Scattering properties of pulverized solid fuel particles in air and oxy-fuel combustion

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Agenda

- Theory
- Experimental setup
- Results
- Summary & Outlook
Solid fuel combustion

Incident radiation
Mie-Theory

Reflection
Absorption
Refraction
Diffraction
Mie-theory

- Analytical solution of Maxwell-equations for spherical, homogeneous particle
  - Size parameter \( x = \frac{\pi D}{\lambda} \)
  - Complex index of refraction (IOR) \( m = n + ik \)
  - Calculation:
    - Scattering phase function \( \Phi \)

Mie-Theory

Incident radiation

\( D \)
Mie inversion

- Specification of a random start value $m_z$
- Calculating difference of $\Phi_{\text{exp}}$ und $\Phi_z$
- Minimizing difference

\[ m = m_z \]
\[ x = \frac{\pi D}{\lambda} \]

\[ \min_m || - \Phi_{\text{exp}} || \]
Experimental setups

- Particle needs to be contactless

Setup A  
(Aachen)

Setup B  
(Bochum)
Setting A (Aachen)

IR-Emitter

Levitator

\[ \Delta \theta_i = \arctan \left( \frac{D_{\text{lens}}}{d} \right) \]

\[ \Delta \theta_i = 30^\circ \]

- \( D_p: 300 - 2000 \, \mu m \)
- \(~4h\) operation time
Experimental setups

Setup A

Setup B
Setting B (Bochum)

Particle streak

Colombian bituminous coal

Flat flame burner

Quartz glass wall

Gas inlet

$O_2/CO_2$

$O_2/N_2$
Setting B (Bochum)

Movable plate
Setting B (Bochum)

90° off-axis parabolic mirrors, silver coated

Beam dump

90° off-axis parabolic mirrors silver coated
$\Delta \theta = 5^\circ$
Setting B (Bochum)

Forward scattering

θ = 30° - 150°

Backward scattering

Ocean optics flame fiber spectrometer (200-1000nm)

Near-infrared mini-spectrometer (900-2550nm)

FTIR
Difference between A&B

- Setting A (Aachen)
  - one single particle
  - non-reacting at room temperature

- Setting B (Bochum)
  - particle flow
  - Non-reacting and reacting particles
### Difference between A&B

<table>
<thead>
<tr>
<th></th>
<th>Aachen</th>
<th>Bochum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δθ</td>
<td>30°</td>
<td>5°</td>
</tr>
<tr>
<td>N</td>
<td>9</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>0 - 22°</td>
<td>30° – 150°</td>
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<tr>
<td></td>
<td>60° – 120°</td>
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<tr>
<td>D</td>
<td>≈ 700μm</td>
<td>180 μm</td>
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</tbody>
</table>
Results

Phase function comparison of cold coal

- Both datasets analyzed by inverse Mie theory
- IORs:
  - $m = 1.401 + 0.146i$ (single particle)
  - $m = 1.401 + 0.143i$ (particle streak)

- Peak at 90°
- Trend to backscattering
Results

Phase function comparison of cold and burning coal

- Cold coal compared with burning coal in regions of clear char burnout
- Coal diameter of 180μm
- Exemplary chosen wavelength of 500nm
- No huge differences in shape, sightly higher backscattering from burning particles
Results

Wavelength dependent IOR of cold and burning coal

- Observed wavelength ranges:
  - 550nm to 800nm (single particle)
  - 410nm to 800nm (particle streak)
- IORs:
  - Cold single particle: Real and imaginary part constant
  - Cold particle streak: Real and imaginary part slightly decrease with increasing wavelength
  - Burning particle streak: Real and imaginary part slightly decrease with increasing wavelength, both lower than for cold coal
Outlook/Summary

■ Two experiments that measure phase function
  ● Levitator vs. particle streak

■ Mie theory doesn’t reproduce scattering measurement exactly.
  ● We assume non-sphericity is connected to this observation

■ Next steps:
  ● GMM, DLA cluster
  ● Fuel type, coal, biomass
  ● Reacting particles at different burning stages
THANK YOU!

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