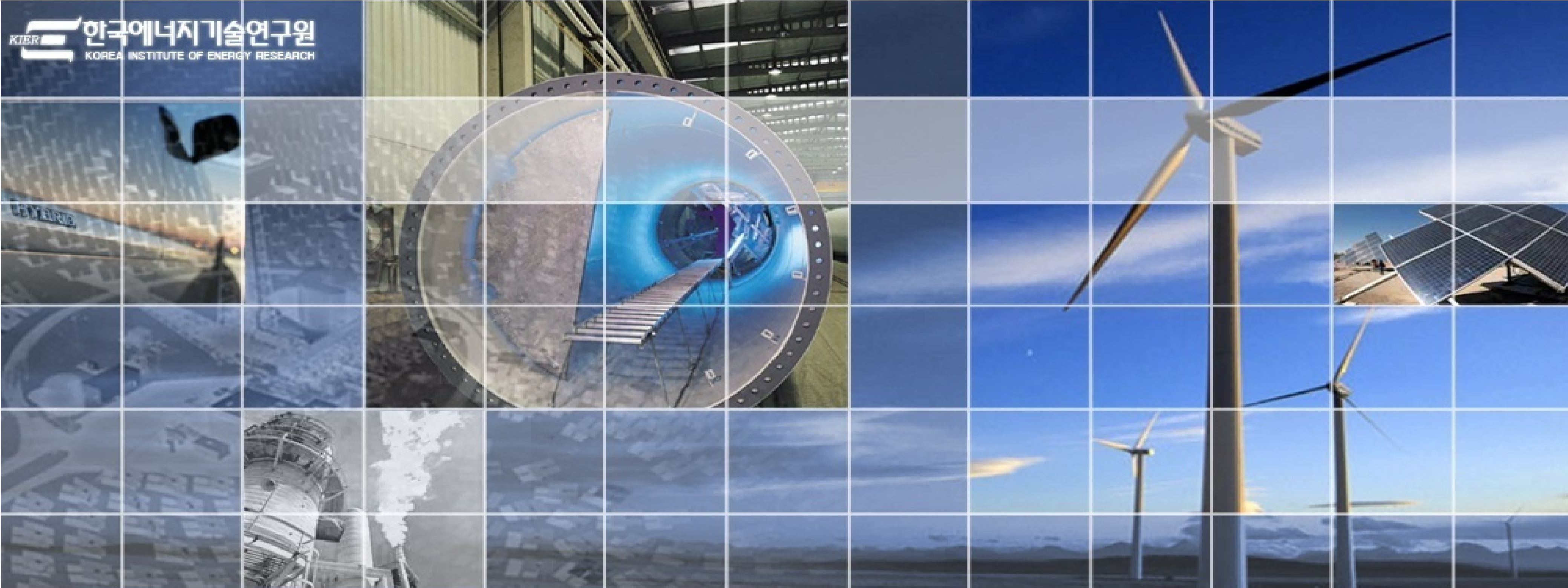

Demonstration of Ammonia-Gasoline Dual Fuel System in a Spark Ignition Internal Combustion Engine

