Experimental and Numerical Investigation of the Effect of Inhomogeniety on HCCI Combustion

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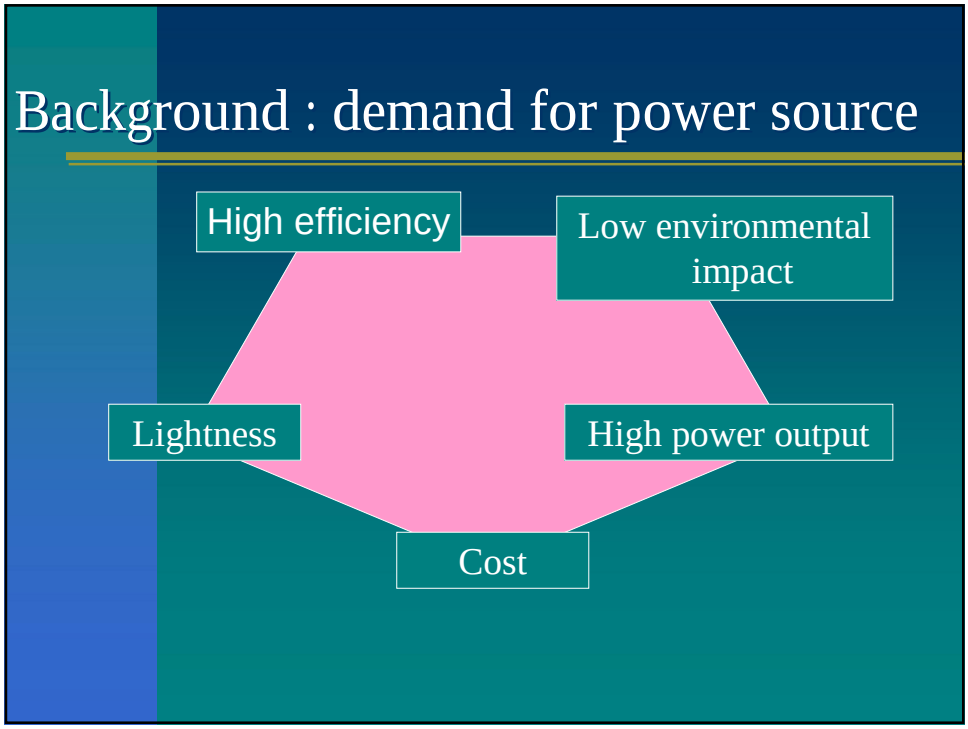
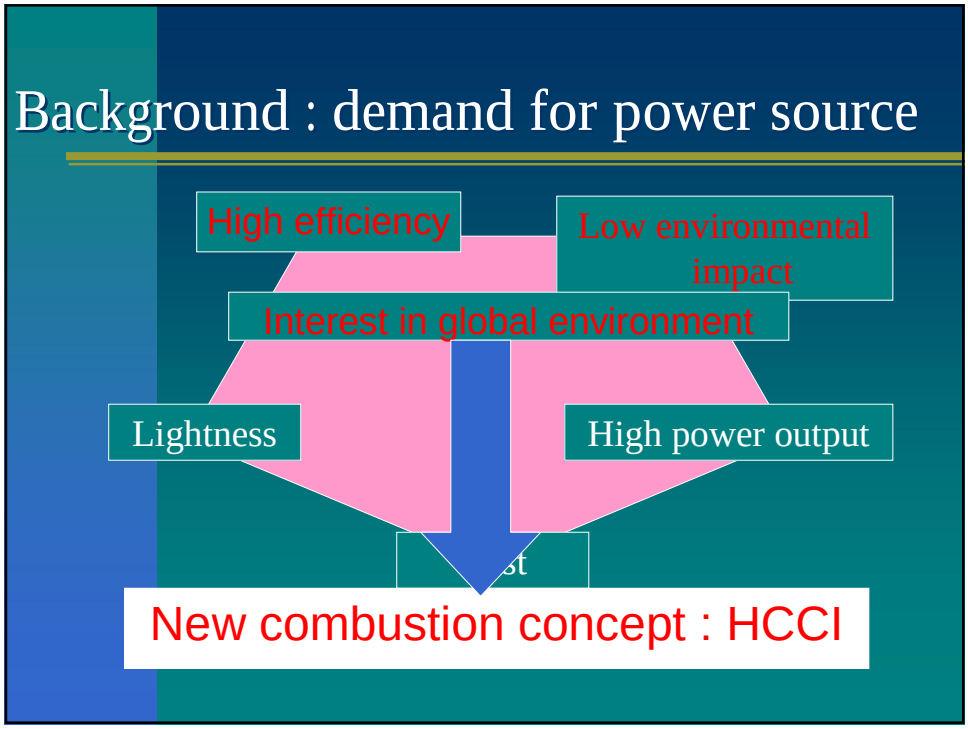
- Background and objective
- Experiment
  - Setup
  - Result and questions
- Simulation
  - Setup
  - Result and questions
- Conclusion


