Streamers and their applications.

Guus Pemen, Bert van Heesch, Wilfred Hoeben
Faculty of Electrical Engineering

a.j.m.pemen@tue.nl
Pulsed corona discharges

Primary streamers

Secondary or late streamers (can be avoided by using short pulses)

fast ICCD end-on views

TU/e Technische Universiteit Eindhoven University of Technology
Quantification of O-radical yields

Primary yield increases if velocity is increased (because local E-field increases and consequently so does the electron energy)

Secondary or late streamers (can be avoided by using short pulses)
Quantification of O-radical yields

7.0 mole/kWh corresponds to 5.3 eV/molecule.

Theoretical cost to produce an O* radical is 3 eV.

Thus more than half of the available energy is used to produce O* radicals.

O* radical yield as function of voltage and pulse width. The rise rate of the pulses was fixed 2.2-2.7 kV/ns. DC bias: 0-20 kV.
Emission intensities of SPS(0,0) and FNS(0,0)

Electron energies during primary streamer propagation are assumed to be much larger than the energy in the secondary streamer development.

Electron energy for N₂⁺(B²Σ_u⁺) generation by direct electron impact excitation from the N₂ ground state is 18.7 eV. It is assumed that the stronger the FNS(0,0) emission, the larger the average electron energy.
Experimental setup

- **Rise-time**: 7.7 ns, **FWHM**: 16 ns
- **Peak value**: 56.6-57.9 kV

**Diagram Details**:
- **EMC cabinet**
- **Camera**
- **Fluorescent plate**
- **266 nm, 8 ns, 2.5 mJ YAG laser**
- **Plasma reactor**
- **Time [ns]**
  - Range: from -100 to 140 ns
  - Voltage [kV]
  - Range: from 0 to 60 kV

**Graph**

- Shows a voltage-time graph with a peak at 7.7 ns.
- The graph displays a clear peak at 56.6-57.9 kV.
Optical characteristics – air
Time integrated - shutter 30 ns

11.6 mm 56.6 kV, 50 A
16.4 mm 57.2 kV, 22 A
21.6 mm 57.9 kV, 8.5 A
28.4 mm 57.9 kV, 3A

Longer gap distance:
- Less current, more branches,
- Smaller diameter, smaller velocity.
Optical characteristics – air

Time resolved - 11.6 mm gap, shutter 0.5 ns

Primary streamer development in about 2 ns (6.10^6 m/s)

Secondary streamers, total duration about 40 ns.
Optical characteristics – air

Time resolved - 21.6 mm gap, shutter 1 ns

Primary streamer development in about 6 ns (4.10^6 m/s)

Little secondary streamers, total duration about 25 ns.
Laser absorption – air
Visualization of density gradients (shockwaves)

Formation of elliptical shockwaves at anode.
Followed by hemispherical ones at the cathode.

Initial velocity 880 m/s.
“Slows” down to 420 m/s after about 20 μs.

Apparently sufficient energy has been deposited in the gas to create substantial gas heating.
Applications

**Air**
- **Odor**
  - Food, Agro
  - Petrochem
- **Volatile Chemical Compounds**
  - Traffic, Power plants
- **Fine Dust, NOx, SOx**
  - Hospitals, Agro
- **Virus and Micro-organisms**
  - Incinerators, P plants
- **Dioxins, Heavy Metals**

**Water**
- **Seismic, Fracture**
  - Marine Industry
- **Virus and Micro-organisms**
  - Food, Waste water
- **Chemical Compounds**
  - Waste + Proc. water

**Process**
- **Gas Conditioning, Reforming**
  - Green+Proc. Industry
- **Plasma Catalysis**
  - Green+Proc. Industry
- **Plasma Combustion, Gasification**
  - Powergen, Recycling

