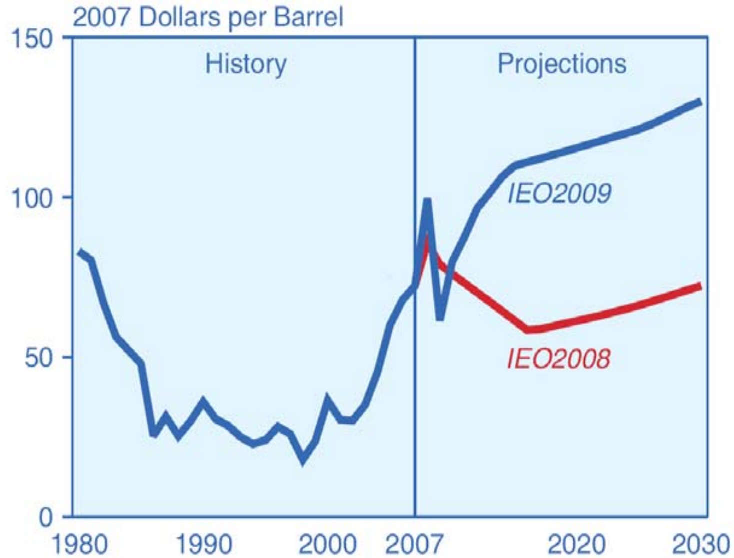
Background(I)

- **Gaseous emissions and CO_2 regulations are significantly more stringent than before**
- **Concerning about depletion of conventional fuels increases**

Low carbon fuel and advanced engine technology are required

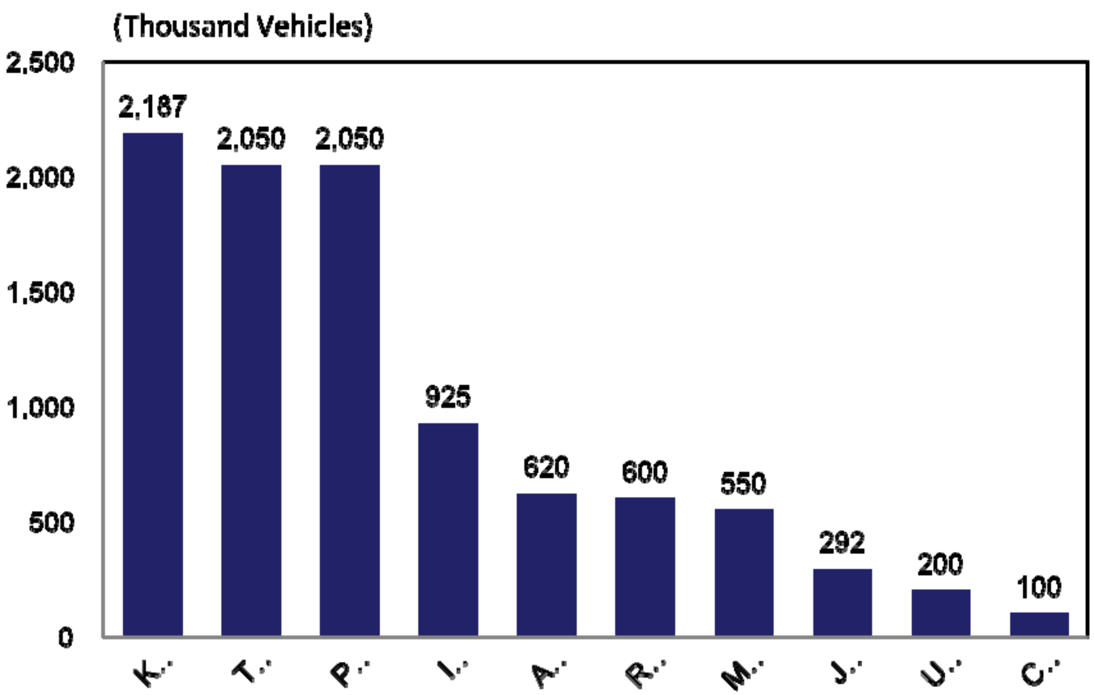
LPG Direct Injection Spark Ignition



Sources; EIA

Background(II)