Background : demand for power source
High efficiency
Low environmental impact
Lightness
High power output
Cost


Background : demand for power source
High efficiency
Low environmental impact
Interest in global environment
Lightness
High power output
New combustion concept : HCCI

Background : merit and demerit of HCCI engines

○High efficiency	high compression ratio overall lean combustion rapid heat release
○ Low NOx and Soot	low temperature combustion lean combustion everywhere

×No classical device to control combustion

×Very narrow operation range

- too rapid combustion makes noise
- incomplete combustion under low load

Background : rate of heat release

- Chemical reaction simulation gives short duration of heat release with 0-dimensional, perfect homogeneous condition
- Longer heat release is observed in experiment
- ⇒How the combustion occurs and develops?
- ⇒Something makes combustion gentle

- Imperfect homogeneity may be one reason
  ⇒Inhomogeneity is a key to expand the limit?

Objective : How the operation range can be expanded by inhomogeneity?

- low load condition
  - stratified mixture enhances ignition and combustion stability?
- high load condition
  - stratified mixture and sequential combustion

  ⇒longer heat release duration?

Other issue may arise?

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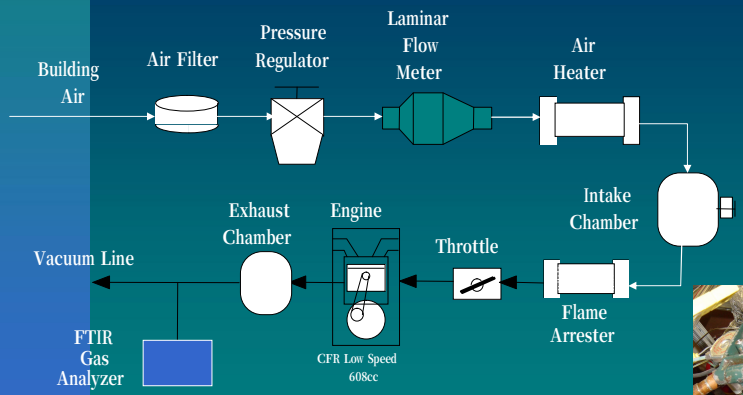
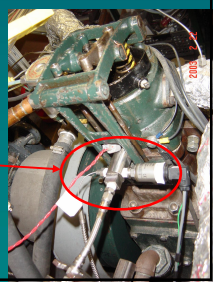
Diagram of Experiment System



- Swirl Injector installed



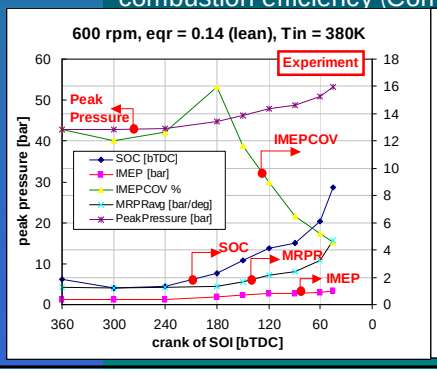
Experimental conditions

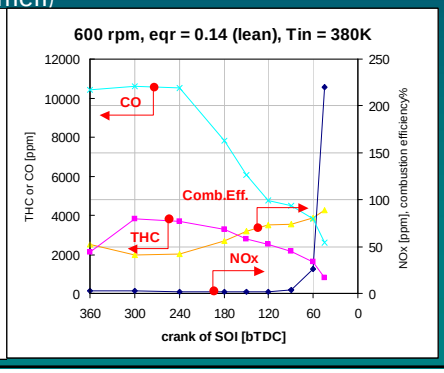
- CFR Engine 82.6x114.3, 608cc, 4 stroke
- Engine speed 600-1800rpm
- Intake air temperature 380K
- Compression ratio 16.55
- Coolant temperature 80℃
- Fuel PRF, ON:91.8
- Fuel supply
  - Direct injection (The same type is used for port injection)
    - Type hollow cone
    - Injection pressure 5MPa
    - Cone angle 30deg.

