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STUDY ON THE INFLUENCE OF ETHANOL ON THE SOOT FORMATION IN PREMIXED ETHYLENE FLAMES

Isabel Frenzel[1], Dimosthenis Trimis[2,1]

[1]TU Bergakademie Freiberg, Institute of Thermal Engineering, Freiberg, Germany
[2]Karlsruhe Institute of Technology, Engler-Bunte-Institute, Division of Combustion Technology, Karlsruhe, Germany

Aim

- Study on influence of ethanol on soot formation in selected fuel-rich atmospheric pressure laminar premixed ethylene/oxygen/argon flames
- Study on influence of residence time (height above the burner HAB), equivalence ratio ϕ and C/O ratio on Particle Size Distribution Functions (PSDFs)
- In-situ probe sampling with suitable gas conditioning and online analysis using a Scanning Mobility Particle Sizer (SMPS)

Investigated ethylene/ethanol flames

- Two series of tests:
  - Ethylene/oxygen/argon flame ($C_2H_4/O_2/Ar$ = 0.139/0.181/0.680) at ϕ = 2.3 = const. (C/O = 0.77) and stepwise addition of ethanol: 5% - 50% of total carbon feed
  - Ethylene/oxygen/argon flame ($C_2H_4/O_2/Ar$ = 0.128/0.183/0.689) at C/O = 0.7 = const. (ϕ = 2.1) and stepwise addition of ethanol: 5% - 30% of total carbon feed
- Inlet gas temperature of 323 K, atmospheric pressure, cold gas velocity of 8 cm/s (at 273 K and 1 atm)

Experimental setup

- Oil-cooled flat flame model burner (McKenna burner [1]) with bronze plug (Ø 60 mm) and N_2 - shroud
- Stabilization plate at HAB = 30 mm
- Fluid supply via Bronkhorst MFCs (Δϕ = ± 0.03)
- Direct evaporator for liquid fuel (type aSTEAM from aDROP GmbH)
- Mixing of fuel and oxidizer via special mixing chamber
- Conditioning of reactants at 323 K after evaporating the liquid fuel at higher temperature
- Sample probe (Al_2O_3 > 99.5%, 9 mm ID, 10 mm OD) with Ø 0.3 mm orifice
- Dilution ratio ~$2\cdot10^4$ (uncertainty < ± 24%)
- Type S thermocouple (Ø 0.5 mm, ΔT = ± 80 K) for temperature measurement

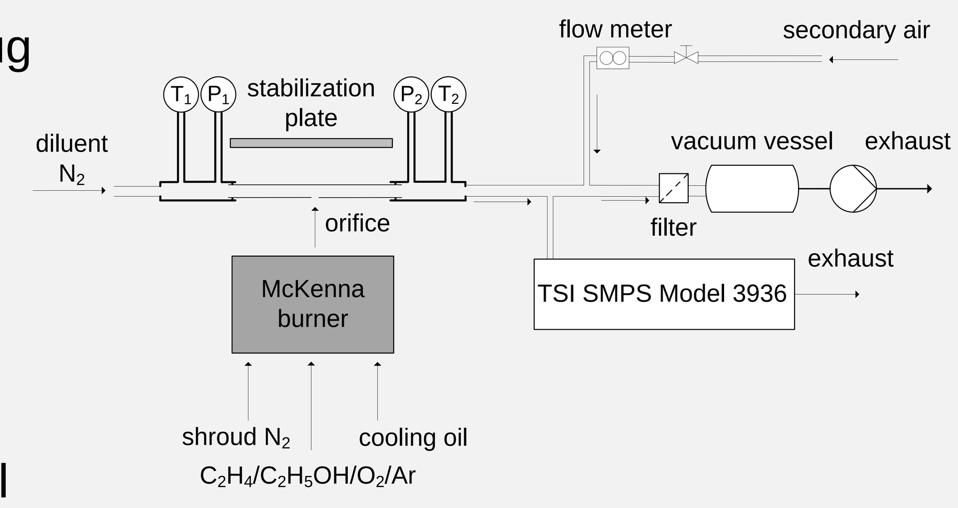

Figure 1. Schematic of experimental setup (similar to [2])

