# COMBUSTION AND EXHAUST EMISSION IN COMPRESSION IGNITION ENGINES WITH DUAL- FUEL SYSTEM


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**ENGINE-EXPO 2008 – OPEN TECHNOLOGY FORUM**
**STUTTGAT, 7 MAY 2008**

# APPLICATIONS OF DUAL FUEL SYSTEMS IN CI ENGINES

- Application of alternative fuels, particularly from biomass
- Air mixtures of ethanol or ethanol-diesel cannot be applied in CI engines due to physic-chemical properties (viscosity, suface tension, corrosion etc.)
- Diesel engines can work very well by using of dual fuelling system with chosen proportion of both fuels
- Electronically controlled multipoint port injection of ethanol and direct injection of diesel oil in CI engines
- Electronically controlled multipoint port injection of CNG as a main fuel and direct injection of diesel oil as a pilot fuel (initiation of self-ignition)
- Experimental works on dual fuel diesel engines in Poland since 1980 (Cracow University of Technology, Radom University of Technology, ATH Bielsko Biala)

## Diesel oil – ethanol fuelling system in direct injection CI engine

### ENGINE SPECIFICATION

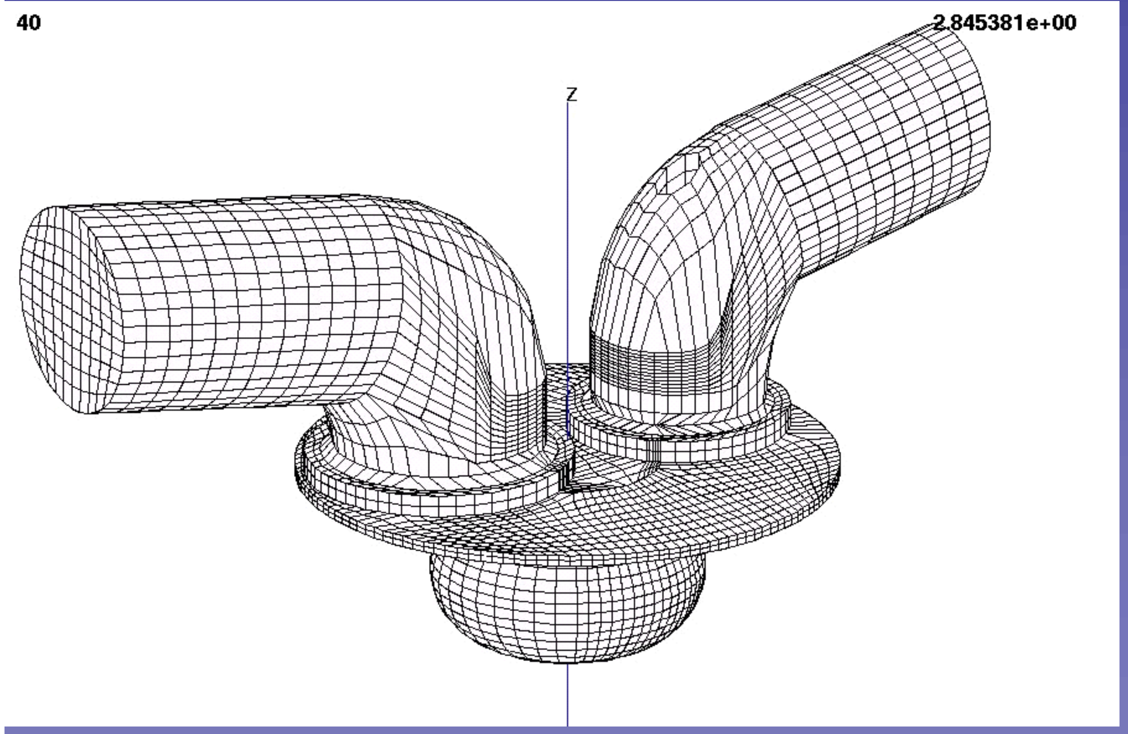
| | |
|---|---|
| Engine type | - Andoria 1HC102 4-stroke CI |
| Cylinder number | - 1 horizontal |
| Bore | - 102 mm |
| Stroke | - 120 mm |
| Capacity | - 980 $cm^3$ |
| Compression ratio | - 17 |
| Nominal power | - 11 kW/2200 rpm |
| Number of inlet valve | - 1 |
| Number of exhaust valve | - 1 |
| Injector | - 1 |
| Position of injector | - 45º to cylinder axis |

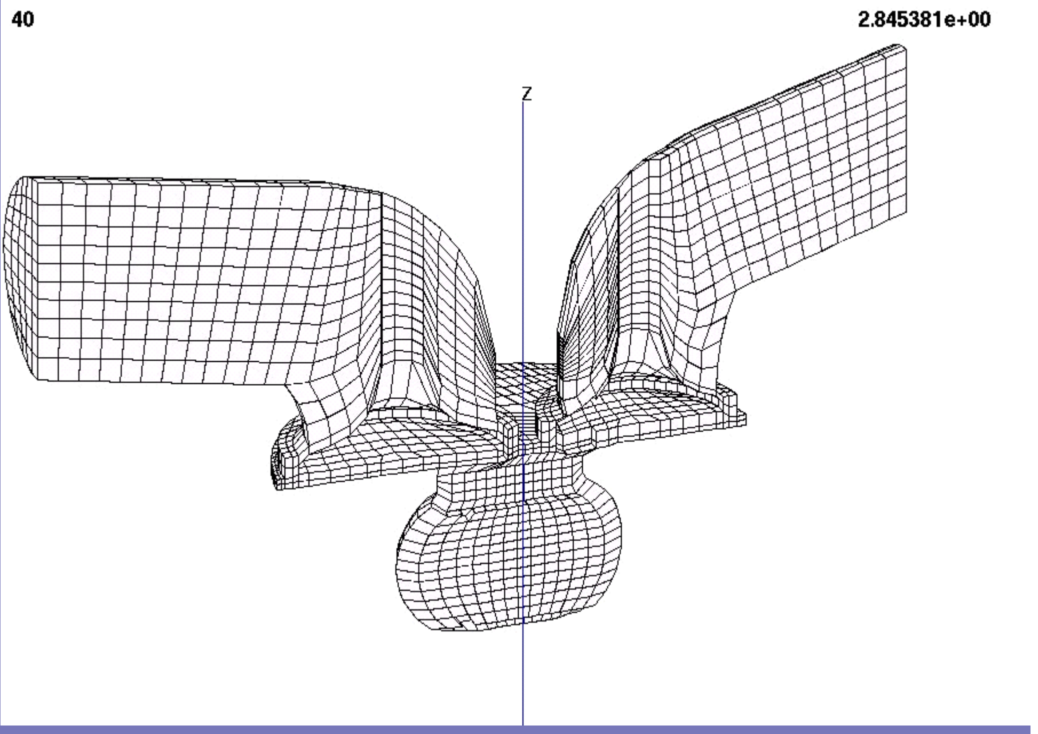
**Analysis of engine work fuelled with diesel oil + ethanol:**

1. Simulation study by CFD KIVA3V program
2. Experimental tests on dynamometer stand

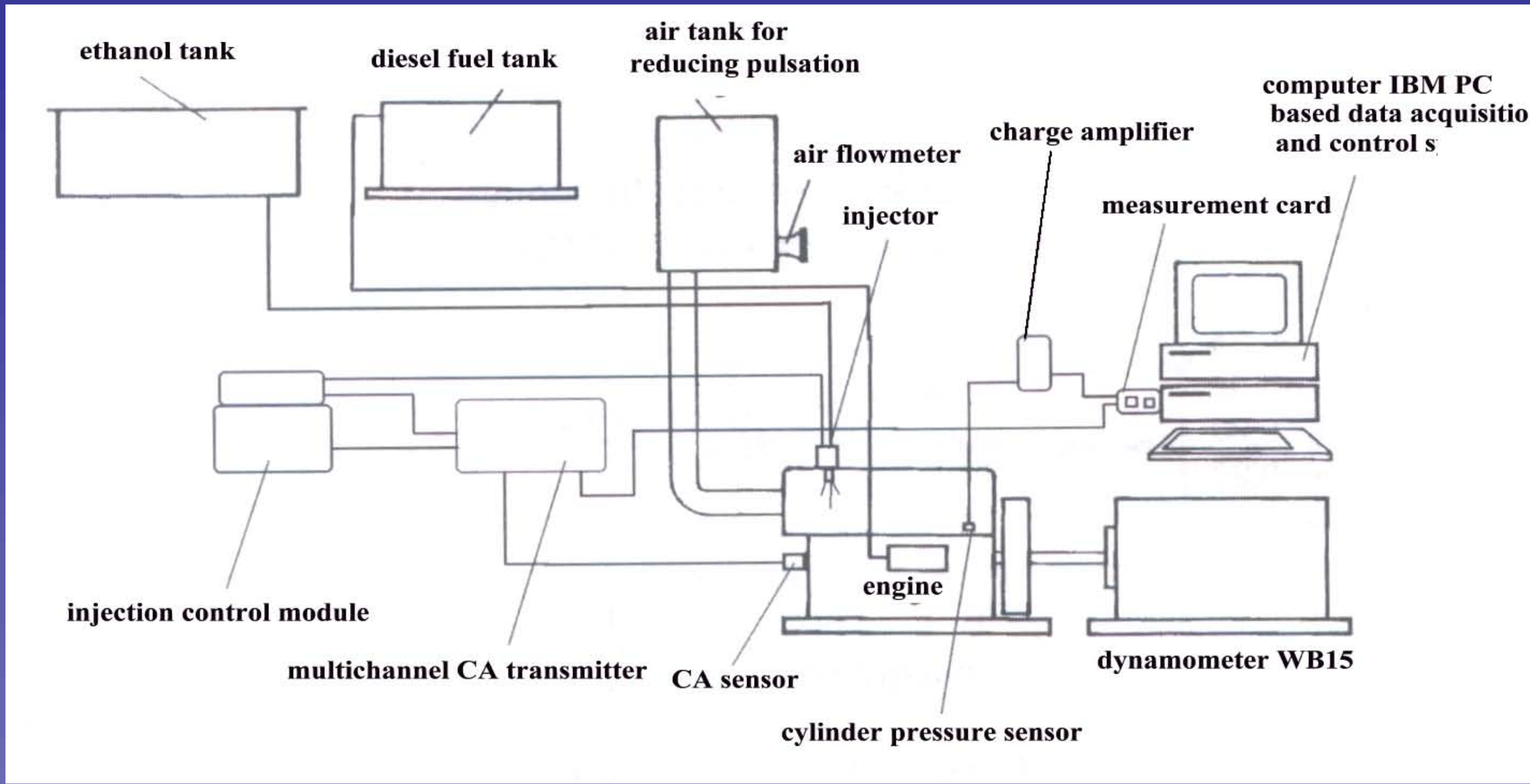
# SIMULATION OF DUAL FUEL COMBUSTION in Andoria 1HC102 diesel engine (program KIVA3V)

