Evolution of tar compounds in raw gas from a pilot-scale underground coal gasification (UCG) trial

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Recent UCG projects in Central Mining Institute (GIG)

**HUGE**
2007 - 2010

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

**HUGE2**
2011 - 2014

**COGAR**
2013 - 2016

**TOPS**
2013 - 2016

**Coal2Gas**
2014 - 2017

**Funding sources:**
- EU Research Fund for Coal and Steel
- National Centre for Research and Development (NCBR)
- EU 7th Framework Programme
Pilot-scale UCG installation

Site selection

Coal Mine „Wieczorek”
UCG pilot plant „Wieczorek”
Location of UCG gasifier
Coal seam No. 510
Geological profile

Overlying strata thickness: ~430 m

Coal seam thickness: 5.5 m
UCG pilot plant „Wieczorek”

Geometries of gasification channels

Chodnik badawczy dla udostępnienia georeaktora

Otwory badawcze

Pokład 501

Połączone otwory badawcze o średnicy 200 mm wykonane w kształcie litery "V"
UCG pilot plant „Wieczorek”
Installation flow chart

Gas collection and purification

Supply

Underground section

Legenda
1. Separator smoły
2. Zbiornik smoły
3. Zbiornik ścieków
4. Chłodnica
5. Georeaktor
6. Układ posadzki
7. Zbiornik wody
8. Zbiornik i parownica azotu
9. Zbiornik i parownica tlenu
10. Sprężarka powietrza
11. Separator wody
12. Wytylator (sprężarka wodokrężna, sprężarka Roots'a)
13. Komora spalania z palnikiem
14. Pompa wody obiegowej
UCG pilot plant „Wieczorek”
Underground galleries
UCG pilot plant „Wieczorek”
Drilling of gasification channels
UCG pilot plant „Wieczorek”
Surface UCG gas purification module
### Coal characteristics

<table>
<thead>
<tr>
<th></th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>$W_t$</td>
<td>7.00%</td>
</tr>
<tr>
<td>Ash</td>
<td>$A_r$</td>
<td>10.07%</td>
</tr>
<tr>
<td>Total sulphur</td>
<td>$S_t^r$</td>
<td>0.92%</td>
</tr>
<tr>
<td>Calorific value</td>
<td>$Q_i^r$</td>
<td>25 272 kJ/kg</td>
</tr>
<tr>
<td>Carbon</td>
<td>$C_t^a$</td>
<td>66.00%</td>
</tr>
<tr>
<td>Volatiles</td>
<td>$V^a$</td>
<td>28.68%</td>
</tr>
<tr>
<td>Roga index</td>
<td>RI</td>
<td>0.0</td>
</tr>
</tbody>
</table>
# Pilot-scale UCG trial

## Summary results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification agent</td>
<td>Air, oxygen, carbon dioxide</td>
</tr>
<tr>
<td>Agent supply rate, Nm³/h</td>
<td>600-650</td>
</tr>
<tr>
<td>Experiment duration, days</td>
<td>56</td>
</tr>
<tr>
<td>Average gas production, Nm³/h</td>
<td>800</td>
</tr>
<tr>
<td>Average gas composition, %:</td>
<td></td>
</tr>
<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>
<td>CO</td>
<td>16</td>
</tr>
<tr>
<td>N₂</td>
<td>61</td>
</tr>
<tr>
<td>Average gas heating value, MJ/Nm³</td>
<td>3.50</td>
</tr>
<tr>
<td>Total coal consumption, tons</td>
<td>250</td>
</tr>
</tbody>
</table>
Pilot-scale UCG trial
Gas composition vs. Time
UCG tar evolution studies
<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GC undetectable tars</td>
<td>preasphaltenes, asphaltenes, heaviest tars (pitch)</td>
</tr>
<tr>
<td>2</td>
<td>Heterocyclic compounds.</td>
<td>phenol, cresol, quinoline, pyridine</td>
</tr>
<tr>
<td>3</td>
<td>Aromatic components - light hydrocarbons.</td>
<td>toluene, xylenes, ethylbenzene (excluding benzene)</td>
</tr>
<tr>
<td>4</td>
<td>Light polyaromatic hydrocarbons (2-3 rings PAHs).</td>
<td>naphthalene, indene, biphenyl, anthracene</td>
</tr>
<tr>
<td>5</td>
<td>Heavy polyaromatic hydrocarbons (4-rings PAHs).</td>
<td>fluoranthene, pyrene, crysene</td>
</tr>
<tr>
<td>6</td>
<td>GC detectable, not identified compounds</td>
<td>unknown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compound/group of compounds</th>
<th>Sampling method</th>
<th>Determination method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BTEX:</strong>&lt;br&gt;Benzene,&lt;br&gt;Toluene,&lt;br&gt;Ethylbenzene,&lt;br&gt;Xylenes (o-, m- p- isomers)</td>
<td>Sampling on sorbent tube with activated carbon (SKC Anasorb CSC, 600 mg)</td>
<td>Gas chromatography with FID detector (AGILENT 7890A)</td>
</tr>
<tr>
<td><strong>15 PAHs:</strong>&lt;br&gt;Naphthalene (NaP), Acenaphthene (AcP), Fluorene (Flu), Phenanthrene (Phe), Anthracene (AnT), Fluoranthene (Fla), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenzo(a,h)anthracene (DBA), Benzo(g,h,i)perylene (BghiP), Indeno(1,2,3-cd)pyrene (IND)</td>
<td>Sampling on sorbent tube with polymer resin (SKC XAD-2, 600 mg)</td>
<td>Gas chromatography with MS detector (AGILENT 7890A)</td>
</tr>
<tr>
<td><strong>Phenols:</strong>&lt;br&gt;Phenol (hydroxybenzene)&lt;br&gt;o – Cresol&lt;br&gt;m – Cresol&lt;br&gt;p – Cresol</td>
<td>Sampling on sorbent tube with silica gel (SKC Silica Gel, 600 mg)</td>
<td>Gas chromatography with FID detector (AGILENT 7890A)</td>
</tr>
</tbody>
</table>
UCG pilot plant „Wieczorek”
Tar sampling point