Results for ethylene/ethanol flames with constant ϕ = 2.3

Figure 2. Pictures of ethylene/ethanol flames with different ethanol percentage of the total carbon feed at constant equivalence ratio (ϕ = 2.3)

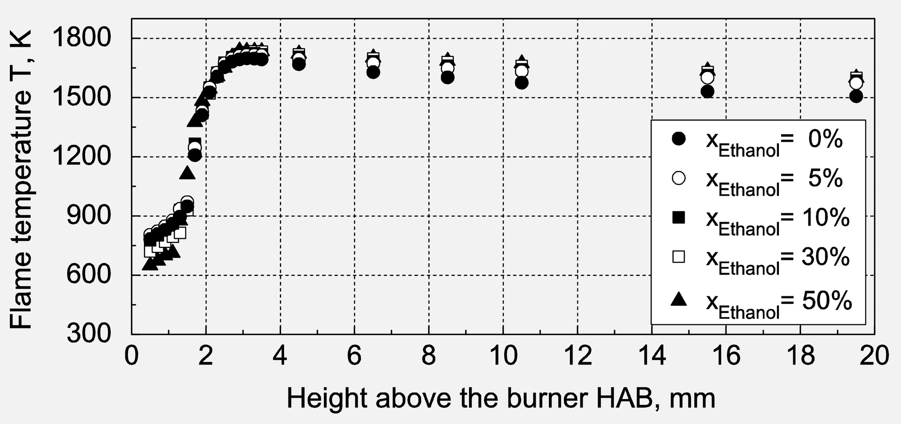

Figure 3. Radiation-corrected axial flame temperature profiles in ethylene/ethanol flames at constant equivalence ratio (ϕ = 2.3)

- Flame temperatures are similar independent of ethanol content
- With increasing ethanol content shift of PSDs to smaller diameters ($x_{Ethanol}$ = 50% at HAB = 12 mm: bimodal → unimodal)
- Ethanol doped flame undergoes a slow down process on soot formation
- Observed effects are consistent with results obtained by others [3, 4]

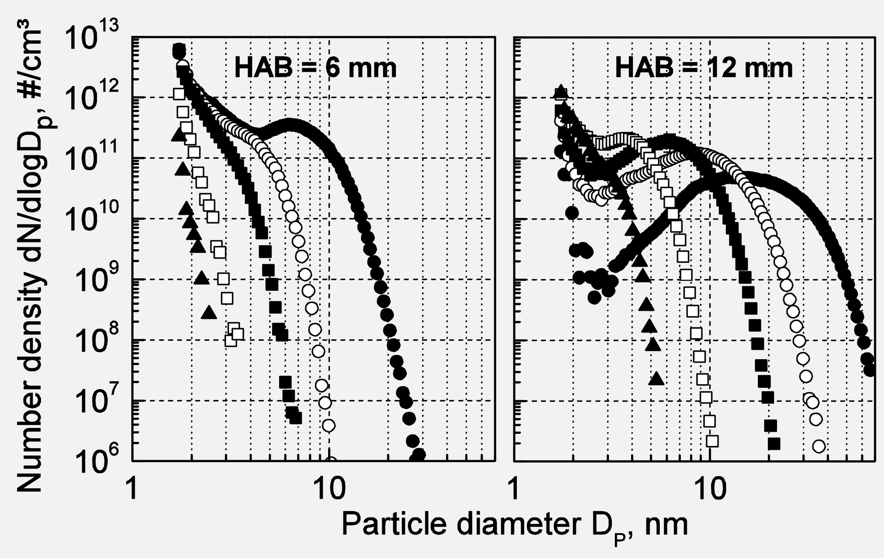

Figure 4. Variation of PSDFs in ethylene/ethanol flames at constant equivalence ratio (ϕ = 2.3) at HAB=6 mm and HAB = 12 mm

