Combustion Simulation Investigation of Large Natural Gas Engine

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- Background
- Introduction of M23G gas engine
- Simulation investigation of combustion
  - Intake port
  - Gas inlet nozzle
  - Pre-chamber&Piston top
- Summary

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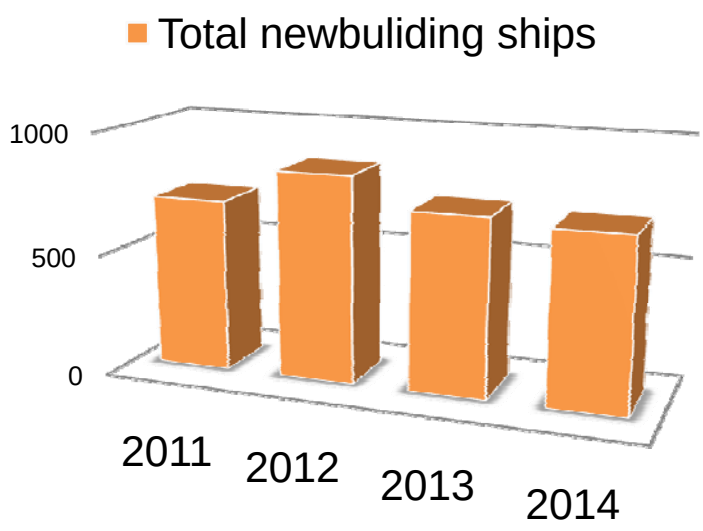
Shanghai Marine Diesel Engine Research Institute (SMDERI), founded in 1963, is attach to China Shipbuilding Industry Corporation(CSIC.)

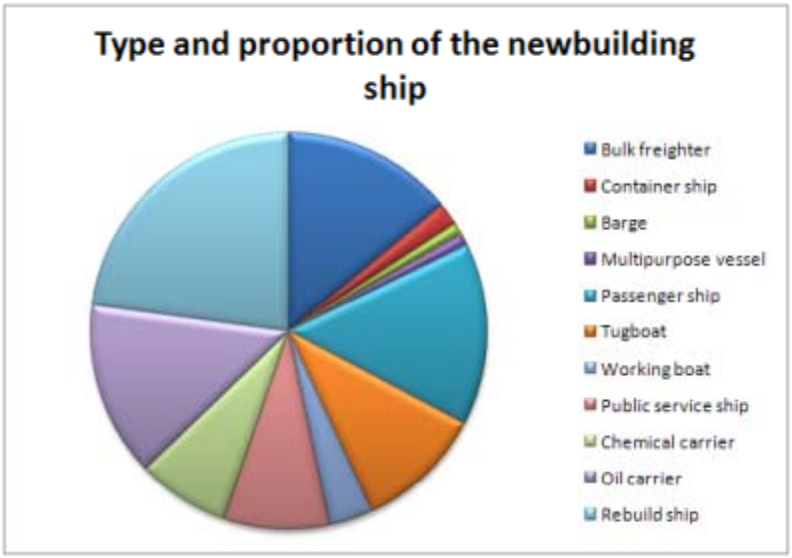
Main strategic business:

- ❑Diesel and gas engine
- ❑Stirling engine
- ❑Power system integration
- ❑ Ship automation system
- ❑ Energy-saving and environment protection equipments
- ❑ Energy service

Background

There are quite large marine engine market in China.





*Detail date quoted from CCS

The total inland and coastal newbuilding ships in China, during 2011 to 2014.

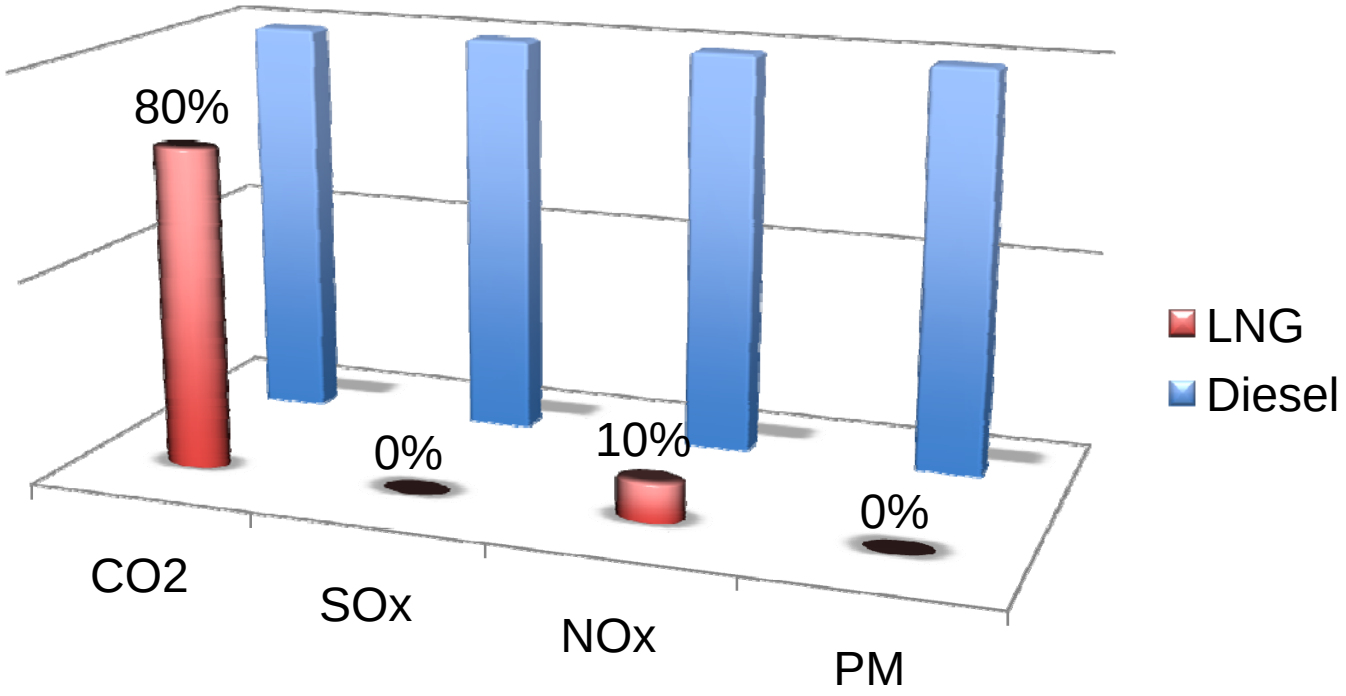
The proportion of each type for inland and coastal newbuilding ships in China, during 2011 to 2014.

Background

Most of newbuilding ships use diesel engine for system, the power range is 1000~4000kW.

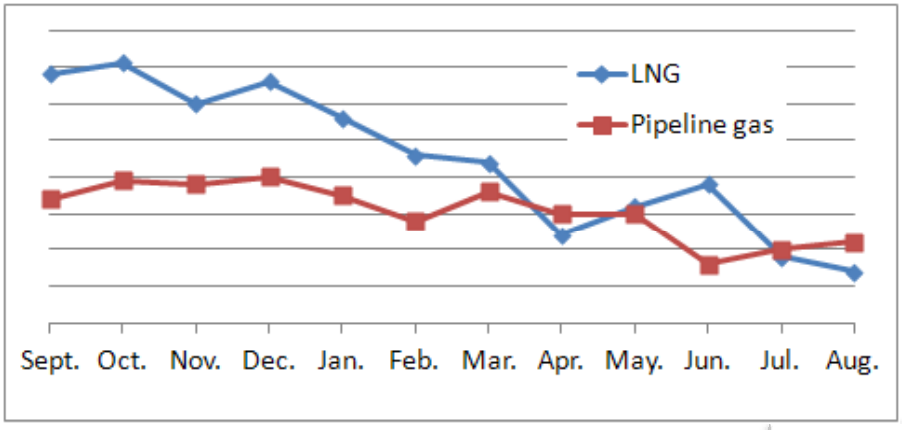
And they can just fulfill the IMO Tier Ⅰ emission limits, and made lots of exhaust pollution along the inland and coast.