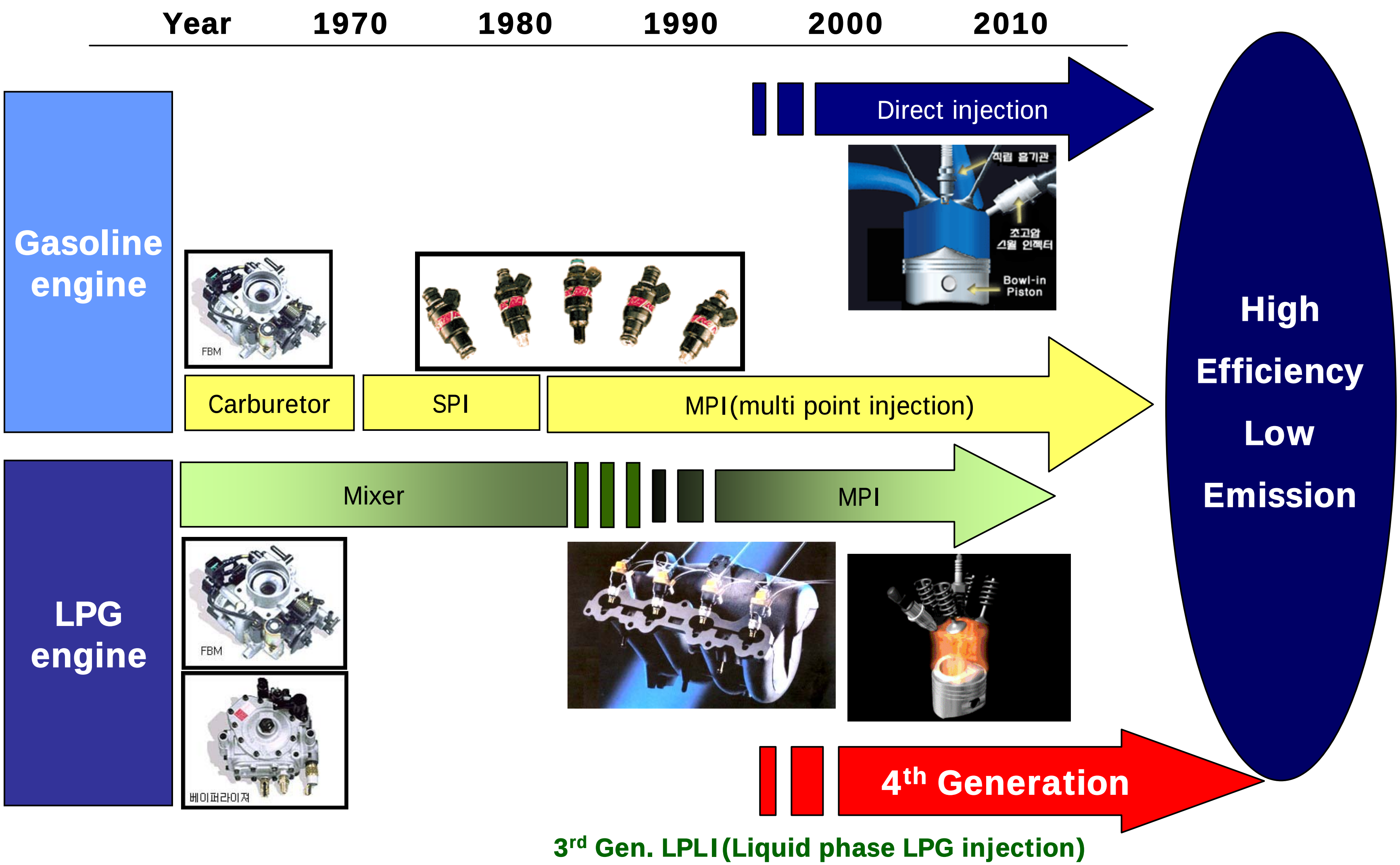
- Korea is #1 in terms of the number of LPG vehicles in the world (over 2M cars and 1.5K stations)
- The government allows LPG only for taxi, SUV, van, and mini car
- Most of LPG vehicles are produced by Korean OEMs rather than aftermarket