## ENGINE MESH

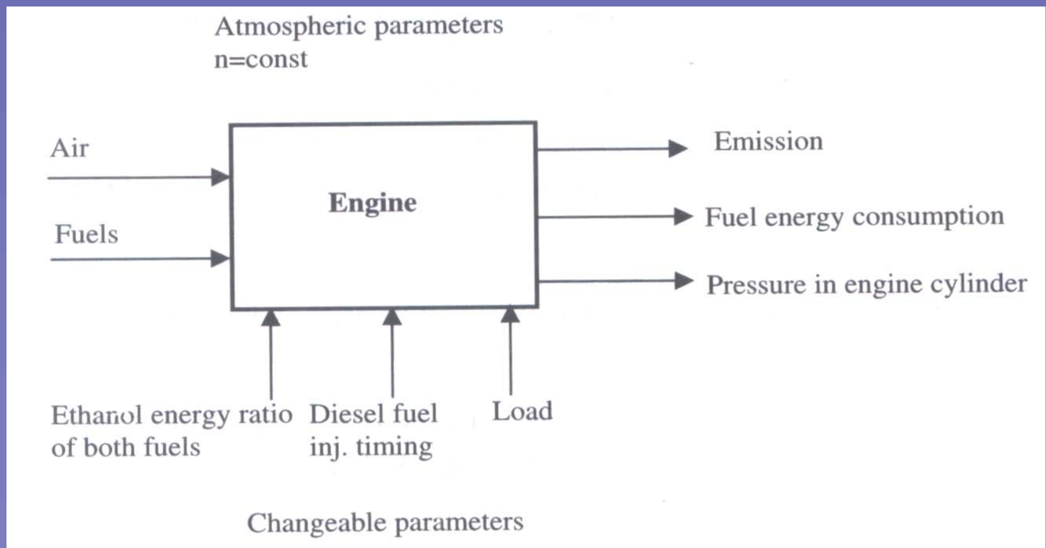


# Experimental stand of dual fuel CI engine (ethanol + DF)

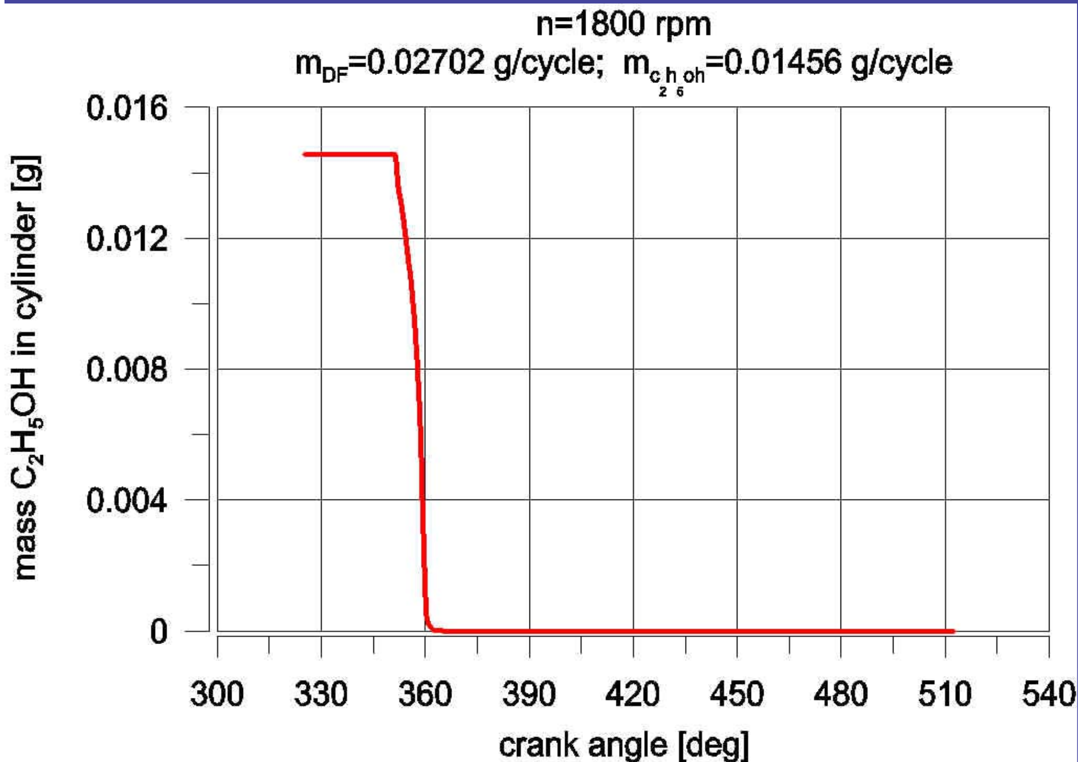



## Diagram of dual fuel system

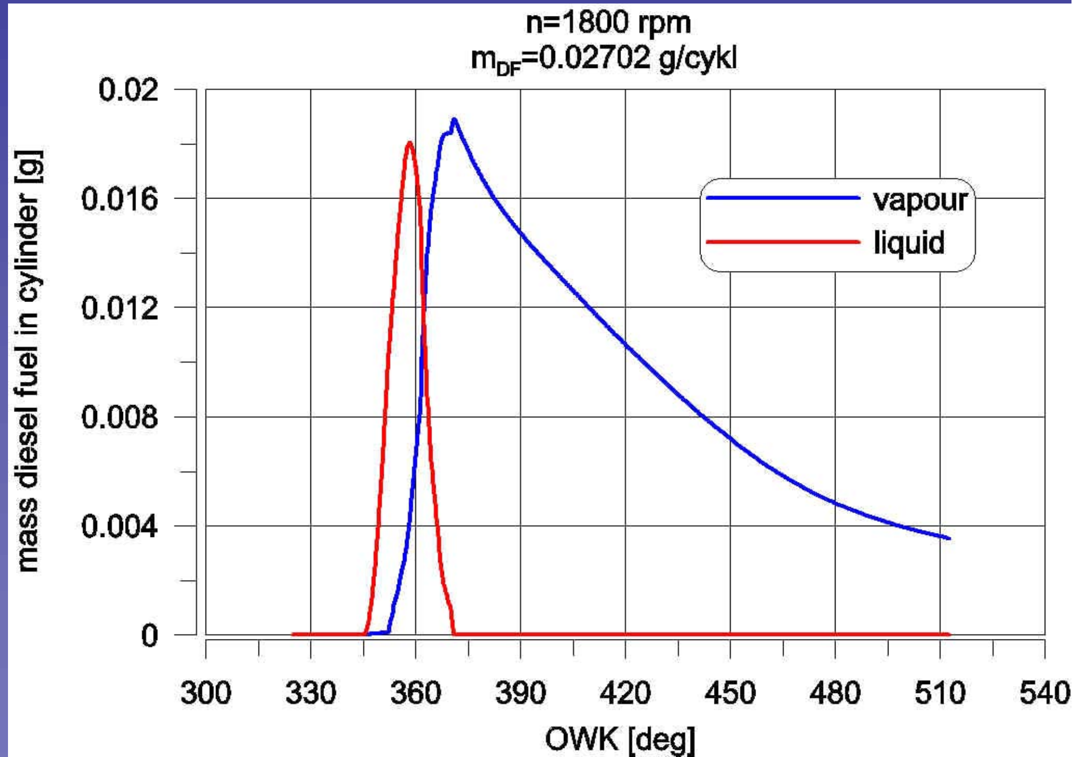


# Simulation results

Combustion of ethanol at 1800 rpm



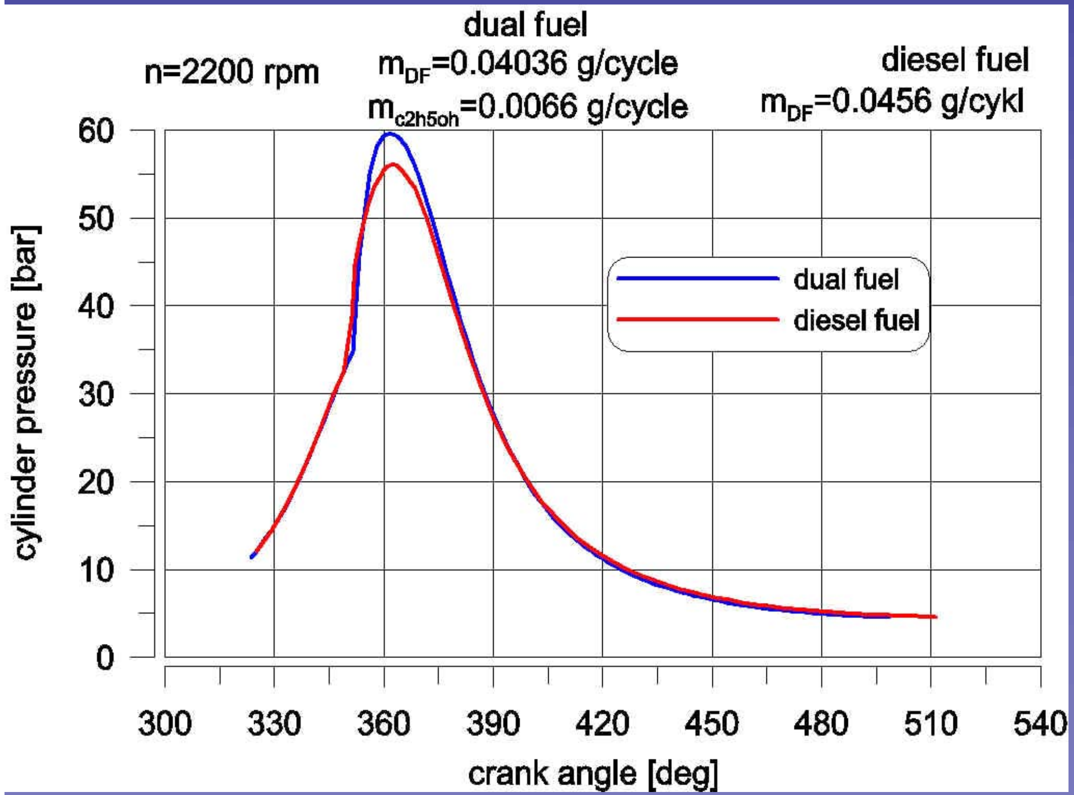

Evaporation and combustion of diesel fuel at 1800 rpm



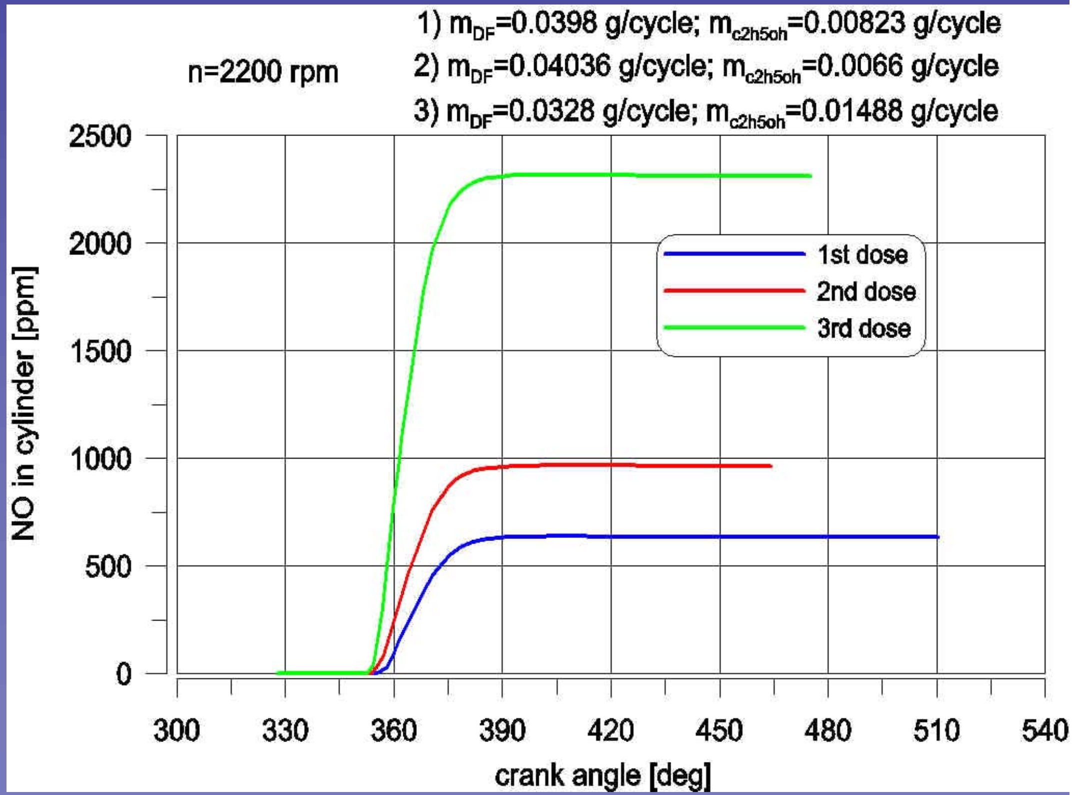
# Simulation results

n=2200 rpm

Comparison of cylinder pressure at 2000 rpm for diesel fuel and dual fuel (ethanol + DF)