Background



Using gas can make a much lower pollution level than diesel.

Background



*Detail date quoted from Asiachem.com

Last 12 months in China, the import price about LNG and pipeline gas.

船机类型	单缸排量（SV）（L/缸）	额定净功率（P）（kW）	CO (g/kWh)	HC+NO_X (g/kWh)	PM (g/kWh)
第 1 类	SV<0.9	P≥37	5.0	5.8	0.3
	0.9≤SV<1.2		5.0	5.8	0.14
	1.2≤SV<5		5.0	5.8	0.12
第 2 类	5≤SV<15	P<2000	5.0	6.2	0.14
		2000≤P<3700	5.0	7.8	0.14
		P≥3700	5.0	7.8	0.27
	15≤SV<20	P<2000	5.0	7.0	0.34
		2000≤P<3300	5.0	8.7	0.50
		P≥3300	5.0	9.8	0.50
	20≤SV<25	P<2000	5.0	9.8	0.27
		P≥2000	5.0	9.8	0.50
	25≤SV<30	P<2000	5.0	11.0	0.27
		P≥2000	5.0	11.0	0.50


GB
中华人民共和国国家标准

船舶压燃式发动机排气污染物排放限值及测量方法（中国第一、二阶段）

环境保护部
国家质量监督检验检疫总局

NOx and PM emission from the ship must be reduced to a lower level in the near future.

"Limits and measurement methods for exhaust pollutants from marine compression ignition engines (CHINA Ⅰ, Ⅱ)"

Background

Complete, being build, and plan to build LNG receiving station, along the river and coast in China.

West-to-East Natural Gas Transmission Project

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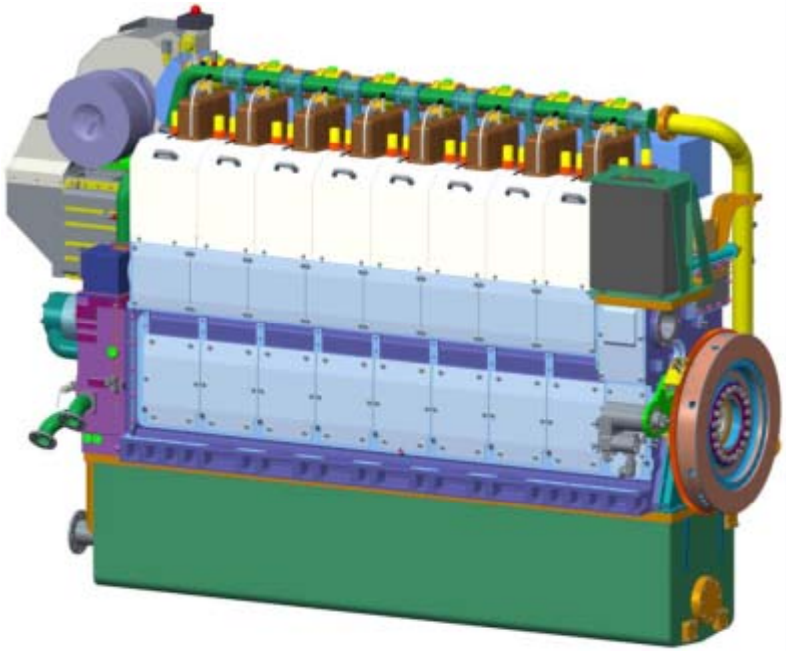
Introduction of M23G gas engine

■Prototype engine is a 210mm bore size diesel engine-CS21 diesel engine

- 6,8,9 cylinders, 900~1000rpm
- Power range:1320~1980kW
- Conventional fuel system/Common rail
- IMO Tier Ⅱ / IMO Tier Ⅲ with SCR
- For marine and power generation application
- With independent intellectual property rights

Introduction of M23G gas engine



■M23G gas engine specification

- Bore:230mm,Stroke:320mm
- 6,8,9 cylinders, 900~1000rpm
- Power range：1200kW-1800kW@1000rpm
- Pre-chamber spark ignition, Gas port injection, A/F ratio control
- Fulfill with IMO Tier Ⅲ limits and requirements with Ministry of Environmental Protection in China, without any after-treatment
- For marine and power generation application
- Inherently safe design for marine application

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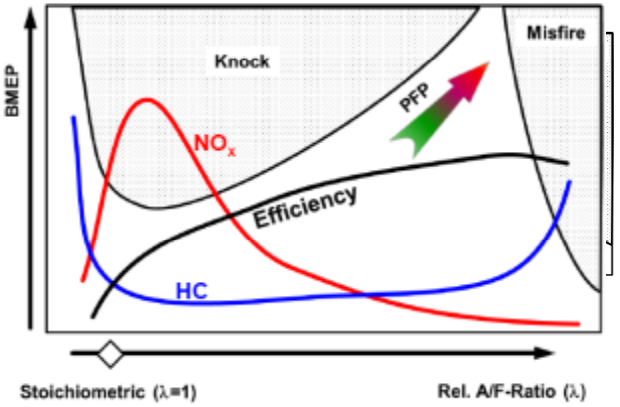
Simulation investigation of combustion

- *Key point of lean-burn combustion*



Flow and mixture status

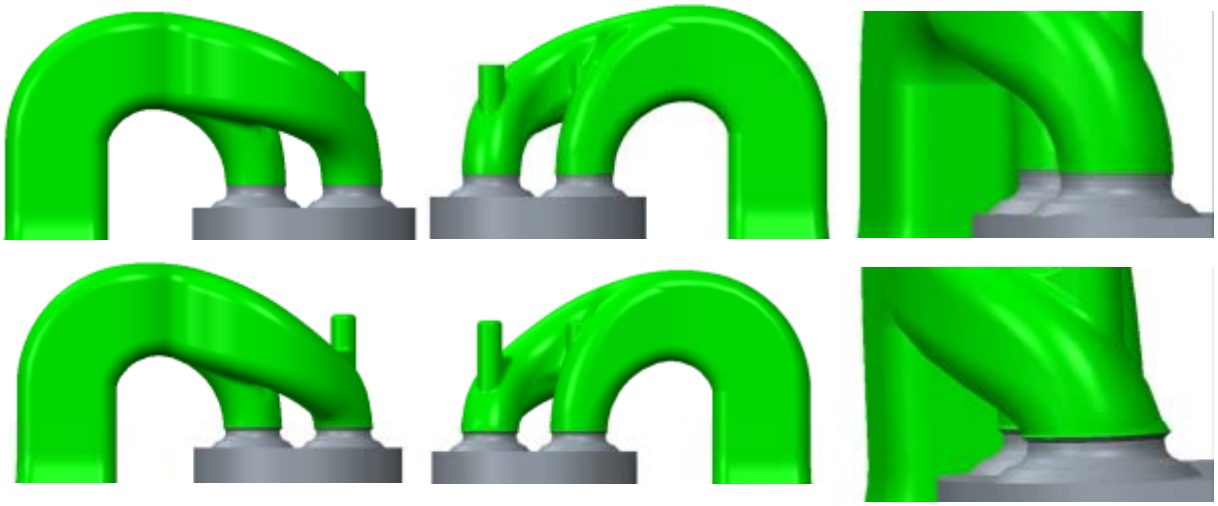
- Intake port
- Gas inlet nozzle

Ignition and jet flow flame

- Pre-chamber
- Piston top

Simulation investigation of combustion

- *Intake port*



Lower swirl

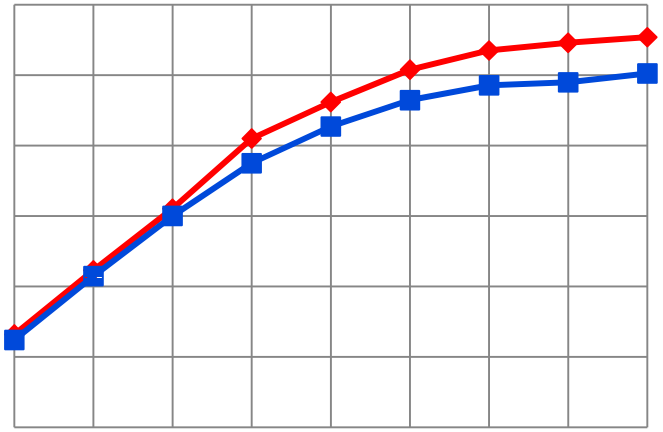
Higher swirl

The lower swirl intake port is modelling from the diesel engine.