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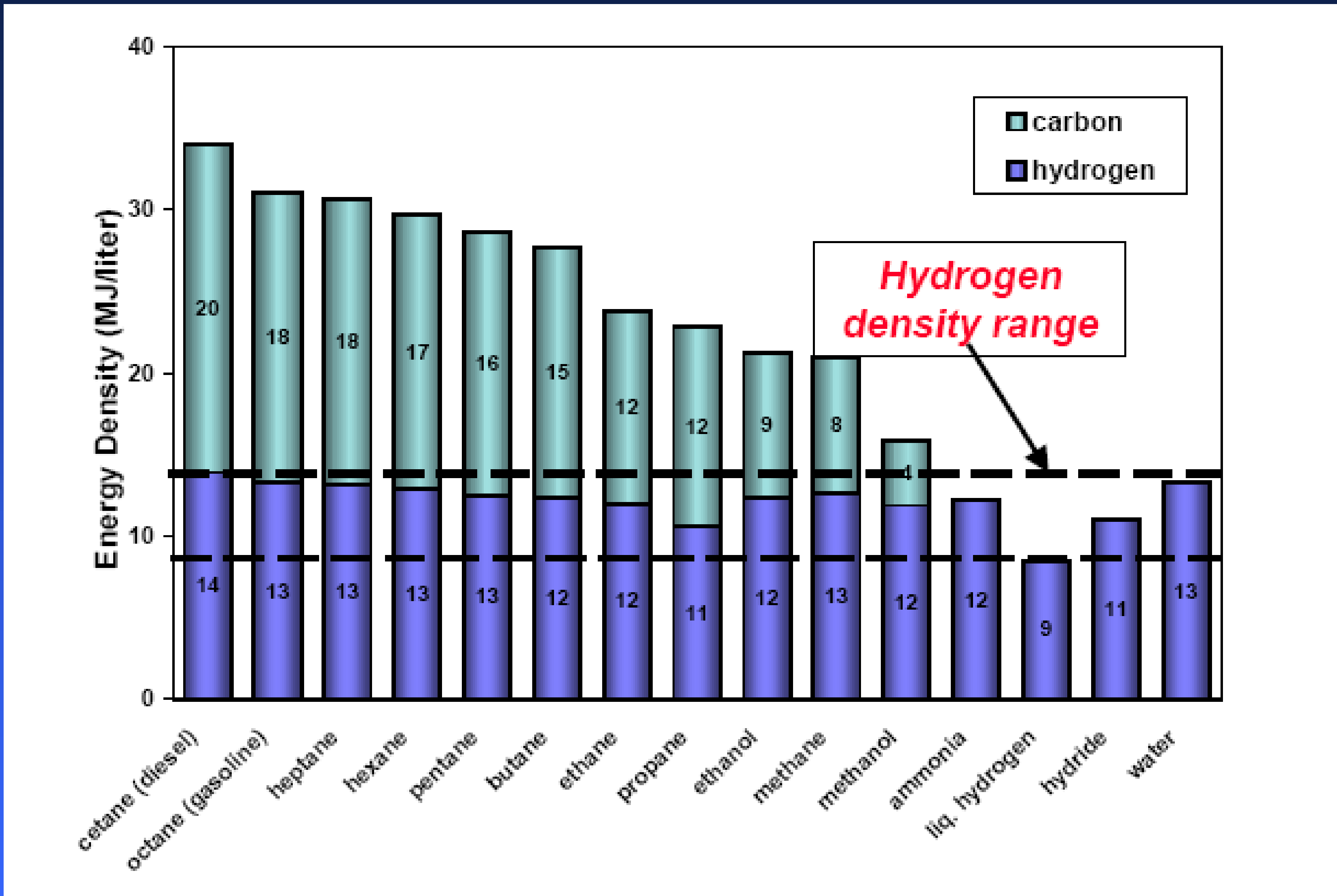
The Ideal Transportation fuel

- Can be produced from any raw energy source (i.e. wind, solar, biomass, coal, nuclear, hydro etc.)
- Is cost effective
- Has significant storage and delivery systems already in place
- Environmentally friendly
- Can be used in any prime mover (i.e. diesel engines, fuel cells, SI engines, gas turbines, etc.)
- Has a proven, acceptable safety record

Ammonia Basic

- Ammonia (NH3) can be produced from any raw energy source, including all fossil, renewable and nuclear sources.
- Ammonia is cost competitive with gasoline as a transportation fuel
- Ammonia has extensive, worldwide transportation and storage infrastructure already in place
- Ammonia is very environmentally friendly when used as a transportation fuel and produces only N_2 and H_2O at the tailpipe with low-cost emissions controls.
- Ammonia has been successfully demonstrated in SI engines, CI engines, and fuel cells.

Energy density(LHV) for fuels in liquid state



 From George Thomas, BES workshop 5/13/03

End Use Applications

- Spark-Ignition Internal-Combustion Engines (w/hydrogen or ethanol)
- Diesel Engines (w/biodiesel and/or DME)
- Direct Ammonia Fuel Cells
- Gas Turbines
- Gas Burners (including residential furnaces)

Progress accomplished

- **Flex fuel (gasoline/ammonia) vehicle** successfully driven from Michigan to California (nh3 Car)
- Over **50% efficiency** demonstrated in a SI engine (HEC)
- **Irrigation pump** demonstration with SI engine (HEC)
- **Direct ammonia fuel cell** bench-scale demonstration (Howard U.)
- 1.5 Mw **wind to ammonia demonstration** funded, construction underway (U. Minn. Morris)
- 95% ammonia, 5% diesel, 110% rated power in a John Deere **diesel engine** (IEC/ISU)

Combustion Equation

- $(0.790\ N_2 + 0.210\ O_2) + 0.024 \times b\ C_6H_{11} + 0.280 \times (1-b)\ NH_3 \Rightarrow$
$(0.930 - 0.140 \times b)\ N_2 + (0.420 - 0.288 \times b)\ H_2O + 0.144 \times b\ CO_2$

- □ Gasoline is the combustion promoter.

- □ b = Chemical Equivalence basis gasoline fraction.
  $0 \le b \le 1$.

