Experience of Central Mining Institute in underground coal gasification - research and pilot test

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(Central Mining Institute)

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Plan of presentation

- Clean Coal Technology Centre
- Laboratory ex-situ tests on large blocks of coal
- In-situ trials in Experimental Mine Barbara, Mikołów, Poland
- Pilot test in KW K W ieczorek mine in operation, Katowice, Poland
Clean Coal Technology Centre

The aim of the investment was to build the experimental area for research and development in the laboratory as well as semi-pilot and pilot (PDU) scale for efficient and Clean Coal Technologies.

- Research Laboratories
- Engineering group for process modelling
- Technological installations
- Process Development Units
CCTC - Katowice
Katowice - research laboratories

Leading interdisciplinary works i.e. in the line of:

- Identifying the resources of coal and accompanying fossil fuels
- Analysing the basics of coal processing and of the properties of the products
- Preparing coal for various application technologies, and especially researching coal properties
- Process engineering and nanotechnology
- Identifying the CO$_2$ storage potential
- Minimising the environmental impact
- Environmental research and monitoring
Research on kinetics and thermodynamics of reaction

Examples of devices:

- Pressurized thermo-gravimetrics analyser connected with mass spectrometer
- Analyser TPR/TPO/TPD
- Analyser Autosorb iQ Quantachrome
- FTIR Spectrometer Nicolet iS50
- Micro-autoclaves
- Analyser for chlorine
- AXIO Microscope
- X-ray diffractometer D8 Discover Bruker
Automatic analyser for chlorine content determining
The AXIO Microscope for determination of the reflectance of vitrinite and macerals group composition
X-ray diffractometer D8 Discover Bruker
Static model of CO2 tank located in Dębowiec layers in the area of Upper Silesia Coal Basin
Mikołów Experimental mine Barbara
- technological units

Leading R&D works in laboratory, large laboratory and PDU scale i.e. on the following stands:

- Stand for research on ambient pressure and high pressure coal gasification applying reactors simulating the coal bed
- Stand for researching coal gasification in fixed and moving bed systems
- Stand for researching direct coal hydrogenation
- Stand for research on gas separation methods applying PSA and membranes
- Stand for testing gas combustion in turbines and gas engines
- Stand for analysing various aspects of UCG in real conditions in generators constructed in the coal bed
CCTC Mikołów - Technological workshop
CCTC Mikołów - Technological workshop
Installation for pressured simulation of ucg
Installation for pressured simulation of ucg
Installation for pressure swing adsorption gas separation
An installation for ucg gas cleaning
An installation for UCG gas cleaning
Recent UCG projects in Poland

**HUGE**
2007 - 2010

Elaboration of coal gasification technology for a high efficiency production of fuels and electricity
2010 - 2015

**HUGE2**
2011 - 2014

**Funding sources:**
- EU Research Fund for Coal and Steel
- National Centre for Research and Development (NCBiR)
- EU 7th Framework Programme

**COGAR**
2013 - 2016

**TOPS**
2013 - 2016
UCG aspects under study

- Technical infrastructure for UCG
- Technological aspects
- Environment and safety
- Gas utilization
- Coupled UCG-CCS

HUGE (RFCS)
HUGE2 (RFCS)
CO GAR (RFCS)
TOPS (7th FP)
Elaboration of coal gasification... (NCBiR)
Projects HUGE & HUGE2

**Aims:**
Theoretical and experimental exploration of the possibilities of in-situ production of **hydrogen-rich** gas through the **underground coal gasification (UCG)** technique

**HUGE 2** – Safety and Environmental Aspects
**Ex-situ experimental installation**

**Installation parameters**

- **Coal seam dimensions**: 2.5 x 0.8 x 0.8 m
- **Gasification agent**: Oxygen, air, steam
- **Gasification temperature**: up to 1600°C
- **Gasification pressure**: Atmospheric
Examples of large coal samples
Post-gasification studies
Field-scale UCG experiments at Experimental Mine „Barbara” in Mikołów