LPG Hybrid car by Hyundai Motors

LPG fuel supply system

The 32nd IEA/TLM

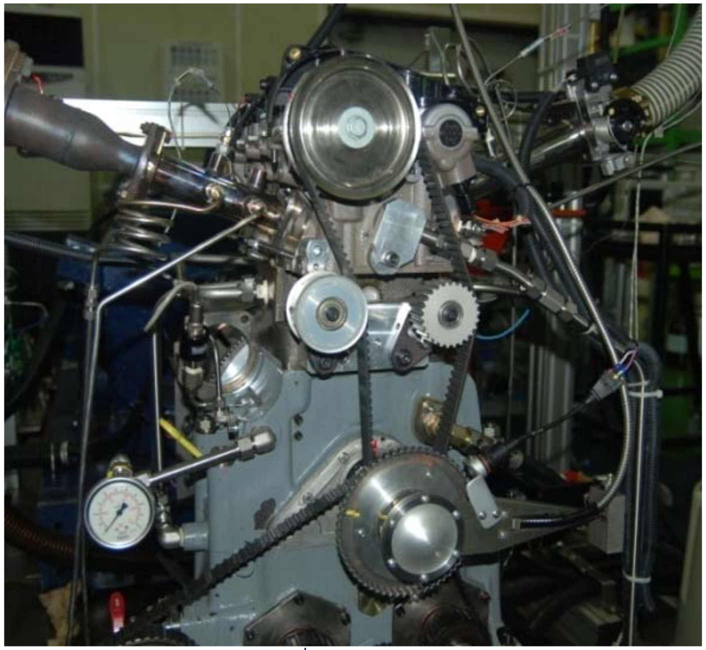


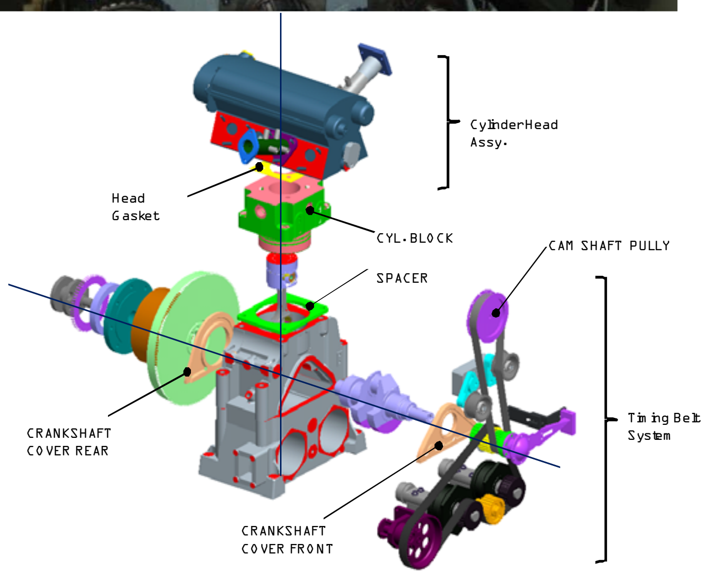
Scopes

- **Feasibility of LPG DISI(direct injection spark ignition)**
  - Combustion characteristics through heat release analysis
  - Engine-out gaseous emissions (CO, HC, NOx)
  - Nano particle emission(Number and size distribution)

All of the above is compared to gasoline DISI

Engine Test Facility





- **Single cylinder engine modified with a commercial DISI(direct injection spark ignition) gasoline engine(2.0 L)**

Engine specifications

Engine type	DOHC 4V/V
Displacement	498 cc
Bore x Stroke	83 x 92 mm
Compression Ratio	10.5:1
Fuel injection pressure	Up to 120 bar
Cam adjustment	Intake only
Fuel injector type	Solenoid

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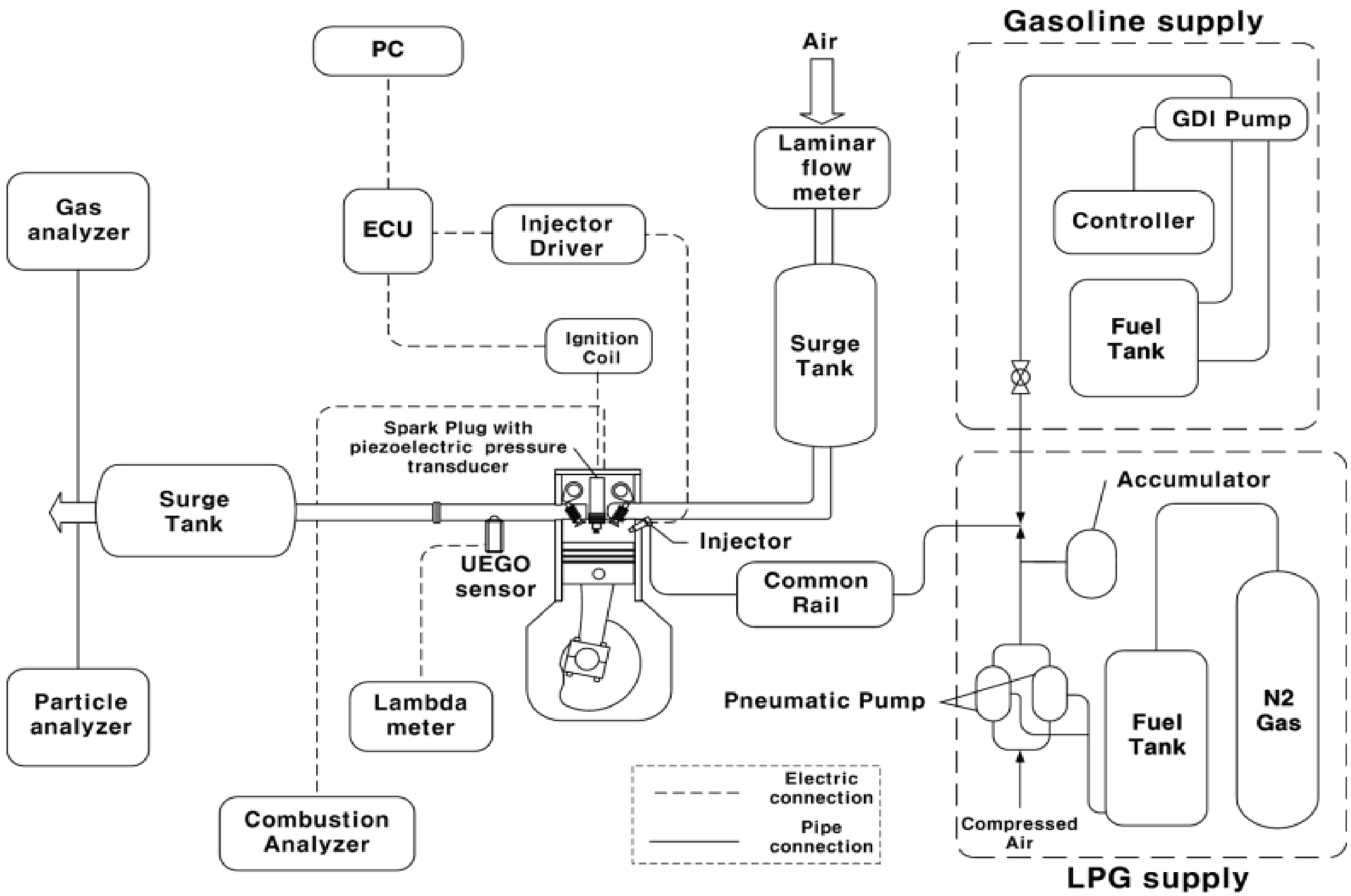
Experimental apparatus