40% replacement of gasoline into NH3 gives

Reduction of CO_2 more than 200 Mton yearly

Objective

- Ammonia internal combustion engine
- A vehicle prototype

BI-FUEL : Gasoline / LPG

↓

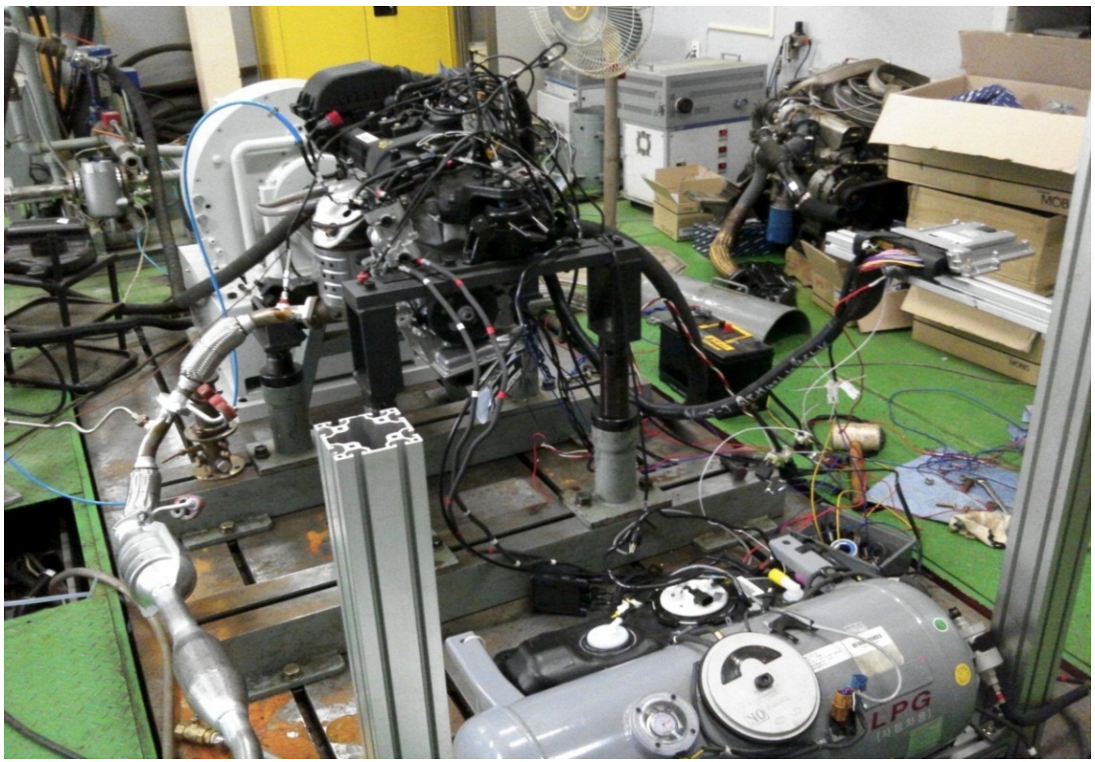
Dual fuel : Gasoline + Ammonia

- Performance development with ammonia fuel
  - Substitution of gasoline upto 70%
  - Gasoline equivalent power output

- Ammonia + Gasoline dual fuel vehicle prototype
  - Fuel consumption : above 10 km/ℓ *(10 L/100 km)*

Installation of the test engine

- HMC Kappa 1.0 LPG-gasoline bi-fuel engine
- Baseline test – LPG only
- RP-ECU – Wiring, Matching for Sensors/Actuators, Start problems



Specification of the test engine

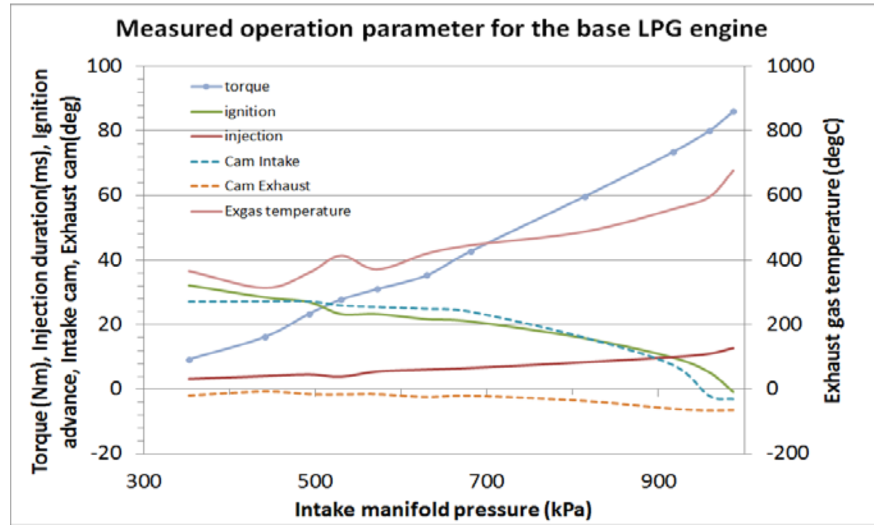
Number of cylinders		3
Bore x Stroke (mm)		71.0 x 84.0
Displacement (cc)		998
Compression ratio		10.5 : 1
Firing order		1-2-3
Intake valve	Opening	BTDC 22.5°~ATDC 27.5°
	closing	ABDC 3.7°~ABDC 53.7°
Exhaust valve	Opening	BBDC 40.6°~BBDC 0.6°
	closing	BTDC 12.6°~ATDC 27.4°

