In-situ gasification of shallow lignite: Results of an EU study for a potential demonstration site in Romania

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Objectives and tasks of the COAL2GAS Project

Overall objective of the COAL2GAS Project:
► to evaluate the feasibility of UCG in shallow lignite seams, geologically, technically and environmentally and to illustrate this for a selected deposit in Romania.

- Definition of site selection and design criteria to allow transfer to other potential targeted deposits;
- Geological and hydrogeological research and assessment of suitability;
- Impact and effect of subsidence in old mining areas and of remaining pillars prior to and after mine closure on UCG operations and vice versa;
- Selection of suitable UCG process operation and design of drill and panel pattern;
- Design of monitoring techniques for operations and environmental protection;
- Development of risk assessment framework and database with risk factors;
- Draft design of utilization scheme and adaptation of UCG project design;
- Establishment of appropriate techniques for decompletion and long term safekeeping.
The area of the Oltenia coal deposit is situated within the Getic Depression, which is regarded as the Tertiary foredeep that developed in front of the Southern Carpathians in Romania.

- Total of 22 lignite seams
- Seams A to VII correspond to “Dacian” stage (Pliocene), VIII to XII correspond to “Romanian” stage (Pliocene), XIII and younger to the Pleistocene
- Thickness variation common
- Deposited in a fluvial environment (Gilbert-Type Delta)
- At selected sites coal seams generally dip towards SE at shallow angles (3-4°)

Drilling and testing

Geophysical well logging
Geological and geotechnical core logging and sampling

Site selection ► test site
Local stratigraphy

Seam IX

**Total thickness: 4.3 – 5.0 m.**
Usually developed with a thicker (about **2.1 – 3.6 m**) upper coal layer, and a thinner lower bed that sometimes contains several clayey coal layers. The two coal beds are separated by a waste rock parting with a thickness of **0.5 – 1.3 m**.

Seam VIII

\{ **Total thickness of up to 10.4 m** (split up into 3 coal plies). The upper, most attractive coal seam layer has a thickness of about **4.2 m**. It rests on a **1.55 / 2.5 m** thick clay and partly silty parting. \}

Seam VI-VII

Seam V

Seam IV
3D geologic model (Petrel), EU-DEM topography layer with superimposed satellite imagery and drill holes as well as modeled horizons for seam bases VIII (upper plane) and V (lower plane).

- Seam VIII depth of floor (left) and total thickness (right).

- Seam V<sub>upper</sub> depth of floor (left) and total thickness (right).
Coal petrography of seam VIII
- High huminite content (89 %, mainly humotelinite (57.8%))
- Low liptinite (6.2%) and inertinite contents (0.3%)
- Significant mineral content (4.4%), mainly pyrite (1.7%) and clay minerals (2.6%)

### Coal quality parameters (averages)

<table>
<thead>
<tr>
<th>Seam</th>
<th>Higher heating value</th>
<th>Lower heating value</th>
<th>Total Moisture</th>
<th>Inherent Moisture</th>
<th>Ash</th>
<th>Volatile matter</th>
<th>Fixed carbon</th>
<th>Volatile matter</th>
<th>Fixed carbon</th>
<th>Sulphur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>as received (kcal/kg)</td>
<td>wt%, as received</td>
<td>wt%, as received</td>
<td>wt%, dry basis</td>
<td>wt%, dry basis</td>
<td>wt%, daf</td>
<td>wt%, daf</td>
<td>wt%, as received</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>2845</td>
<td>45.6</td>
<td>13.5</td>
<td>17.4</td>
<td>50.4</td>
<td>32.2</td>
<td>61.2</td>
<td>38.8</td>
<td>1.83</td>
<td></td>
</tr>
<tr>
<td>VI-VII</td>
<td>2746</td>
<td>39.9</td>
<td>12.9</td>
<td>24.6</td>
<td>46.3</td>
<td>28.9</td>
<td>62.5</td>
<td>37.5</td>
<td>1.85</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>3142</td>
<td>43.7</td>
<td>14.5</td>
<td>13.4</td>
<td>52.7</td>
<td>34.0</td>
<td>48.3</td>
<td>39.3</td>
<td>1.91</td>
<td></td>
</tr>
</tbody>
</table>
Large scale gasification experiments

Ex-situ atmospheric pressure UCG installation
0.8 x 0.8 x 6.0 m

Ex-situ simulation of high pressure UCG
0.4 x 0.4 x 3.5 m

Technical parameters:
- coal type: lignite, hard coal
- coal seam length: 3.5 m
- gasification pressure: max 50 bar
- gasification temperature: max 1600°C
- coal seam inclination: 0, 15, 30, 45°
Large scale gasification experiments

Gasification reagent: O₂/steam

Atmospheric pressure

Average calorific value ~ 7 MJ/Nm³

Gasification reagent: O₂/steam

Gasification pressure: 10 bar

3 distinct gasification phases were distinguished

Changes in gas calorific value over the course of the gasification experiments: atmospheric / 10 bar

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Atmospheric</th>
<th>Gasification stage</th>
<th>Total/ Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated total coal consumption (kg)</td>
<td>790</td>
<td>140.8</td>
<td>131.1 313.1 585</td>
</tr>
<tr>
<td>Average coal consumption rate (kg/h)</td>
<td>8.2</td>
<td>10.8</td>
<td>8.1 7.5 8.8</td>
</tr>
<tr>
<td>Average gas production rate (Nm³/h)</td>
<td>6.1</td>
<td>0.63</td>
<td>0.70 0.60 0.6</td>
</tr>
<tr>
<td>Average reactor power (kW)</td>
<td>8.1</td>
<td>4.9</td>
<td>6.5 1.6 4.3</td>
</tr>
<tr>
<td>Gross energy efficiency (%)</td>
<td>33.4</td>
<td>15.5</td>
<td>27.2 7.3 16.7</td>
</tr>
</tbody>
</table>
Large scale gasification experiments

