Large scale experimental simulations of underground coal gasification (UCG) process with selected European lignites

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Lignites, the recoverable reserves of which are estimated at 18 percent of the total global coal reserves, remain a crucial contributor to the energy supply in many countries.

They are characterised by high moisture contents, reaching up to 60 wt%, poor calorific values and high susceptibility to spontaneous ignition (must be used in close proximity to their mining sites).

The issue of the suitability of high-moisture lignites for UCG is still questionable due to many technological difficulties to be solved, e.g. poor gas quality, low thermal efficiency and water management.

Regarding the UCG of lignites, most of the global research activities were focused on hard lignite (meta-lignite).
**Objectives**
The overall objective of the COAL2GAS Project is to evaluate the feasibility of UCG in shallow lignite seams, geologically, technically and environmentally and to illustrate this for a selected deposit in Romania. A future pilot will be prepared focusing on environmental protection. Chances will be assessed for other similar European deposits.

**Project Consortium**

Project co-funded by the European Commission under the Research Fund for Coal and Steel (RFCS)
Lignite bulk samples for ex-situ UCG tests: Origin

- "Pesteana" Open Pit Mine
  CEO Oltenia
  (Romania)

- Premogovnik Velenje
  (Slovenia)
Lignite bulk samples for ex-situ UCG tests: Origin

„Pesteana” Open Pit Mine
CEO Oltenia (Romania)

Premogovnik Velenje
(Slovenia)
Lignite bulk samples for ex-situ UCG tests: Delivery
# Lignite characteristics: Proximate and ultimate analysis

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Velenje</th>
<th>Oltenia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>As received</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Total moisture $W_t$, %</td>
<td>31.62</td>
<td>45.64</td>
</tr>
<tr>
<td>2</td>
<td>Ash $A_t$, %</td>
<td>4.29</td>
<td>8.86</td>
</tr>
<tr>
<td>3</td>
<td>Volatiles $V_t$, %</td>
<td>43.67</td>
<td>25.78</td>
</tr>
<tr>
<td>4</td>
<td>Total sulphur $S_t$, %</td>
<td>0.51</td>
<td>1.49</td>
</tr>
<tr>
<td>5</td>
<td>Calorific value $Q_i$, kJ/kg</td>
<td>13 615</td>
<td>10 642</td>
</tr>
<tr>
<td></td>
<td><strong>Analytical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Total moisture, %</td>
<td>11.13</td>
<td>11.49</td>
</tr>
<tr>
<td>7</td>
<td>Ash $A^a$, %</td>
<td>5.57</td>
<td>14.42</td>
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<tr>
<td>8</td>
<td>Volatiles $V^a$, %</td>
<td>56.76</td>
<td>41.98</td>
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<tr>
<td>9</td>
<td>Heat of combustion $Q_s^a$, kJ/kg</td>
<td>19 719</td>
<td>20 001</td>
</tr>
<tr>
<td>10</td>
<td>Calorific value $Q_i^a$, kJ/kg</td>
<td>18 427</td>
<td>18 860</td>
</tr>
<tr>
<td>11</td>
<td>Total sulfur $S^a$, %</td>
<td>0.66</td>
<td>2.43</td>
</tr>
<tr>
<td>12</td>
<td>Carbon $C_t^a$, %</td>
<td>49.86</td>
<td>49.49</td>
</tr>
<tr>
<td>13</td>
<td>Hydrogen $H_t^a$, %</td>
<td>4.67</td>
<td>3.94</td>
</tr>
<tr>
<td>14</td>
<td>Nitrogen $N^a$, %</td>
<td>0.64</td>
<td>1.34</td>
</tr>
<tr>
<td>15</td>
<td>Oxygen $O_d^a$, %</td>
<td>27.83</td>
<td>17.12</td>
</tr>
</tbody>
</table>
Lignites characteristics: Fischer assay
Lignites characteristics: Sulphur speciation

าน


total sulphur [%] pyritic sulphur [%] sulphate sulphur [%] ash sulphur [%] combustible sulphur [%]

Valenje (SLO) Oltenia (RO)
(1) reagents supply system, (2) gasification chamber, (3) water scrubber, (4) gas cooler, (5) separator, (6) filters
Ex-situ UCG experimental installation: Characteristics

