Modern trends of electron accelerators application for flue gas treatment

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Basis of electron beam flue gas treatment technology
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
Conventional flue gas treatment process vs. Electron Beam Flue Gas Treatment

Limestone-Gypsum Process (SO$_2$ removal)
Ammonia Selective Catalytic Reduction Process (NO$_x$ removal)

Electron Beam Flue Gas Treatment Process
Electron beam flue gas treatment

Plasma generation by electron beam irradiation

- Electron Beam Irradiation
- Electromagnetic radiation
- Gas plasma formation

Reaction:
- Radical formation
- Combustion flue gas

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:

• $\text{HCl}$, $\text{HF}$ etc.
• Volatile Organic Hydrocarbons (VOC)
• Dioxins
• Others…
Advantages of EBFGT technology

- Simultaneous removal of SO$_2$ and NO$_x$, multi-pollution control system
- High removal efficiency
- High flexibility of installation
- Dry process
- Wasteless process, usable by-product
- Simple facility construction
- Easy retrofitting
Potential processes suitable for application of electron beam flue gas treatment technology

- Energy and heat generation
- Oil refineries
- Waste incinerators (municipal and medical)
- Cement and concrete production
- Metal production (ore sintering)
- And 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
The results of industrial plant operation proved the applicability of the technology to treatment of industrial flue gases.

By-product composition:

- (NH₄)₂SO₄: 45-60%
- NH₄NO₃: 22 - 30%
- NH₄Cl: 10 - 20%
- moisture: 0.4 - 1%
- water insoluble parts: 0.5 - 2%
Modern trends of electron beam flue gas treatment technology development
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
- acenaphtene
- anthracene
- fluoranthene
- pyrene
- benzo(a)pyrene
- dibenzo(a,h) anthracene

VOC removal efficiency

![Graph showing removal efficiency of PAHs (%)]
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 $\mu$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 (%) vs Dose (kGy)
Process improvement
NO$_x$ removal in the presence of TiO$_2$ catalyst

Process mechanism:

$\text{TiO}_2 + \text{electron beam} \rightarrow e^- + \text{hole}^+$

$h^+ + \text{TiO}_2 - \text{H}_2\text{O} \rightarrow \text{OH}^* + \text{H}^+$

$e^- + \text{TiO}_2 - \text{O}_2 \rightarrow \text{O}^{2-}$

$\text{TiO}_2 + \text{NO} \rightarrow \text{TiO}_2 - \text{NO}$

$\text{TiO}_2 - \text{NO} + \text{OH}^* \rightarrow \text{TiO}_2 - \text{HNO}_2$

$\text{TiO}_2 - \text{HNO}_2 + \text{OH}^* \rightarrow \text{TiO}_2 - \text{NO}_2 + \text{H}_2\text{O}$

$\text{TiO}_2 - \text{NO}_2 + \text{OH}^* \rightarrow \text{HNO}_3(\text{aq})$
Reaction chamber construction improvement

Typical dose distribution in the reactor

Considered reactor construction

Variant 1

Variant 2

Variant 3
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 installation at INCT, Warsaw

Removal efficiencies obtained during laboratory research

<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>
Other fuels application – results of research

ARABIAN FUEL OIL + 10% Light Oil

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

Dose effect on SO\(_2\) and NO\(_x\) removal

Previous works results
General view of the pilot plant at one of Saudi ARAMCO refineries.

Pilot plant research

Design data:

- Volumetric flow rate (wet basis): 2,000 Nm³/h
- Temperature: 300°C
- Pressure: atmospheric
- Composition (wet basis):
  - N₂: 71.62% vol.
  - CO₂: 11.24% vol.
  - O₂: 3.14% vol.
  - H₂O: 13.83% vol.
- Pollutants concentration:
  - SO₂: 1503 ppmv
  - NOₓ: 233 ppmv
  - Dust: 170 mg/Nm³

Assumed removal rates:

- SO₂: 95%
- NOₓ: 70%
- Dust: 98%
Pilot plant research
The byproduct

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>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>&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>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

| 41 | 39 | 300 | 17 | 420 | 2800 |
|----|----|-----|----|-----|------|--------------------------------------------|
| US EPA CFR40 Part. 503 |

| 75 | 20 | 150 | 500 | 5 | 180 | 1350 |
|----|----|-----|-----|---|-----|------|---------------------------------------------|
| Canadian Fertilizer Act (1996) |

| 50 | 50 | 140 | 2 |
|----|----|-----|---|----------------------------------|
| Polish standard |

| 32.2 | 276.8 | 12.9 | 17.8 | 72.3 |
|------|-------|------|------|------|------|
| mean values of heavy metals concentrations in fertilizers marketed in the Kingdom of Saudi Arabia |
Studies on application of EBFGT technology for marine Diesel engines
Studies on application of EBFGT technology for marine Diesel engines

The conceptual scheme of EBFGT installation for marine applications

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>SO₂</td>
<td>1525 mg/Nm³ (2.7% S)</td>
<td>56 mg/Nm³ (0.1% S)</td>
<td>96 %</td>
</tr>
<tr>
<td>NOₓ</td>
<td>2816 mg/Nm³</td>
<td>520 mg/Nm³</td>
<td>81 %</td>
</tr>
</tbody>
</table>
Application of EBFGT technology for municipal waste incineration

Experimental installation in Takahama Clean Center
New possibilities of process implementation
EBFGT facility in TPS Svioloza, Bulgaria (design phase)

Plant visualization
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>3800 mg/Nm³ (1330 ppm,v) 1400 mg/Nm³ (682 ppm,v) 400 mg/Nm³</td>
</tr>
</tbody>
</table>

Emission limits for TPS Sviloza (according to directive 2001/80/EC, 6% O₂, dry gas):

- SO₂  1080 mg/Nm³
- NOₓ  600 mg/Nm³
- Dust 100 mg/Nm³

Required removal rates:

- SO₂  72%
- NOₓ  57%
TPS Sviloza, Bulgaria

Conceptual scheme of EBFGT plant in TPS Sviloza
EBFGT technology application for liquid fuels – possible implementation

Main design parameters:

Volumetric flow rate 160 000 Nm$^3$/h

Pollutants concentrations (wet base)
- $\text{SO}_2$ - 1900 ppmv
- $\text{NO}_x$ - 240 ppmv
- Dust - 170 mg/Nm$^3$

Required removal rates:
- $\text{SO}_2$ - 90 %
- $\text{NO}_x$ - 50 %

Location: one of refineries in Saudi Arabia
EBFGT technology application for liquid fuels – possible implementation

Conceptual scheme of 160 000 Nm$^3$/h capacity demonstration plant
EBFGT technology upscaling

- A 1 000 000 Nm³/h capacity unit is concerned
- High power accelerators are developed
- Costs lowering is obtained

ELV 12 accelerator, EB-Tech, Republic of Korea
Thank You for Your Attention

My visit card:

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