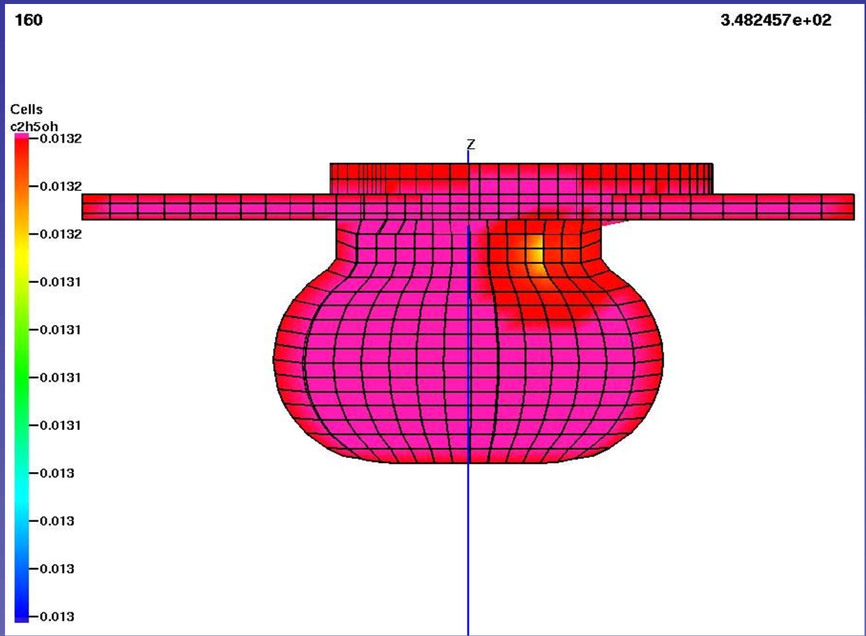



NO cylinder mass concentration for different dual fuel mixtures

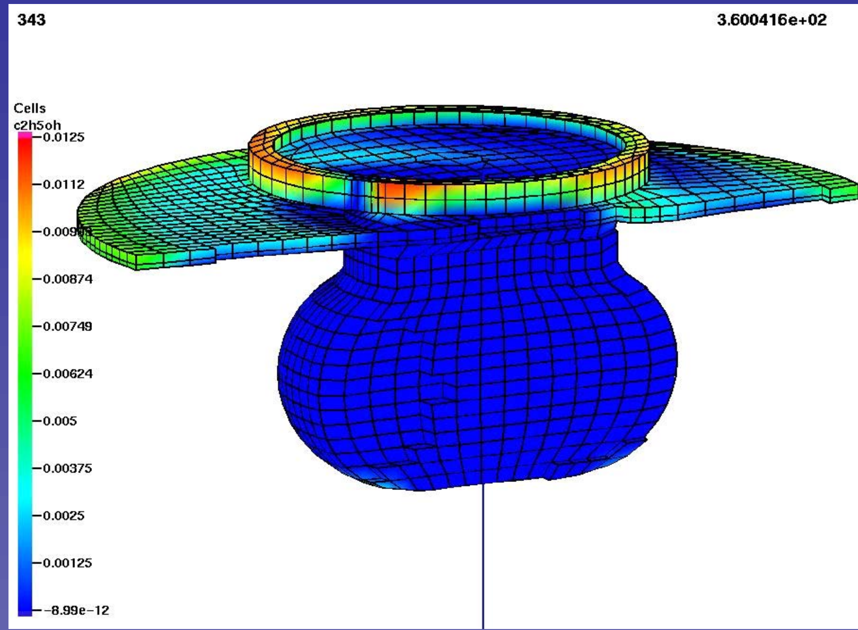


# Simulation results

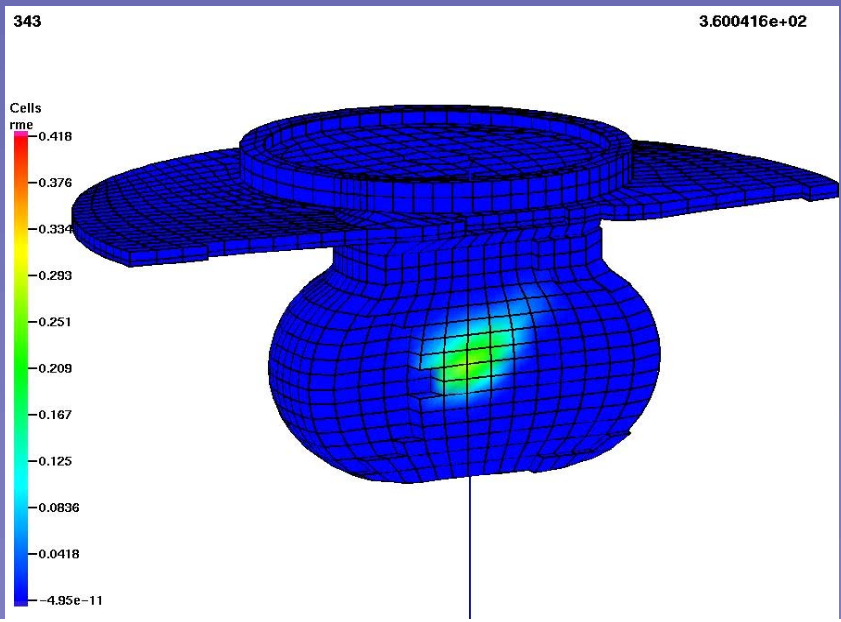
## Ethanol mass ratio at 12 deg BTDC



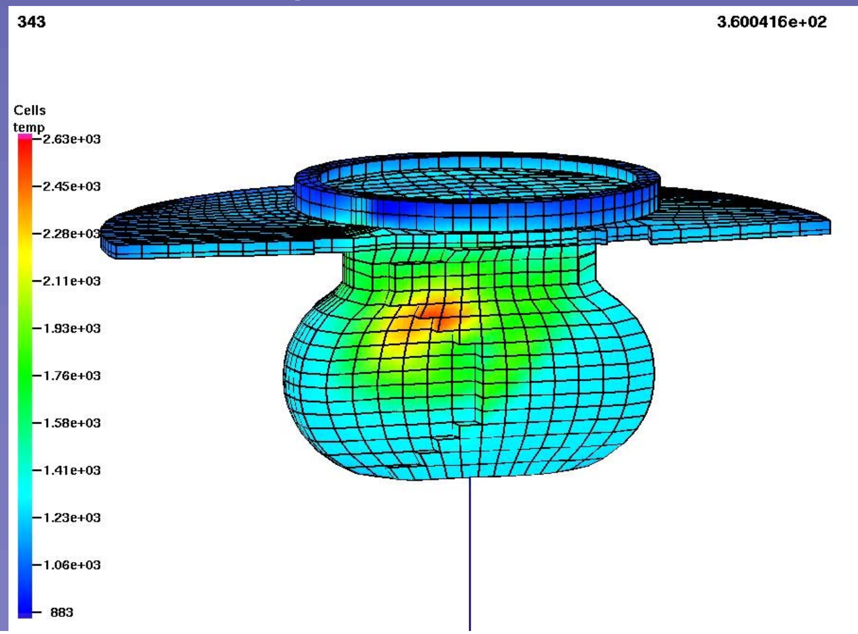

## Ethanol mass ratio at TDC



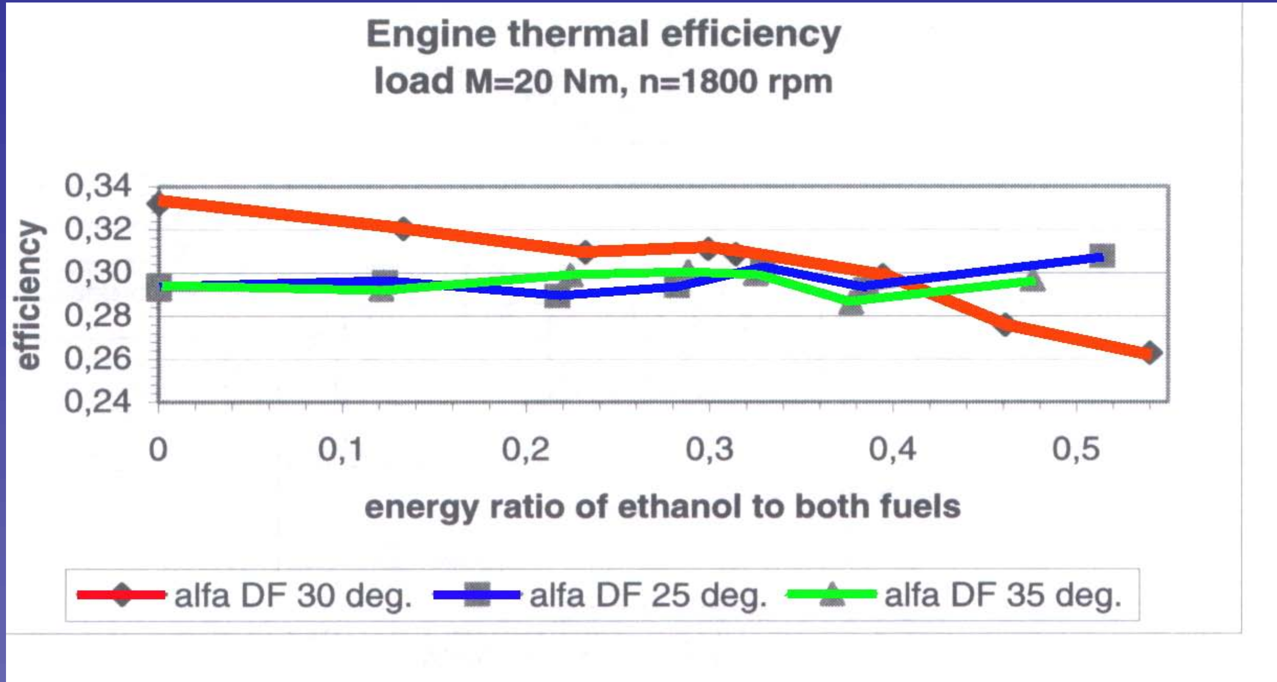

## DF vapour mass ratio at TDC

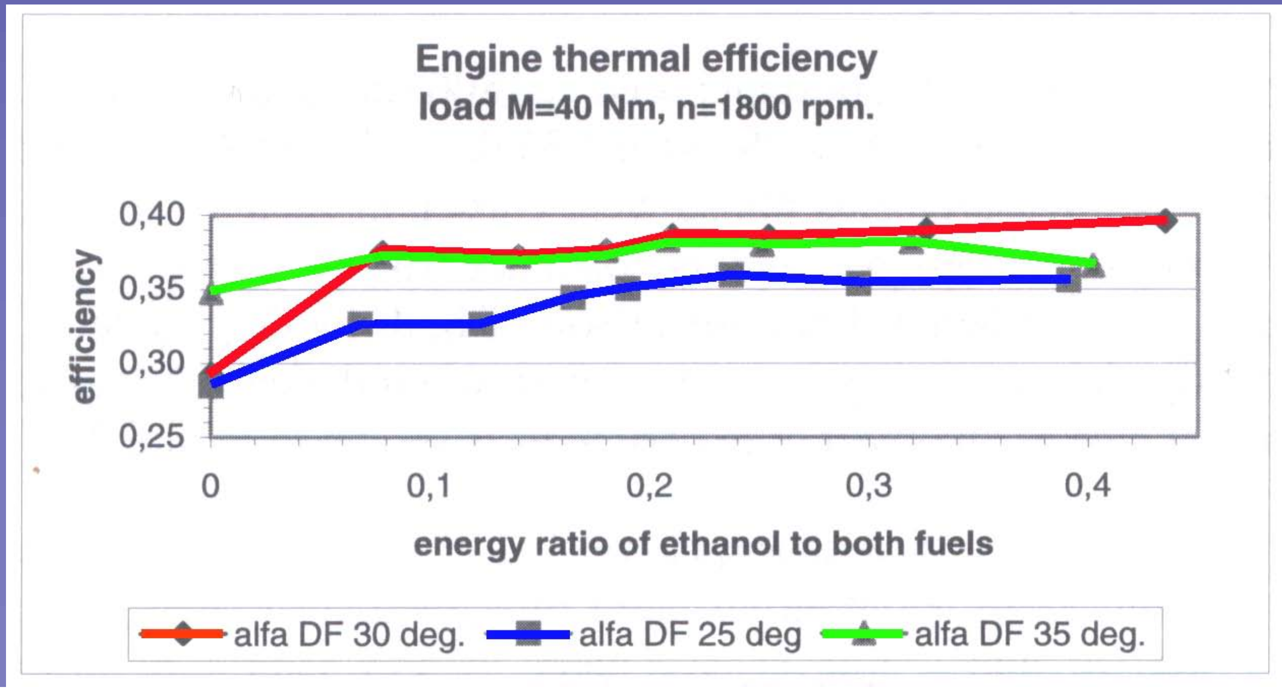



## Temperature at TDC



# Engine thermal efficiency for different loads and energy ratio of ethanol to both fuels

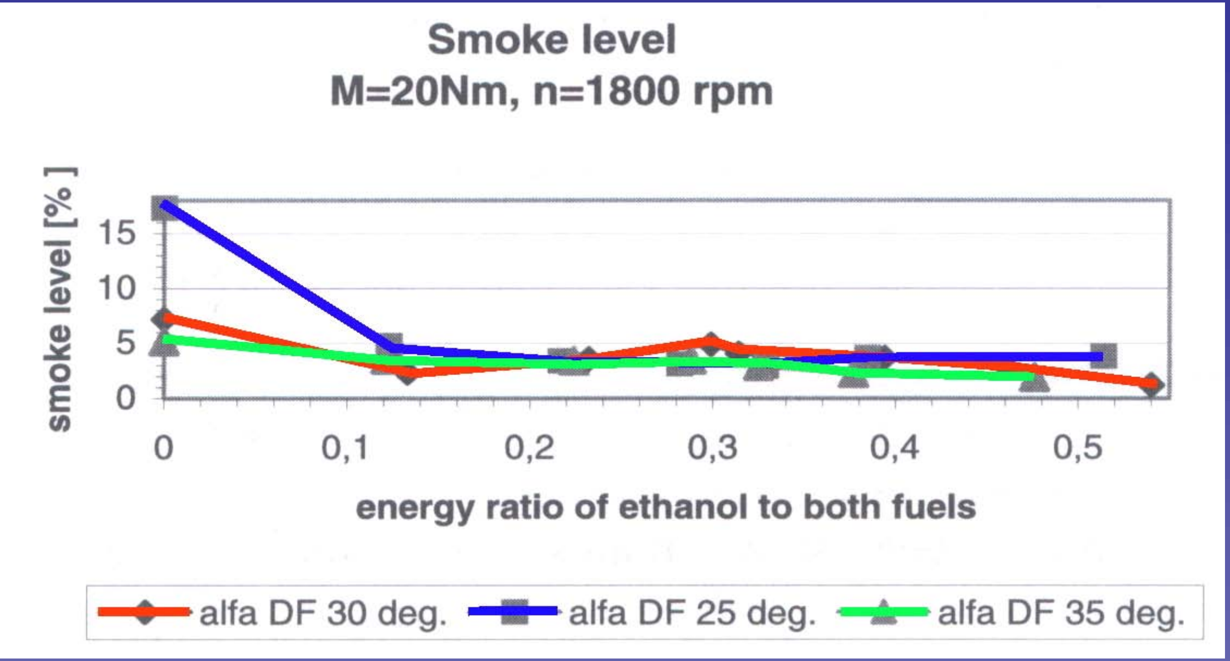


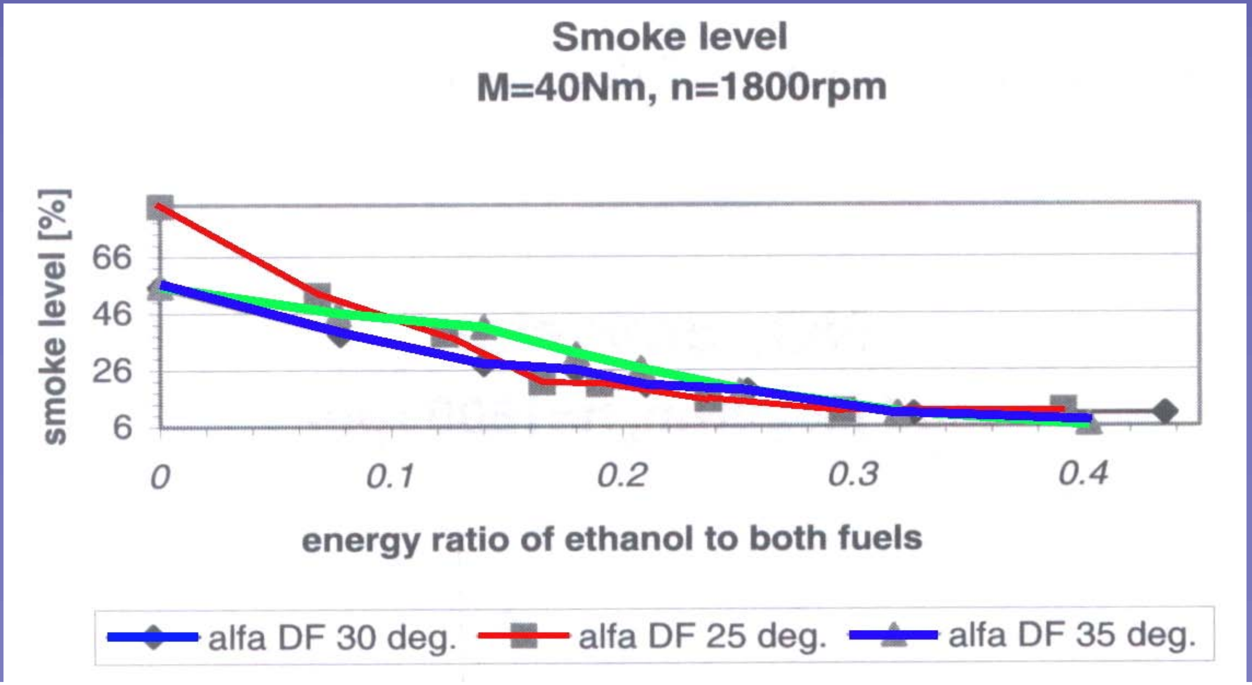

**Experimental results**

alfa DF – injection timing of DF

## Engine smoke level for different loads and energy ratio of ethanol to both fuels

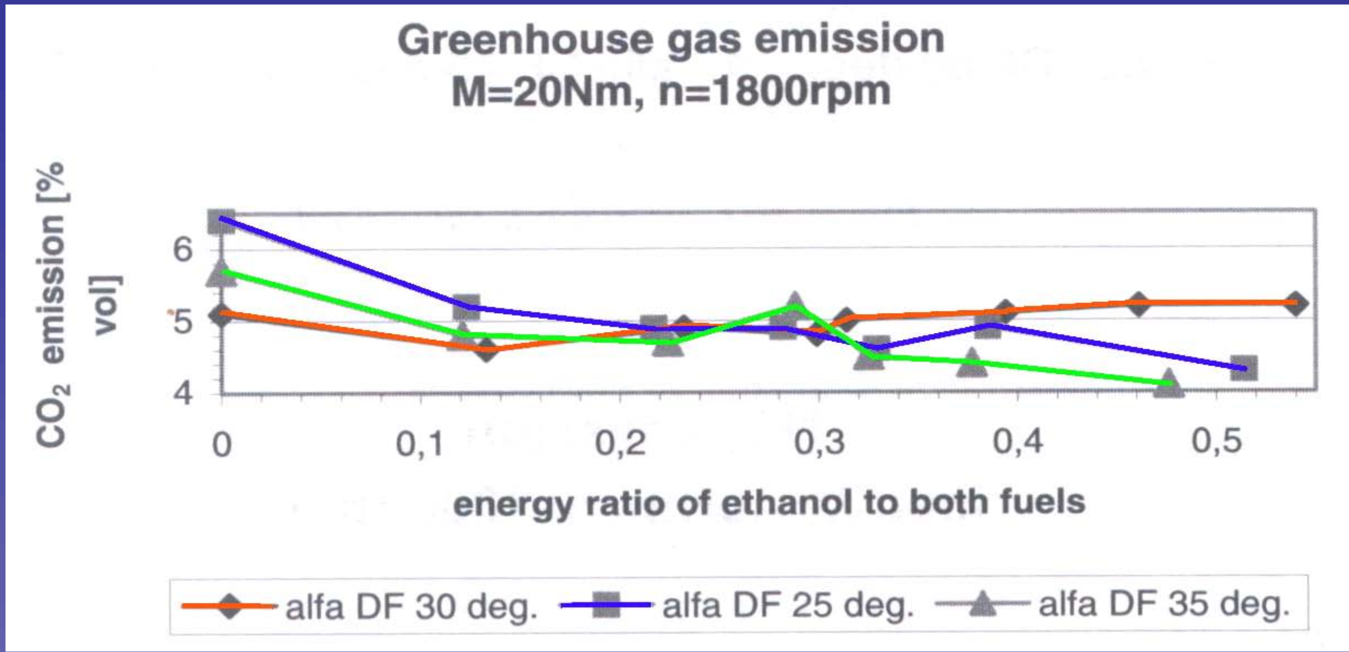



**Experimental results**



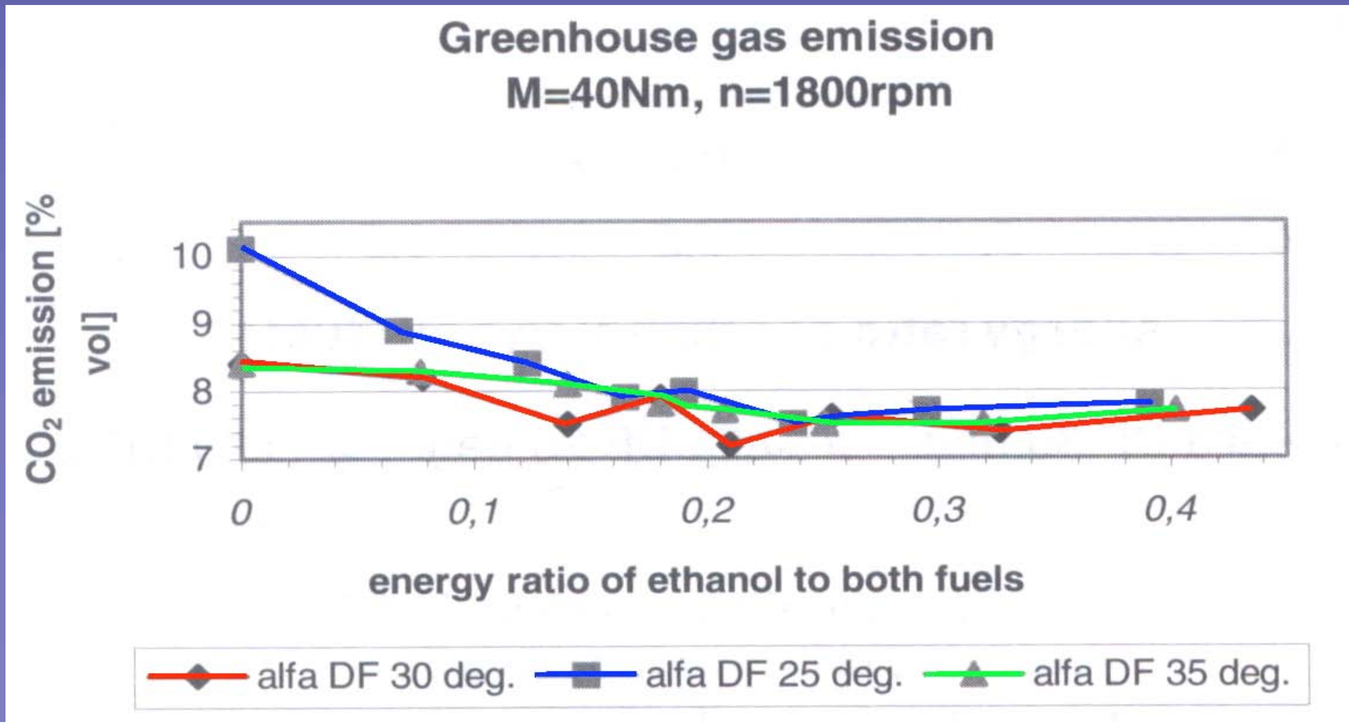

alfa DF – injection timing of DF

## Engine $CO_2$ volume concentration for different loads and energy ratio of ethanol to both fuels

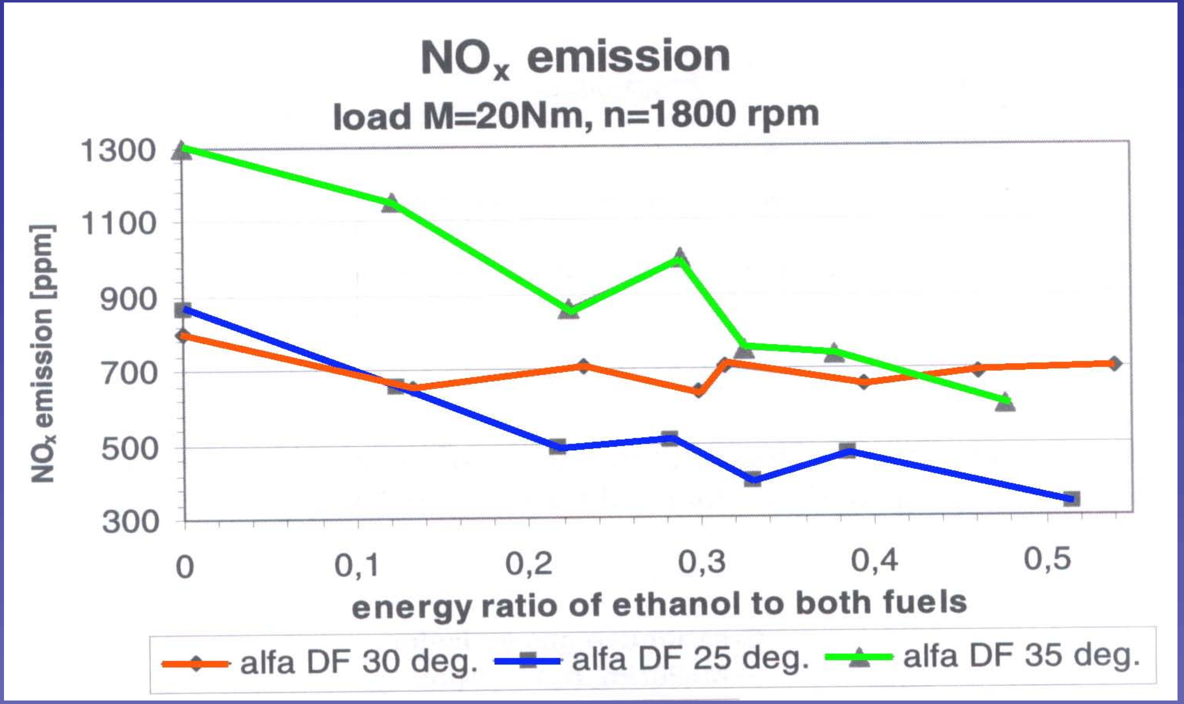


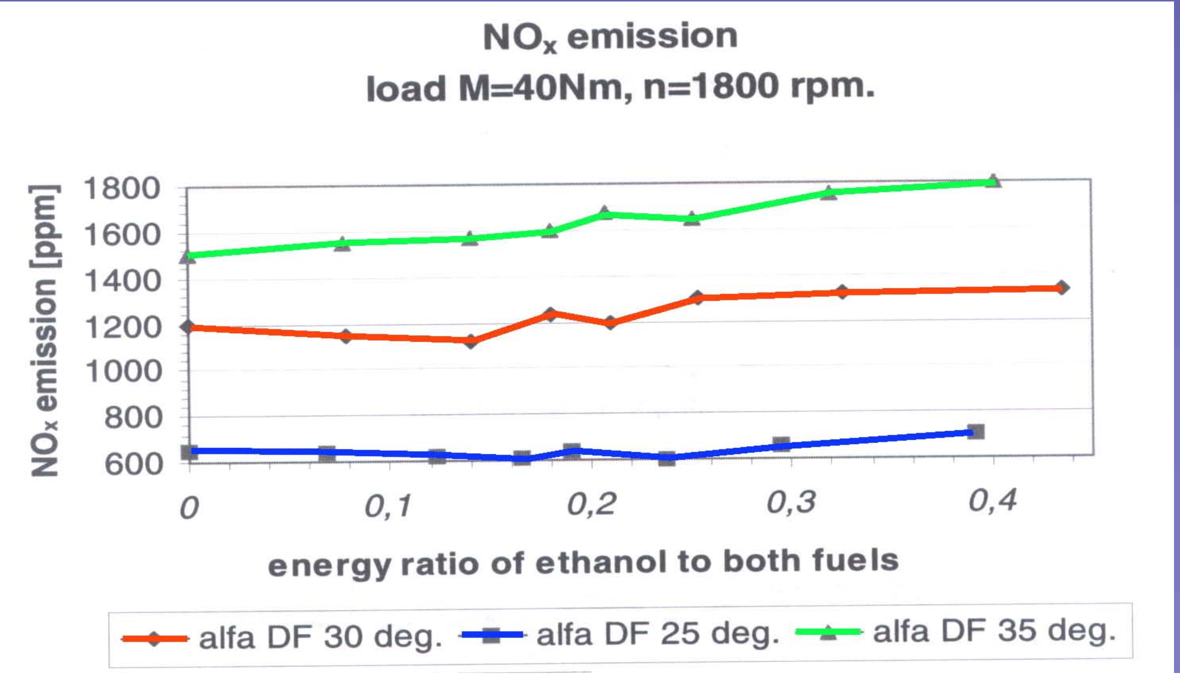

**Experimental results**

alfa DF – injection timing of DF