Engine Operating Conditions

Operating conditions

Test fuels	Gasoline, LPG*
Engine speed	1500 rpm
Engine load	IMEP 2 ~ 10 bar
Fuel injection pressure	60, 90, 120 bar
Fuel injection timing	BTDC 300 CAD
Air excess ratio(λ)	0.8, 0.9, 1.0, 1.1, 1.2 (only for particle measurements)

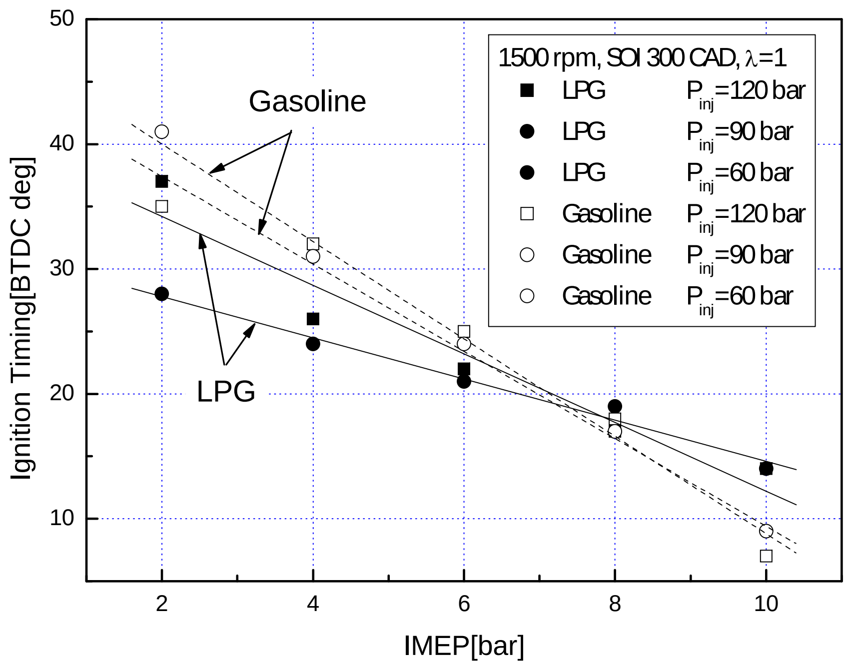
Gasoline/LPG fuel properties

Chemical Name	n-Butane	Gasoline
Chemical structure	C4H10	C8H15
Liquid density (kg/m3)	579	750
Molecular weight (g/mol)	58.12	98
Stoichiometric A/F ratio	15.46	14.6
Boiling point(C)	-0.5	30/190
Low Heating Value(MJ/kg)	45.31	44.12
Research Octane Number	91.8	98

* LPG fuel composition in this work was 90% mol butane and 10% mol propane close to *summer season standard in South Korea.*

MBT ignition timings

- MBT ignition timing of LPG is slightly changed than those of gasoline
- LPG would have less cyclic variation because ignition initiates near TDC

