Gaseous emissions during oxy-fuel combustion of sewage sludge in a circulating fluidized bed
INTRODUCTION

1. Increasing production of sewage sludge in Poland creates environmental problems with its disposal.


3. Thermal treatment of sludge becomes an attractive option because:
   • It significantly reduces the volume of waste material
   • It minimizes odour and destroys toxic compounds
   • It allows energy recovery from the sludge (LHV > 6.0 MJ/kg)

4. Problems associated with sewage sludge incinerators include:
   • Emission of greenhouse gases
   • Ash disposal

5. Oxy-fuel combustion technology is the most promising option for the reduction of greenhouse gas emissions from combustion of fossil fuels and incineration of biological and industrial waste materials.
OXY-FUEL COMBUSTION PROCESS

Air → Oxygen plant → N₂ → O₂ → BOILER → Flue gas cleaning → Generator

Fuel → BOILER → Flue gas cleaning → Condensation → H₂O

CO₂ recycle → CO₂ → Condensation

Steam turbine
OBJECTIVE AND SCOPE OF INVESTIGATION

Objective: To determine the influence of fuel characteristic and oxidizing atmosphere on emissions of pollutants during combustion in a bench-scale circulating fluidized-bed reactor.

Scope:
1. Analyses of tested fuels,
2. Measurements of NO, N₂O and SO₂ during combustion in air and in O₂+CO₂ mixtures (oxy-fuel combustion),
3. Analysis of collected data.
EXPERIMENTAL APPARATUS

1 – combustion chamber
2 – cyclone
3 – downcomer
4 – loop seal
5 – fuel particles
6 – insulation
7 – drain valve
8 - preheater
9 – card
10 - computer
11 – temperature control system
12 – gas cylinders
13 – air compressor
14 - pressure regulators
15 – rotameters
16 – valves
17 – mixer
18 – gas analyser
19 – ventilation duct

T1–T3 – S-type thermocouples
EXPERIMENTAL CONDITIONS

Temperature: 850°C
Pressure: ambient
Bed material: silica sand, $d_{50} \sim 200 \mu m$
Fuels: dry sewage sludge, wooden biomass (willow), bituminous coal
Fuel sample mass: 0.5 g
Composition of fluidizing gas:

1. Air (base case)
2. 21% $O_2$ and 79% $CO_2$
3. 30% $O_2$ and 70% $CO_2$
4. 40% $O_2$ and 60% $CO_2$
## ANALYSES OF TESTED FUELS

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Sewage sludge</th>
<th>Basket willow</th>
<th>Bituminous coal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate analysis (air-dry basis)</strong></td>
<td></td>
<td></td>
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<tr>
<td>Moisture (M), %</td>
<td>4.9</td>
<td>6.9</td>
<td>8.7</td>
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<tr>
<td>Ash (A), %</td>
<td>36.4</td>
<td>1.4</td>
<td>18.9</td>
</tr>
<tr>
<td>Volatile matter (VM), %</td>
<td>51.4</td>
<td>76.3</td>
<td>26.8</td>
</tr>
<tr>
<td>Fixed carbon (FC), % (by difference)</td>
<td>7.3</td>
<td>15.4</td>
<td>45.6</td>
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<tr>
<td>Higher heating value (HHV), MJ/kg</td>
<td>13.55</td>
<td>18.20</td>
<td>22.75</td>
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<tr>
<td><strong>Ultimate analysis (dry, ash-free basis)</strong></td>
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</tr>
<tr>
<td>Carbon (C), %</td>
<td>52.49</td>
<td>49.59</td>
<td>73.30</td>
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<tr>
<td>Hydrogen (H), %</td>
<td>6.69</td>
<td>5.99</td>
<td>4.30</td>
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<td>Sulphur (S), %</td>
<td>2.46</td>
<td>0.03</td>
<td>2.29</td>
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<tr>
<td>Nitrogen (N), %</td>
<td>7.27</td>
<td>0.33</td>
<td>1.10</td>
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<tr>
<td>Oxygen (O), % (by difference)</td>
<td>31.09</td>
<td>44.06</td>
<td>19.01</td>
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</table>
RESULTS – NO EMISSIONS

Air

21% O₂ + 79% CO₂

30% O₂ + 70% CO₂

40% O₂ + 60% CO₂
RESULTS – RELATIVE NO EMISSIONS

Influence of oxidizing atmosphere on NO emissions

![Bar chart showing relative NO emissions for sewage sludge and coal under different oxygen percentages.](chart.png)
RESULTS – N₂O EMISSIONS

Air

21% O₂ + 79% CO₂

30% O₂ + 70% CO₂

40% O₂ + 60% CO₂
RESULTS – RELATIVE N$_2$O EMISSIONS

Influence of oxidizing atmosphere on N$_2$O emissions

![Bar chart showing relative N$_2$O emissions for sewage sludge and coal under different oxidizing atmospheres.](chart)
<table>
<thead>
<tr>
<th></th>
<th>Air</th>
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<tr>
<td><strong>Conversion of fuel-N to NO, %</strong></td>
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<tr>
<td>Sewage sludge</td>
<td>9.3</td>
<td>9.9</td>
<td>9.6</td>
<td>11.3</td>
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<tr>
<td>Coal</td>
<td>25.6</td>
<td>36.1</td>
<td>34.2</td>
<td>36.5</td>
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<tr>
<td><strong>Total conversion of fuel-N to NOₓ, %</strong></td>
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<tr>
<td>Sewage sludge</td>
<td>25.2</td>
<td>28.8</td>
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<tr>
<td>Coal</td>
<td>45.5</td>
<td>62.6</td>
<td>47.2</td>
<td>47.6</td>
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</tbody>
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RESULTS – SO₂ EMISSIONS

- **Air**
  - 21% O₂ + 79% CO₂
  - 30% O₂ + 70% CO₂
  - 40% O₂ + 60% CO₂

- **21% O₂ + 79% CO₂**
- **30% O₂ + 70% CO₂**
- **40% O₂ + 60% CO₂**
RESULTS – RELATIVE $SO_2$ EMISSIONS

Influence of oxidizing atmosphere on $SO_2$ emissions

![Graph showing relative SO2 emissions for sewage sludge and coal under different oxidizing atmospheres. Air, 21% oxy, 30% oxy, and 40% oxy are compared.]
CONCLUSIONS

1. Dry sewage sludge contains much more volatile matter, ash and nitrogen than the reference coal.

2. Instantaneous and average emissions of NO, N$_2$O and SO$_2$ for the combustion of sewage sludge in all atmospheres were much higher than those for the combustion of reference coal.

3. The SO$_2$ concentration profile for sewage sludge has a bimodal distribution which may suggest that SO$_2$ originated from both organic and inorganic sulphur sources.

4. Relative NO emissions for sewage sludge were insensitive to O$_2$ content up to 30% then they increased sharply. In the case of coal, combustion in O$_2$+CO$_2$ atmosphere caused sharp increase in NO emissions.

5. Relative emissions of N$_2$O for sewage sludge and coal have similar patterns. The highest emissions occurred for combustion in the 21% O$_2$ + 79% CO$_2$ mixture, then they decreased with increasing O$_2$ content.

6. SO$_2$ emissions for sewage sludge were insensitive to the composition of oxidizing atmosphere. In the case of coal, the highest emissions occurred for combustion in the 21% O$_2$ + 79% CO$_2$ mixture, then they decreased with increasing O$_2$ content.