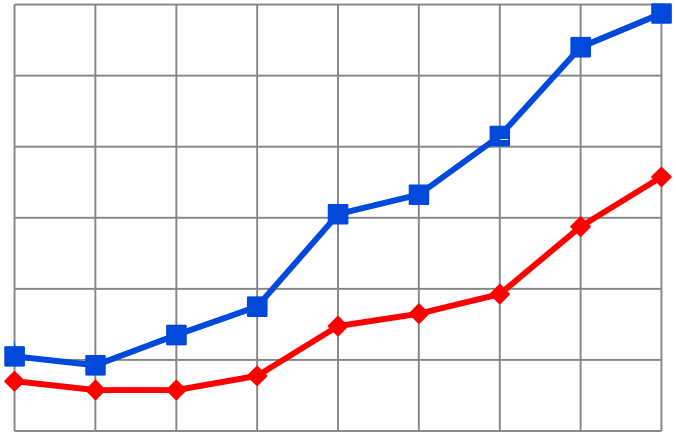
Simulation investigation of combustion

- *Intake port*

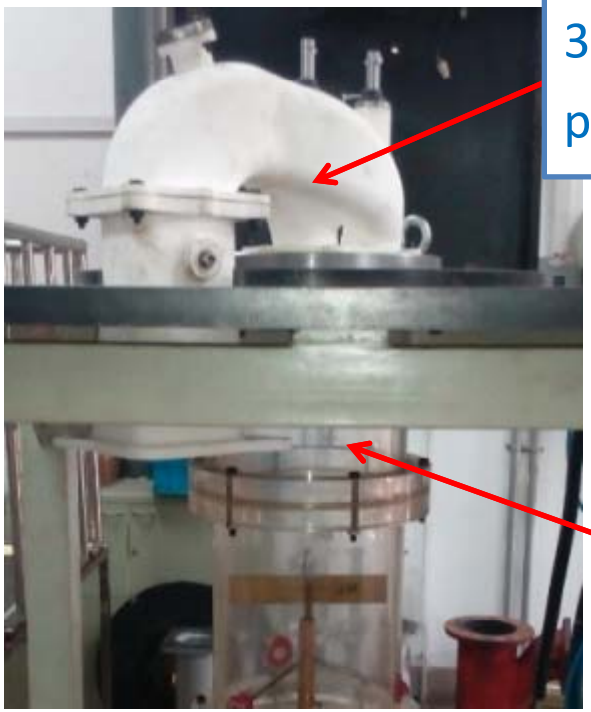
Flow coefficient



Swirl number



Valve lift



3D printing intake port pattern

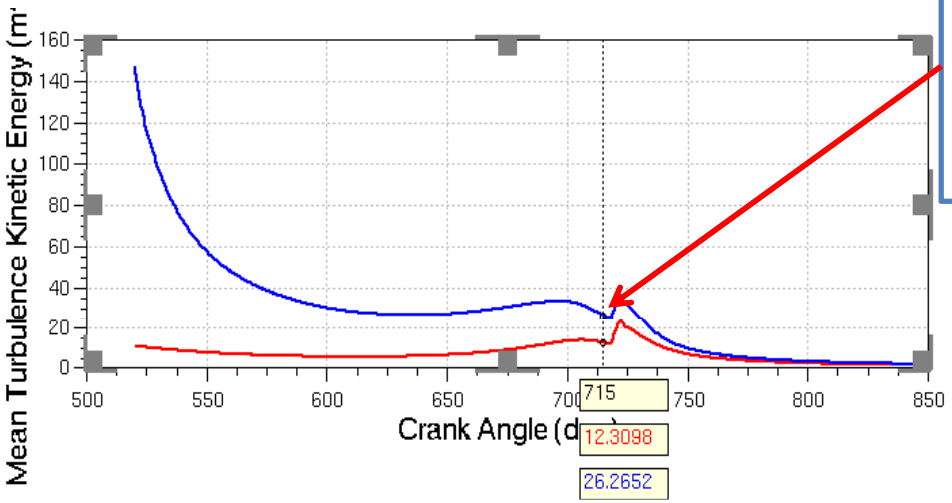
Flow test rig

Higher swirl

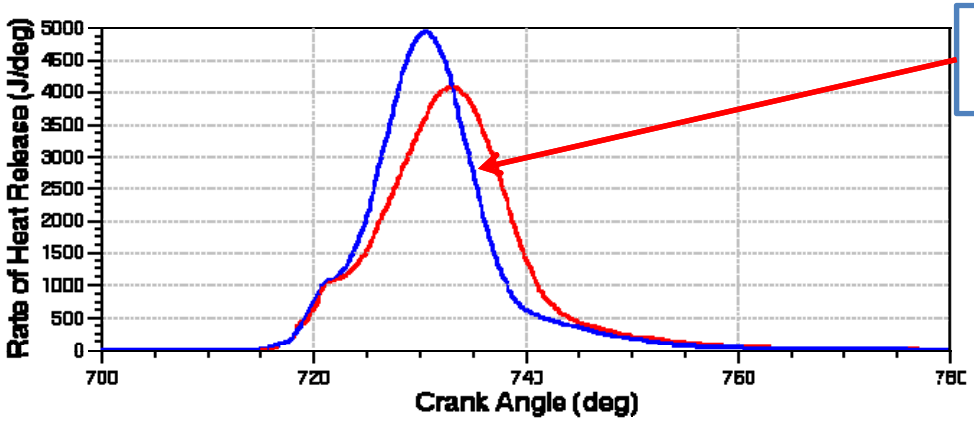
Lower swirl

Simulation investigation of combustion

- *Intake port*



■High swirl number intake port has higher Turbulence kinetic energy (TKE) at the start of combustion (SOC)