**Time to demonstration**
Application – syngas conditioning

Biomass + Sunlight → Gasification → CO$_2$ + CO + H$_2$ + CH$_4$ + tars

Resulting in: Electric Power, Fuel
## Tar composition

Components with high individual dewpoints cannot be tolerated

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>mass % in tar</th>
<th>(T_{dew, wet}) (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>(C_6H_6)</td>
<td>67.56</td>
<td>32</td>
</tr>
<tr>
<td>Toluene</td>
<td>(C_7H_8)</td>
<td>1.28</td>
<td>32</td>
</tr>
<tr>
<td>Naphtalene</td>
<td>(C_{10}H_8)</td>
<td>17.86</td>
<td>33</td>
</tr>
<tr>
<td>Penol</td>
<td>(C_8H_6O)</td>
<td>0.12</td>
<td>32</td>
</tr>
<tr>
<td>Pyrene</td>
<td>(C_{16}H_{10})</td>
<td>2.94</td>
<td>114</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>(C_{14}H_{10})</td>
<td>4.27</td>
<td>91</td>
</tr>
<tr>
<td>Fluorene</td>
<td>(C_{13}H_{10})</td>
<td>0.53</td>
<td>35</td>
</tr>
<tr>
<td>Indene</td>
<td>(C_9H_8)</td>
<td>1.35</td>
<td>32</td>
</tr>
<tr>
<td>4-Methylstyrene</td>
<td>(C_9H_{10})</td>
<td>0.04</td>
<td>32</td>
</tr>
<tr>
<td>1-Methylnaphtalene</td>
<td>(C_{11}H_{10})</td>
<td>0.13</td>
<td>32</td>
</tr>
<tr>
<td>2-Methylnaphtalene</td>
<td>(C_{11}H_{10})</td>
<td>0.26</td>
<td>32</td>
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<tr>
<td>Biphenyl</td>
<td>(C_{12}H_{10})</td>
<td>0.50</td>
<td>12</td>
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<tr>
<td>Acenaphtalene</td>
<td>(C_{12}H_8)</td>
<td>0.29</td>
<td>14</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>(C_{16}H_{10})</td>
<td>2.83</td>
<td>113</td>
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<tr>
<td>Pyridine</td>
<td>(C_5H_5N)</td>
<td>0.04</td>
<td>32</td>
</tr>
</tbody>
</table>

Dewpoint of each tar component, based on total tar concentration of 20 g/Nm\(^3\), at 1 bar.
Lab investigations (1/3)

**Pulsed power:**
- 20 - 40 kV
- 5 ns rise time, 50 ns wide
- 0.4 J/pulse
- 1 – 100 pulse/second

**Properties:**
- Volume 56 L
- Reactor volume 20 L
- Temp 200 – 800 °C
- Velocity 6 – 12 m/s

**Measurements:**
- FTIR, pressure,
- Temperature, SPA,
- Pulse energy, # pulses

**Model compound:**
- Naphthalene C_{10}H_{8}
Lab investigations (2/3)

Effect of temperature on naphthalene removal in synthetic fuel gas

- 200 deg.C, dry
- 200 deg.C, wet
- 400 deg.C, dry
Lab investigations (3/3)

Corona energy density for 90% removal (kJ/Nm³)

- fuelgas (N₂ + 12% CO₂ + 20% CO + 17% H₂ + 1% CH₄)
- N₂ + 10% CO₂ + 10% CO + 10% H₂
- N₂ + 10% CO₂ + 10% CO
- N₂ + 10% CO₂

Most favourable kinetics at 400 °C.

Hydrogen hampers the process.

Effect of gas composition and temperature.
Mechanism (1/2)

Dominant reactions (by order of importance):

\[ \text{N}_2(A) + C_{10}H_8 \rightarrow \text{products} \]
\[ \text{N}^2D + C_{10}H_8 \rightarrow \text{products} \]
\[ \text{N}_2(A) + \text{N}_2(A) \rightarrow \text{N}_2 + \text{N}_2(A) \]
\[ \text{O} + C_{10}H_8 \rightarrow H + C_{10}H_7O \]
\[ \text{CO} + \text{N}_2(A) \rightarrow \text{N}_2 + \text{CO} \]
\[ \text{CO}_2 + \text{N} \rightarrow \text{CO} + \text{NO} \]
\[ \text{CO}_2 + \text{N}^2D \rightarrow \text{CO} + \text{NO} \]
\[ \text{NO} + \text{N} \rightarrow O + \text{N}_2 \]
\[ \text{NO} + \text{NH} \rightarrow H + \text{N}_2O \]
\[ \text{NO} + \text{NH} \rightarrow \text{OH} + \text{N}_2 \]
\[ \text{NO} + \text{NH} \rightarrow O + \text{N}_2H \]
\[ \text{O} + \text{H}_2 \rightarrow H + \text{OH} \]
\[ \text{O}^1D + \text{H}_2 \rightarrow H + \text{OH} \]
\[ \text{OH} + C_{10}H_8 \rightarrow \text{H}_2O + C_{10}H_7 \]
\[ \text{H}_2 + C_{10}H_7 \rightarrow H + C_{10}H_8 \]
\[ \text{diffusion} \rightarrow C_{10}H_8 \]
Mechanism (2/2)

Example of an important naphthalene decomposition pathway.

Backformation reactions, involving H and OH radicals, seem to hamper the process. That's why the energy requirements are higher for gas compositions containing H$_2$. 
Demonstrator

20 kW corona power.
10,000 – 30,000 m³/hr
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