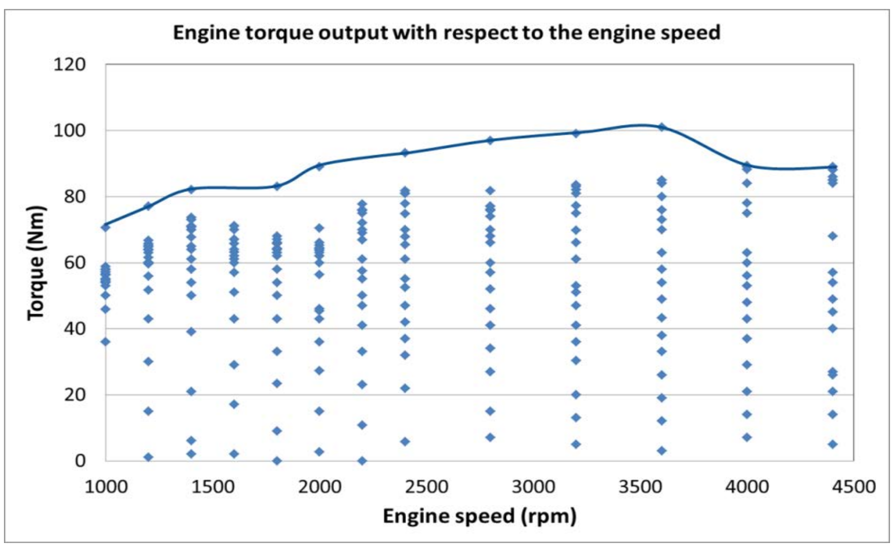
- Separated LPG-Gasoline bi-fuel
- Full variable valve timing (VVT)
- Variable intake system (VIS)

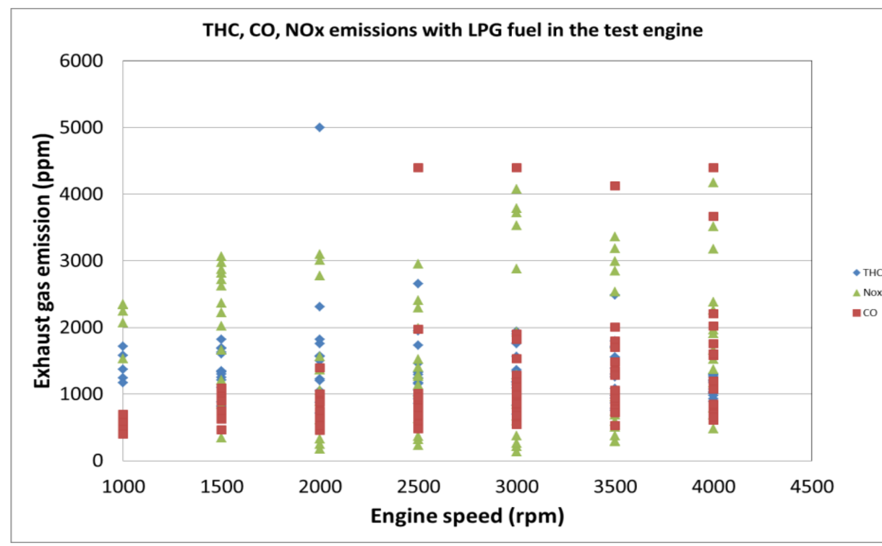
Baseline performance (LPG)

- Flat torque output with RPM
- Maximum torque = 101 Nm at 3600 rpm
- High level of NOx and moderate CO, HC emissions

- Target assessment for ammonia engine

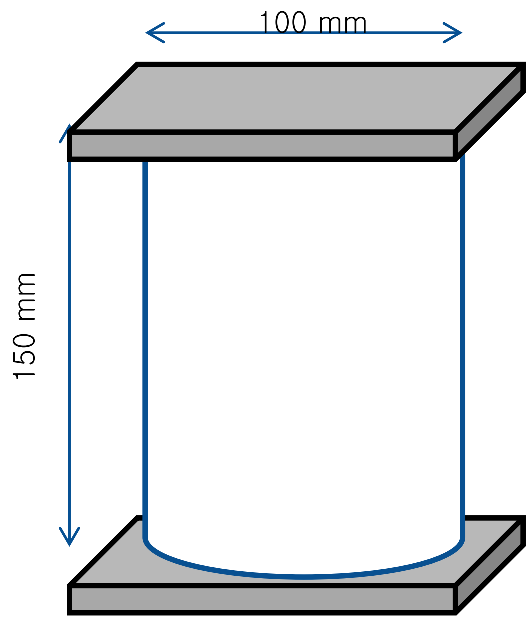






Immersion test method

- Immersion of the relavant parts into ammonia liquid
- Reinforced glass window
- Corrosive material analyses