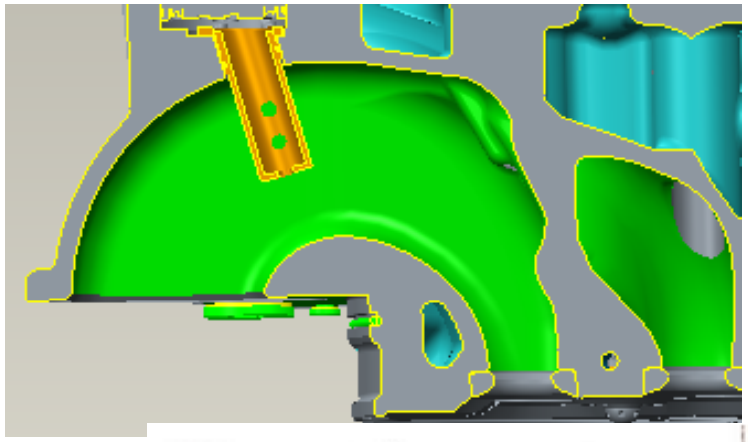
■Higher TKE makes faster combustion

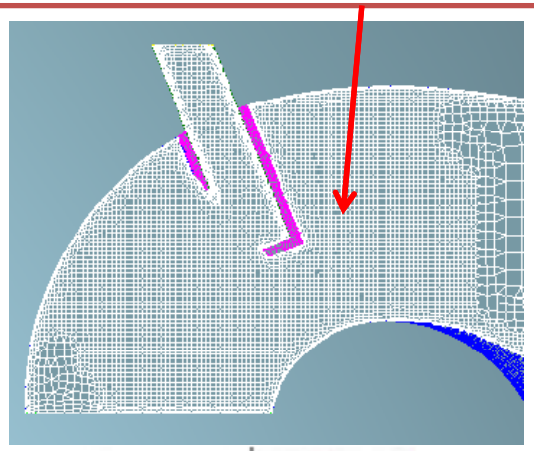
Higher swirl
Lower swirl

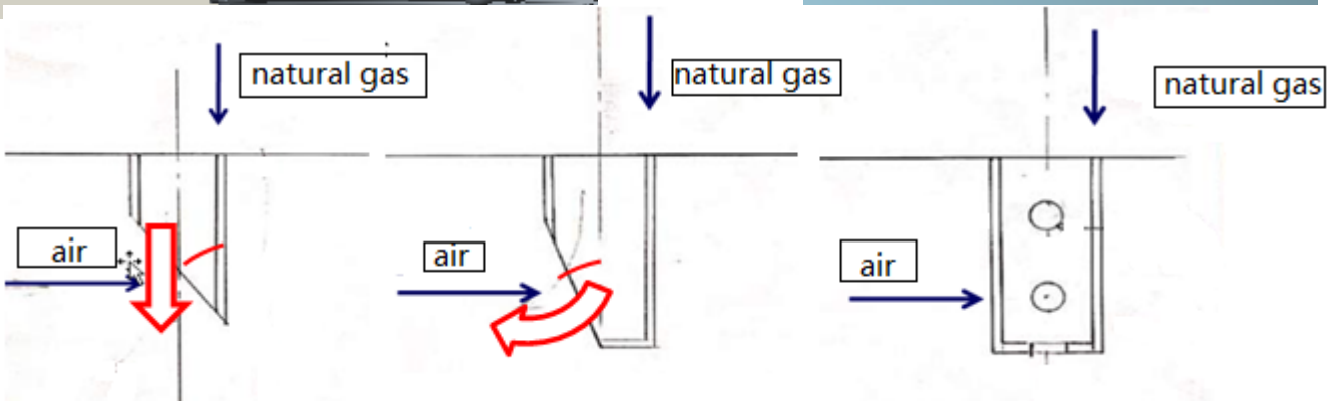
Simulation investigation of combustion

- *Gas inlet nozzle*

■Cells concentration near by the nozzle







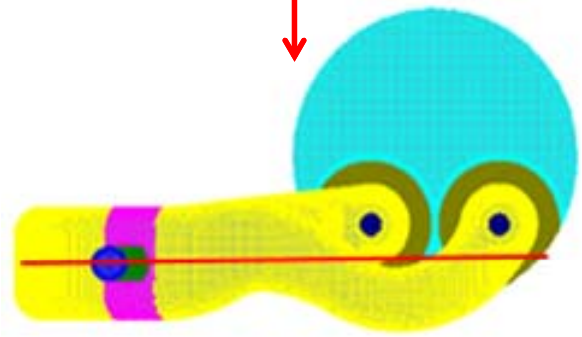
Bevel angle cut　　Half bevel angle cut　　Multiholes

CIMAC

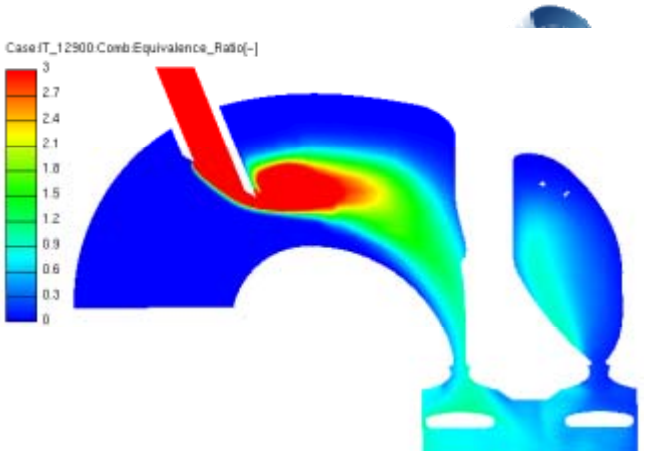
Simulation investigation of combustion

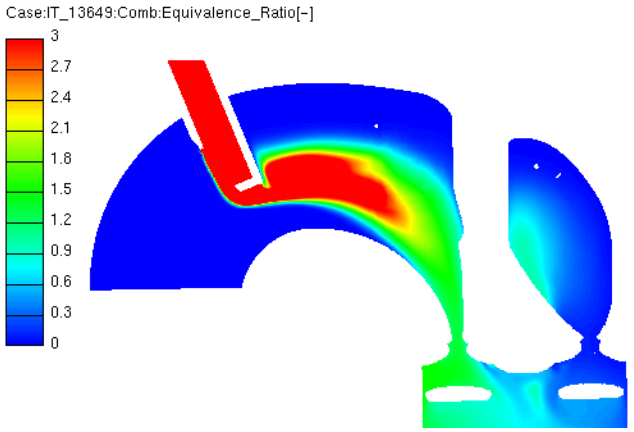
•*Gas inlet nozzle*

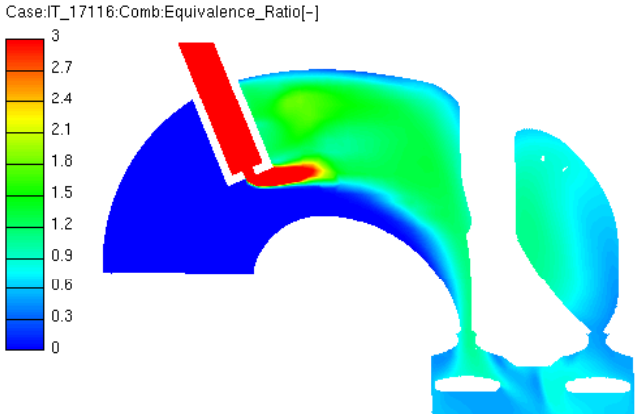
■Equivalence ratio distribution along the vertical section in the intake port



■Multi-holes has the better mixture effect



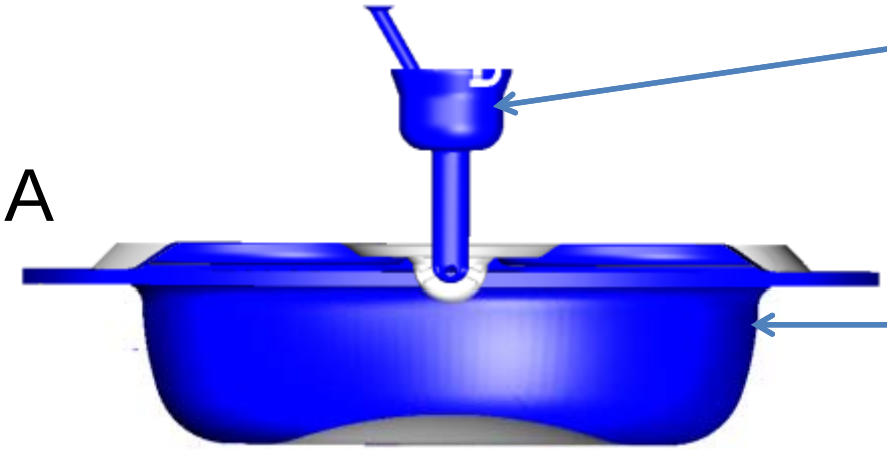




Simulation investigation of combustion

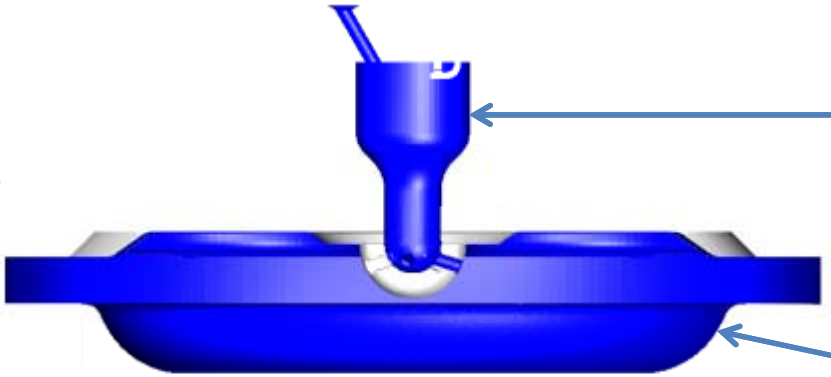
- *Pre-chamber&Piston top*

A



- Vpc is 1.5% of Vc
- 6 holes around the end of nozzle
- Long and slender neck
- Step between upper part and neck
- Very short clearance for squish
- Deep bowl with up at the bottom central of piston top for turbulence