# Engine NOx volume concentration for different loads and energy ratio of ethanol to both fuels

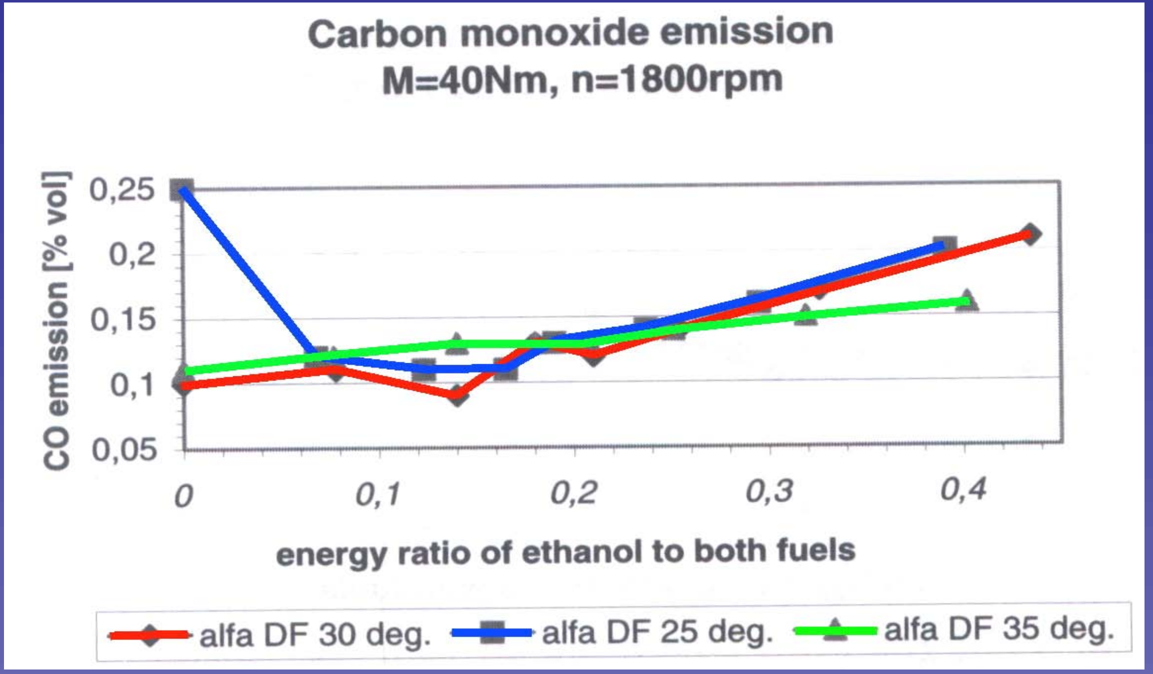


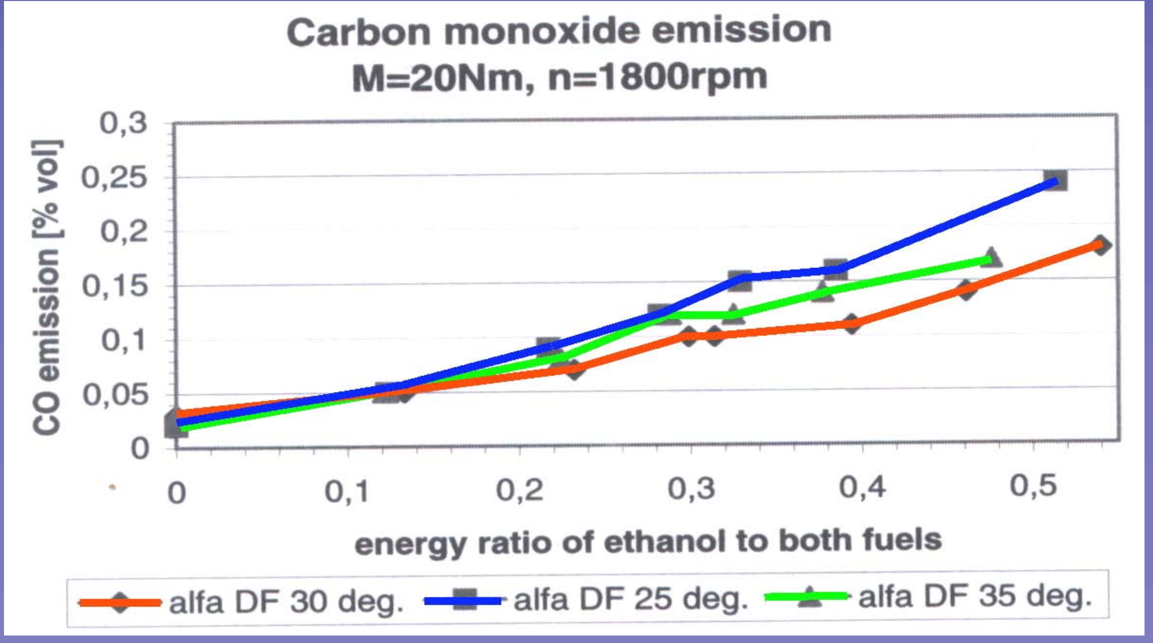

**Experimental results**

alfa DF – injection timing of DF

# Engine CO volume concentration for different loads and energy ratio of ethanol to both fuels

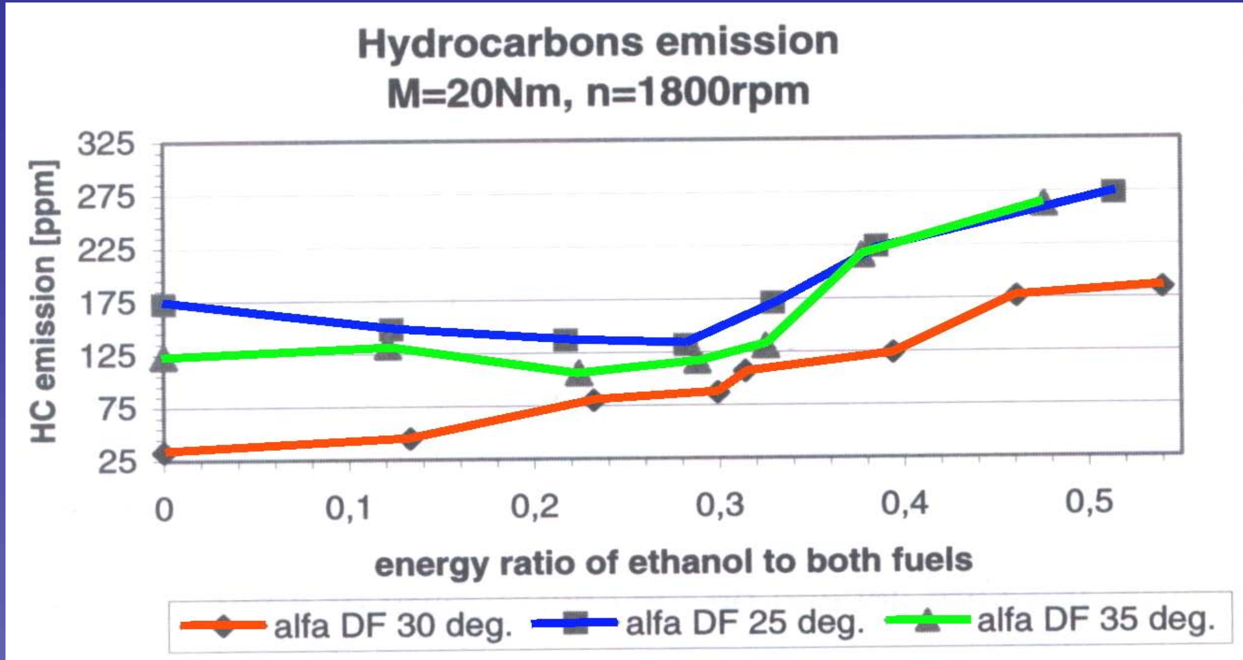


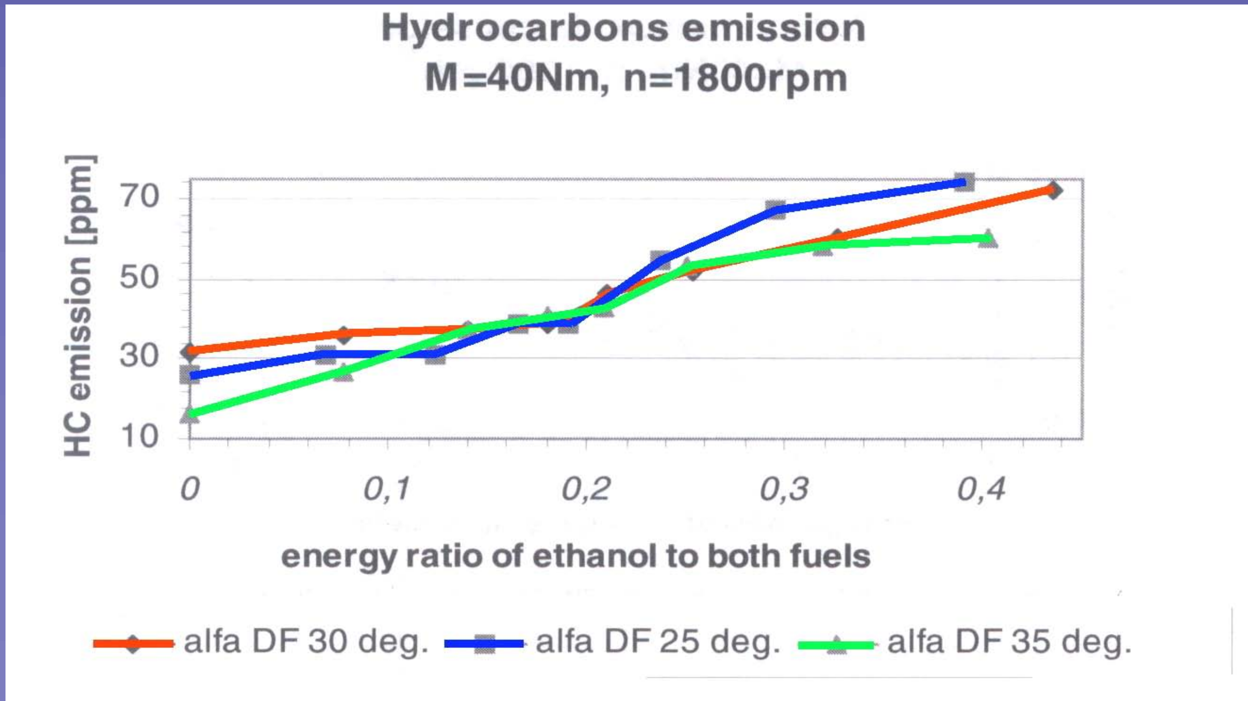

**Experimental results**




alfa DF – injection timing of DF

# Engine hydrocarbons volume concentration for different loads and energy ratio of ethanol to both fuels

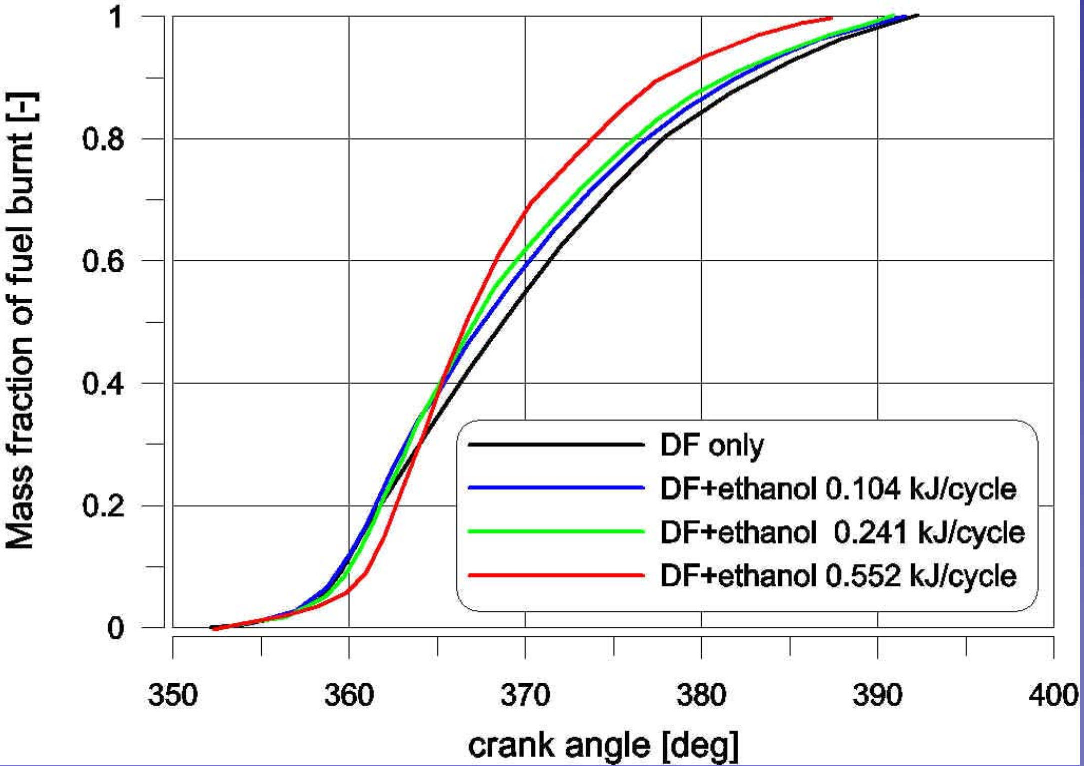


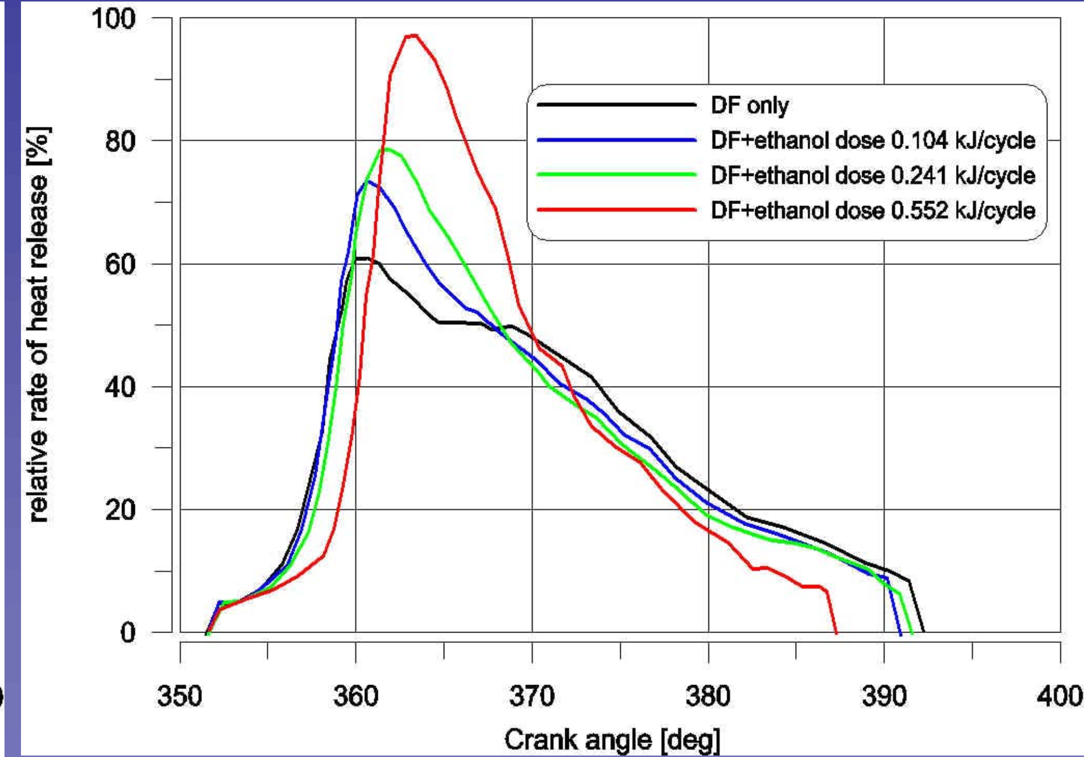

alfa DF – injection timing of DF

# Combustion characteristics of ethanol + DF in CI engine

Mass fraction of fuel burnt




Relative ratio of heat release



# CNG + DF FUELLING SYSTEM

- CNG port injection → homogenous CNG-air mixture in cylinder
- Pilot dose of diesel oil → autoignition
- Autoignition temperature of CNG is higher than diesel oil
- CNG combustion is initiated by the first burnt evaporated fuel droplets outside of the injected diesel oil stream