Experimental Result at 600rpm

Effect of injection timing under **low load** condition

- Equivalent ratio fixed at 0.14(COV.(IMEP)=10% with port injection)
- Delayed SOI from 180BTDC to150BTDC and more:
  - 10% of heat release timing Start to Advance
  - ⇒Inhomogeniety around these Conditions enhances ignition
  - Increase of Maximum of pressure rise rate(MRPR) and combustion efficiency (Comeff)

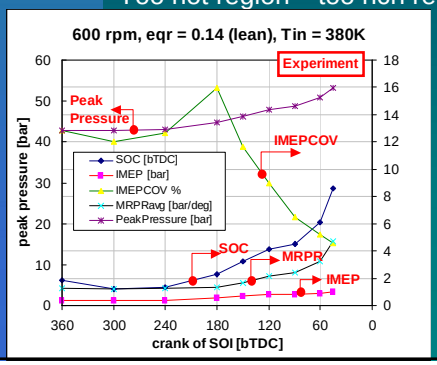


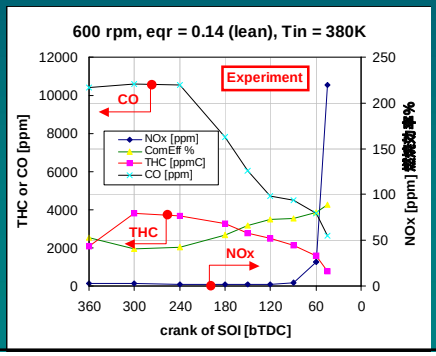


Experimental Result at 600rpm

Effect of injection timing under **low load** condition cont.

- Delayed SOI :
  - Decrease of COV.(IMEP) and CO emission
- Very high CO emission around 10000ppm for early injection
  - Oxidation process stops up to CO for homogeneous conditions
- Rapid NOx emission increase with SOI=60 ° BTDC
  - Too hot region – too rich region

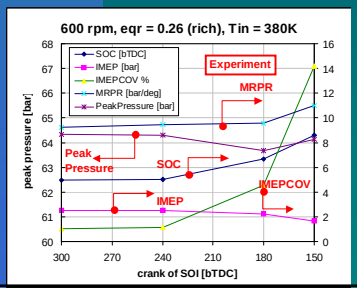


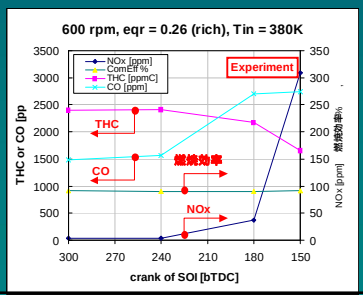


Experimental Result at 600rpm

Effect of injection timing under **high load** condition

- Equivalent ratio fixed at 0.26
  - Maximum of pressure rise rate(MRPR) =10bar/deg with port injection
- Effect of injection timing: Similar to low load case for
  - 10% of heat release timing, MRPR
- Comeff stays the same (89－91%)
- Increase of COV.(IMEP), CO and NOx emission

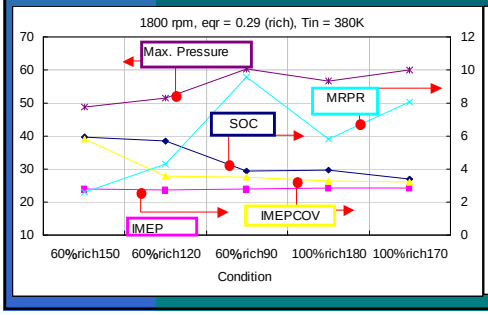


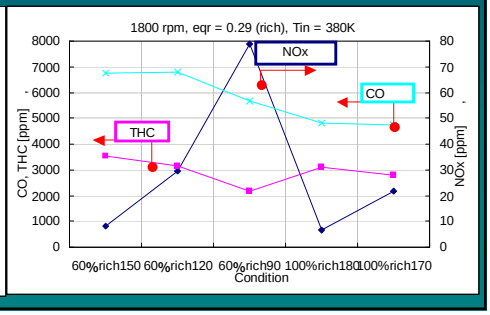


Experimental Result at 1800rpm

Effect of injection timing and DI ratio

- Equivalent ratio fixed at 0.29
  - MRPR=10bar/deg with port injection
- Advance in injection : similar to 600rpm case for
  - MRPR increase
  - SOC timing advance
    - (after TDC for 1800rpm:before TDC for 600rpm)
  - NOx emission increase

