New trends in electron beam flue gas treatment

Andrzej Pawelec

Institute of Nuclear Chemistry and Technology, Warsaw, Poland

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Some history

• Early phase (Japan, 1970s)

• Pilot plants phase (Japan, USA, Germany, Poland 1980s, 1990s)

• Industrial plants phase (China, Poland, late 90s)

• Recent attempts (China, Bulgaria, Middle East)

Present operating plant:

• EBFGT at Pomorzany Power Station, Poland

• New facilities under construction
Emission of pollutants

Total emission in BSR countries in tonnes per year
**Emission of pollutants**

Emission structure in Poland in 2009 as typical emission structure in Baltic Sea Region

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<table>
<thead>
<tr>
<th>Category</th>
<th>SO2</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy generation</td>
<td>52.14</td>
<td></td>
</tr>
<tr>
<td>Combustion processes in industry</td>
<td>33.19</td>
<td>19.21</td>
</tr>
<tr>
<td>Non industrial combustion processes</td>
<td>28.04</td>
<td></td>
</tr>
<tr>
<td>Industrial processes except combustion</td>
<td>0.38</td>
<td>0.76</td>
</tr>
<tr>
<td>Transport</td>
<td>43.26</td>
<td></td>
</tr>
<tr>
<td>Waste management</td>
<td>0.21</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Electron beam flue gas treatment technology
Electron beam flue gas treatment

Plasma generation by electron beam irradiation

Electron Beam

Reactor

Electron Accelerator

Radial formation

Electrical Power Supply

NH₃

Ammonia

Flue gas

ESP

Byproducts

(NH₄)NO₃, (NH₄)₂SO₄

Reactants

HNO₃, H₂SO₄

Radicals

OH, O, HO₂

Major components

N₂, O₂, H₂O

Carbon dioxide

Toxic molecules

NOₓ, SOₓ

Recovery
Pollutants removed by EB method

The method has been designed for simultaneous removal of:

• \( \text{SO}_2 \)
• \( \text{NO}_x \)

Also there proceeds removal of other pollutants as:

• \( \text{HCl, HF etc.} \)
• \( \text{Volatile Organic Hydrocarbons (VOC)} \)
• \( \text{Dioxins} \)
• \( \text{Others…} \)
Industrial demonstrational flue gas treatment plant
EPS Pomorzany, Poland
EPS Pomorzany – general view
The facility

Main operational data

- Flue gas flow rate: 100 000 - 270 000 Nm³/h
- Pollutants removal efficiency:
  - SO₂: 95%
  - NOₓ: 70%
- Total accelerators power: 1.04 MW
- Inlet flue gas parameters:
  - Temperature: 130 – 150° C
  - SO₂ concentration: 1500 – 2200 mg/Nm³
  - NOₓ concentration: 400 – 600 mg/Nm³
- Ammonia water consumption: 150 – 300 kg/h
- By-product yield: 200 – 300 kg/h
Plant operation results

The results of industrial plant operation proved the applicability of the technology to treatment of industrial flue gases.

By-product composition:

- \((\text{NH}_4)_2\text{SO}_4\): 45-60%
- \(\text{NH}_4\text{NO}_3\): 22 - 30%
- \(\text{NH}_4\text{Cl}\): 10 - 20%
- moisture: 0.4 - 1%
- water insoluble parts: 0.5 - 2%
Future of electron beam flue gas treatment technology
EBFGT development

- Accelerators improvement
- Adjustment for various pollutants – multipollutant control
- Adjustment for various technological processes
- Costs lowering
- New implementations
Application for new pollutants removal
VOC removal

naphtalene  acenaphthene  anthracene  fluoranthene

pyrene  benzo(a)pyrene  dibenzo(a,h) anthracene

VOC removal efficiency

Removal efficiency of PAHs (%)

without NH3  NH3
Mercury removal

Mercury oxidation proceeds in reaction chamber

\[ \text{Hg}^0 \xrightarrow{\text{oxidation}} \text{Hg}^{2+} \xrightarrow{\text{removal}} \]

At medium energy levels, approximately 98% of gaseous mercury vapor was readily oxidized.