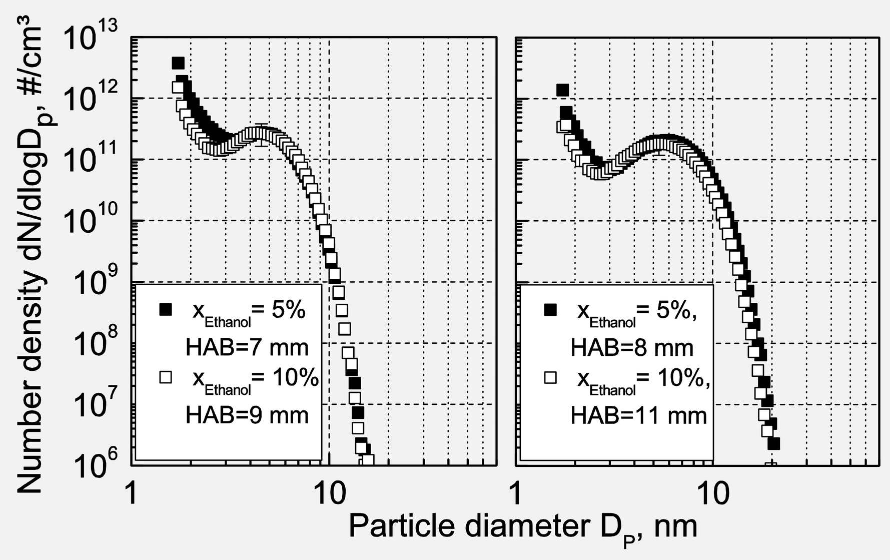

Figure 5. Comparison between similar PSDFs in ethylene/ethanol flames with 5% and 10% ethanol percentage of the total carbon feed at constant equivalence ratio (ϕ = 2.3) at different HABs

Results for ethylene/ethanol flames with constant C/O ratio = 0.7

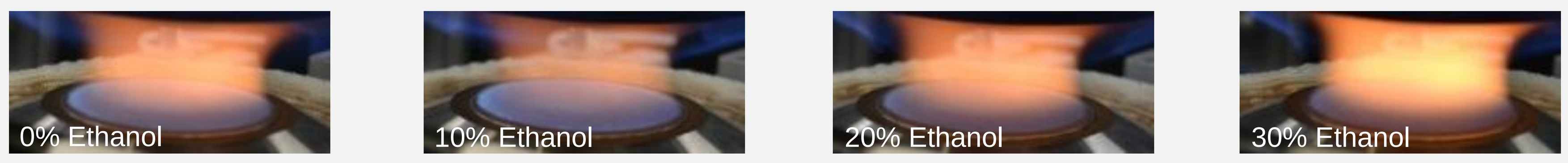

Figure 7. Pictures of ethylene/ethanol flames with different ethanol percentage of the total carbon feed at constant C/O ratio (C/O = 0.7)