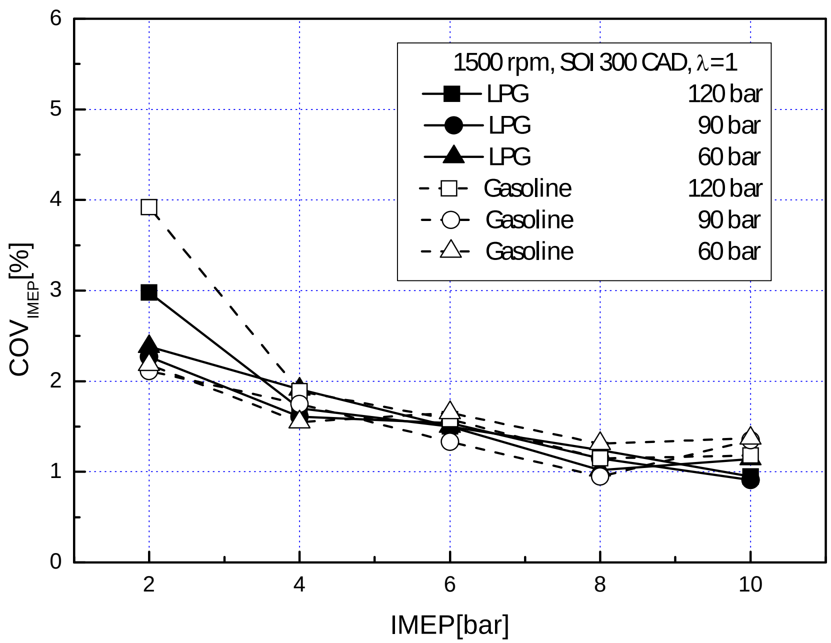


Cyclic Variations - COV_{IMEP}

- COV_{IMEP} is held less than 2% regardless of injection pressure(except for IMEP=2 bar)

- COV_{IMEP} rises as injection pressure increases(P_{inj}=120 bar and IMEP=2 bar)

- Fuel spray in low ambient density and temperature at low load condition has longer penetration length and interaction between air and fuel is weakened



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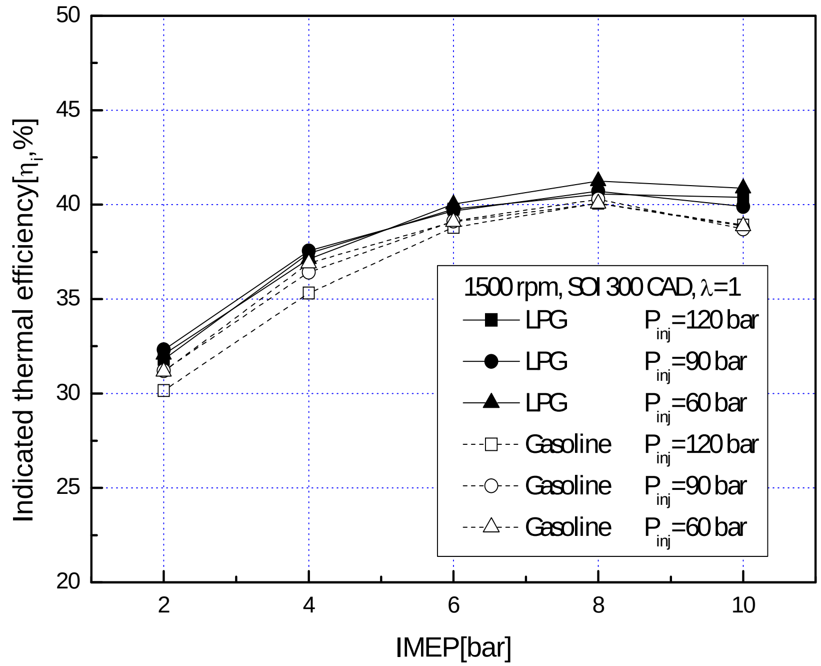
Indicated thermal efficiency

- The thermal efficiency of LPG features slightly higher in the load sweeps.
- Thermal efficiency for both fuels saturate at IMEP=8 bar and then decrease at IMEP=10 bar.
- Ignition time retards due to engine knocking shorten total burn duration at IMEP=10 bar
- Faster combustion of LPG compensate for lack of octane number.

