TECHNO ECONOMIC ANALYSIS OF PREPARATION AND IMPLEMENTATION OF UNDERGROUND COAL GASIFICATION

Dimitrijević Bojan1, Šubaranović Tomislav1, Ilić Saša1

ABSTRACT

In view of quantity and quality of available resources, especially necessity for rational utilization of primary energetic resources (so, not just secondary), we are in situation to conquer technology of exploitation unbalanced resources, and excavation loses of balanced resources, as well. Method without alternative, for these coal resources is Underground Coal Gasification (UCG).

The most important activity is conscientious access to choose an optimal location for UCG. It’s necessary to consider amount of coal that is able to gasify, and estimate total volume of produced gas from UCG. Treatment of capital investment and technical costs of production have very significant place because we pay special attention to that.

Key words: coal, underground gasification, borehole and linking boreholes, capital investments, current production costs.

INTRODUCING

Considering that growing need for energy bring increasing coal exploitation and consequently decrease of balanced coal reserves, idea for rational use of primary energetic resources became more and more real.

With those circumstances, we are in the situation to looking for new technologies of unbalanced coal reserves utilization as well as exploitation of excavation loses coal of balanced resources. An applicable method for these coal resources is Underground Coal Gasification (UCG).

During planning activities for UCG is most important approach for optimal location choice. It is necessary establishing amount of coal suitable for UCG, and in that mean estimate total volume of produced gas, too.

INFLUENTIAL PARAMETERS OF UCG

Influential parameters regarding question if is particular coal deposit suitable for Underground Coal gasification are, among others: coal reserves (unbalanced and excavation loses of balanced coal resource), coal seam depth as well as ash, moisture and flying particles

1 Faculty of Mining and Geology University of Belgrade
from coal. From this aspect are significant some global postulations, as follow [2]:

- On mines with sufficiently explored reserves, with developed facilities and mining tradition is important to know whether in frames of exploration areas is planned UCG partly or in whole excavated fields.
- Mines which can be normally developed as in previous case, with difference regarding additional resource explorations for future development planning.
- Mines with limited resources, and with coal trade limitations, when must be take into consideration redirection of production and finishing of coal exploitation after exhausted of coal reserves.
- Mines without larger perspective and mostly with local importance – exploitation factors are un-rentable, without possibilities of technology improvement although coal reserves may be considerable.

In the aim of better utilization of UCG on selected deposit is necessary to determine dominant direction of gas-permeability by orientation boreholes and his core samples and by core analysis obtain information about permeability direction and system of cracks orientation between two boreholes [1] and on base of this information validate optimal location of injection boreholes regarding productive borehole and his spatial disposition.

Natural permeability of coals is changeable by quality. Low quality coals, for example lignite and often some kind of soft brown coals, have mostly enough natural permeability and therefore UCG is regularly possible without particular borehole joining by channels.

If is decided to perform “borehole joining” by channels, usually by fracturing, it is necessary to determine power consumption for channel making (kWh by one meter of channel length). This cost belongs to coal seam preparation costs for UCG (together with drilling operations). The other costs are: investment and installation costs (compressor station, control system and process flow analysis, so on), gas generator exploitation costs, especially expressed as costs for energy needed for providing gasification agents.

Gasification agents providing for fracturing require determination of energy consumption:

$$E = \frac{1}{u} \cdot \frac{1}{\eta_u} \cdot \rho_L \cdot V \cdot \frac{n}{n-1} \cdot R \cdot T_u \left[ \frac{p_{\infty}}{p_{\infty}} \right]^{\frac{n-1}{n}}$$  \( \text{(kWh/m') (1)} \)

Where are:

- $u$ - Progression speed of gasification front:
\[ u = \frac{m}{A_{\text{gen}} \cdot \rho_u} \text{ (m/s)} \]  