- Applying of the homogenous air-natural gas mixture enable using the same conventional diesel engine without reducing of the compression ratio
- Big dose of pilot diesel fuel can cause higher hydrocarbon emission and smoke level
- Combustion process of CNG and DF depends on mass ratio of both fuels and spray characteristic of injectors

# Modelling thermo-chemistry

**Chemical oxidation reaction of diesel oil:**

$4\ C_{13}H_{23} + 75\ O_2 \Rightarrow 52\ CO_2 + 46\ H_2O$

**Chemical oxidation reaction of natural gas:**

$CH_4 + 2\ O_2 \Rightarrow CO_2 + 2\ H_2O$

$2\ C_2H_6 + 7\ O_2 \Rightarrow 4\ CO_2 + 6\ H_2O$

$C_3H_8 + O_2 \Rightarrow CO_2 + H_2O$

**Mass of CNG for the same combustion energetic value**

$$m_{\mathrm{CNG}} = \left(m_{1\mathrm{DF}} - m_{2\mathrm{DF}}\right)\frac{Q_{w\mathrm{DF}}}{Q_{w\mathrm{CNG}}}$$

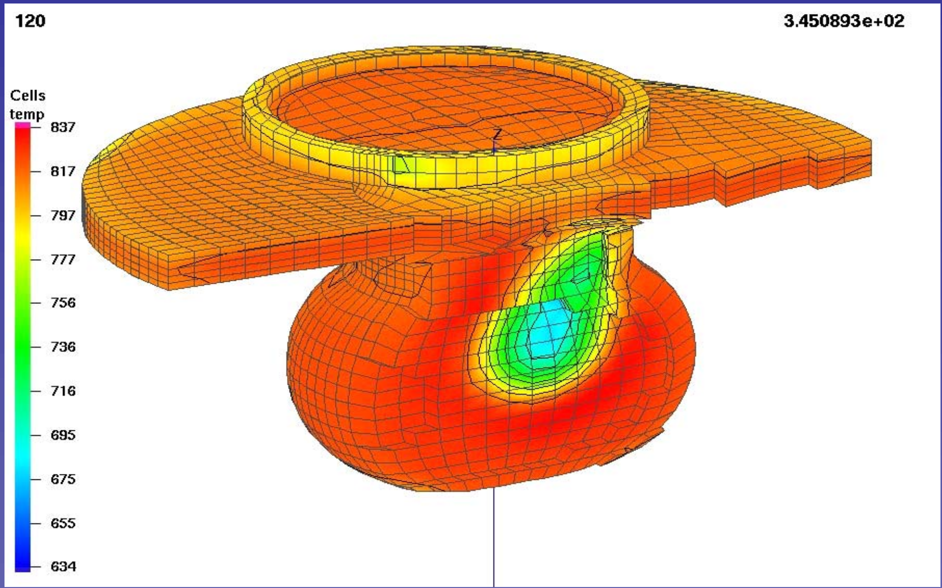
Calculated mass of CNG for full loads and one work cycle:

| | | |
|---|---|---|
| 1. | 0,0169 g/cycle | n = 1200 rpm |
| 2. | 0,3276 g/cycle | n = 1800 rpm |
| 3. | 0,0436 g/cycle | n = 2200 rpm |

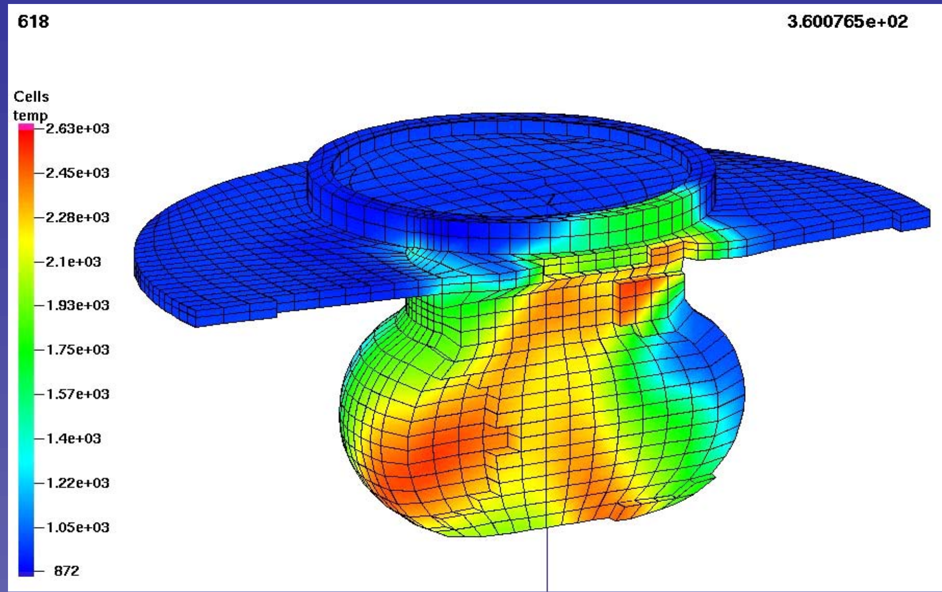
$$\lambda_r = \frac{m_{air}}{m_{\mathrm{DF}}\left(\frac{A}{F}\right)_{\mathrm{DF}} + m_{\mathrm{CNG}}\left(\frac{A}{F}\right)_{\mathrm{CNG}}}$$