**Technical parameters:**
- coal type: lignite, hard coal
- coal seam length: 7 m
- gasification pressure: max 0.5 bar
- temperature: max 1600 °C
- coal seam inclination: 0, 15, 30, 45°
UCG experimental simulations: Coal seam preparation
Artificial coal seam: Geometry and thermocouples

Inlet Wylot
0.25 m 1.25 m 2.25 m 3.25 m 4.25 m 5.25 m 6.25 m
15 19 18 17 16 15
12 11 10 9 8 7
5 4 3 2 1

Outlet
6.25 m
6 13 14 20 21

Gasification channel

Coal seam

0.70 m

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UCG experimental simulations: Artificial seam of lignite
UCG experimental simulations: Installation of thermocouples
UCG experimental simulations: Reactor closure
**UCG experiments:** Oxidants supply and gas production rates

**Premogovnik Velenje**  
(Slovenia)

**CEO Oltenia**  
(Romania)

**Graphs:**

- **Premogovnik Velenje** shows the gas production and oxygen supply rate over time.
- **CEO Oltenia** demonstrates the flow rate for steam and oxygen over time.

**Key Points:**
- Premogovnik Velenje and CEO Oltenia are locations for UCG experiments.
- The graphs illustrate the flow rates for steam and oxygen supply.

**Steering Committee:**
- Premogovnik Velenje (Slovenia)
- CEO Oltenia (Romania)
Results: Changes in gas composition

Premogovnik Velenje
(Slovenia)

CEO Oltenia
(Romania)

Concentration, % vol.

Time, h

CO2
H2
N2
CH4
CO

Steam/O₂  Steam
**Results:** Average gas composition

<table>
<thead>
<tr>
<th>Coal</th>
<th>CO₂</th>
<th>C₂H₆</th>
<th>H₂</th>
<th>O₂</th>
<th>N₂</th>
<th>CH₄</th>
<th>CO</th>
<th>H₂S</th>
<th>CV, MJ/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velenje</td>
<td>52.5</td>
<td>0.2</td>
<td>21.0</td>
<td>1.0</td>
<td>2.0</td>
<td>4.3</td>
<td>18.6</td>
<td>0.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Oltenia</td>
<td>63.3</td>
<td>0.2</td>
<td>21.3</td>
<td>0.2</td>
<td>1.5</td>
<td>2.7</td>
<td>10.2</td>
<td>0.6</td>
<td>4.8</td>
</tr>
</tbody>
</table>
**Results:** Changes in gas calorific value

- **Premogovnik Velenje** (Slovenia)
  - Average: 6.4 MJ/Nm$^3$

- **CEO Oltenia** (Romania)
  - Average: 4.8 MJ/Nm$^3$
**Results:** Temperature distribution

**Premogovnik Velenje**  
(Slovenia)

![Graph showing temperature distribution over time for Premogovnik Velenje](image)

**CEO Oltenia**  
(Romania)

![Graph showing temperature distribution over time for CEO Oltenia](image)

Inlet

Outlet

Gasification channel

www.gig.eu
## Results: Material and energy balance data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Velenje</th>
<th>Oltenia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated total coal consumption (kg)</td>
<td>730</td>
<td>790</td>
</tr>
<tr>
<td>Average coal consumption rate (kg/h)</td>
<td>6.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Average gas production rate (Nm$^3$/h)</td>
<td>5.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Average reactor power (kW)</td>
<td>10.3</td>
<td>8.1</td>
</tr>
<tr>
<td>Gross energy efficiency (%)</td>
<td>44.6</td>
<td>33.4</td>
</tr>
</tbody>
</table>
Post experimental studies: Solid residues

- Dried lignite
- Char
- Ash
Analysis of UCG residues: Scope

- Gas and water transport properties
- Mechanical properties
- Mineralogical studies
- Leaching tests (organic and inorganic contaminants)
1. The UCG experiments demonstrated that the **physicochemical properties** of the feed lignite considerably affect the in-seam gasification process.

2. Because the excessive water leads to the substantial decrease in the gasification efficiency, the coal **moisture content** is one of the crucial parameters.

3. Nevertheless, the results obtained indicate that UCG may be a **feasible option** for exploitation of lignite deposits, especially in the case of moderately wet lignites, such as Velenje lignite.

4. Recovery of the **physical heat** of gas on the surface is one of the options that can be considered for the improvement of the overall process performance.
Thank you for your kind attention!

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