Immersion test for injectors and fuel line

- Corrosion checkup for the LPG parts (injectors, pump etc.)
- Some sealant was prune to be corrosive (1)
- HNMR, Kalrez elastomer are the substitutes

<0 min>

<30 min>

<75 min>

HNBR

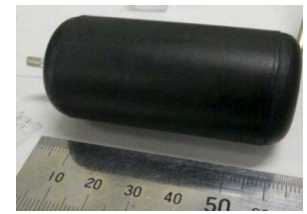
Kalrez

Immersion test for the fuel tank assembly

- Corrosion check for the parts inside fuel tank including LPG pump
- All the sealants and the level floater should be replaced.
- In-line type delivery pump is recommended for monitor and service.

<different sealants>

<electrodes>



<metal parts in the tank>

<Fuel delivery lines>

<level floater>

Feed pump

Before immersion

After 12 hrs

Fuel injection effect

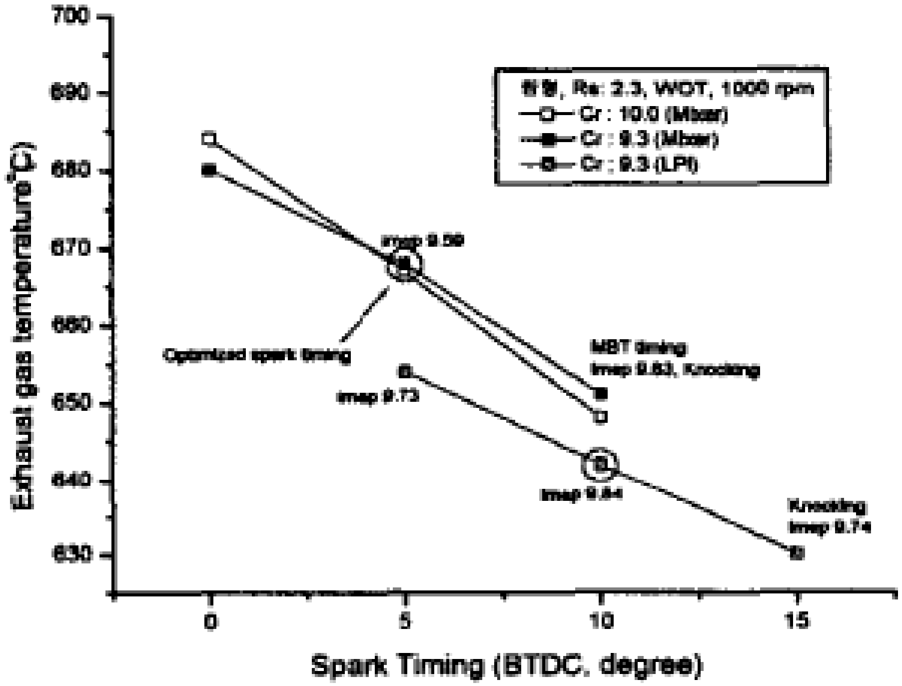


Fig. 7. Engine performance results of LPi and mixer fuel supply systems

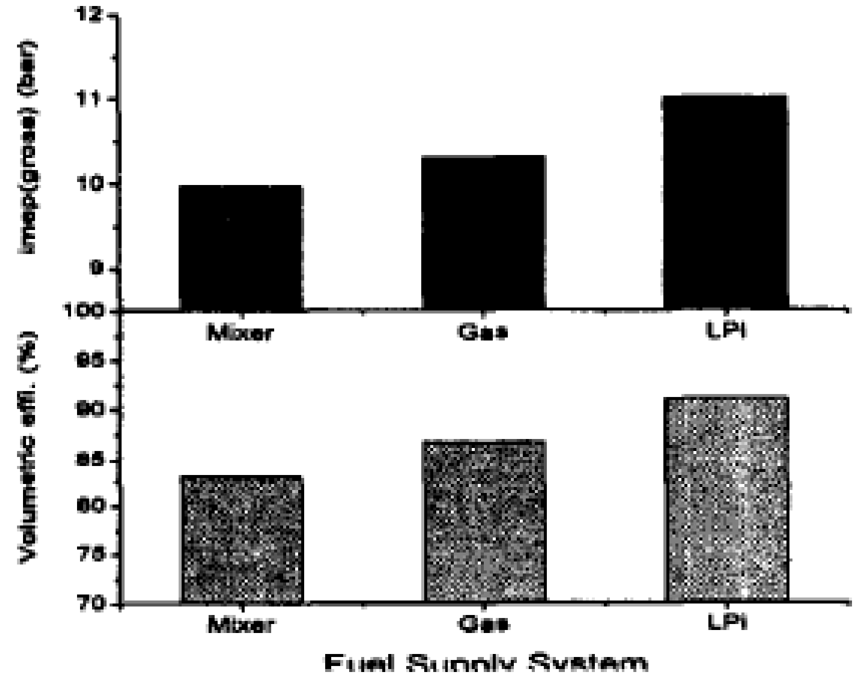
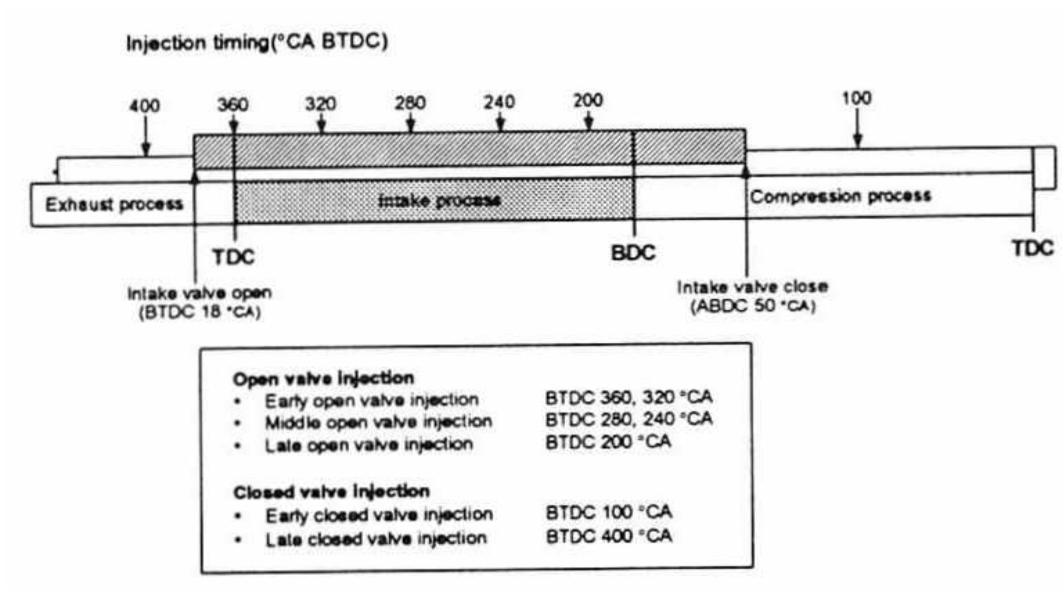
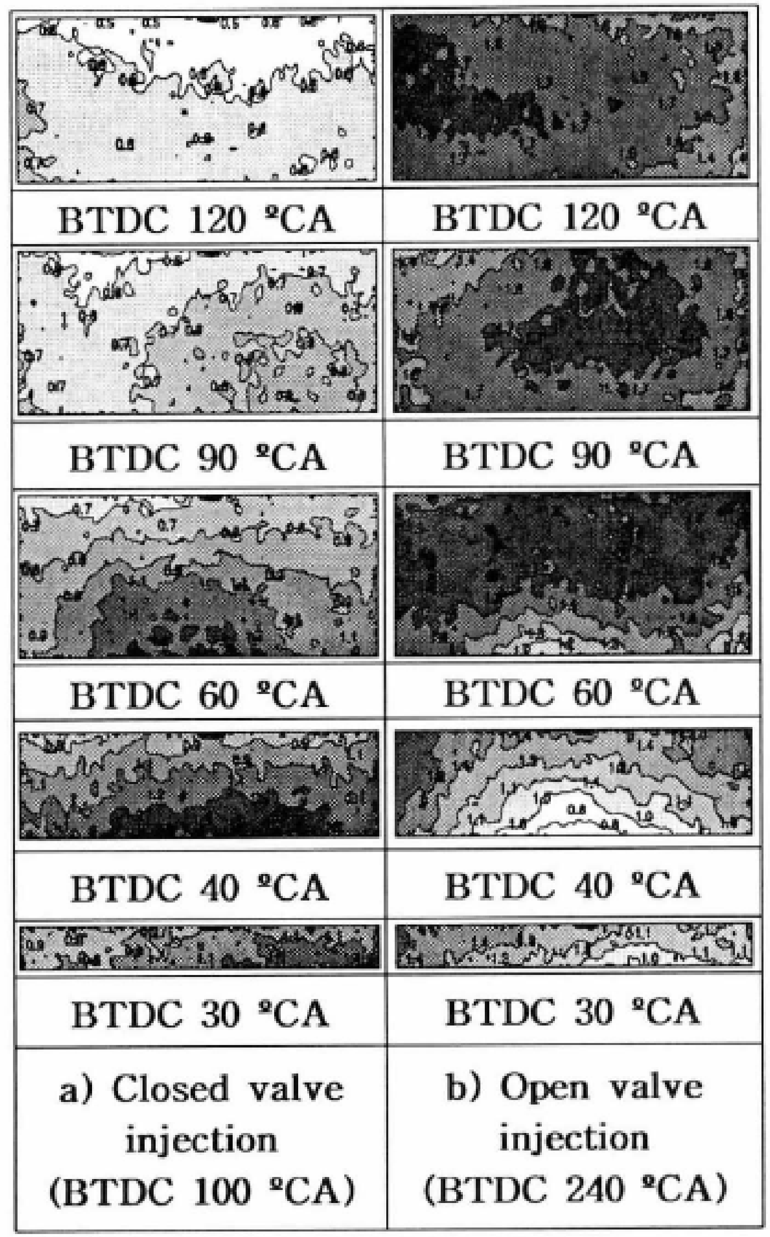