# Cylinder temperature

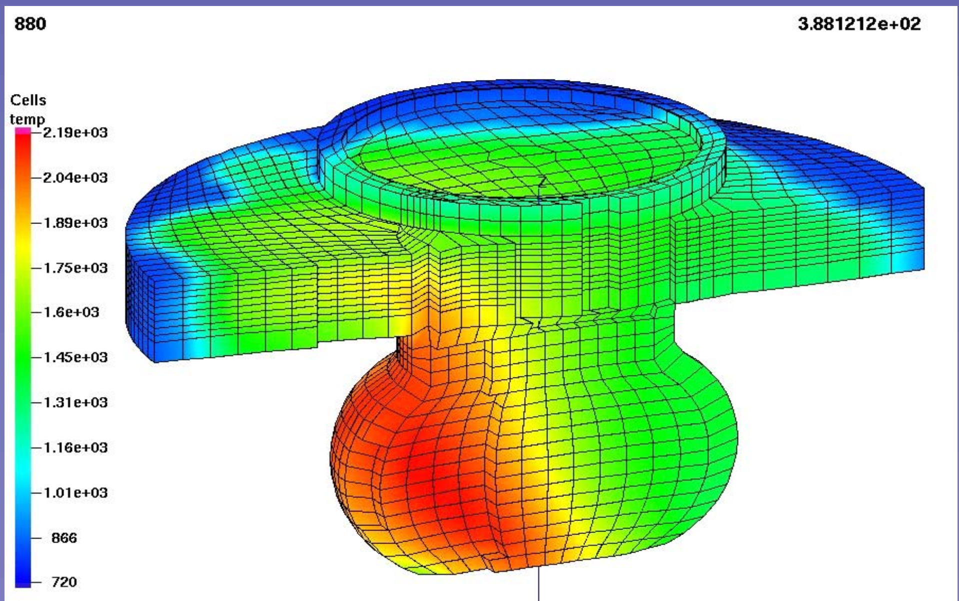
## 15 deg BTDC



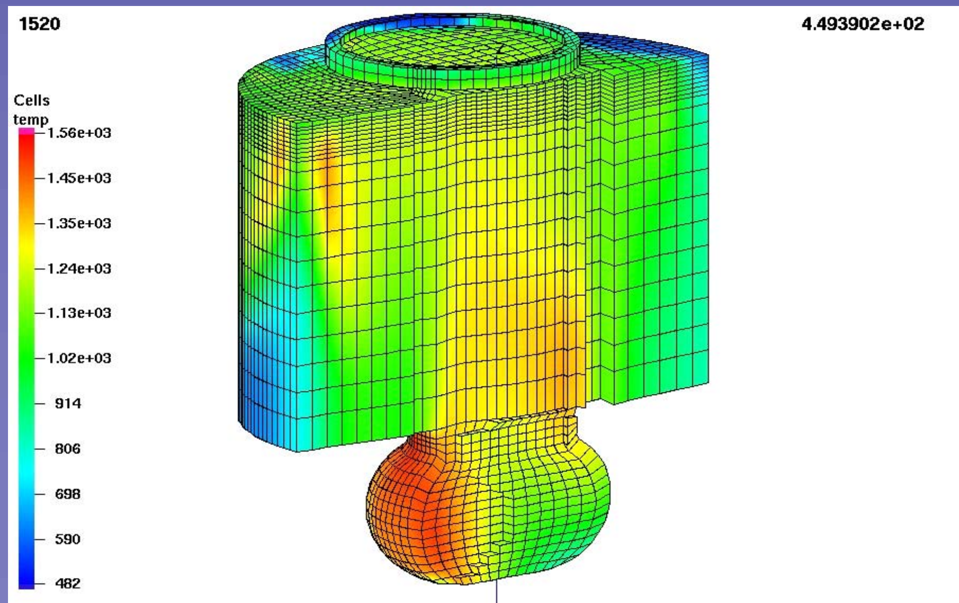

## TDC




## 28 deg ATDC

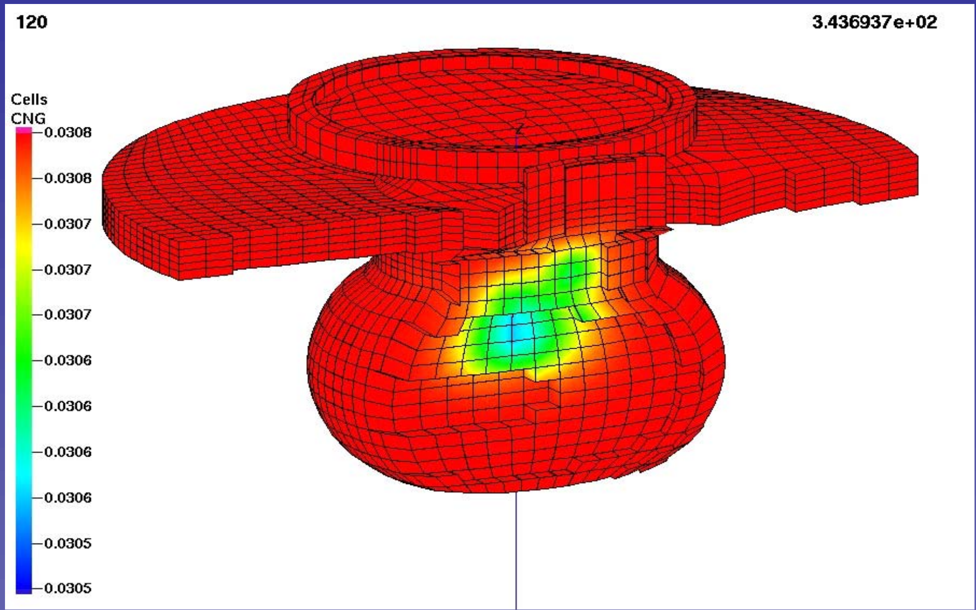



## 89 deg ATDC

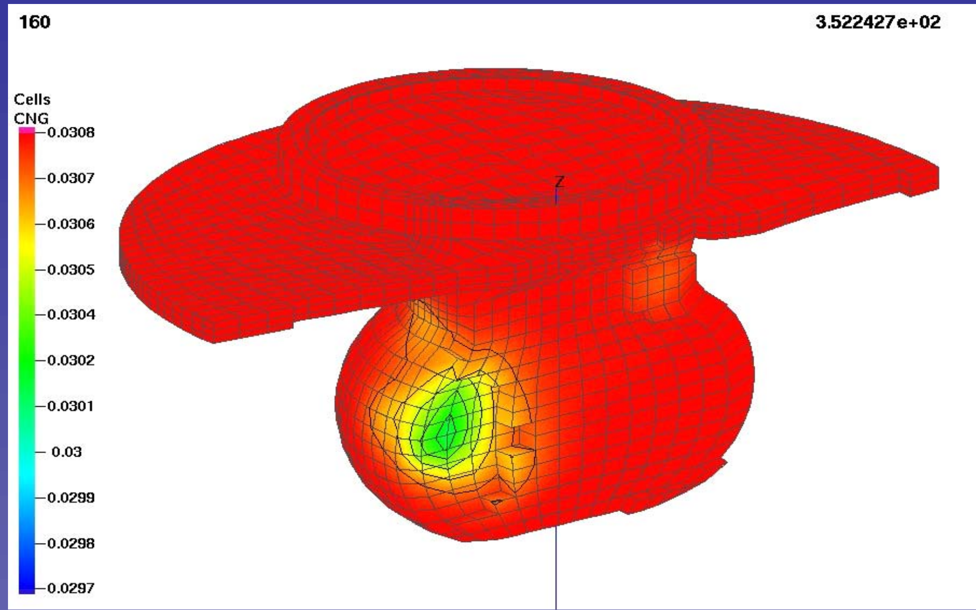


# Mass concentration of CNG – 1800 rpm

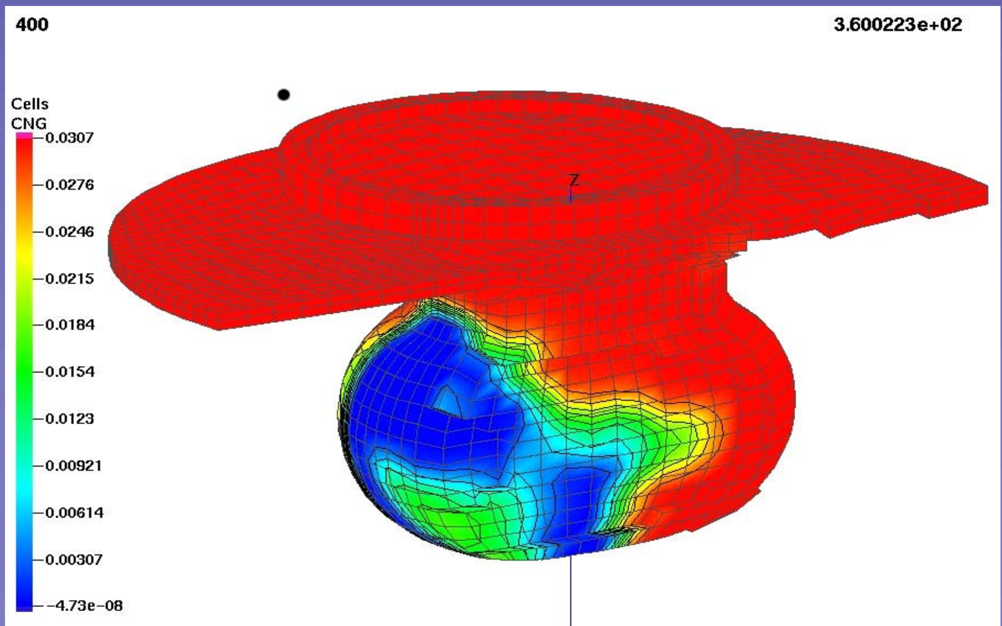
## 16 deg BTDC



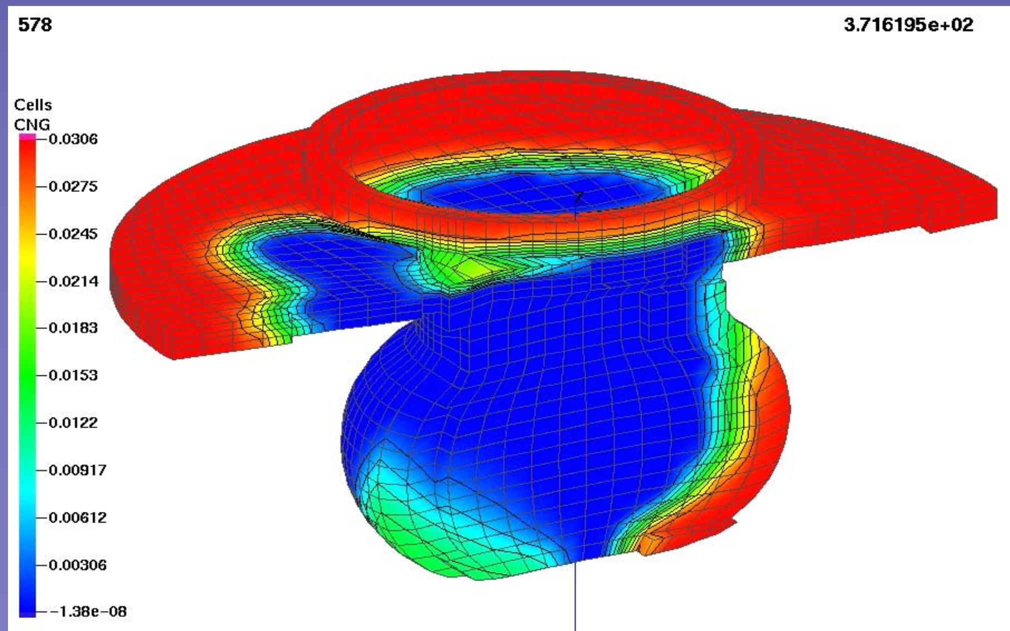

## 8 deg BTDC




## TDC



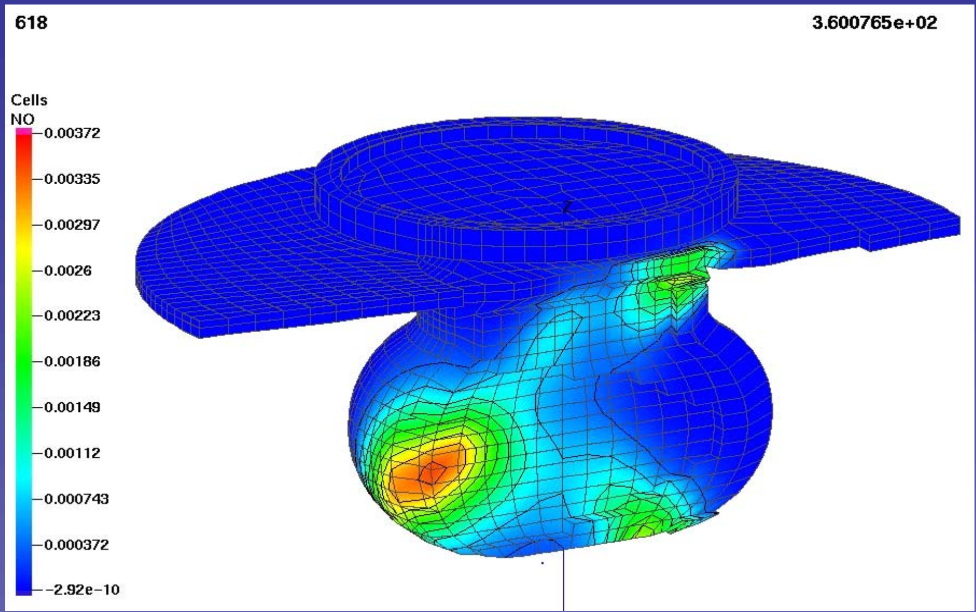

## 11 deg ATDC

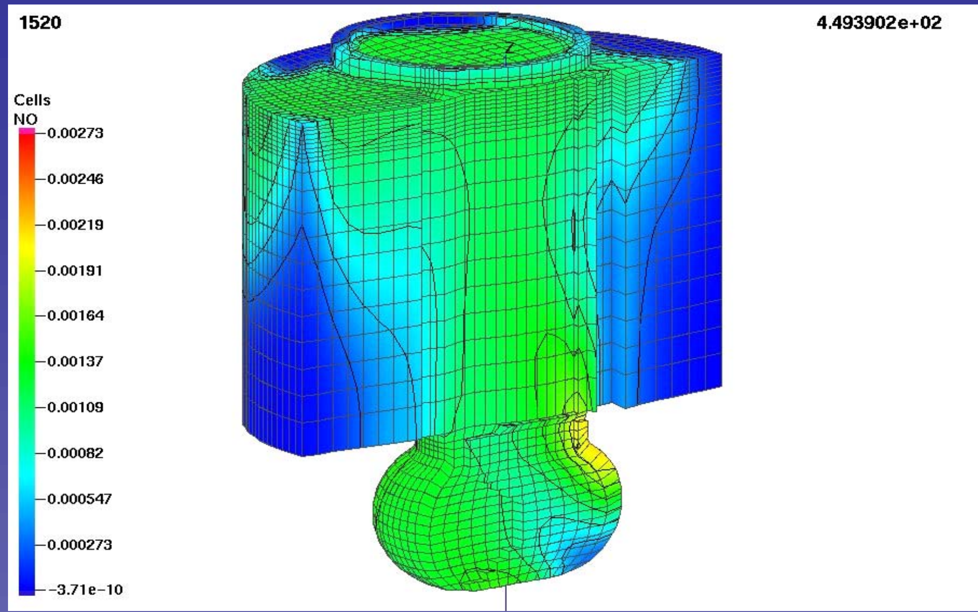


# NO concentration – 1200 rpm

**TDC**

**90 deg ATDC**

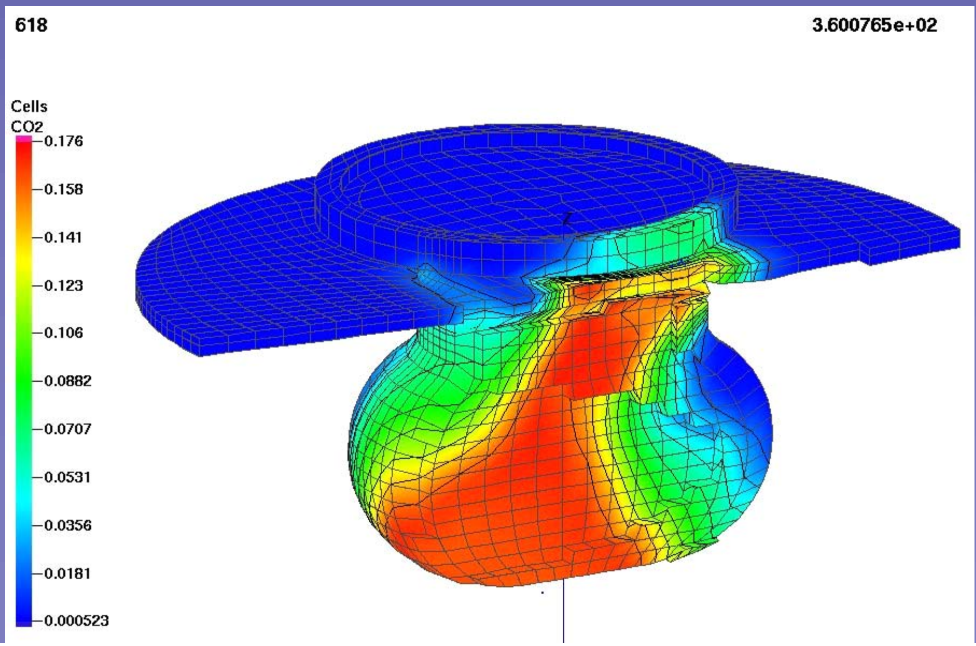


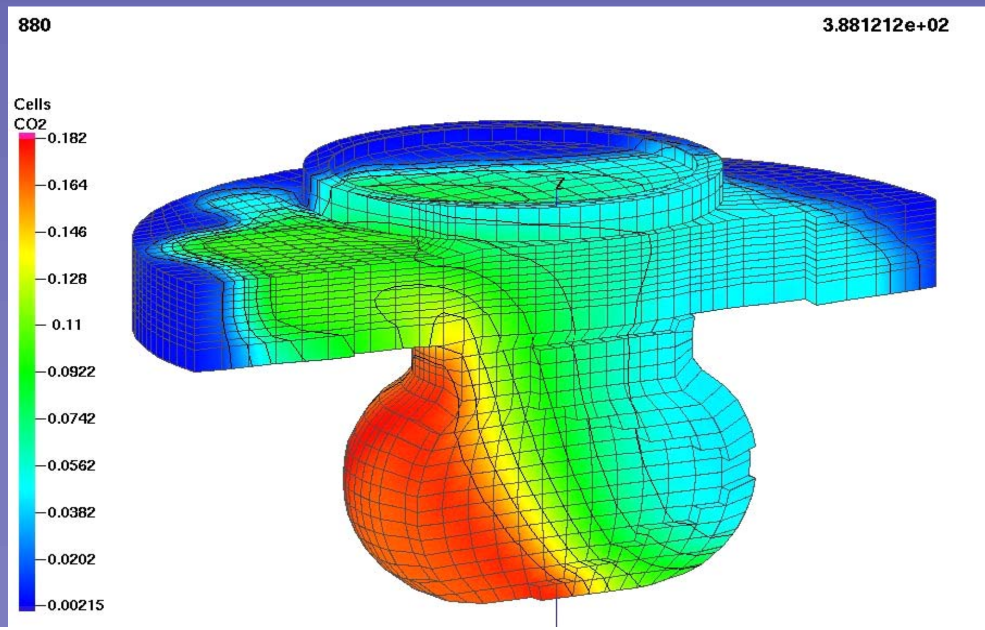




# $CO_2$ mass concentration – 1200 rpm

**TDC**

**28 deg ATDC**

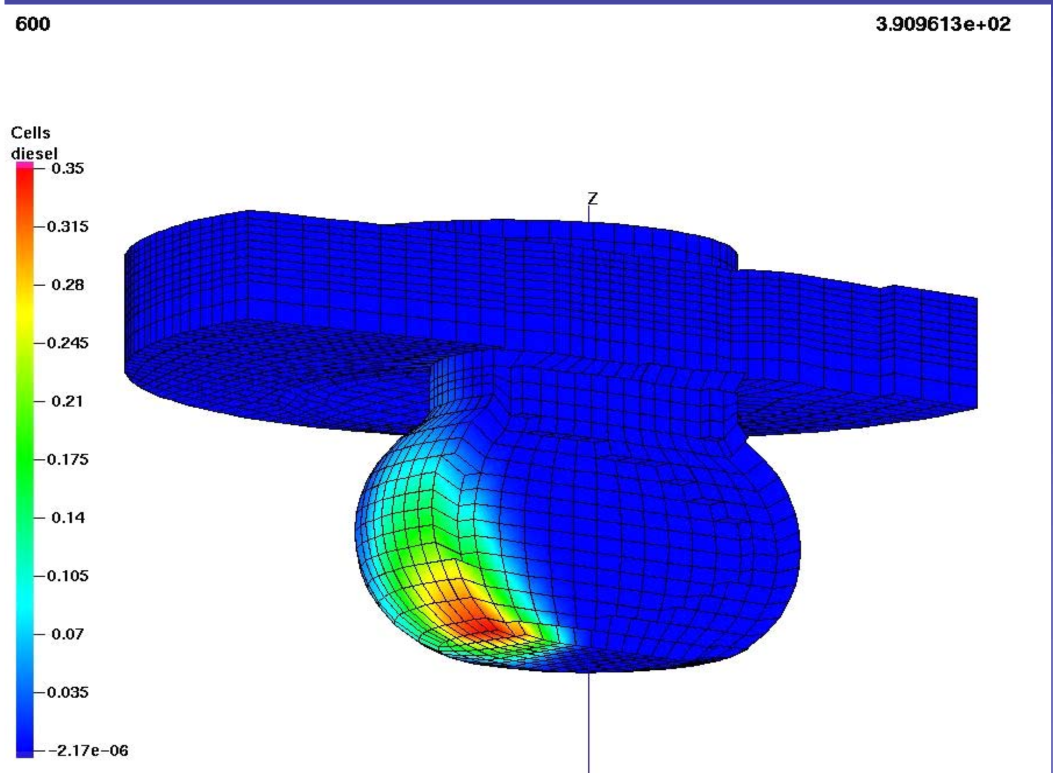


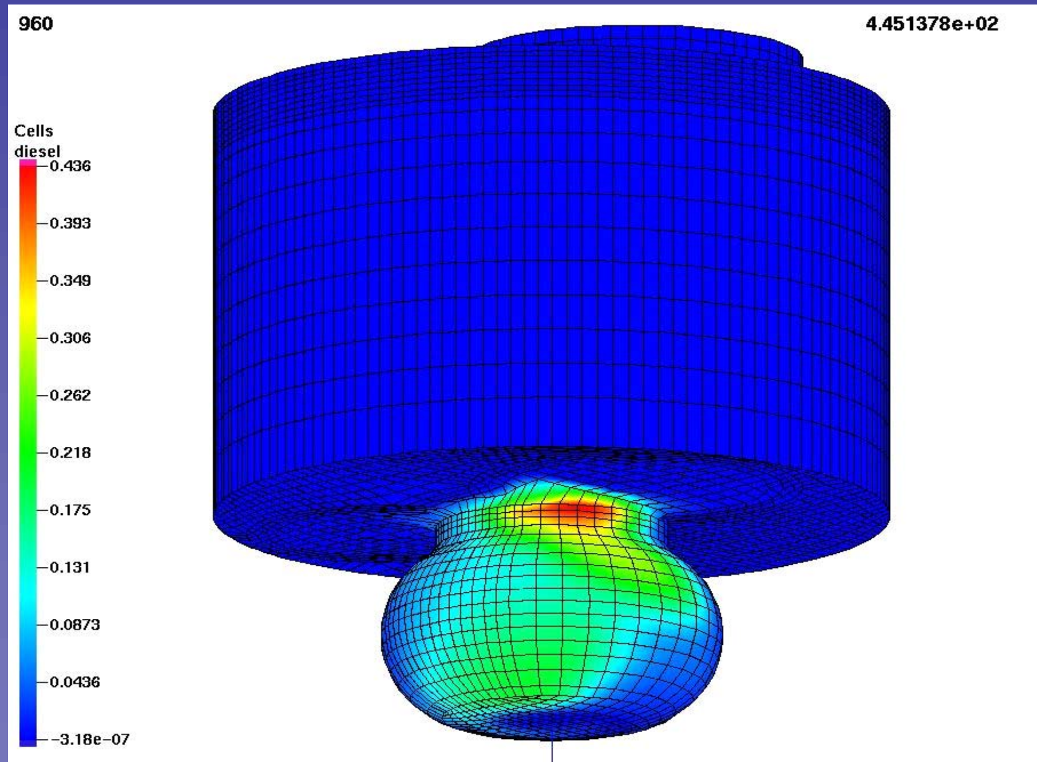
# Simulation results Andoria 1HC 102

## Diesel oil mass concentration – 2200 rpm

30 deg ATDC

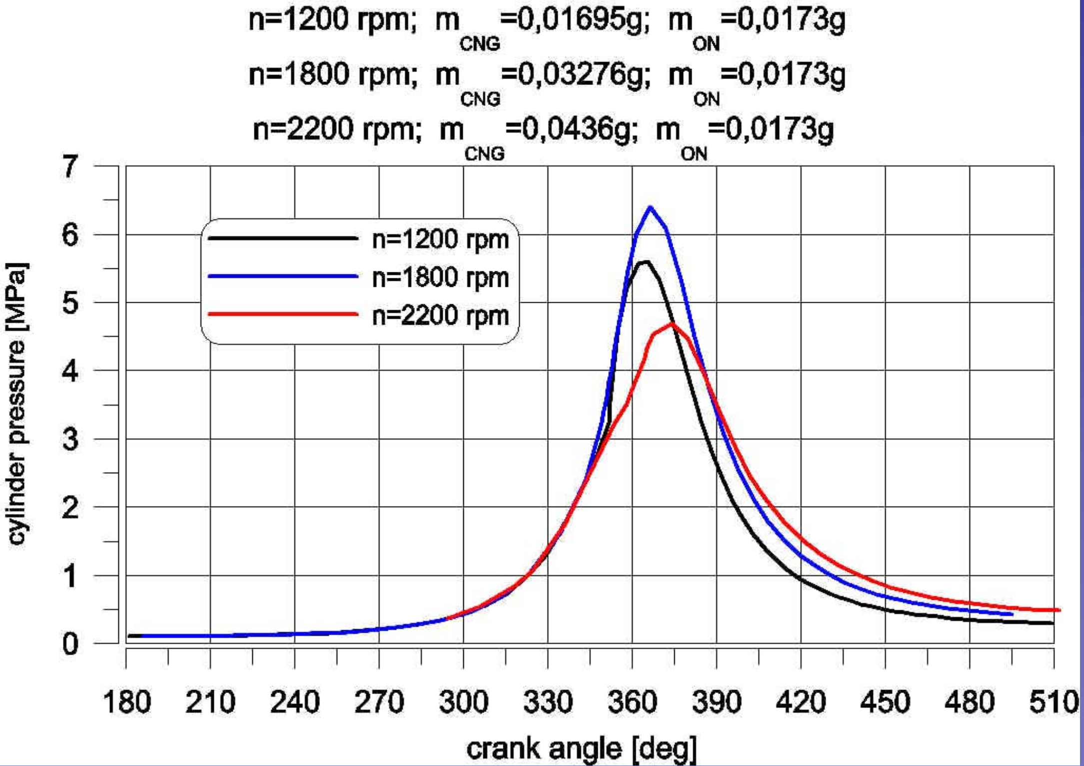



90 deg ATDC

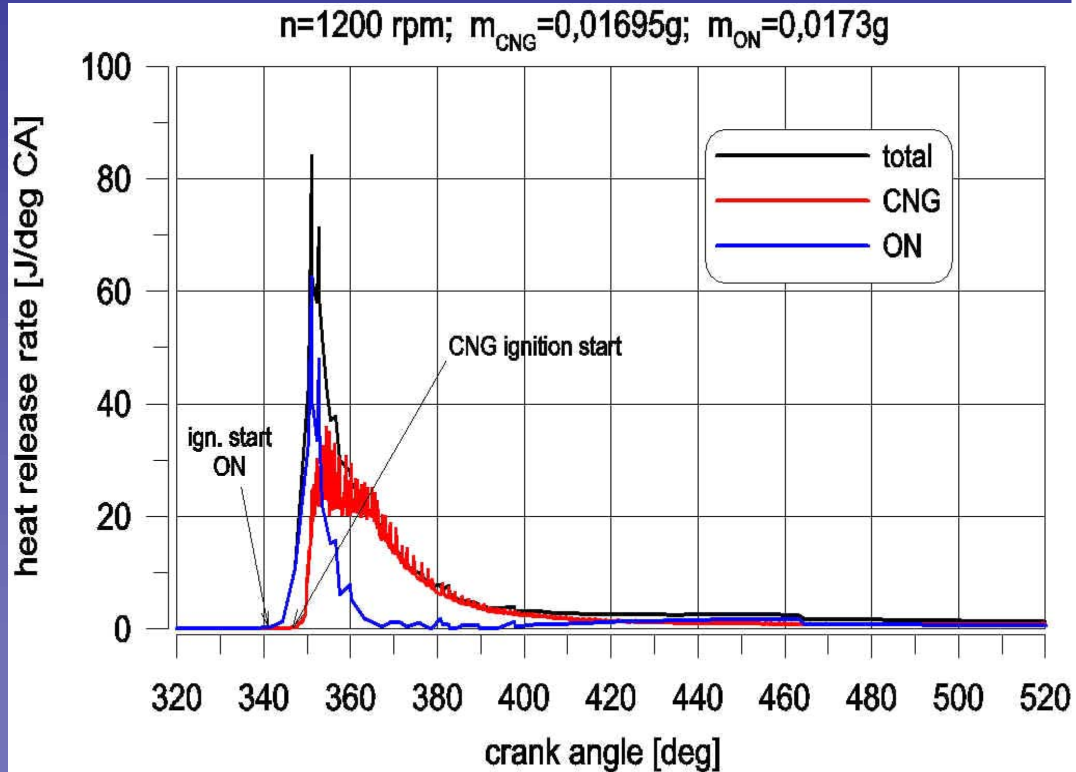