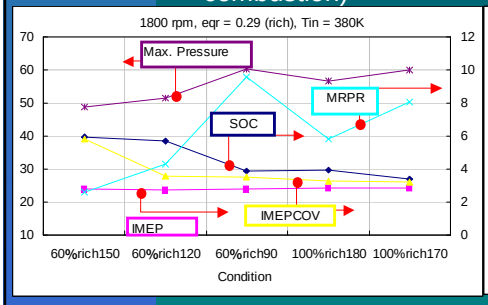


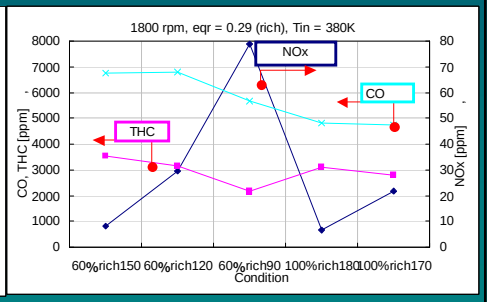


Experimental Result at 1800rpm

Effect of injection timing and DI ratio cont.

- SOI for NOx emission increase
  - More advance for DI100% than DI60%
- Higher CO emission for 1800rpm than 600rpm (1600-2400ppm for max.load) :
  - Shorter Duration with high temperature
  - More Delayed combustion (expansion with progress of combustion)





Summary and question to Experimental Result

- Delayed SOI :
  - Advance of 10% of heat release timing
  - High MRPR and combustion efficiency for low load
  - ⇒Inhomogeniety enhances ignition
  - Decrease of COV.(IMEP) and CO emission for low load
  - Increase of COV.(IMEP) and CO emission for high load
  - ⇒Optimized inhomogeniety to enhance ignition
- Very high CO emission for homo and low load
  - Oxidation process stops up to CO for homogeneous conditions
- Higher CO emission for 1800rpm than 600rpm
  - Shorter and More Delayed combustion
- Rapid NOx emission increase with certain SOI
  - Too hot region – too rich region : where is the threshold?

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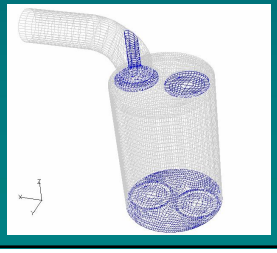
Simulation setup

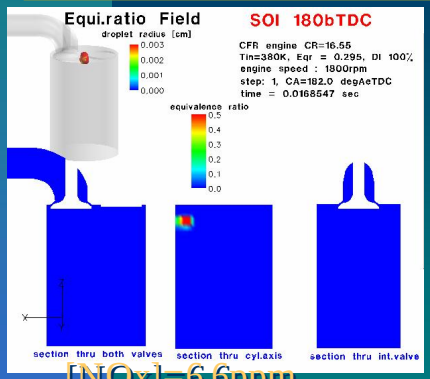
Wall Temperature	
CylinderBore	400 K
Combustion chamber	420 K
Piston	420 K
Intake valve	373 K
Exhaust Valve	420 K
Intake Port	373 K
Exhaust port	420 K
Initial temperature in each region	
Combustion Chamber	550 K
Intake Port	380 K
Exhaust port	400 K
Fuel	341 K

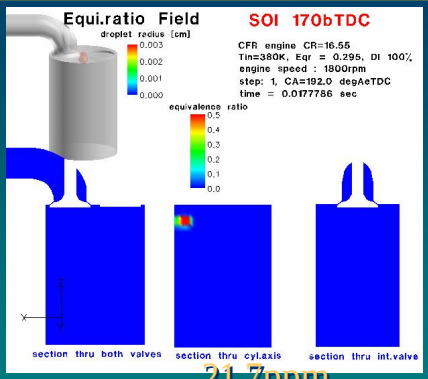
- Simulation code:KIVA
- Simulation period:from IVO to TDC
- Spray model was validated by test rig condition
- Fuel property : isooctane
- Reaction is not considered



Simulation Result example

1800rpm, DI100%



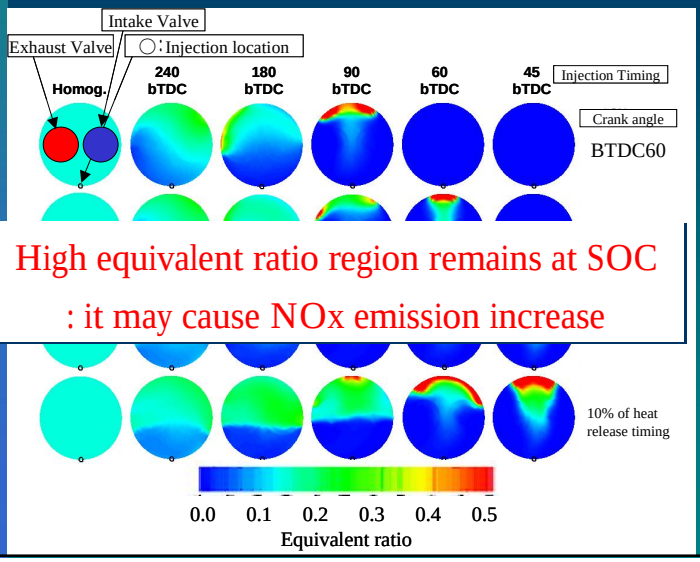


[NOx]=6.6ppm 21.7ppm

Difficult to distinguish the difference between these data!