(Vary from 0.5 to 2 m/day, i.e. from 0.000006 to 0.000023 m/s),

\[ \eta_u \] - Utilization degree of coal on UCG (from 70 to 90%),

\[ \rho_L \] - Air density (kg/m³),

\[ \nu \] - Volumetric air flow, using in process (m³/h),

\[ n \] - Polythopre exponent,

\[ T_u \] - Input air temperature (K),

\[ \rho_i \] - Injection pressure (Pa),

\[ \rho_{at} \] - Environmental pressure (Pa),

\[ R \] - Gaseous constant of air (J/kgK),

\[ m \] - Mass air flow (kg/s),

\[ A_{\text{gen}} \] - Cross section surface of gas-generator, i.e. channel (m²),

\[ \rho_n \] - Coal density (t/m³).

Considering coal amount planned for UCG, it is important to observe UCG process, with occasionally taking gas sample from productive borehole to evaluate chemical composition (mostly existence of CO, CO₂, H₂ and CH₄). Then is possible to determine amount of gasify coal as:

\[ m_c = \frac{M_C}{M_{CO}} \cdot m_{CO} + \frac{M_C}{M_{CO_2}} \cdot m_{CO_2} + \frac{M_C}{M_{H_2}} \cdot m_{H_2} + \frac{M_C}{M_{CH_4}} \cdot m_{CH_4} \]  

Where are:

\[ m_c \] - Coal mass which is gasified in time unit

\[ m_{CO}, m_{CO_2}, m_{H_2}, m_{CH_4} \] - mass of components created in time, as gas content

\[ M_C, M_{CO}, M_{CO_2}, M_{H_2}, M_{CH_4} \] - mol mass of coal and gas components

Based on known component concentration, either by verified mathematical models or based on gas sampling from productive borehole it is possible to determine low calorific value of gas mixture, i.e. gas from UCG.

\[ H_d = \sum_{i=1}^{3} c_i \cdot H_{di} \text{ (kJ/m}^3) \]  

Where are:

\[ c_i \] - concentration of CO, H₂ and CH₄ (CO₂ is not in calculation because it is inert gas)

\[ H_{di} \] - calorific values of three components, which are:
CO:  $H_{dCO} = 12.644 \left( \frac{kJ}{m^3} \right)$,  
$H_2$:  $H_{dH2} = 10.760 \left( \frac{kJ}{m^3} \right)$ and  
$CH_4$:  
$H_{dCH4} = 35.797 \left( \frac{kJ}{m^3} \right)$.

After all, also may be considering thermal efficiency of process for expected gas:

$$\eta_t = \frac{m_g \cdot \sum c_i \cdot H_{d}}{m_c \cdot H_{dc}}.$$  \hspace{1cm} (5)

This is, according to world’s experience, in range between 50 and 75%.

**CAPITAL INVESTMENTS AND PRODUCTION COSTS**

Considering capital investment and current production costs, on the basis of several studies performed worldwide (as [3]), results are different, in dependence of either horizontal or dip seam. For total capital investment (100%) each element are given in Table 1. Current production costs are given in Table 2.

**Table 1 - Elements of whole capital investment**

<table>
<thead>
<tr>
<th>Elements of capital investment</th>
<th>Horizontal seam %</th>
<th>Dip seam %</th>
</tr>
</thead>
<tbody>
<tr>
<td>section preparation, mechanical operations</td>
<td>4,6</td>
<td>13,6</td>
</tr>
<tr>
<td>compressors station</td>
<td>19,0</td>
<td>23,4</td>
</tr>
<tr>
<td>control measuring equipment and gas processing system</td>
<td>9,5</td>
<td>12,0</td>
</tr>
<tr>
<td>pipelines</td>
<td>30,0</td>
<td>16,4</td>
</tr>
<tr>
<td>electro power supply</td>
<td>3,4</td>
<td>6,4</td>
</tr>
<tr>
<td>boreholes and lining pipes</td>
<td>3,0</td>
<td>0,3</td>
</tr>
<tr>
<td>indirect costs</td>
<td>6,0</td>
<td>3,6</td>
</tr>
<tr>
<td>technological and administrative costs</td>
<td>7,5</td>
<td>7,5</td>
</tr>
<tr>
<td>unpredictable costs</td>
<td>17,0</td>
<td>16,8</td>
</tr>
<tr>
<td><strong>TOTAL CAPITAL INVESTMENT</strong></td>
<td><strong>100,0</strong></td>
<td><strong>100,0</strong></td>
</tr>
</tbody>
</table>

In the horizontal seam, capital investments are in relation to so called “conditional gas-generator”, while costs for each next gas generator are included with current costs of production.