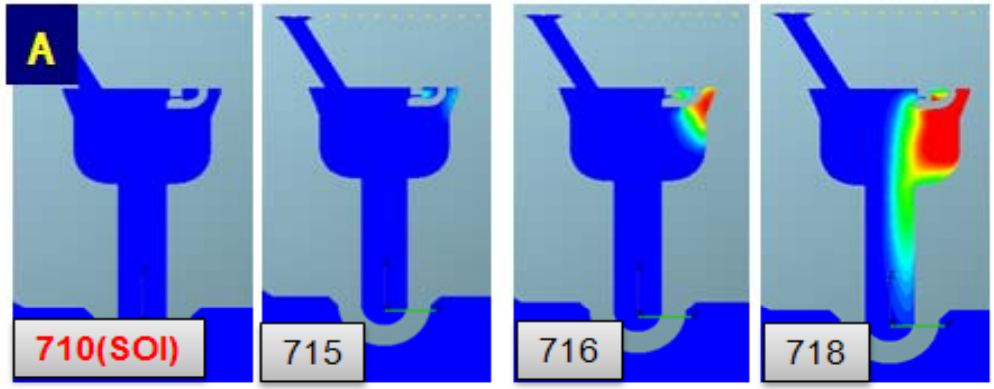
B



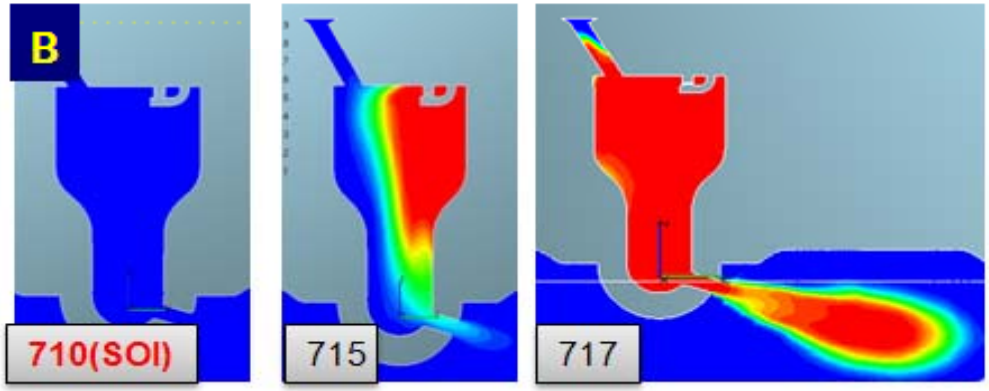
- Vpc is 2.5% of Vc
- 7 holes around the end of nozzle
- Short and thick neck
- Smooth connection upper part and neck
- Higher clearance for decrease HC emission
- Shallow bowl with flat bottom

Simulation investigation of combustion

- *Pre-chamber&Piston top*



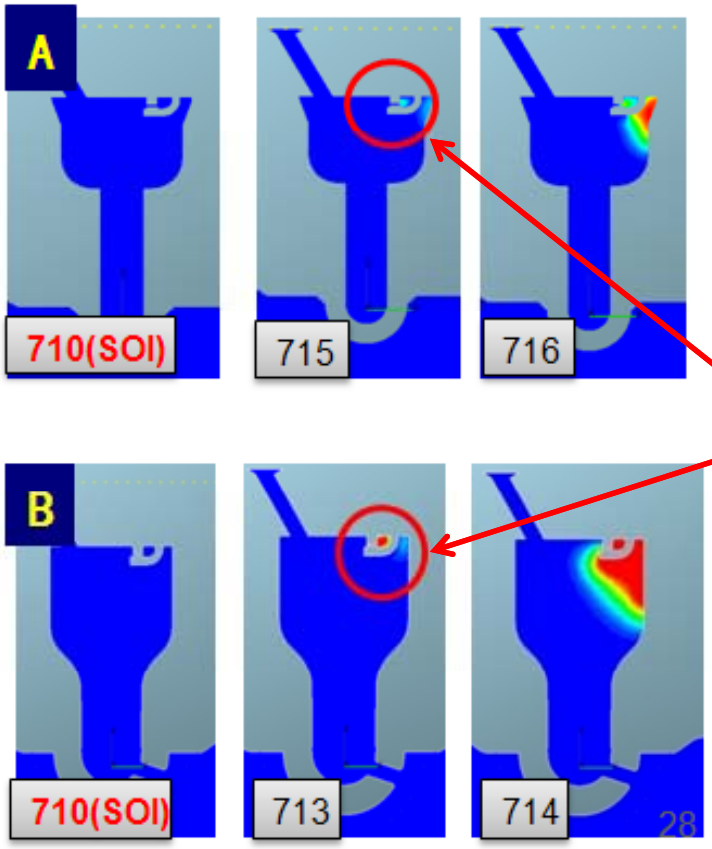
■***Combustion reaction progress*** in pre-chamber and main chamber can show the difference obviously