Experiments were performed for following parameters:

- Hg concentration in gas: about 16 \( \mu \text{g/m}^3 \)
- Applied doses of E-beam: 2.5 – 10 kGy

Dioxin removal

Electron beam

Flue gas

Active species
(OH, O₃, e, etc)

Dissociation > Dechlorination

Dissociation & Dechlorination

PCDDs

PCDFs

PCBs

Decomposition Efficiency (%)

0 10 20 30

Dose (kGy)

0 20 40 60 80 100
Process improvement
NO\textsubscript{x} removal in the presence of TiO\textsubscript{2} catalyst

**Process mechanism:**

TiO\textsubscript{2} + electron beam $\rightarrow$ $e^-$ + hole$^+$

h$^+$ + TiO\textsubscript{2}- H\textsubscript{2}O $\rightarrow$ OH$^*$ + H$^+$

e$^-$ + TiO\textsubscript{2}-O\textsubscript{2} $\rightarrow$ O$^{2-}$

TiO\textsubscript{2} + NO $\rightarrow$ TiO\textsubscript{2}-NO

TiO\textsubscript{2}-NO + OH$^*$ $\rightarrow$ TiO\textsubscript{2}-HNO\textsubscript{2}

TiO\textsubscript{2}-HNO\textsubscript{2} + OH$^*$ $\rightarrow$ TiO\textsubscript{2}-NO\textsubscript{2} + H\textsubscript{2}O

TiO\textsubscript{2}-NO\textsubscript{2} + OH$^*$ $\rightarrow$ HNO\textsubscript{3}(aq)
Reaction chamber construction improvement

Typical dose distribution in the reactor

Considered reactor construction
Reaction chamber construction improvement

Gas velocity profiles in the reactors
Reaction chamber construction improvement

The results of calculation
New possibilities of process application
Other fuels application – fuel oils

Laboratory intalation at INCT, Warsaw

<table>
<thead>
<tr>
<th>Oil type</th>
<th>SO₂</th>
<th>NOₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arab Medium</td>
<td>97.2 %</td>
<td>91.1 %</td>
</tr>
<tr>
<td>Arab Heavy</td>
<td>99.9 %</td>
<td>90.4 %</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>99.5 %</td>
<td>87.7 %</td>
</tr>
</tbody>
</table>

Removal efficiencies obtained during laboratory research
Other fuels application – results of research

ARABIAN FUEL OIL + 10% Light Oil

- **SO$_2$**
  - Concentration: 1426 ppmv
- **NO$_x$**
  - Concentration: 160 ppmv
- Inlet temperature ($T_{inlet PV}$): 65-67°C
- Humidity: 9.58% (V)
- NH$_3$ Stoichiometry: 0.93

**Dose effect on SO$_2$ and NO$_x$ removal**

Previous works results
Pilot plant research

General view of the pilot plant at one of Saudi ARAMCO refineries.
Pilot plant research

Design data:

- Volumetric flow rate (wet basis) 2,000 Nm\(^3\)/h
- Temperature 300° C
- Pressure atmospheric
- Composition (wet basis):
  - N\(_2\) - 71.62% vol.
  - CO\(_2\) - 11.24% vol.
  - O\(_2\) - 3.14% vol.
- Pollutants concentration:
  - SO\(_2\) - 1503 ppmv
  - NO\(_x\) - 233 ppmv
  - Dust - 170 mg/Nm\(^3\)

Assumed removal rates:

  - SO\(_2\) 95%
  - NO\(_x\) 70%
  - Dust 98%

\[
\begin{align*}
\text{SO}_2 & : 1360-1420 \text{ ppmv} \\
\text{NO}_x & : 136-144 \text{ ppmv}
\end{align*}
\]

\[
\begin{align*}
\text{Gas flow rate: } & \text{620 Nm}^3/\text{h} \\
\text{Gas temp. at PV inlet: } & 82.3^\circ \text{C} \\
\text{Gas humid. at PV inlet: } & 10.3\% \text{ vol.}
\end{align*}
\]

\[
\begin{align*}
\text{SO}_2 & : 1360-1420 \text{ ppmv} \\
\text{NO}_x & : 136-144 \text{ ppmv}
\end{align*}
\]

\[
\begin{align*}
\text{Gas temp. at PV inlet: } & 62.3^\circ \text{C} \\
\text{Gasflow rate: } & \text{620-920 Nm}^3/\text{h} \\
\text{Gas humid. at PV inlet: } & 9.98-10.3\% \text{ vol.}
\end{align*}
\]
Contents of heavy metals (mg/kg) in the byproduct and limits for heavy metals content in the NPK fertilizer established in some countries