Simulation Result

Effect of injection timing under 600rpm **low load** condition

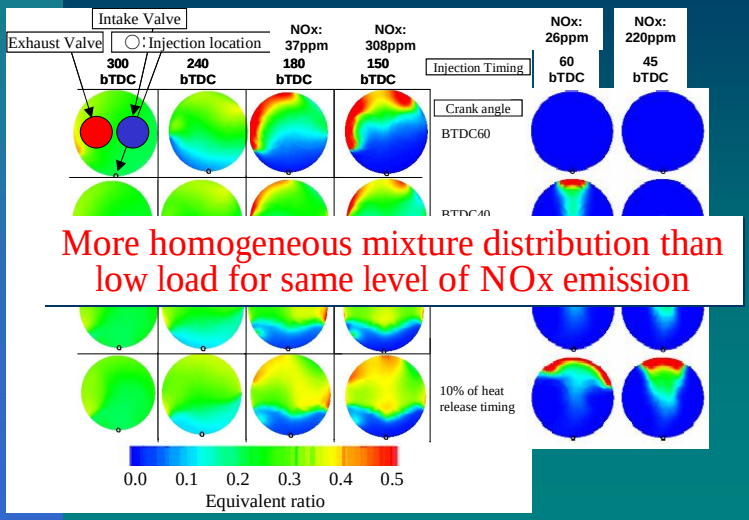


High equivalent ratio region remains at SOC

: it may cause NOx emission increase

Simulation Result

Effect of injection timing under 600rpm **high load** condition



More homogeneous mixture distribution than low load for same level of NOx emission

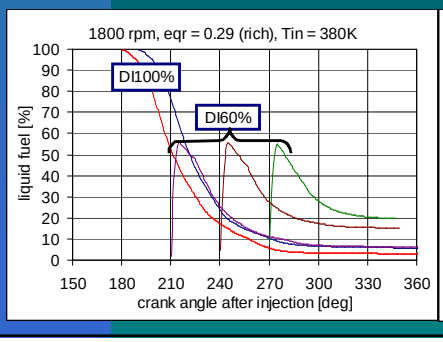
Simulation Result

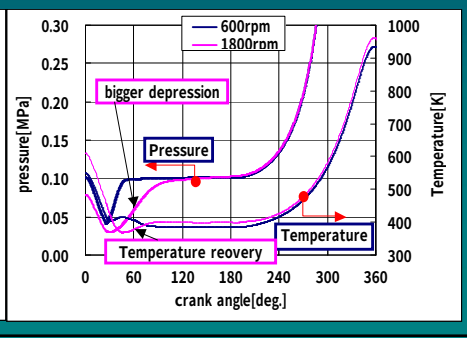
Effect of injection timing and engine speed

- Late injection : increase of liquid fuel remaining around TDC
- Temperature at TDC increase
  - 925-935K（600rpm）⇒959-969K(1800rpm)

  ←Cylinder pressure depression after IVO

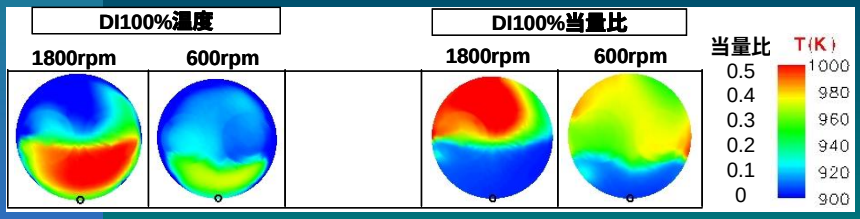
  ⇒temperature rise by pumping work





Comparison of inhomogeniety
600rpm vs1800rpm

- 0.4mm under upper surface SOI:bTDC180



- Stronger inhomogeniety remains at 1800rpm than 600rpm

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Conclusion

- low load condition
  - stratified mixture enhances ignition and combustion stability?:YES
- high load condition
  - longer heat release with stratified mixture? : No
- other issues?
  -NOx emission increases very rapidly and it is very close to stable combustion condition
  -Higher combustion temperature is acceptable for NOx free operation with higher engine speed
  -Proper level of mixture stratification optimizes NOx free HCCI operation