■During the whole process, B has faster combustion reaction progress than A

Simulation investigation of combustion

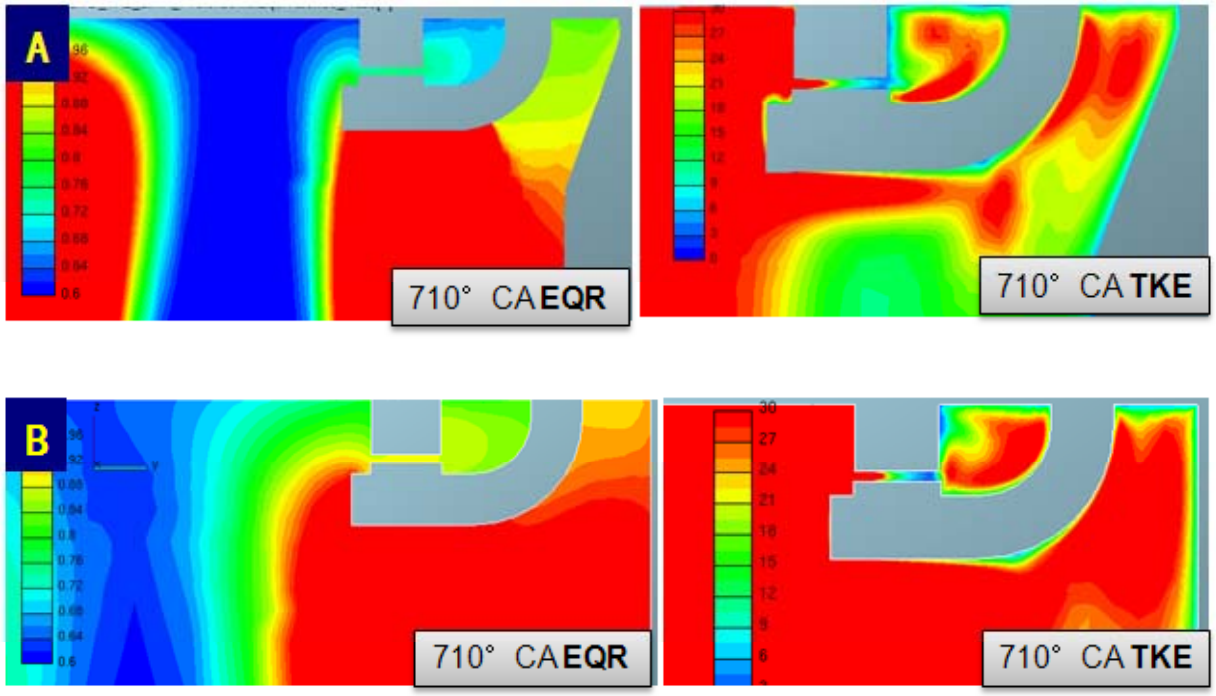
- *Pre-chamber&Piston top*



■Around the spark plug, B come out the earlier initial flame core than A

Simulation investigation of combustion

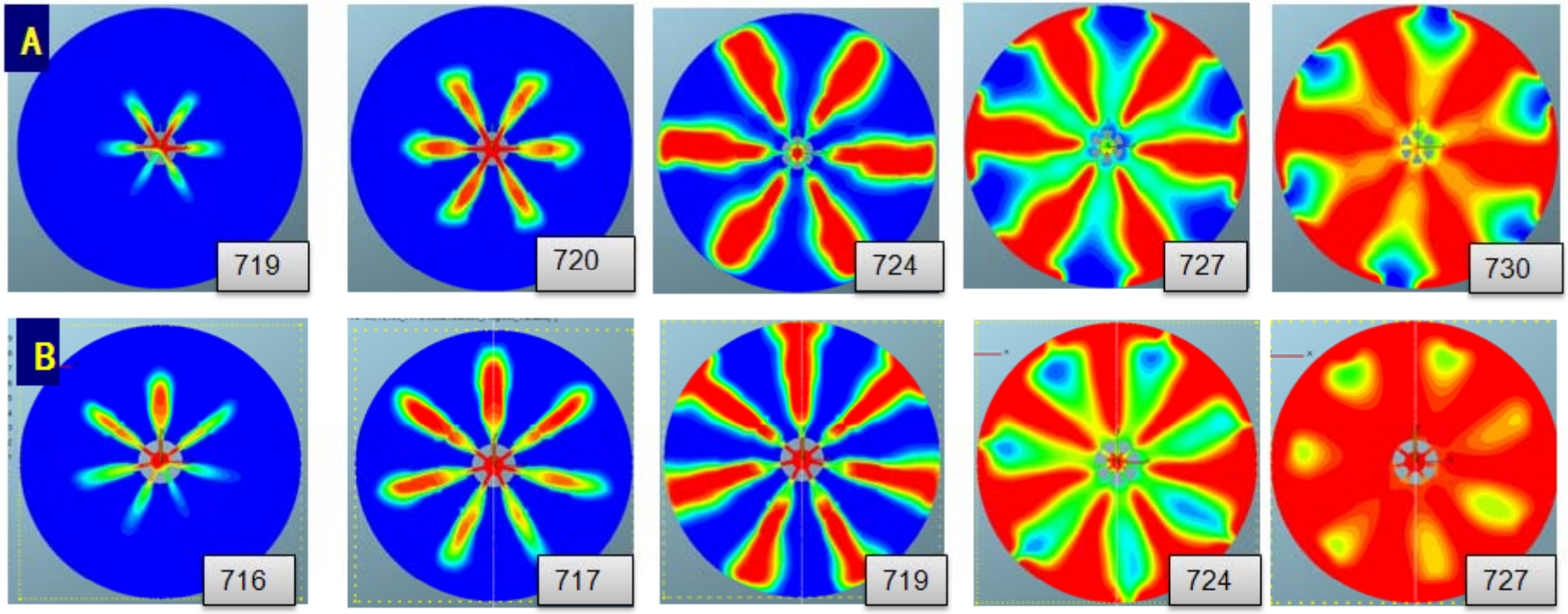
- *Pre-chamber&Piston top*



- At the SOI, B has the higher EQR(equivalence ratio) and TKE around the spark plug.

Simulation investigation of combustion

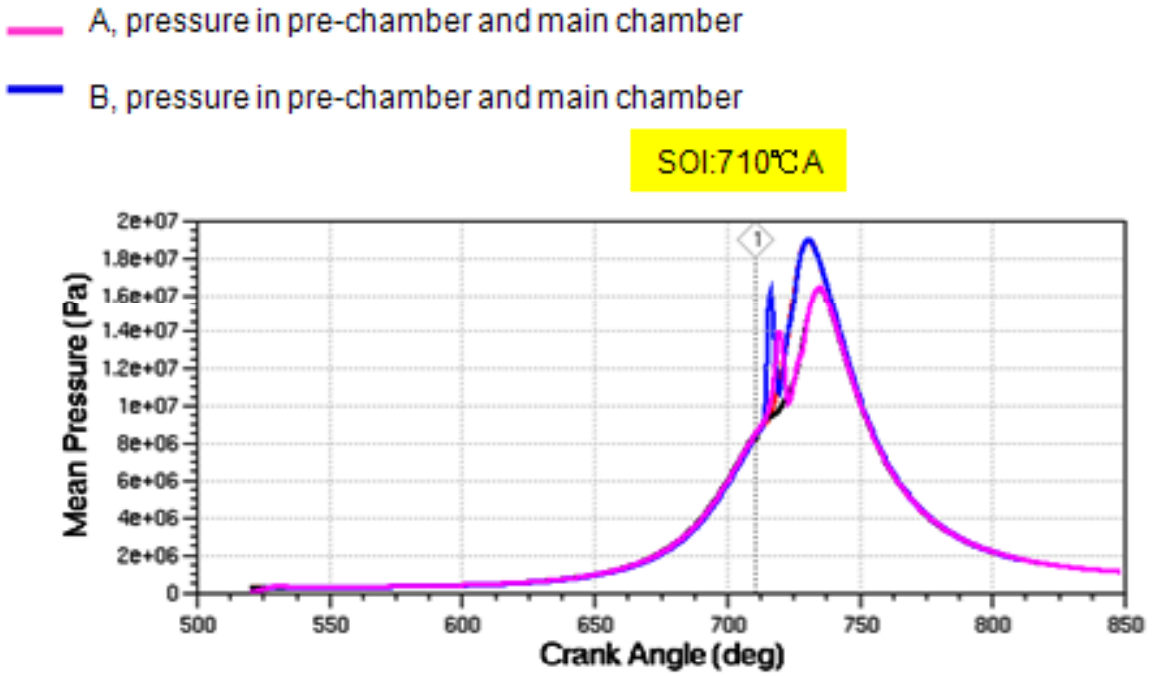
- *Pre-chamber&Piston top*



■ When the torch flame into main chamber, the combustion reaction progress in B is more faster than A, that will be good for efficiency.

Simulation investigation of combustion

- *Pre-chamber&Piston top*

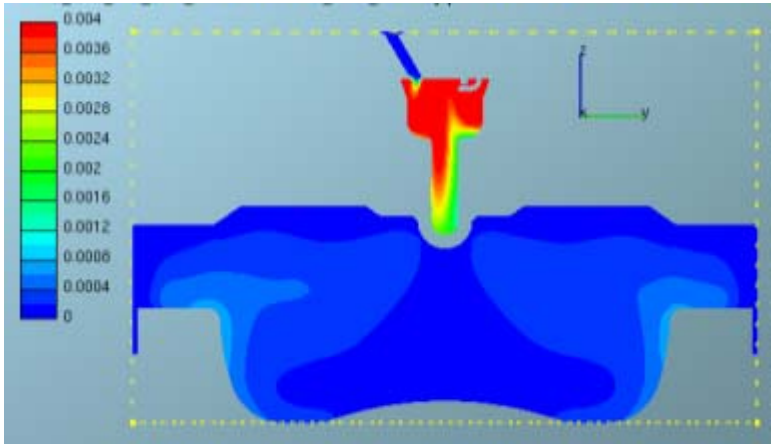


■Due to the bigger volume and earlier shaping of initial flame core, pressure in pre-chamber with B is much higher than A, so the peak firing pressure in main chamber also higher, that corresponds to the combustion reaction progress .

