The effect of EGR on HCCI combustion – impact of diluting, thermal and chemical aspects: experimental and numerical approaches

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Objectives :

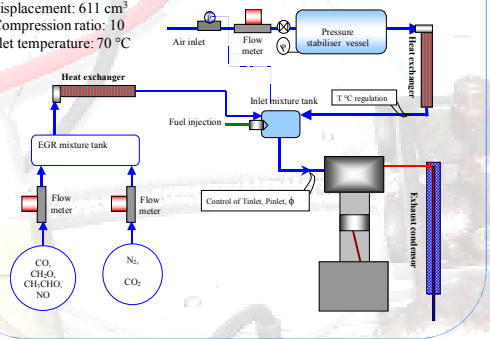
Investigate the influence of EGR on the HCCI combustion: hereby the impact of several aspects of EGR on the auto-ignition process is examined experimentally:

- Impact of dilution by N_2 and CO_2
- Impact of the EGR temperature
- Impact of chemical actives species such as CO, NO, CH_2O and CH_3CHO

A previously reduced and validated PRF mechanism is used for further interpretation

Experimental set-up

CFR engine
Engine speed: 600 rpm
Displacement: 611 cm^3
Compression ratio: 10
Inlet temperature: 70 °C



Auto-ignition in internal combustion engines by HCCI mode:

✓The HCCI (Homogeneous Charge Combustion Ignition) mode presents much advantages:

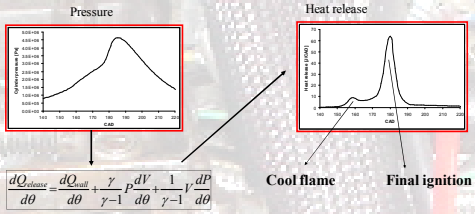
- ✓Reduction of emissions of NO_x, particulate matters
- ✓Increase of combustion efficiency
- ✓Reduction of CO_2 emissions

✓However, when conditions are not optimal, the emissions of hydrocarbons and CO could be too elevated

✓PRINCIPAL PROBLEM: CONTROLLING THE AUTO-IGNITION PROCESS

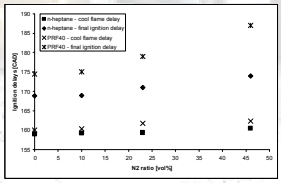
PROMISING SOLUTION: CONTROLLING BY EXHAUST GAS RECIRCULATION

AUTO-IGNITION PROCESS is investigated by AUTO-IGNITION DELAYS

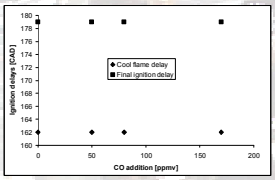


$$\frac{dQ_{release}}{d\theta} = \frac{dQ_{wall}}{d\theta} + \frac{\gamma}{\gamma-1} P \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dP}{d\theta}$$

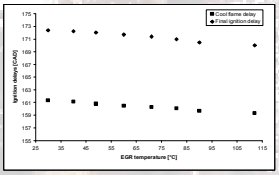
- Generally, the auto-ignition process occurs in two stages, interceded by an NTC
- The auto-ignition delays are a summary of the whole process
- Studying the influence of the EGR on the auto-ignition delays allows an overall study of the influence of EGR on the auto-ignition process



ϕ = 0,32 with n-heptane and PRF40 as the fuels



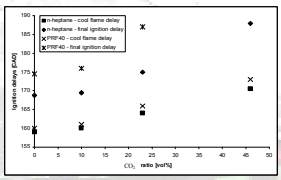
ϕ = 0,32 with PRF40 as the fuel



ϕ = 0,41 with PRF40 as the fuel and 23 vol% EGR

- Dilution makes the ignition delays increase, meaning a decrease in the overall reactivity – CO_2 has a greater effect than N_2
- The EGR temperature increases the overall kinetics
- No significant influence for CO
- The species NO has two effects:
  - $NO + HO_2 = OH + NO_2$ increasing reactivity
  - $NO + OH + M = HONO + M$ decreasing reactivity
- Formaldehyde seems to increase the ignition delays apparently by:
  - $CH_2O + OH => H_2O + HO_2 + CO$
- Acetaldehyde seems to have a similar influence. However, the effect is not clear and should be investigated furthermore

- The fuel PRF40 is more sensitive to changes in the EGR composition than n-heptane



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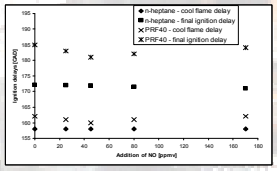

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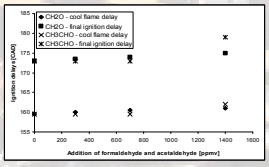

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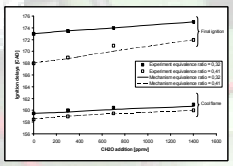
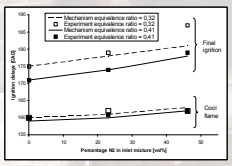


Comparison model/experiments:
ϕ = 0,32/0,41 with PRF40 as the fuel in 23 vol% EGR



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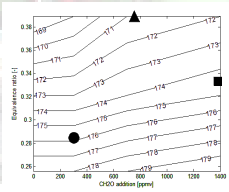

Mapping: ignition delay as function of ϕ and CH_2O addition 23 vol% EGR, T_{inlet} = 70°C, ε = 10,2 and PRF40 as the fuel

Perspectives :

✓Numerical interpretation of the auto-ignition phenomena, using the PRF mechanism, incorporating more EGR chemical species

✓Wider experimental validation

✓Proposition for the control of the auto-ignition process, using EGR

Conclusions :

✓Influence of simulated EGR on auto-ignition delays in an internal combusiton engine in HCCI mode has been studied:

- ✓Dilution: reduces the overall reactivity and increases the ignition delays, CO_2 having a stronger effect due to its higher heat capacity. A fuel having a lower burn rate is more sensitive to dilution
- ✓EGR temperature: the effect is clear, increasing the overall kinetics and decreasing the ignition delays
- ✓Chemically active species:
  - ✓CO: no significant effect has been observed in the investigated range
  - ✓NO: has the ability to decrease and increase the ignition delay following its reactivity. The effect is more clear for the fuel having a lower burn rate, PRF40.
  - ✓CH_2O and CH_3CHO : decreases the overall reactivity by sharing OH radicals with the fuel, increasing thereby the ignition delays

✓A reduced PRF mechanism has been validated experimentally for some EGR parameters

- ✓The validation is quite satisfactory with respect to the ignition delays
- ✓The PRF mechanism can be used to interpret the behaviour of the auto-ignition process influenced by EGR parameters.