<table>
<thead>
<tr>
<th></th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
<th>Co</th>
<th>Pb</th>
<th>Hg</th>
<th>Ni</th>
<th>Zn</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
<td>0.43</td>
<td>0.03</td>
<td>1.01</td>
<td>&lt;0.03</td>
<td>63.5</td>
<td>18.3</td>
<td>averaged values for byproducts collected by cartridge bag filter</td>
</tr>
<tr>
<td></td>
<td>0.24</td>
<td>0.09</td>
<td>1.61</td>
<td>0.03</td>
<td>0.54</td>
<td>1.41</td>
<td>22.80</td>
<td>1476</td>
<td>byproducts collected by ESP</td>
</tr>
</tbody>
</table>

Limits for heavy metals content in NPK fertilizer

<table>
<thead>
<tr>
<th></th>
<th>41</th>
<th>39</th>
<th>300</th>
<th>17</th>
<th>420</th>
<th>2800</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>20</td>
<td>150</td>
<td>500</td>
<td>5</td>
<td>180</td>
<td>1350</td>
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<tr>
<td></td>
<td>50</td>
<td>50</td>
<td>140</td>
<td>150</td>
<td>2</td>
<td>180</td>
<td>1350</td>
</tr>
<tr>
<td></td>
<td>32.2</td>
<td>276.8</td>
<td>12.9</td>
<td>17.8</td>
<td>72.3</td>
<td>mean values of heavy metals concentrations in fertilizers marketed in the Kingdom of Saudi Arabia</td>
<td>Polish standard</td>
</tr>
</tbody>
</table>
Studies on application of EBFGT technology for marine Diesel engines
Studies on application of EBFGT technology for marine Diesel engines

Pollutants' concentrations at the inlet and outlet of the EBFGT installation

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Inlet</th>
<th>Outlet</th>
<th>Removal rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO(_2)</td>
<td>1525 mg/Nm(^3) (2.7% S)</td>
<td>56 mg/Nm(^3) (0.1% S)</td>
<td>96 %</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>2816 mg/Nm(^3)</td>
<td>520 mg/Nm(^3)</td>
<td>81 %</td>
</tr>
</tbody>
</table>

The conceptual scheme of EBFGT installation for marine applications
Application of EBFGT technology for municipal waste incineration

Experimental installation in Takahama Clean Center
New possibilities of process implementation
# TPS Sviloza, Bulgaria

## Design parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric flow rate (Nm³/h, wet base, real oxygen concentration)</td>
<td>608,000 Nm³/h (max) 488,000 Nm³/h (nominal)</td>
</tr>
<tr>
<td>Inlet flue gas parameters</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>140° C</td>
</tr>
<tr>
<td>Flue gas composition:</td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>75.75%</td>
</tr>
<tr>
<td>O₂</td>
<td>9.95%</td>
</tr>
<tr>
<td>CO₂</td>
<td>8.3%</td>
</tr>
<tr>
<td>H₂O</td>
<td>6.0%</td>
</tr>
<tr>
<td>Inlet pollutants concentrations (6% O₂, dry gas)</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>3800 mg/Nm³ (1330 ppmₐ)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>1400 mg/Nm³ (682 ppmₐ)</td>
</tr>
<tr>
<td>Dust</td>
<td>400 mg/Nm³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission limits for TPS Sviloza (according to directive 2001/80/EC, 6% O₂, dry gas):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>1080 mg/Nm³</td>
</tr>
<tr>
<td>NOₓ</td>
<td>600 mg/Nm³</td>
</tr>
<tr>
<td>Dust</td>
<td>100 mg/Nm³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Required removal rates:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>72%</td>
</tr>
<tr>
<td>NOx</td>
<td>57%</td>
</tr>
</tbody>
</table>
TPS Sviloza, Bulgaria
Plant location
Conceptual scheme of EBFGT plant in TPS Sviloza