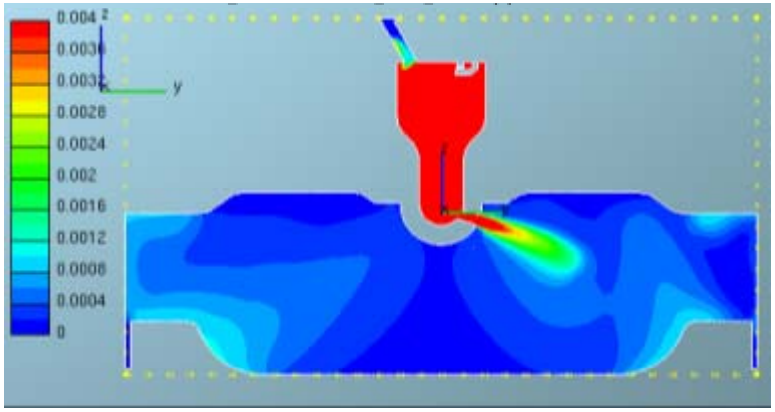
Simulation investigation of combustion

- *Pre-chamber&Piston top*

- Mainly NOx emission were generated in the pre-chamber
- B has more NOx emission than A



A

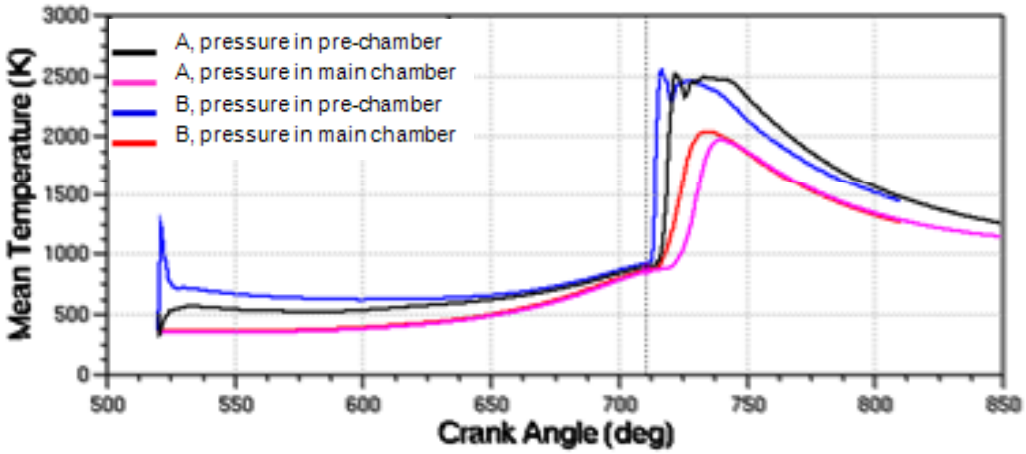


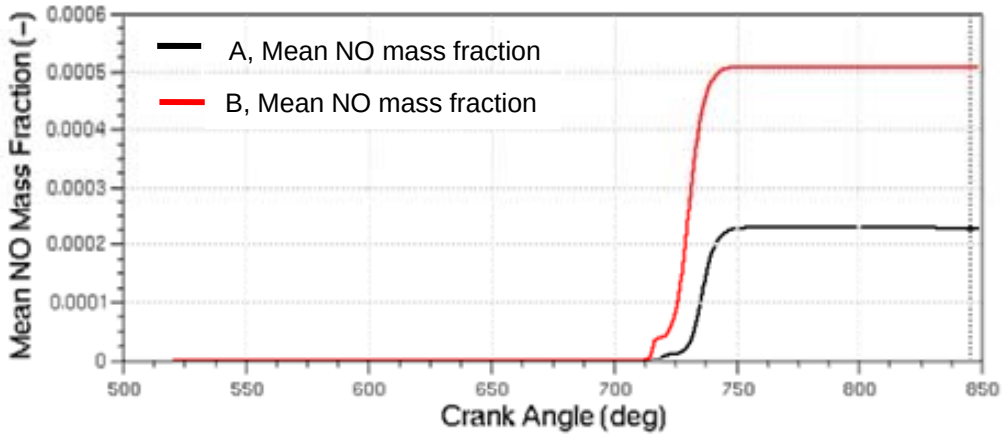
B

Simulation investigation of combustion

•*Pre-chamber&Piston top*

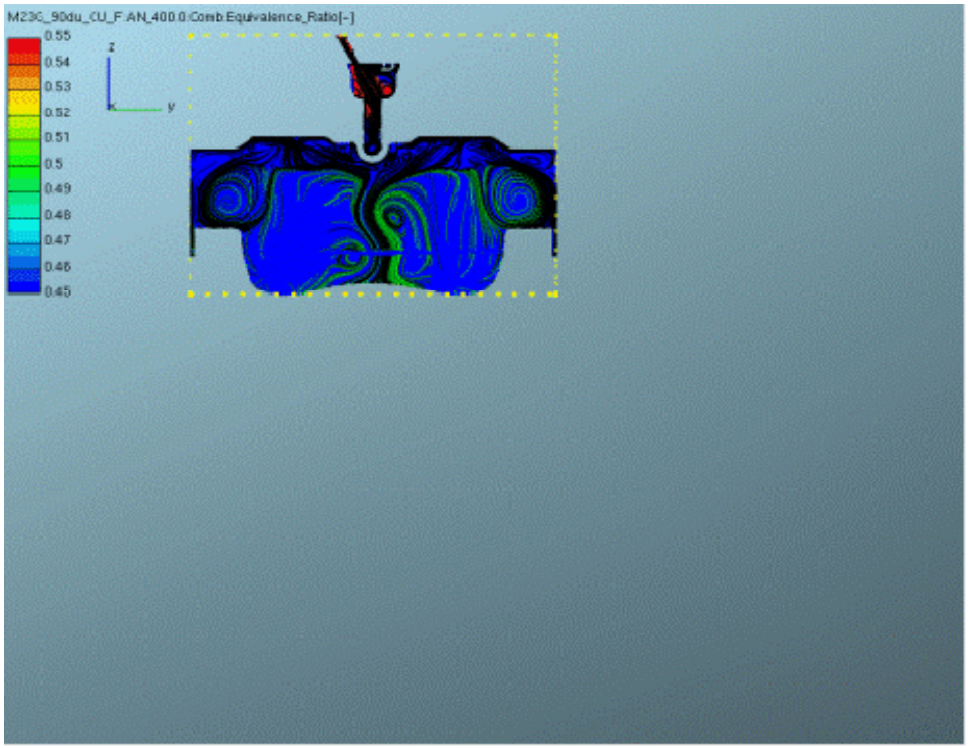
- Due to the highly temperature in, most of NOx were generated in pre-chamber
- Meanwhile, higher pressure come along with higher temperature, that is why B has more NOx than A.