Map of mine workings and land surface of the HUGE test site
Scheme of the in-situ installation

- Supplying system
- Monitoring
- Gas collecting system
- Flare
- Suction fan
- Ground
- Pit shaft
- Air shaft
- Georeactor
- Dewatering system

1. Oxygen
2. Air
3. Water
4. Nitrogen
Georeactor’s input wall and inlet
Coal seam ignition
Operating conditions and general gasification results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Gasification agent</td>
<td>oxygen</td>
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<tr>
<td>Air/Oxygen supply rate, Nm³/h</td>
<td>120-150 / 10 - 40</td>
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<tr>
<td>Experiment duration, hours</td>
<td>355</td>
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<tr>
<td>Average gas production, Nm³/h</td>
<td>202</td>
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<tr>
<td>Average gas composition, %</td>
<td></td>
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<tr>
<td>CO₂</td>
<td>16.4</td>
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<tr>
<td>H₂</td>
<td>14.7</td>
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<tr>
<td>CH₄</td>
<td>1.5</td>
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<tr>
<td>CO</td>
<td>13.4</td>
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<tr>
<td>N₂</td>
<td>52.9</td>
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<tr>
<td>Average gas heating value, MJ/Nm³</td>
<td>3.75</td>
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<tr>
<td>Total coal consumption, kg</td>
<td>22 100</td>
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<td>Process energy efficiency, %</td>
<td>56</td>
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</table>
Investigation of the post-gasification cavity

Char, semi-char

Bottom ash

Roof rock
Numerical modelling of UCG hydrogeology – E Mine

Groundwater flow model (2D)

Darcy’ law:

\[ u = -K\nabla H \]

\[ S \frac{\partial H}{\partial t} + \nabla \cdot (-K \nabla H) = Q_s \]

Contaminant transport model

Advective - dispersive transport:

\[ \frac{\partial C}{\partial t} + \nabla \cdot (-\theta D \nabla C + uC) - \lambda R \theta C = 0 \]
Contaminant transport in coal seam and selected rocks

Normalized isolines of naphtalene ($c/c_0$)

1 year  3 years  10 years  20 years

Shale 1

Shale 2

Coal

Char

Normalized isolines of naphtalene ($c/c_0$)
### Project TOPS

#### TECHNOLOGY OPTIONS FOR COUPLED UNDERGROUND COAL GASIFICATION AND CO$_2$ CAPTURE AND STORAGE (TOPS)

<table>
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<th>PARTICIPANT NO</th>
<th>PARTICIPANT ORGANISATION NAME</th>
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<tr>
<td>1 (COORDINATOR)</td>
<td>IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE (IMPERIAL)</td>
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<td>SEAMWELL INTERNATIONAL LTD. (SEAMWELL)</td>
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<td>TECHNISCHE UNIVERSITET DELFT (TUD)</td>
<td>NETHERLANDS</td>
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<td>6</td>
<td>UNIVERSITY OF GLASGOW (UoG)</td>
<td>UNITED KINGDOM</td>
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<td>PREMOGOVNIK VELENJE, D.D. (CM-VELENJE)</td>
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<td>THE GEOLOGICAL SURVEY OF DENMARK AND GREENLAND (GEUS)</td>
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<td>KATOWICKI HOLDING WĘGLOWY S.A (KHW SA)</td>
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<td>UNIVERSITY OF CALGARY (UNICALGARY)</td>
<td>CANADA</td>
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<td>16</td>
<td>THE TRUSTEES OF INDIANA UNIVERSITY (INDIANA)</td>
<td>USA</td>
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Workpackages and experimental stands

**WP2**
Experimental investigations in thermo-chemical processes involved in UCG - reagent and produced gas quality assessment/optimisation

**WP4**
Assessment of environmental impacts and risk

**WP5**
Storage options and coupling the UCG-CCS processes
Polish UCG project supported by The National Centre for Research and Development

Developing a technology of coal gasification for high efficient production of fuels and electric power
Pilot scale UCG experiment in one of the Upper-Silesian coal mines – KWK Wieczorek