Fig. 8. Engine output and volumetric efficiency with LPG fuel supply systems

Source : LPG gas engine TFT in KIMM

Fuel injection strategy

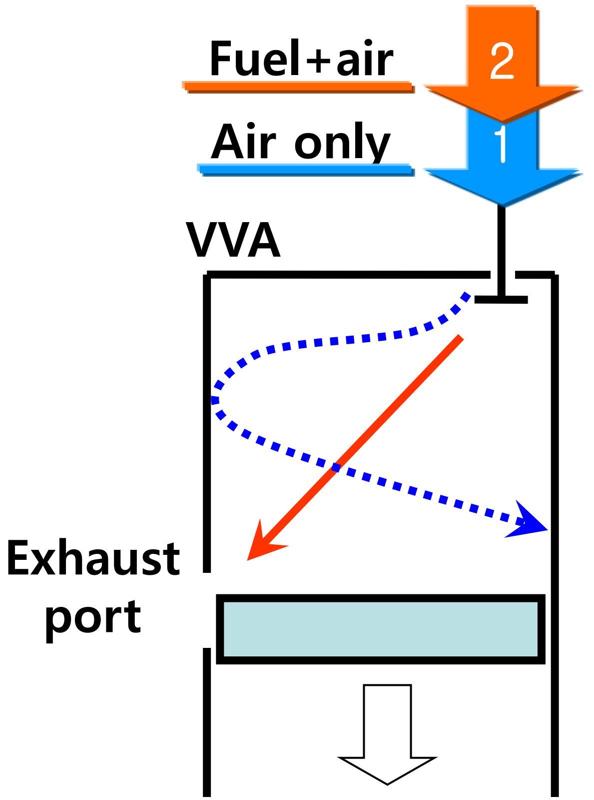




Source : Co-work with LPG gas engine TFT, KIMM

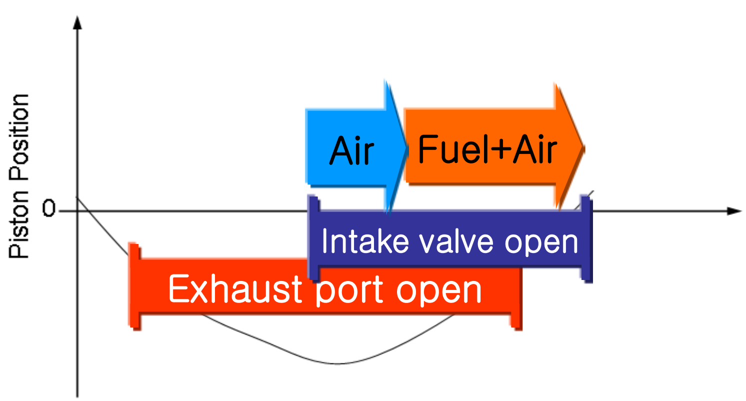
In a two stroke engine

KIER 한국에너지기술연구원 KOREA INSTITUTE OF ENERGY RESEARCH

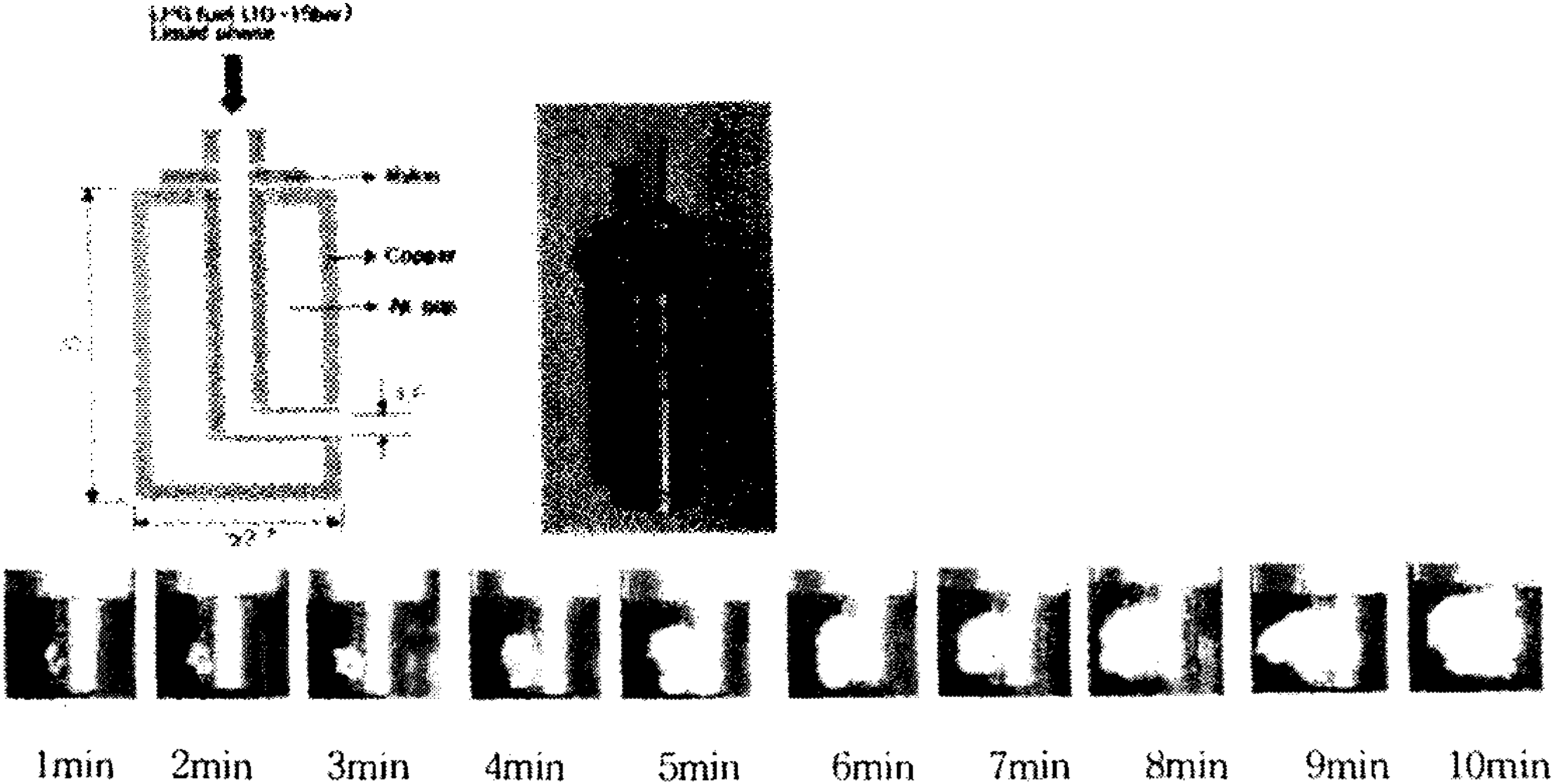


Scavenging strategy

1. stable stoke attainment
2. Effective piston work
3. Minimizing port-valve overlap
4. Minimizing unburned fuel going out
5. Fuel stratification – rich mixture near the spark plug
6. Utilizing internal EGR – to suppress NOx formation



Injector icing



(LPG P/B=6/4, fuel supply pressure : 12bar, air flow rate: 9.2L/min)

Fig. 4 Formation of the icing with time (air temperature of 20℃ , 80 % of humidity)

NOx, NH3 slip problem

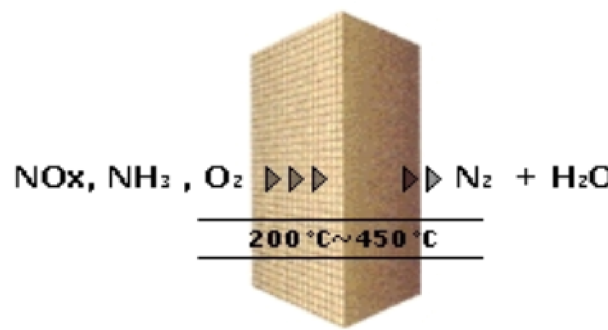
- Increase in NOx emission with fuel load
- NO emission is far from fuel mix ratio (relative gasoline quantity)
  - Small increase in NO2 with ammonia combustion up to 10~40 ppm
  - Steep increase in the fuel lean conditions
- Unburned NH3 (NH3 slip) increases with NH3
  - Not a big deal in fuel lean condition

- **AOC** (Ammonia Oxidation Catalyst) to deal with NH3 slip
- **SCR** (Selective Catalytic Reduction) to reduce both NOx and NH3

SCR 촉매반응 개요

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$



Summary 1

- LPG-gasoline dual fuel system conversion is completed
- NH_3 corrosion test was conducted to prepare the fuel supply system
- Considerations to lead better performance with respect to the fuel supply strategy

Future work

- LPG-gasoline dual fuel system
- Ammonia-gasoline dual fuel system
- Vehicle installation of the ammonia fuel system
- Vehicle evaluation (Fuel consumption)

Thank you
for your attention !