Combustion Aerosols: Formation and Properties

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Types of Combustion Particles

1. organic carbon
1 - 100 nm

2. soot
black (elemental) carbon
10 nm – 1 µm

3. residual fly ash
from combustion of solids
(coal, wood)
0.1 µm – 100 µm

4. secondary particles
formed by oxidation reactions of combustion gases w/ atmosphere
examples
$SO_x \rightarrow SO_3^-$ or $SO_4^{2-}$
$NO_x \rightarrow NO_3^-$
Carbonaceous Particles

- Devolatilization
- Pyrolysis (cracking)
- Condensation nucleation
- Soot formation

Temperature:
- 400°C
- 600°C
- 1000°C

Time

EC – Elemental Carbon, OC – Organic Carbon

High EC content

High OC content
Elemental & Organic Carbon Content

<table>
<thead>
<tr>
<th>source</th>
<th>EC / TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>cigarette smoke</td>
<td>0.01</td>
</tr>
<tr>
<td>meat smoke</td>
<td>0.00 – 0.04</td>
</tr>
<tr>
<td>candle (normal burning)</td>
<td>0.04</td>
</tr>
<tr>
<td>fireplace</td>
<td>0.1 – 0.2</td>
</tr>
<tr>
<td>gasoline vehicles</td>
<td>0.10 – 0.4</td>
</tr>
<tr>
<td>diesels</td>
<td>0.15 – 0.9</td>
</tr>
<tr>
<td>coal ash (stoker)</td>
<td>0.8 – 0.9</td>
</tr>
<tr>
<td>sooting candle</td>
<td>0.95</td>
</tr>
</tbody>
</table>

EC – Elemental (black) Carbon, TC – Total Carbon

modified from
Soot Formation

Nanostructure of Soot

Soot Formation in Nonpremixed Flames

Oxy-fuel combustion

\[ \text{C}_2\text{H}_4/\text{Air} \]
\[ T_{ad} = 2370 \text{ K} \]

\[ \text{C}_2\text{H}_4+\text{CO}_2/\text{O}_2 \]
\[ T_{ad} = 2540 \text{ K} \]

- Soot-Free
- High Temp.
- Turbulent
- Stable, unpiloted
- Low-\( \text{NO}_x \)
- High \( \text{CO}_2 \) exhaust concentration for carbon capture

B. Kumfer, S. Skeen, R. Axelbaum
*Combust Flame* (2008)
B. Kumfer, S. Skeen, R. Chen, R. Axelbaum
*Combust Flame* (2006)
Fly ash particles

Vaporization – Nucleation – Condensation – Coagulation Pathway

Submicron Ash
Fractal aggregates of primary particles
20 – 100 nm

Layered composition

Supermicron Ash

Submicron particles from fragmentation

Residual Ash Formation Pathway

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## Metals content in coal

<table>
<thead>
<tr>
<th>Element</th>
<th>ppm(m)</th>
<th>Element</th>
<th>ppm(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>5,000 – 410,000</td>
<td>Co</td>
<td>1 – 90</td>
</tr>
<tr>
<td>Al</td>
<td>3,000 – 23,000</td>
<td>Zn</td>
<td>3 – 80</td>
</tr>
<tr>
<td>Fe</td>
<td>340 – 23,000</td>
<td>V</td>
<td>2 – 77</td>
</tr>
<tr>
<td>Ca</td>
<td>50 – 12,300</td>
<td>Ni</td>
<td>2 – 60</td>
</tr>
<tr>
<td>S</td>
<td>300 – 10,000</td>
<td>Li</td>
<td>4 – 63</td>
</tr>
<tr>
<td>K</td>
<td>100 – 6,500</td>
<td>Nb</td>
<td>5 – 41</td>
</tr>
<tr>
<td>Na</td>
<td>100 – 6,000</td>
<td>As</td>
<td>1 – 60</td>
</tr>
<tr>
<td>Mg</td>
<td>240 – 3,500</td>
<td>Pb</td>
<td>1 – 60</td>
</tr>
<tr>
<td>Ti</td>
<td>200 – 1,800</td>
<td>Ga</td>
<td>0.3 – 60</td>
</tr>
<tr>
<td>Ba</td>
<td>20 – 1,600</td>
<td>Nd</td>
<td>4 – 30</td>
</tr>
<tr>
<td>Sr</td>
<td>17 – 1,000</td>
<td>Sc</td>
<td>3 – 30</td>
</tr>
<tr>
<td>Cr</td>
<td>100 – 400</td>
<td>Ce</td>
<td>1 – 30</td>
</tr>
<tr>
<td>Zr</td>
<td>28 – 300</td>
<td>Y</td>
<td>3 – 25</td>
</tr>
<tr>
<td>P</td>
<td>6 – 300</td>
<td>La</td>
<td>0.3 – 30</td>
</tr>
<tr>
<td>Sn</td>
<td>1 – 400</td>
<td>Sb</td>
<td>0.1 – 30</td>
</tr>
<tr>
<td>Mn</td>
<td>5 – 240</td>
<td>Cd</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Cu</td>
<td>3 – 250</td>
<td>Se</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Rb</td>
<td>1 – 150</td>
<td>Hg</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Legend:
- regulated under Clean Air Act
- more concentrated in submicron fly ash