  (Butane RON: 91.8, Gasoline RON: 98)



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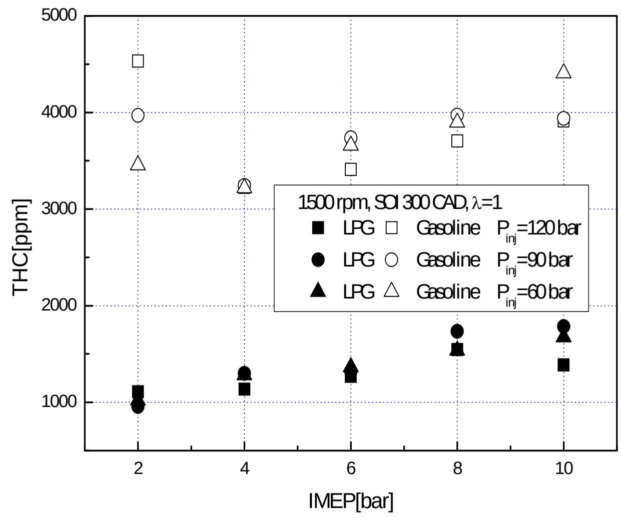
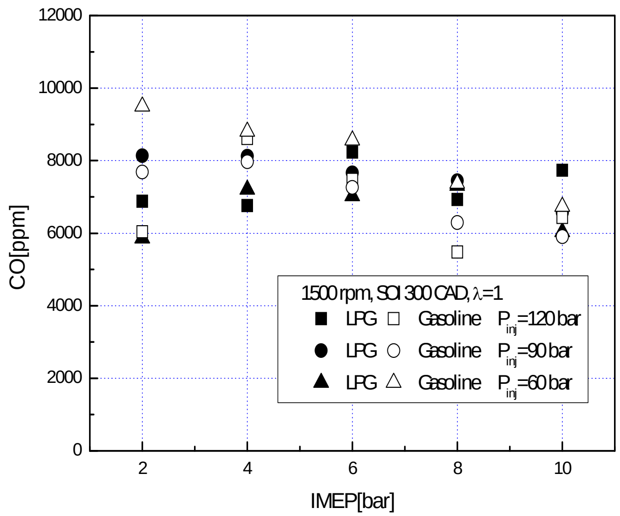
Gaseous emission(THC, CO)

- Hydrocarbon emissions for gasoline rises to a level of three-fold than those of LPG
- THC for gasoline increases at IMEP=2 bar due to low combustion stability
- CO emissions present similar value for both fuels because the engine was operated at λ=1.0, and a early injection condition.





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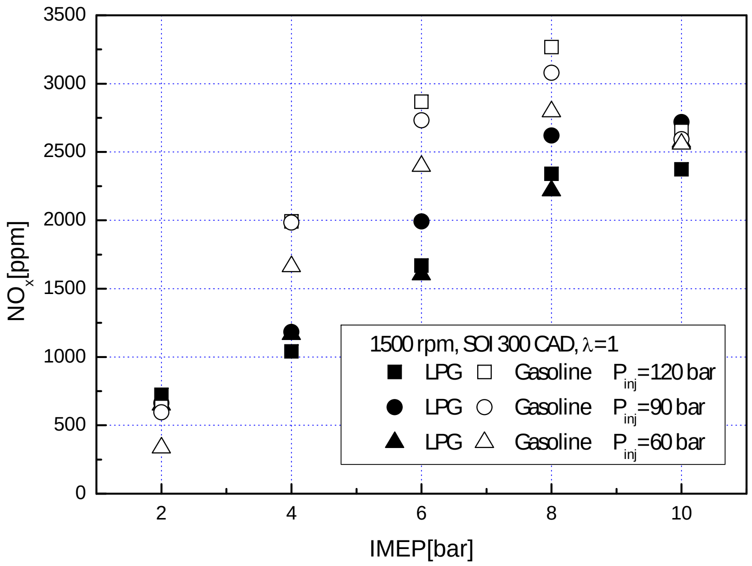
Gaseous emission(NOx)

- NO_x emissions are consistently increased along IMEP and NO_x of gasoline is higher than that of LPG for most cases

- Knocking phenomena makes ignition timing retard at IMEP =10 bar, and NO_x starts to abruptly decrease.



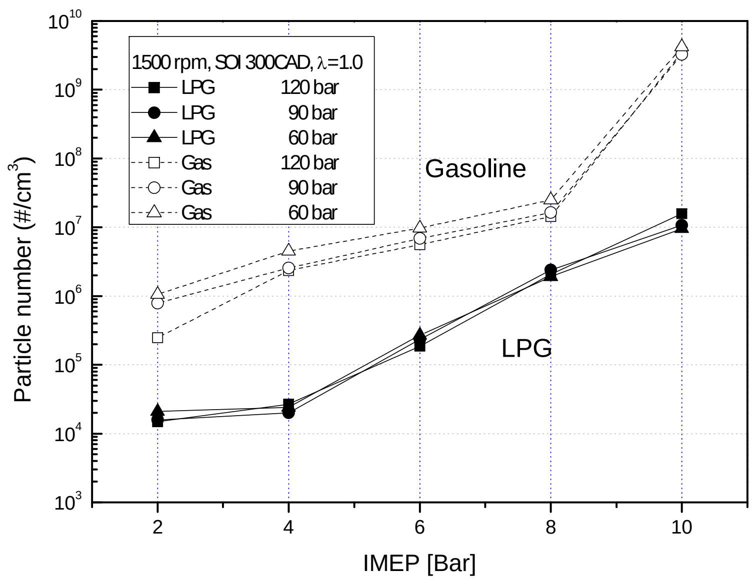
Particle Number Concentration

Engine load sweep

- Particle emission level from LPG is lower by a factor of 100 compared to gasoline

