Influence of EGR on Post-injection Effectiveness in a Heavy-duty Diesel Engine

Introduction
Soot particles emitted by diesel engines are dangerous for the environment and for living organisms. Emission legislation around the world is becoming increasingly stringent, demanding better understanding of the physics of soot formation to design countermeasures. One such measure being heavily researched is the addition of a small fuel post-injection. In this numerical study based on data from a heavy-duty research diesel engine [1], we investigate the effect of post-injection on soot evolution and governing processes, and the influence of exhaust gas recirculation on the interaction between post- and main-injections.

Soot model: two-equations model [6]

1. Particle inception:
   \[ \frac{dn_{soot}}{dt} = \alpha_{in} \left( \frac{C_{soot}}{C_{soot}^{*}} \right) \]
2. Particle surface growth:
   \[ \frac{dn_{soot}}{dt} = \frac{v_{soot}}{v_{in}} \left( \frac{C_{soot}}{C_{soot}^{*}} \right) \]
3. Particle oxidation by O:
   \[ \frac{dn_{soot}}{dt} = \frac{v_{soot}}{v_{in}} \left( \frac{C_{soot}}{C_{soot}^{*}} \right) \]
4. Particle oxidation by OH:
   \[ \frac{dn_{soot}}{dt} = \frac{v_{soot}}{v_{in}} \left( \frac{C_{soot}}{C_{soot}^{*}} \right) \]
5. Coagulation:
   \[ \frac{dn_{soot}}{dt} = \frac{v_{soot}}{v_{in}} \left( \frac{C_{soot}}{C_{soot}^{*}} \right) \]

Soot model accounts for simultaneous soot particle inception, surface growth, oxidation by O and OH and coagulation.

Experimental setup [1]
Engine parameters:
- bore: 140 mm (VH=2.34 L)
- CR=11,292 (geom.), 16 (sim.)
- swirl ratio: 0.5
- injector: 8 x 0.131 mm
- fuel: n-heptane
- Measurement techniques:
  - pressure & AHRR
  - 2D natural luminosity
  - planar LII

CFD model

CFD computational setup:
- Commercial CFD code STAR-CD [2]
- 2D grid with 1.0 mm mesh size
- 3D Euler-Langrange approach for droplets
- Conditional Moment Closure (CMC) combustion model [3]
- Reduced mechanism for n-heptane [5]
- Two-equations soot model [6]
- Optical-thin soot radiation model [7]
- Soot differential diffusion effects neglected

Governing equations [3]

- \[ \frac{\partial}{\partial t} \left( \rho \right) + \nabla \cdot ( \rho \mathbf{u} ) = 0 \]
- \[ \frac{\partial}{\partial t} \left( \rho \mathbf{u} \right) + \nabla \cdot ( \rho \mathbf{u} \otimes \mathbf{u} ) = - \nabla \cdot \mathbf{p} + \nabla \cdot \left( \Gamma \nabla \mathbf{u} \right) \]
- \[ \frac{\partial}{\partial t} \left( \rho e \right) + \nabla \cdot ( \rho e \mathbf{u} ) = \nabla \cdot \left( \Gamma \frac{\partial T}{\partial t} \right) \]
- \[ \frac{\partial}{\partial t} \left( \rho \right) = 0 \]
- \[ \frac{\partial}{\partial t} \left( \rho \mathbf{u} \right) = 0 \]
- \[ \frac{\partial}{\partial t} \left( \rho e \right) = 0 \]

Multiple Injections [8]

- Multiple injections using a single total mixture fraction (MF) as the conditioning scalar.
- re-initialisation of conditional temperature and composition in every CMC cell at the time of the first appearance of MF from post injection (Mi8)
- Constraint: MF1 + MF2 = MFT ≤ 1.0

References

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Influence of EGR on Post-injection Effectiveness in a Heavy-duty Diesel Engine Fuelled with n-Heptane

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Soot formation
Soot oxidation
Soot oxidation
Soot volume

Surface oxidation (1-4)

Coagulation (5)

Surface growth (2)

Nucleation (1)

ACETYLENE

Acetylene

Fuel

Combustion Science and Technology

Basel, Switzerland

Euler-Langrange approach for droplets

Coagulation (5)

Nucleation (1)

Surface oxidation (3-4)

Volume fraction

\[ \frac{\partial}{\partial t} \left( \rho \mathbf{u} \right) = - \nabla \cdot \mathbf{q} + \nabla \cdot \left( \Gamma \nabla \mathbf{u} \right) \]

\[ \text{Enhancement of soot oxidation rate}
- \text{order of magnitude enhancement at high EGR (larger soot volume)}
- \text{caused by additional locally available oxygen}
- \text{soot evolution of the low-EGR case shows an initial increase due to added fuel, but subsequent drop due to improved oxidation}
\]

\[ \text{O}_2 \text{ difference (normalised by the O}_2 \text{ distribution of the single-injection case) shows an accumulation of O}_2 \text{ at the tip of the post-injection being pushed into the main flame.} \]

At low ambient oxygen levels, the oxidation rate by O2 is found to rise strongly and is the major contributor to overall oxidation. At high ambient oxygen the contribution of O2 oxidation decreases due to the higher activity of OH caused by the increase in flame temperature.