Tar sampling valve
Raw UCG gas
Evolution of tar compounds in UCG gas

Tar classes

<table>
<thead>
<tr>
<th>Tar group</th>
<th>Concentration, mg/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
</tr>
<tr>
<td>BTEX</td>
<td>1,428.1</td>
</tr>
<tr>
<td>PAHs</td>
<td>477.7</td>
</tr>
<tr>
<td>Phenols</td>
<td>87.7</td>
</tr>
</tbody>
</table>
Evolution of tar compounds in UCG gas

**BTEX**

![Graph showing the evolution of tar compounds in UCG gas](image)
Evolution of tar compounds in UCG gas

Alkyl benzenes

Time, h

Concentration, mg/Nm³

Intensive pyrolysis

Development of pyrolysis zone

Thermal decomposition (loss of alkyl group)

Ethylbenzene
m,p-Xylene
o-Xylene
Evolution of tar compounds in UCG gas

PAHs (light)

![Graph showing the evolution of tar compounds in UCG gas focusing on PAHs (light). The graph illustrates the concentration of various PAHs over time. The x-axis represents time in hours (0 to 1400), and the y-axis represents concentration in mg/Nm³. The graph highlights the intensive pyrolysis, thermal decomposition, and development of the pyrolysis zone.](image-url)
Evolution of tar compounds in UCG gas

PAHs (heavy)

<table>
<thead>
<tr>
<th>Time, h</th>
<th>Concentration, mg/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Acenaphthene</td>
</tr>
<tr>
<td>200</td>
<td>Benzo(a)anthracene</td>
</tr>
<tr>
<td>400</td>
<td>Chrysene</td>
</tr>
<tr>
<td>600</td>
<td>Benzo(b)fluoranthene</td>
</tr>
<tr>
<td>800</td>
<td>Benzo(k)fluoranthene</td>
</tr>
<tr>
<td>1000</td>
<td>Benzo(a)pyrene</td>
</tr>
<tr>
<td>1200</td>
<td>Indeno(1,2,3-cd)pyrene</td>
</tr>
<tr>
<td>1400</td>
<td>Dibenzo(a,h)anthracene</td>
</tr>
<tr>
<td></td>
<td>Benzo(g,h,i)perylene</td>
</tr>
</tbody>
</table>
Evolution of tar compounds in UCG gas

Phenols

![Graph showing the concentration of phenol, o-cresol, and m,p-cresol over time.](image-url)

- Phenol
- o-cresol
- m,p-cresol

Concentration, mg/Nm³

Time, h
**Statistical analysis**

**Principal Component Analysis (PCA)**

- **PC1:** 59.93%
- **PC2:** 29.42%

**High temperature formation**

- Benzen
- BTEX
- Fenantren
- Fluoranten
- PAHs

**Compounds vulnerable to decomposition at high temperature**

- Toluene
- Ethylobenzen
- o-Cresol
- m,p-Ksyril
- Total phenols

*Vulnerable to decomposition at high temperature*
- Concentrations of tar compounds in the raw UCG gas are strongly dependent on the stage of the gasification process and they reflect thermodynamic conditions inside the underground reactor – the early stage of UCG was characterized by highest concentrations of all tar classes under study.

- BTEX was the most abundant group of tar compounds in raw UCG gas, and benzene was found to be a dominant compound (~75%).

- PAHs were identified as the second most abundant class of tars in UCG gas and naphthalene contributed to about 30% of total PAHs.

- Relatively smallest concentrations were observed for phenolic compounds.
Thank you for your attention