Environmental Applications of Electron Beam

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Plasma generation by electron beam

Electron beam generated plasma in the reactor
Electron beam applications for pollution control

- Flue gas purification
- Wastewater treatment
- Sludge hygienization
Wastewater treatment
Conventional wastewater treatment facility - process flow

Influent → Chemical Treatment → Primary Aeration → Sedimentation → 2nd Aeration → Sedimentation → Reservoir

Sedimentation → Thickening → dewatering → Landfill

Effluent
Principles of electron beam wastewater treatment process

Water Molecule → Active Radicals → Harmful Organic in Waste water

- Complete Decomposition
- Partial Decomposition
- Suspended solid
- Monomer to Polymerization
- Removal of Toxic group
- Removal of Color, Odor
- Coagulation
- Bio-Treat

$\text{H}_2\text{O, CO}_2$
Main goals of electron beam wastewater processing

1. Organic pollutants removal
2. Removal of colour
3. Odours removal
4. Water disinfection
E-beam wastewater treatment application

High contaminated water
- Textile dyeing wastewater
- Leachate from landfill area
- Wastewater from petrochemical plant
- Wastewater from papermill
- Wastewater from tanning industry

Low contaminated water
- Underground water
- Water from lakes or marches
- Effluent from municipal plant

Impurities removal (COD, BOD etc.) → Discharge

Disinfection, removal of odour, colour, residuals → Re-use
Pilot wastewater treatment facility, Daegu Dyeing Industrial Complex, Korea

Main facility

80 000 m³/day

Influent

Electron beam irradiation

Tower type biological treatment system

1 000 m³/day

Reservoir

Effluent

Reactor
Sludge hygienization
Typical wastewater treatment process – sludge generation
Biological hazard of sewage sludge

Microorganism concentration per 100 ml

Coliforms 107 – 109
Fecal Coliforms 106 – 108
Fecal Streptococci 106 – 107
Salmonella 1 - 100

Anaerobic spore forming bacteria
Parasites and viruses
Present sludge management ways

- Incineration – high energy demand, expensive
- Sanitary landfill – wasteful, limited availability of land in urban areas
- Sea disposal – possible in limited areas, polluting
- Agricultural use – desirable, needs hygienization
Conventional biosolids preparation methods

1. Digestion
   - Aerobic and anaerobic digestion
   - Stabilised biosolids

2. Lime stabilisation
   - Lime
   - Lime stabilised biosolids

3. Composting
   - Green waste
   - Composting process
   - Composted biosolids

4. Heat treatment
   - Heat stabilised biosolids
   - Pelletisation of biosolids
   - Biosolids pellets

5. Energy from waste
   - External power source
   - Energy recovery

Alternative pathways:
- Biosolids dewatering (solar or mechanical)
- Biosolids cake

Beneficial uses include:
- Agriculture
- Domestic and commercial landscaping
- Forestry
- Further processing

Residuals:
- Landfill
Electron beam sludge hygienization

E-Beam effect in sludge treatment:

\[ \text{radiation} \]

\[ H_2O \rightarrow \cdot OH, H\cdot, e^{-}_aq, H_2, H_2O_2 \]

\[ \cdot OH, H\cdot, e^{-}_aq + \text{DNA of microorganism} \rightarrow \text{Damage in DNA (no duplication)} \]

Scheme of practical application:
Advantages of electron beam sludge treatment

- Inactivation of dangerous microorganisms and parasites
- Removal of pollutants by oxidative degradation
- Elimination of toxicity, color and smell of pollutants and addition of biodegradability by changing chemical structure
- Improvement of precipitation and filtration properties of fine particles of pollutant

About 99.99% of coliform bacteria is removed by application of 3 kGy dose irradiation
Radiation sludge treatment plants