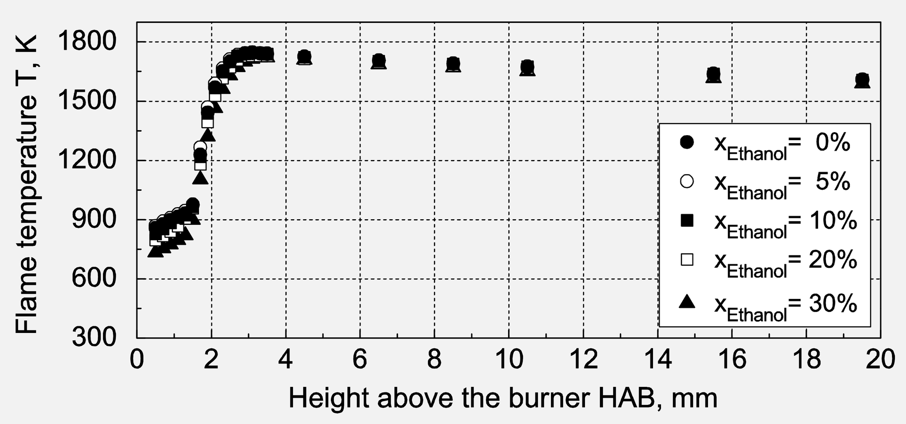

Figure 8. Radiation-corrected axial flame temperature profiles in ethylene/ethanol flames at constant C/O ratio (C/O = 0.7)

- Flame temperatures are similar independent of ethanol content
- With higher amounts of ethanol and constant C/O ratio ϕ is increasing and therefore soot formation increases
- However, PSDFs in pure ethylene flame (ϕ = 2.1) and in flame with 20% ethanol (ϕ = 2.26) are quite similar
- Effect mainly due to fuel structure? (heteroatom O in ethanol)

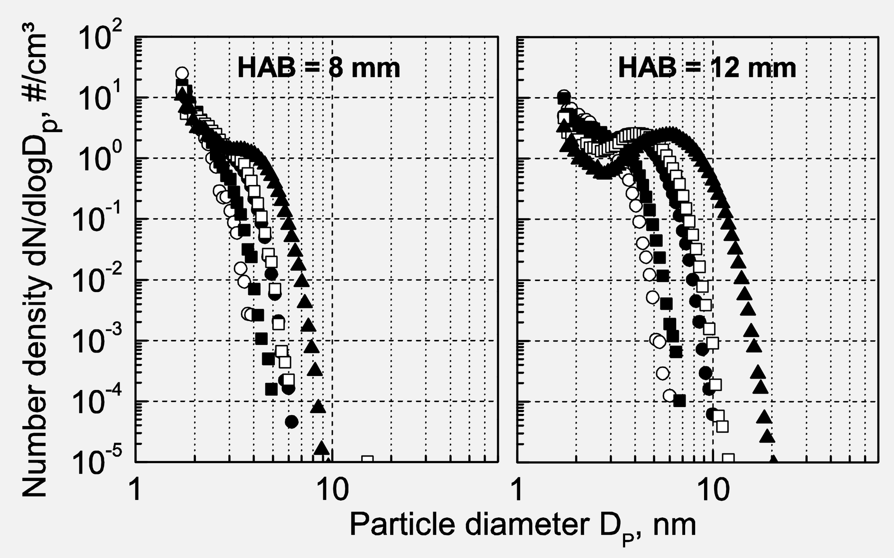

Figure 9. Variation of PSDFs in ethylene/ethanol flames at constant C/O ratio (C/O = 0.7) at HAB = 8 mm and HAB = 12 mm