# Simulation results Andoria 1HC 102

## Cylinder pressure

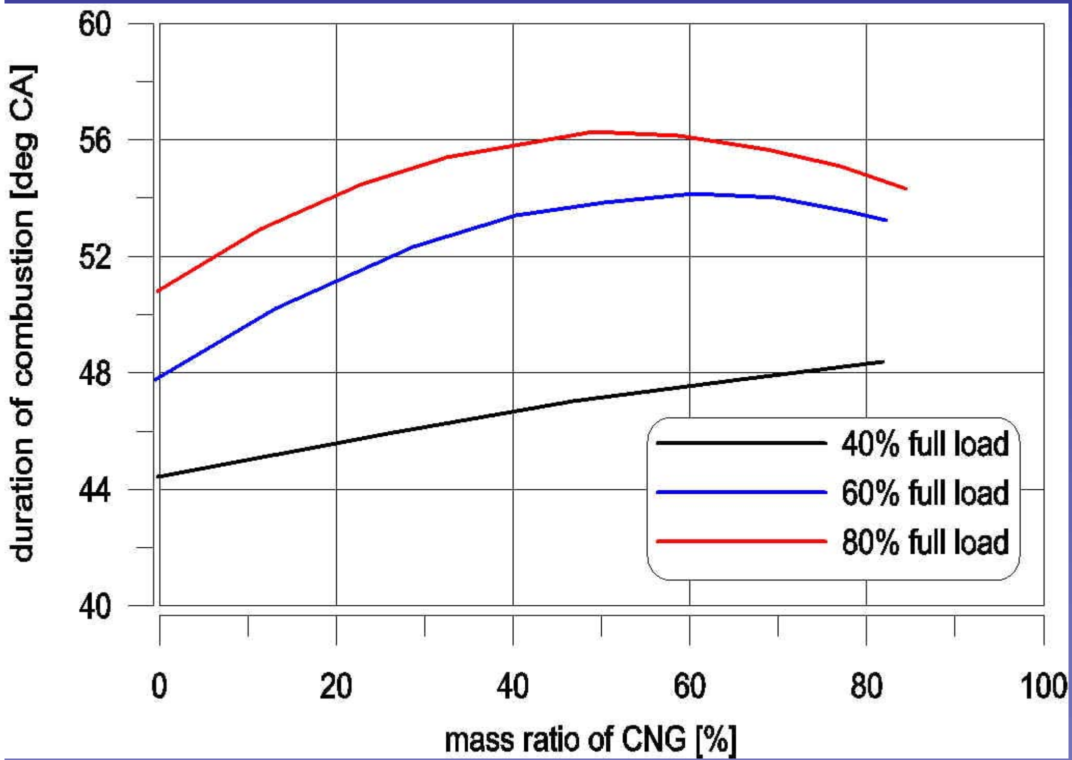



## Heat release

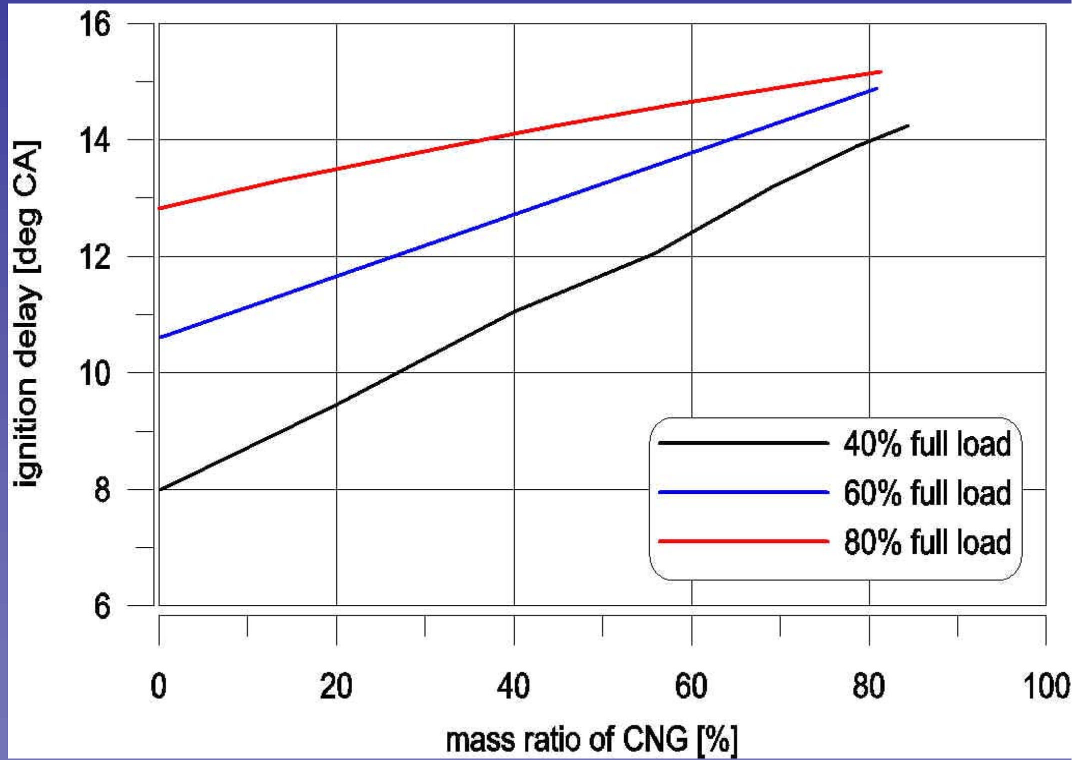


# Experimental tests on CNG-diesel oil CI Andoria 4CT90 engine

## Duration of combustion



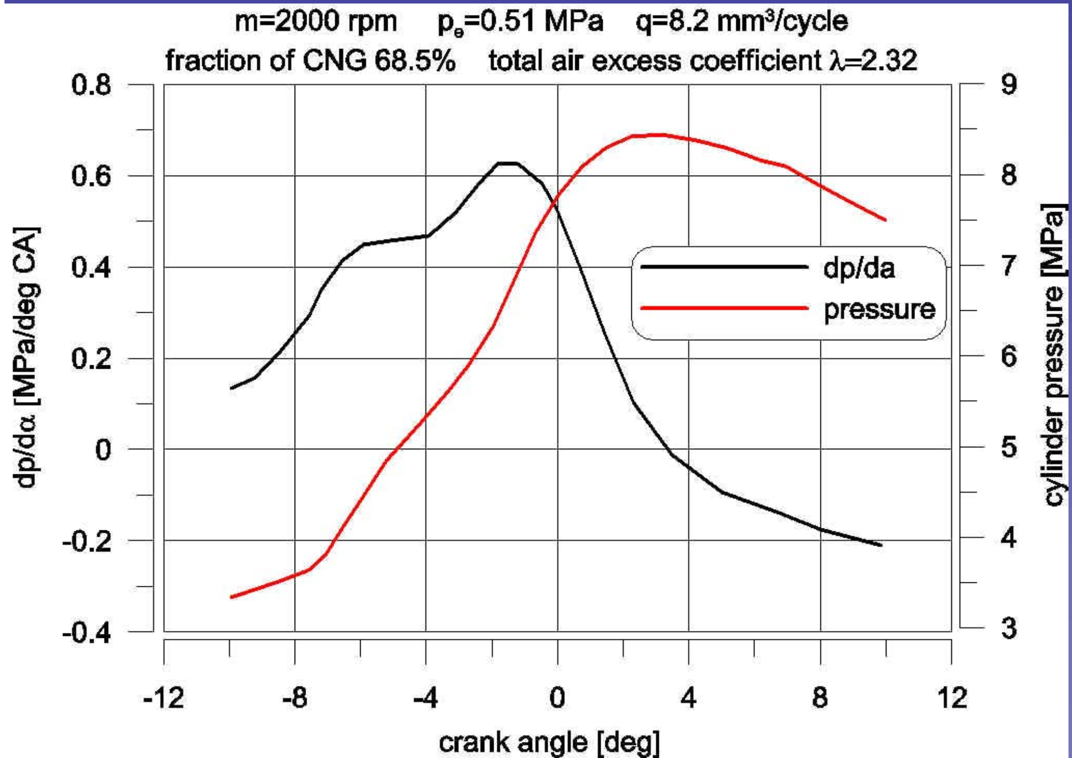

## Ignition delay



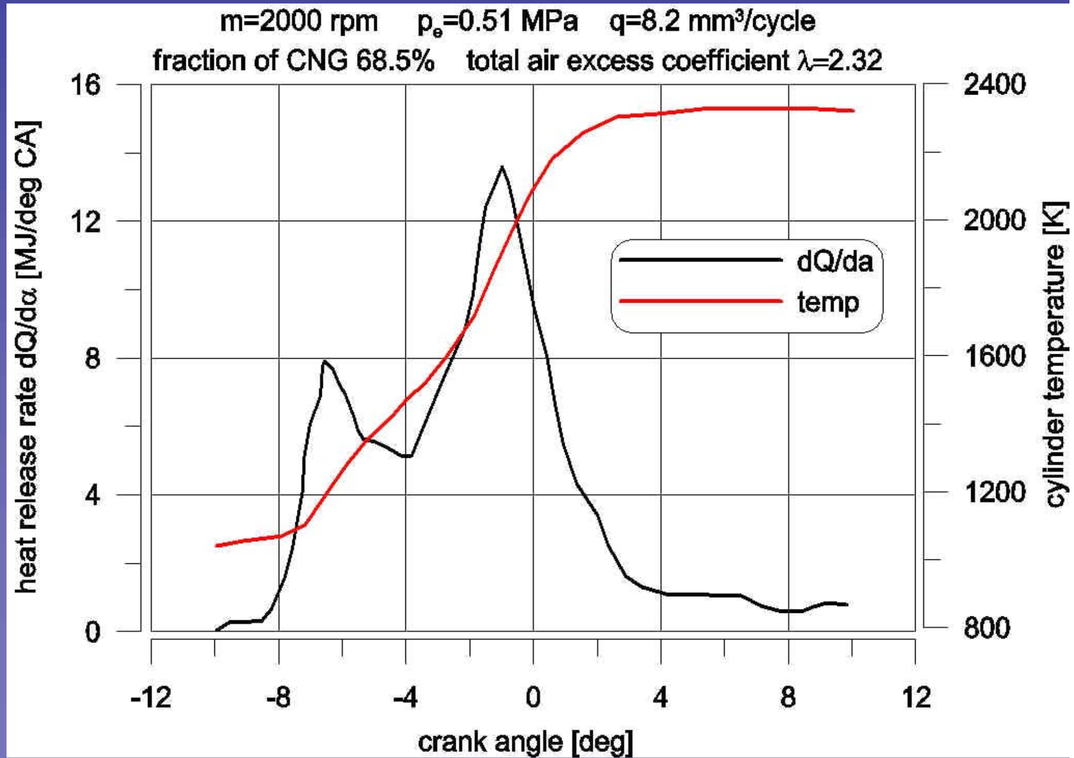
# Experimental tests on CNG-diesel oil CI Andoria 4CT90 engine

## n=2000 rpm

Pressure and pressure rise rate

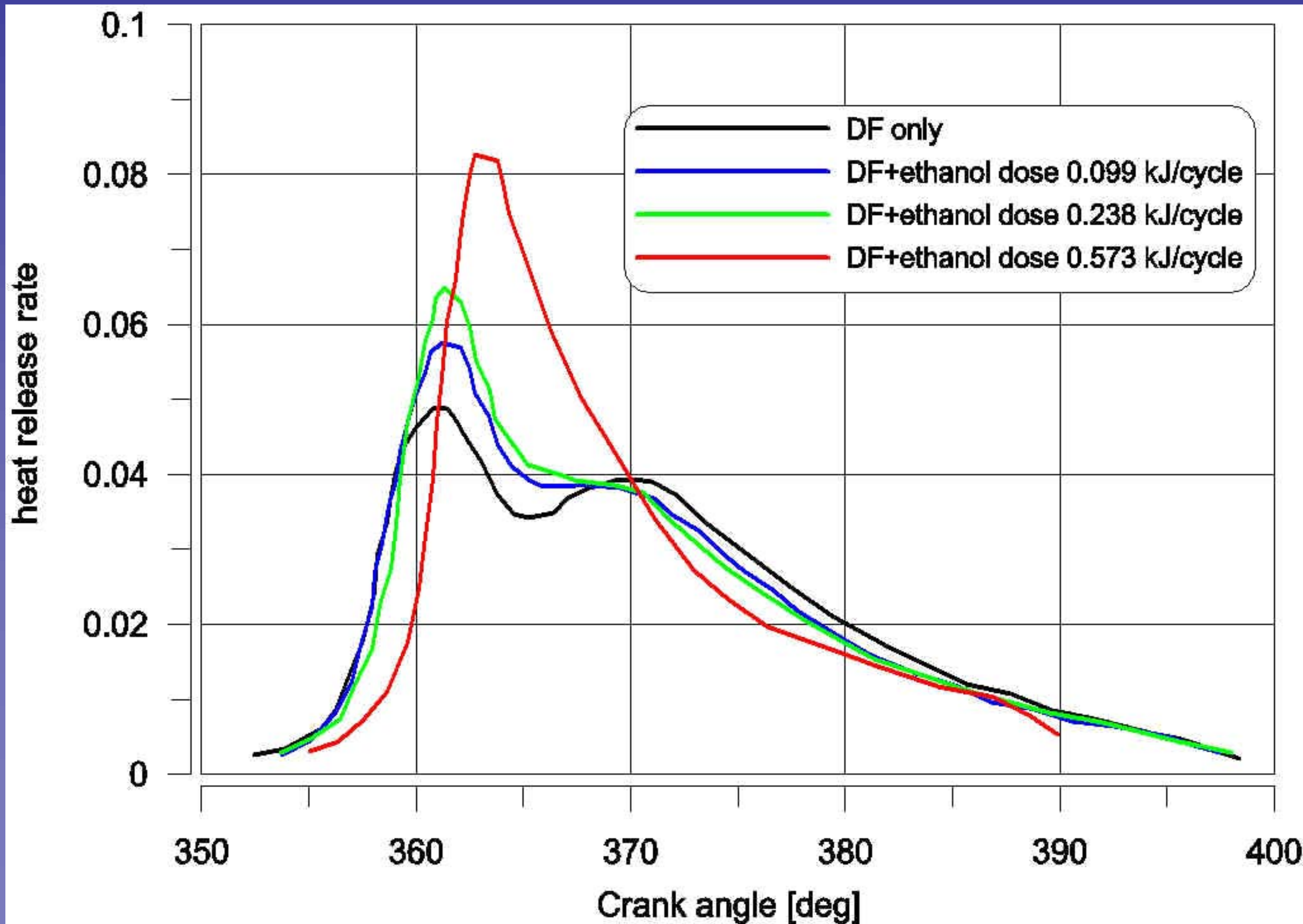



Temperature and heat release rate



# Experimental tests on CNG-diesel oil CI Andoria 4CT90 engine

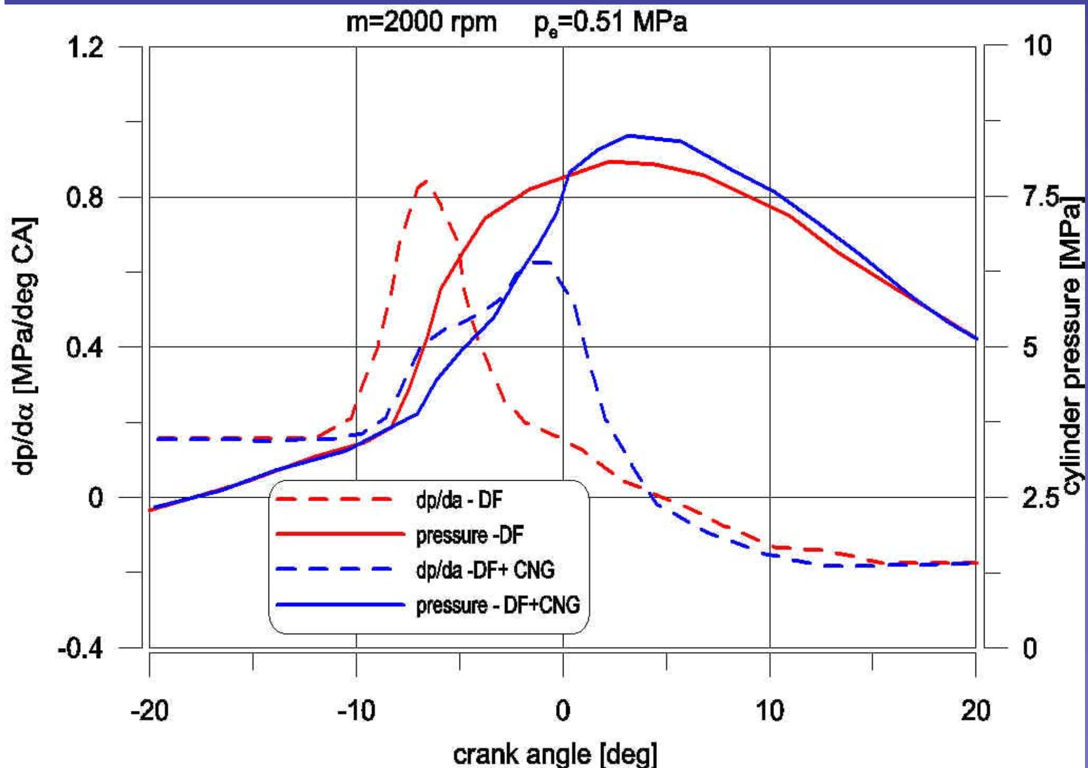
Heat release for different dual fuel mixtures at 1200 rpm
M=40 Nm; timing DF – 25 deg BTDC



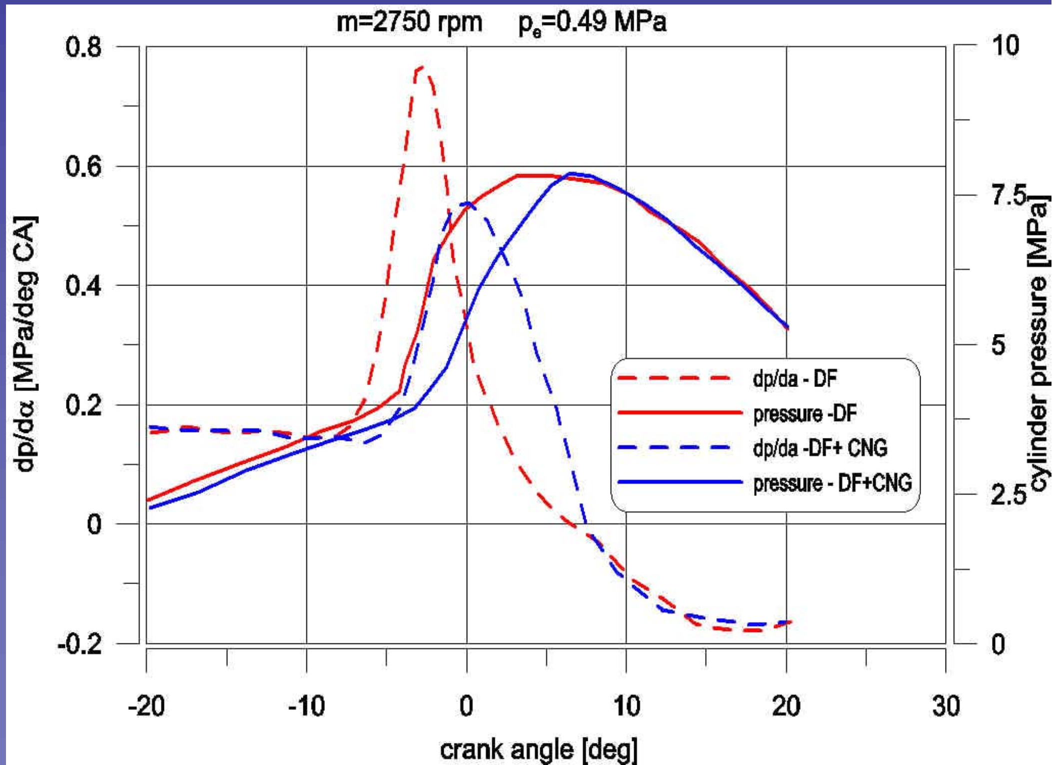
# Experimental tests on CNG-diesel oil CI Andoria 4CT90 engine

## Cylinder pressure and pressure rise rate for diesel fuel and dual fuel (CNG+DF)

n=2000 rpm; bmep = 0.51 MPa




n=2750 rpm; bmep =0.49 MPa



# CONCLUSIONS

1. Ethanol and natural gas may be a good additional fuels for CI engines when being injected into inlet port in a proper proportion to diesel fuel
2. Brake fuel conversion efficiency of dual fuel engines is better than pure diesel engine.
3. Dual fuelling results on lower $CO_2$ emission and smoke level. However, NOx emission increases when using CNG as additional fuel. For the other hand ethanol decreases NOx emission.
4. Ratios of ethanol or CNG to diesel fuel may be optimized regarding efficiency or toxic components of exhaust gases
5. Injection timing of diesel fuel should also be optimized for total efficiency, NOx emission and lower noise
6. Ignition and combustion in dual fuel natural gas engines is yet not fully recognized (combustion duration, kinetics and diffusion controlled combustion, noise, knock and cycle-by-cycle variation
7. Optimization of control parameters in dual fuel diesel engine is still an open problem

Thank you for your attention