Industrial UCG installation design

Partners: Central Mining Institute, Katowice Coal Holding, Academy of Mining and Metallurgy, Kraków
Cost: 20 mln euro
The aim of the project

• Accessibility of coal seam of proper localisation and thickness
• Gasification of coal in pilot scale
• Demonstration an ability of save ignition, gasification and cooling of the process
• Demonstration an ability of using the product of gasification (designing burner, using engine)
• Collection of data for technological project scaled up to demonstration size
Technical assumptions

Coal consumption: 10 ton/day
Duration of trial: 2-3 months, a summer of 2014
Gasification agent: air, CO2, steam (oxygen for starting)
Coal seam thickness: 5.5 m
 Depths of coal layer: 430 m
Accessibility from galleries
Infrastructure requirements - Potential to integrate with existing coal mining infrastructure

1 – geogenerator
2 – sprężarka powietrza
3 – zbiornik i parowica tlenu
4 – zbiornik i parowica azotu
5 – pompy wody
6 – układ podsadzki
7 – część chodnika badawczego wypełniona wodą
8 – układ trzech skrubberów – separatów smoły
9 – separator cyklonowy
10 – zbiornik części stałych
11 – skrubber
12 – osadnik ścieków
13 – pompa wody obiegowej
14 – chłodnica
15 – jednostka podciśnieniowa
16 – komora spalania
Main technical and formal problems

• Choosing the proper place for gasification (Silesia mining area)
• Preparation the trial in working mine
• Getting special permission for the UCG trial
• Fulfilling the regulations of Mining Authorities
Main results

1. Mathematical model of georeactor
2. Procedures for accessibility of coal seams for UCG
3. Technological project of UCG demonstration installation
4. Feasibility study of UCG demonstration installation
5. Development of optimal system of UCG gas utilisation
# Operating conditions and general gasification results

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<tr>
<td><strong>Gasification agent</strong></td>
<td>Air, oxygen, carbon dioxide</td>
</tr>
<tr>
<td><strong>Agent supply rate, Nm³/h</strong></td>
<td>600-650</td>
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<tr>
<td><strong>Experiment duration, days</strong></td>
<td>60</td>
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<tr>
<td><strong>Average gas production, Nm³/h</strong></td>
<td>800</td>
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<tr>
<td><strong>Average gas composition, %</strong></td>
<td>7.5, 14, 1.5, 16, 61</td>
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<tr>
<td>CO₂</td>
<td>7.5</td>
</tr>
<tr>
<td>H₂</td>
<td>14</td>
</tr>
<tr>
<td>CH₄</td>
<td>1.5</td>
</tr>
<tr>
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<td>16</td>
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<tr>
<td>N₂</td>
<td>61</td>
</tr>
<tr>
<td><strong>Average gas heating value, MJ/Nm³</strong></td>
<td>3.50</td>
</tr>
<tr>
<td><strong>Total coal consumption, tons</strong></td>
<td>280</td>
</tr>
</tbody>
</table>
Technological project of UCG demonstration installation

Assumptions:
Amount of gasified coal, $Q = 25\, \text{MJ/kg} \ - 6,5\, \text{Mg/h}$
Amount of obtained gas, $Q = 4,6\, \text{MJ/m}^3 \ - 18\, 450\, \text{m}^3$/h
Air $- 12\, 980\, \text{m}^3$/h
Capacity $- 20\, \text{MW}_{\text{th}}$
Efficiency of seem conversion $- 0,65$
Efficiency of energy production in cogeneration $- 0,78$
Feasibility study of UCG
demonstration installation

A location for the Feasibility study for the prepared
technological project will be chosen
Development of optimal system of UCG gas utilisation

Analysis of possible methods of gas conversion to energy for electricity and heat production:

1. Boilers with burners designed to UCG gas
2. Co-combustion of gas with coal in fluidised bed boilers
3. Gas turbines
4. Gas engines

- heat production
- electricity production in steam turbine
Thank you very much for your attention