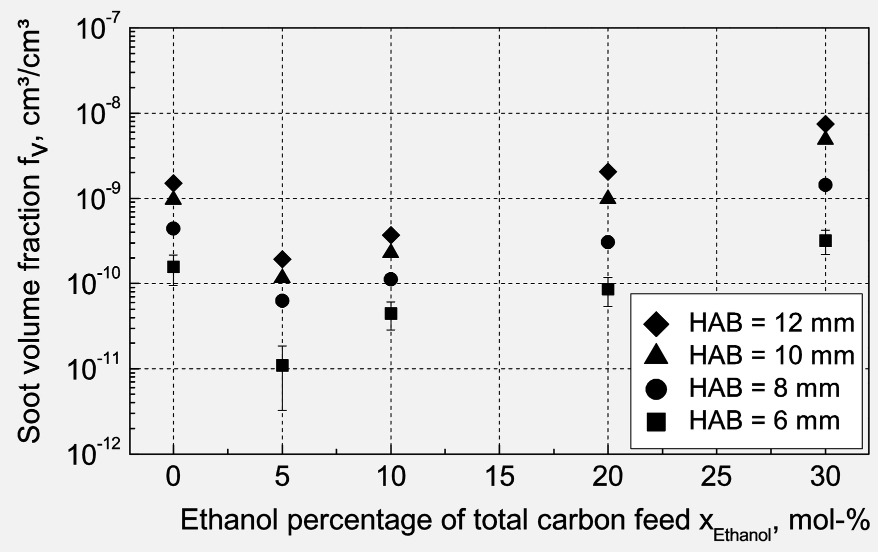

Figure 10. Soot volume fractions of ethylene/ethanol flames as function of ethanol percentage of total carbon feed with constant C/O ratio (C/O = 0.7) at four different HABs.

Results for ethylene/ethanol flames with ϕ = 2.2/2.3/2.4

- Reduction of soot volume with increasing ethanol content in the fuel
- Already 5% of ethanol in the fuel have a significant influence on the soot formation
- Tendency of soot reduction induced by ethanol addition increases at lower equivalence ratios

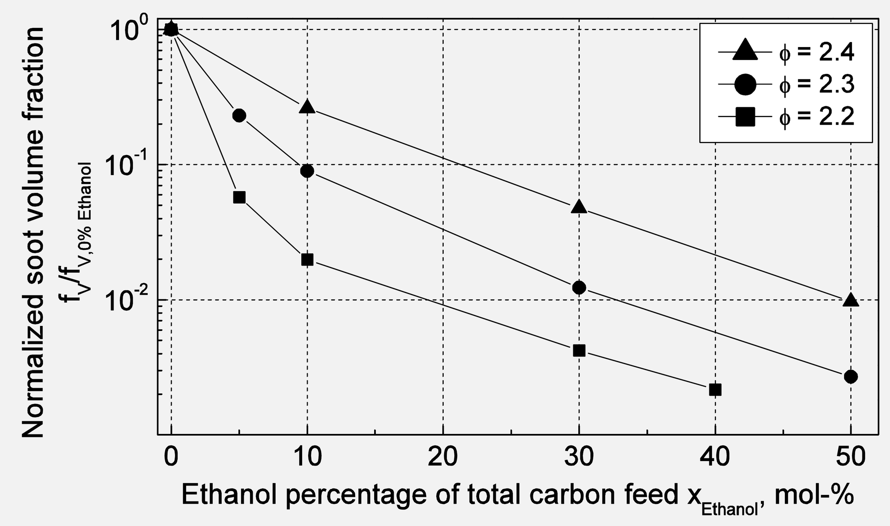

Figure 6. Soot volume fractions of ethylene/ethanol flames normalized with soot volume fractions of pure ethylene flames as function of ethanol percentage of total carbon feed with different equivalence ratios (ϕ = 2.2/2.3/2.4) at HAB = 10 mm

Conclusions

- Addition of ethanol to the fuel leads to a reduction of the soot formation
- For constant equivalence ratio the PSDFs are bimodal in pure ethylene flames and in flames with an ethanol content of < 50%, even for HAB = 12 mm; for 50% ethanol content the PSDFs become unimodal
- The tendency of the reduction of soot formation due to the addition of ethanol is more distinct at low equivalence ratios
- For constant C/O soot formation is increasing with higher amounts of ethanol in the fuel due to the fact that the equivalence ratio increases
- However, the PSDFs in the flame with 20% ethanol and in the pure ethylene flame are quite similar, what leads to the assumption that mainly the fuel structure influences the soot formation

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Dipl.-Ing. Isabel Frenzel
TU Bergakademie Freiberg | Institute of Thermal Engineering | Chair of Gas and Heat Technology | Gustav-Zeuner-Str. 7 | 09599 Freiberg | Germany
Phone: +49 3731 393013 | Fax: +49 3731 393942 I isabel.frenzel@iwtt.tu-freiberg.de | www.gwa.tu-freiberg.de

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