Pilot sludge treatment plants:
- New Mexico, USA (1978)  
  Gamma-ray ($^{137}$Cs)
- Weldel, Germany (1980)  
  Electron beam 50kW (1.0MeV, 50mA)
- Verginia Key, Florida, USA (1984)  
  Electron beam 75kW (1.5MeV/50mA)
- Takasaki, Japan (1991)  
  Electron beam 15kW (2MeV/15kW)
- Sao Paulo, Brazil (1993)  
  Electron beam 25kW (1.5MeV, 25mA)
- Tucuman, Argentina (1998)  
  Gamma-ray ($^{60}$Co)
- Daejeon, Korea (2005)  
  Electron beam 40kW (1.0MeV, 40mA)

Commercial sludge treatment plants:
- Munich, Germany (1973~1984)  
  Gamma-ray ($^{60}$Co)
- Vadodara, India (1989)  
  Gamma-ray ($^{60}$Co)

Planned sludge treatment plants:
- Shafdan, Israel  
  Electron beam 40kW 100kW (2.0MeV, 50mA)
Electron beam flue gas treatment
List of the emission processes in the Baltic Sea Region

Emission structure in Poland in 2009 as typical emission structure in BSR

![Bar chart showing emission structure in Poland in 2009]
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.
Electron beam flue gas treatment
Pollutants removed by EB method

The method has been designed for simultaneous removal of:

• SO$_2$
• NO$_x$

Also there proceeds removal of other pollutants as:

• HCl, 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
Comparison of selected plasma technologies

Annual operational costs of selected flue gas treatment technologies
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 Nm$^3$/h
- Pollutants removal efficiency:
  - $\text{SO}_2$: 95%
  - $\text{NO}_x$: 70%
- Total accelerators power: 1.04 MW
- Inlet flue gas parameters:
  - Temperature: 130 – 150°C
  - $\text{SO}_2$ concentration: 1500 – 2200 mg/Nm$^3$
  - $\text{NO}_x$ concentration: 400 – 600 mg/Nm$^3$
- 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:

- $(\text{NH}_4)_2\text{SO}_4$: 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%
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>

Fig. 14. Schematic diagram of laboratory scale electron-beam flue gas treatment (ERBFST) installation

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Other fuels application – results of research

ARABIAN FUEL OIL + 10% Light Oil

SO₂ and NOₓ removal efficiency [%]

Dose [kGy]

SO₂: 1426ppmv
NOₓ: 160ppmv
T_{inletPV}: 65-67°C
Humidity: 9.58% (V)
NH₃ Stoichiometry: 0.93

Previous works results

Dose effect on SO₂ and NOₓ removal
Pilot plant research

General view of the pilot plant at one of Saudi ARAMCO refineries.
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.
  - H$_2$O: 13.83% 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%
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

<table>
<thead>
<tr>
<th>US EPA CFR40 Part. 503</th>
<th>41</th>
<th>39</th>
<th>300</th>
<th>17</th>
<th>420</th>
<th>2800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian Fertilizer Act (1996)</td>
<td>75</td>
<td>20</td>
<td>150</td>
<td>500</td>
<td>5</td>
<td>1350</td>
</tr>
<tr>
<td>Polish standard</td>
<td>50</td>
<td>50</td>
<td>140</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean values of heavy metals concentrations in fertilizers marketed in the Kingdom of Saudi Arabia</td>
<td>32.2</td>
<td>276.8</td>
<td>12.9</td>
<td>17.8</td>
<td>72.3</td>
<td></td>
</tr>
</tbody>
</table>
Studies on application of EBFGT technology for marine Diesel engines

[Graph showing annual emissions of CO₂, NOₓ, SO₂, PM10, and fuel consumption for Road Traffic, Aviation, and Shipping categories.]

[Map showing NOx emissions from ships for 1997 around the world with color-coded regions.]
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>
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<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>
Application of EBFGT technology for municipal waste incineration

Experimental installation in Takahama Clean Center (dioxin removal)
New possibilities of process implementation
EBFGT facility in TPS Sviloza, Bulgaria (design phase)
EBFGT technology application for liquid fuels – possible implementation

Main design parameters:

Volumetric flow rate 160 000 Nm³/h

Pollutants concentrations (wet base)
- \( \text{SO}_2 \) - 1900 ppmv
- \( \text{NO}_x \) - 240 ppmv
- Dust - 170 mg/Nm³

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

Location: one of refineries in Saudi Arabia
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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