Average gas composition obtained in the particular stages of the experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Composition, %vol.</th>
<th>CV, MJ/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂</td>
<td>C₂H₆</td>
</tr>
<tr>
<td>Atmospheric P.</td>
<td>63.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Stage I</td>
<td>83.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Stage II</td>
<td>72.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Stage III</td>
<td>90.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Average</td>
<td>82.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
A comparison of the UCG methods was done considering the following key performance indicators:

(i) the **gasification efficiency** i.e. the proportion of chemical energy in the coal that is converted into useful energy in the syngas,

(ii) the **oxygen** required to produce a unit of energy from gasification (e.g. tonnes $O_2$ per GJ),

(iii) the **coal mining efficiency** i.e. the proportion of coal “in-place” per module that is successfully gasified (i.e. the geometrical or mining sweep efficiency), and

(iv) the “**Energy Return On Energy Investment (EROEI)**” of the complete resource recovery process (i.e. the energy spent by drilling, and producing and injecting the oxidants compared to the energy produced at the production wellhead).
General layout of well field panels & L-CRIP module performance estimation

Panel layout:
- Future expansion panel;
- Drilling panel;
- Gasification panel;
- Venting and cooling panel; and
- Depleted and decommissioned panel

Summary of key performance indicators

<table>
<thead>
<tr>
<th></th>
<th>Depth (metres below ground level)</th>
<th>50 m</th>
<th>150 m</th>
<th>300 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean coal gasification rate (tonnes/day)</td>
<td>38</td>
<td>114</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>Mean raw syngas production rate (Nm$^3$/day)</td>
<td>55.3</td>
<td>143.1</td>
<td>258.5</td>
<td></td>
</tr>
<tr>
<td>Mean dry syngas heating value (HHV) (MJ/Nm$^3$)</td>
<td>9.2</td>
<td>10.8</td>
<td>12.1</td>
<td></td>
</tr>
<tr>
<td>Total energy converted underground per module (PJ)</td>
<td>0.09</td>
<td>0.14</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>
Well design & engineering for integrity and safety

The module basic well completions of both study cases

Schematic diagram of the basic study case (coal seam VIII, depth 50 to 65 m, net thickness 2.9 m)

Schematic diagram of the optional study case (coal seam V, depth 115 to 135 m, net thickness 4.3 m)
(1) Monitoring of the gasification and mining process:

- in-situ reactor pressures / temperatures;
- injection point retracting positions;
- mass and energy balances around the control volume of the in-situ reactor control;
- residence time distribution of syngas in the in-situ reactor, and
- gas and heat losses.

Instrumentation deployment strategy around an L-CRIP module
(2) Monitoring the main environmental factors

The parameters which have to be monitored in order to perceive any of the environmental risks and to be able to initiate remediation measures are:

- Roof fracturing and subsidence;
- Groundwater and surface water dynamics and quality;
- Monitoring of soil gases;
- Changes of air and water temperature;
- Heating of water from drainage drilling;
- On-site air quality;
- Assessment of surface flora and fauna above the reactor and in its perimeter;
- Soil quality.
Conclusions (1)

- Based on the investigations on the Oltenia deposit and the results of modeling and testing, the coal seams and the selected site can be regarded as generally suitable for conducting a UCG test.

- As result of the RA, the main concern is associated with the shallow depth of the seams and the groundwater, and to limited extent to cavity stability.
  - Although the clay cap rocks are soft and possess low strength, they are beneficial with respect to their sealing capacity.
  - During the study on the formation and release of UCG-related contaminants it was found that the increase in gasification pressure led to decrease in concentrations of organic compounds due to intensified tar cracking phenomena.
  - Consequent and thorough monitoring has to be performed during all phases.
  - The geomechanical numerical modeling indicated limited cavity stability for the foreseen operations. More relevant site-specific geological and geomechanical data need to be collected and evaluated before final decision on the exact UCG location due to their observed variations.
L-CRIP was identified as the optimum UCG module configuration for the Oltenia coalfield, and:

- during gasification, the counter-pressure of the underground reactor(s) should always be maintained significantly less than the minimum hydrostatic pressure of the underground UCG system,
- the design and construction of a UCG module should ensure that the injection point is positioned as low in the coal seam as possible, and
- commercialization of a UCG project should be undertaken by gradually increasing the number of modules operating simultaneously i.e. from two initial reactors to, perhaps, 10 or more.

For advanced surface gasifiers, the use of pure oxygen, instead of air or oxygen-enriched air, is preferred. The main reasons for this are:

- an improved calorific value of the dry syngas produced (from lower than 5 MJ/Nm³ with air to more than 12 MJ/Nm³ with pure O₂),
- an improved gasification efficiency (up to 20% increase); and
- reduced volumes of injection and production gases (thus requiring smaller diameter injection and production well drilling and completion equipment).
The concept and action plans for the **site-specific monitoring** were developed for a UCG test at the Urdari site. The suggested monitoring plan is designed to be a **practical and cost-effective** approach towards monitoring of an UCG test.

In **Romania**, legal and social **acceptance of coal mining is still favorable.**

If the legal and regulatory aspects will be handled, a successful UCG trial could probably lay the foundation for future UCG commercialization in Romania.