- Particle number emissions increased greatly with engine load

- For gasoline fuel, particle emissions are more dependent on fuel injection pressure while particle emission for LPG were comparable



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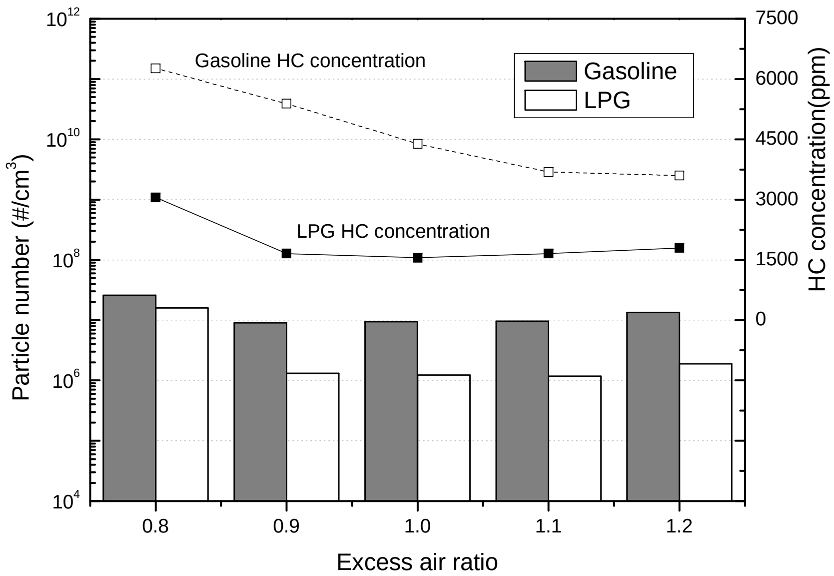
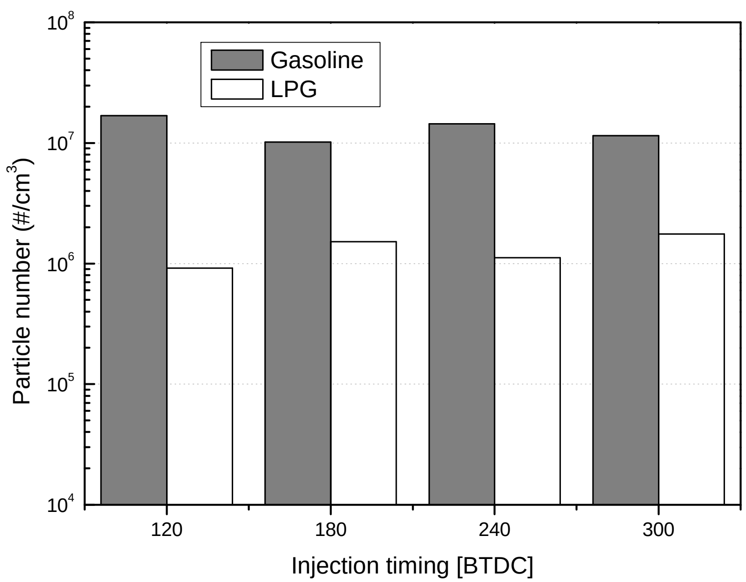
Particle Number Concentration





Excess air ratio sweep

- Gasoline emits **10 times more particles** and HC concentrations are doubled

- Particle number for both of gasoline and LPG represents similar levels in a lean region.

Injection timing sweep

- Fuel injection timing does not significantly affect the particle emission in stoichiometric condition