Simulation investigation of combustion

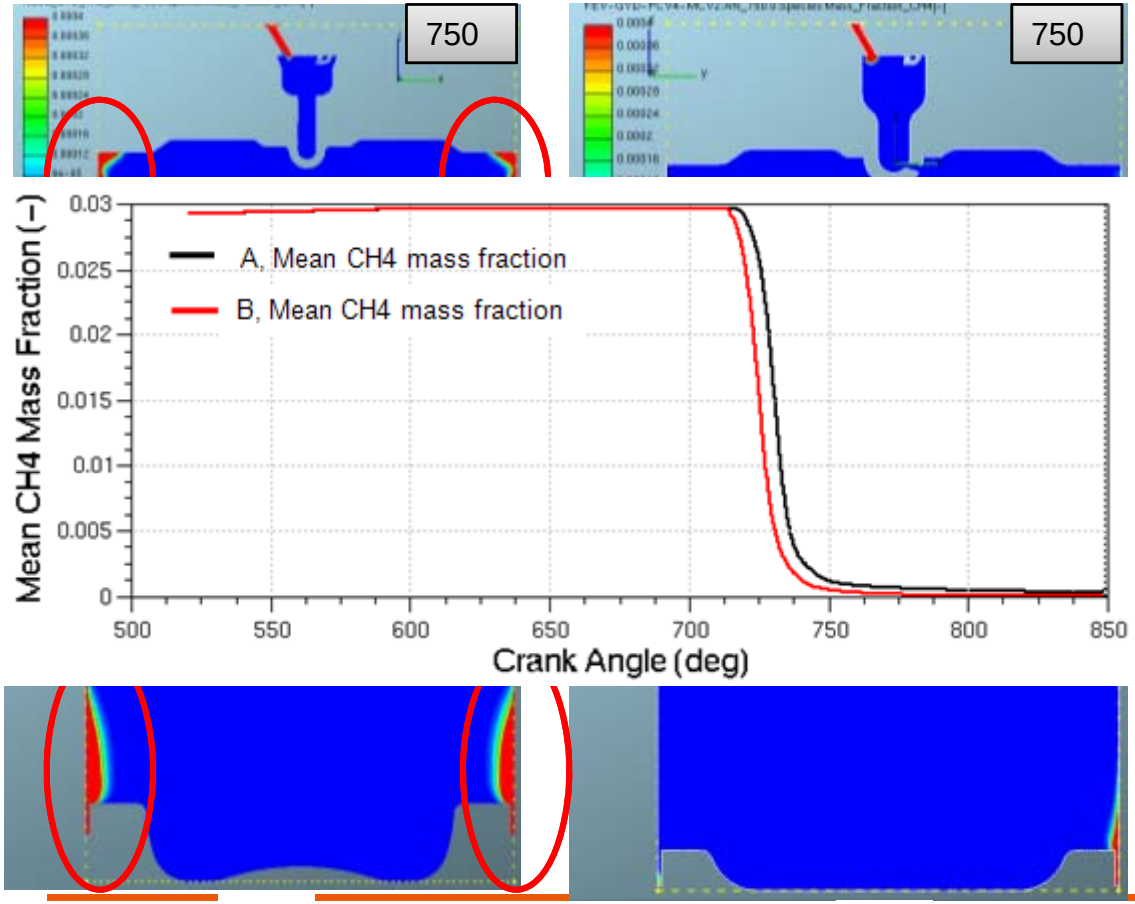
- *Pre-chamber&Piston top*



- Calculation from intake stroke to compression stroke(400~720CA)

Simulation investigation of combustion

- *Pre-chamber&Piston top*

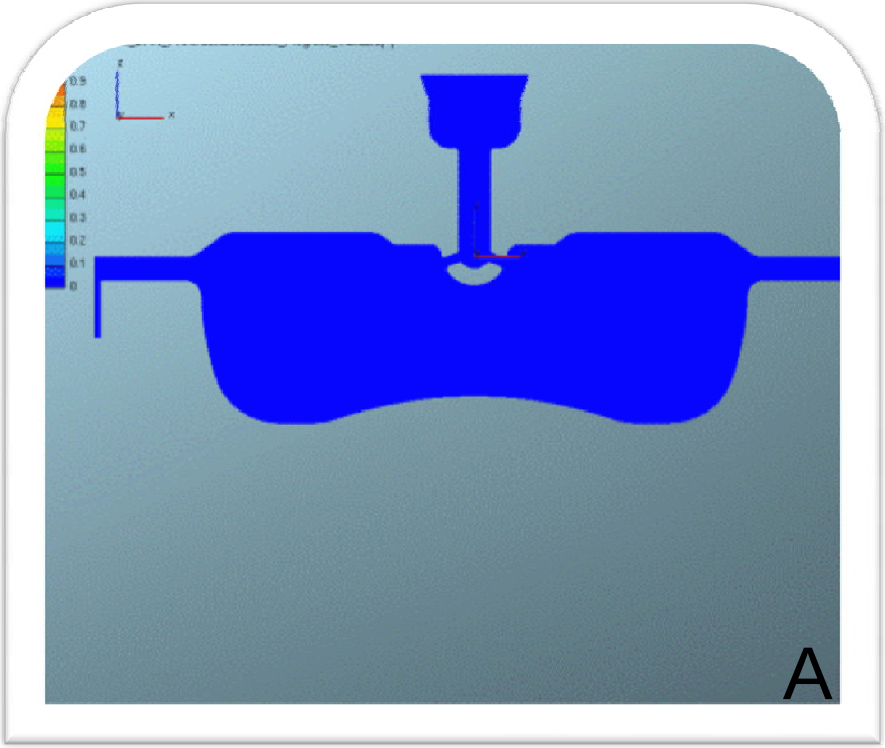


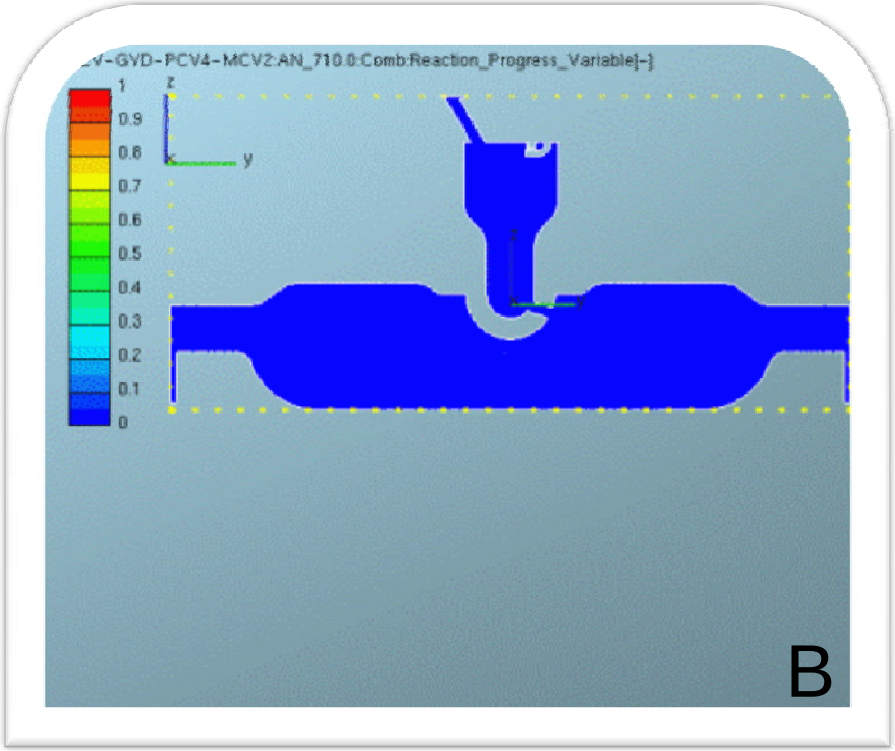
- Unburned HC

- Because of the short clearance, some CH4 between the clearance can not be ignited during whole combustion process, so the A type has more unburned HC in the emission.

Simulation investigation of combustion

- *Pre-chamber&Piston top*





- Whole combustion process with transient CFD simulation result
- For the combustion reaction progress, B is faster than A

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Summary

- To increase the intake port swirl number can accelerate the combustion progress

- For multi-point admission gas engine, use a multi-holes gas inlet nozzle can improve the mixing.

- Bigger volume and round body of pre-chamber, can make more powerful torch flame into main chamber, and accelerate the combustion rate for gain higher efficiency, but come along with higher NOx as consequence.

- Short clearance on the piston top will give some squish effect to generate the tumble in main chamber, but also store some CH4 as unburned HC in the combustion process.

Follow up work

- Optimization simulation of pre-chamber and piston with various compression ratio, swirl number and initial A/F ratio

- Test validation with various test piece of cylinder head(intake port),gas inlet nozzle, pre-chamber and piston top

Thanks for your attention!

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