For dip seam, investments are more significant during section preparation works because of considerable soil work and after that reclamation works. Pipeline costs in dip seam are proportionally lesser. All drilling costs belong to current costs of production.

**Table 2 - Elements of production costs**
<table>
<thead>
<tr>
<th>Elements of production costs</th>
<th>Horizontal seam</th>
<th>Dip seam</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>drilling</td>
<td>11,2</td>
<td>8,1</td>
</tr>
<tr>
<td>working and material costs for mobile segments displacement</td>
<td>1,0</td>
<td>6,0</td>
</tr>
<tr>
<td>drillhole linking</td>
<td>3,1</td>
<td>1,2</td>
</tr>
<tr>
<td>working costs on supplying</td>
<td>2,7</td>
<td>2,6</td>
</tr>
<tr>
<td>current maintenance(and materials)</td>
<td>2,7</td>
<td>2,6</td>
</tr>
<tr>
<td>electro power supply and fuel</td>
<td>22,0</td>
<td>24,0</td>
</tr>
<tr>
<td>wages of staff on gas-generator operation</td>
<td>7,3</td>
<td>8,5</td>
</tr>
<tr>
<td>costs connected with capital investment</td>
<td>50,0</td>
<td>47,0</td>
</tr>
<tr>
<td>TOTAL CAPITAL INVESTMENT</td>
<td>100,0</td>
<td>100,0</td>
</tr>
</tbody>
</table>

On horizontal seam operation, higher costs are for drilling and linking of boreholes and lesser for equipment dislocation, because of all pipeline costs and equipment dislocation cost are included in capital investments. Total investments and current costs for pipeline and equipment dislocations are higher for horizontal than for dip seam deposit.

Supplying costs are related to work in 3 shifts of 8 hours, with usually engaged 5 to 6 workers on one gas generator. Current maintenance costs are taken approximately 2% of capital investments.

Big costs are for electrical power and fuel (diesel) as well as for compressor operation for gasification and borehole linkage.

Greatest part of capital investments and gas price are cost for air compression, pipeline, drilling and borehole linking, which directionally depend of coal seam width, seam depth and distance between boreholes.

On Figure 1 are presented gas prices for horizontal coal seams with width of 6 and 9 meters and for inclined seam with width of 6 m, on different seam bearing depths (H).

![Figure 1](image-url)
Raw gas price grow for 2% with increasing of coal seam bearing depth for every 30 m.
Gas price of dip seams (broken line) is lower then thick horizontal coal seams, starting of gas-generator depth of 180 m and lower. Because gas price is very dependable of position of gasification section, it is necessary very carefully and precise selection of optimal site for UCG performing.

CONCLUSION

By decision for UCG is most important to select optimal location, besides necessity of determination coal amount suitable for gasification and whole volume of gas obtained by UCG.

It is evident that in capital investment and gas price greater part goes for air compressing and pipeline. Drilling and borehole linking are directly tied with thickness and coal seam bearing depth.
Considering these features, because of gas price obtained by UCG greatly depend of precise selection of borehole sites it is very important to liable select optimal area for UCG implementation.

LITERATURE

1. Крејнин Е. В., 1982.: Подземна гасификација угљених слојева, Недра, Москва
5. Симић Р., 2002.: Designed pilot plant for underground lignite gasification in Kostolac coal basin, III International Congress of Brown Coal Mining, Belchatow, Poland, str. 259-266.

Translations into English: Authors