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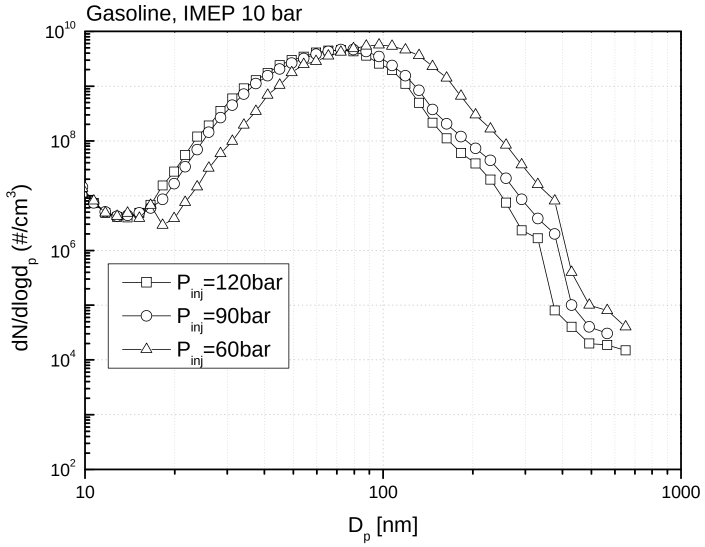
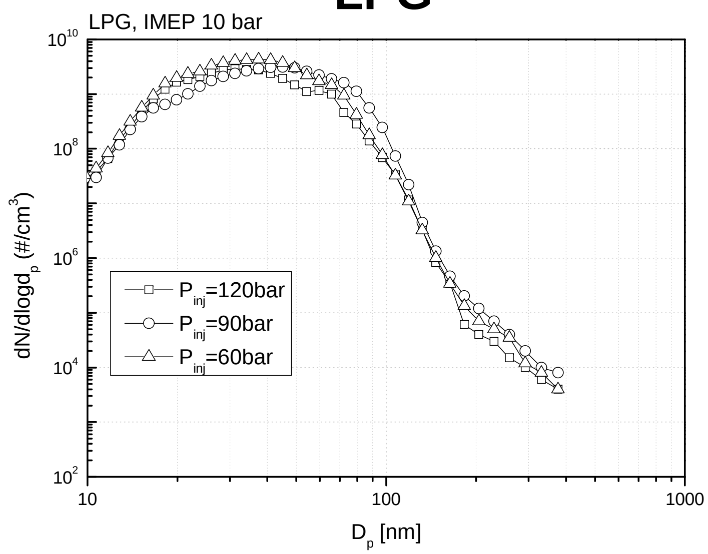
Particle Size Distribution

Gasoline



LPG



- Particle size distribution of gasoline is largely affected by fuel injection pressure and shifted to larger particle size at lower fuel injection pressure

- For LPG , the particle size distributions were nearly identical with the variation of fuel injection pressure and most particles were found below 50 nm(nuclei mode)

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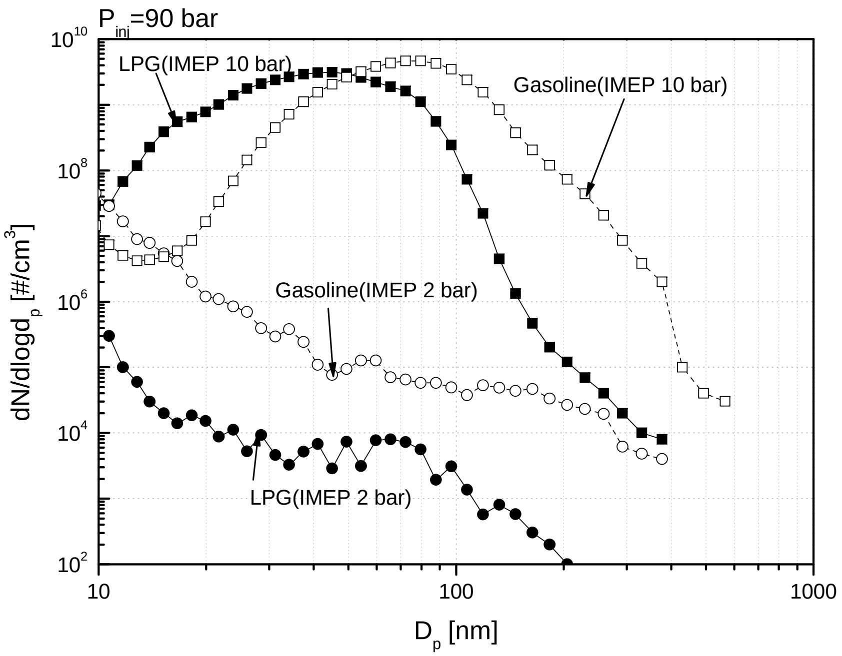
Particle Size Distribution



- At light load(2 bar IMEP) the distribution is broad, and shifted to small particle size
- As load increases, a log normal mode develops, centered at about 40 nm (LPG) and 80 nm (gasoline).

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Conclusions (1)

- Combustion stability was comparable for LPG and gasoline, but at low load with high injection pressure(P_{inj}=120 bar) made combustion stability worse.

- Indicated thermal efficiency of LPG is a little beneficial through all test conditions.

- While THC emissions of gasoline yielded three time more than that of LPG, CO emissions were comparable for both fuels.

- NOx emissions of gasoline were nominally higher except for IMEP= 2 and 10 bar conditions where poor combustion and engine knocking were occurred respectively.

Conclusions (2)

- The particle emission level from LPG was lower by a factor of 100 compared to the results of gasoline due to the rapid vaporization of LPG.

- At light load, the shape of the size distribution is broad, and shifted to small particle size regardless of the fuel type.

Thanks for your attention!