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UNDERGROUND COAL GASIFICATION – POSSIBILITIES IN SLOVENIA

PODZEMNO UPLINJANJE PREMOGA – MOŽNOSTI V SLOVENIJI

Milan Medved[1ℜ], Damjan Konovšek[1]

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Abstract

Slovenia still has significant amounts of unexploited coal; consequently, this article explores the additional option of using this domestic primary energy source, using the underground coal gasification (UCG) methodology.

We described the general recommendations and findings from the UCG tests conducted throughout the world, relating to the testing performed in Velenje. Based on the recommendations and findings of the UCG tests, the descriptions of different technologies and the characteristics of the Velenje coal deposit, we established the most appropriate technology for the gasification of Velenje coal, which is the UCG technology using the ELW method in combination with the modified CRIP method for ignition and underground gasification.

The test geometry and the operating parameters for UCG Velenje have been assessed on the basis of the modular gasification scheme of the company Carbon Energy Pty Ltd (CEPL), which was produced in the scope of the testing conducted in Bloodwood Creek, Australia.

Povzetek

Slovenija ima še veliko zalog neizkoriščenega premoga, zato smo v tem članku raziskovali dodatno možnost izrabe domačega primarnega energetskega vira s podzemnim uplinjanjem premoga (PUP).

[1ℜ] Corresponding author: Milan Medved, Faculty of Energy Technology, University of Maribor, Hočevarjev trg 1, Krško, Slovenia.: +386 41 634 839, E-mail address: milan.medved@outlook.com

[1] Faculty of Energy Technology, University of Maribor, Hočevarjev trg 1, Krško

Opisali smo splošna priporočila in ugotovitve iz testov PUP po svetu, ki se navezujejo na izvedbo poskusa v Velenju. Glede na priporočila in ugotovitve iz testov PUP, opise različnih tehnologij PUP in lastnosti ležišča velenjskega premoga, smo podali najustreznejšo tehnologijo podzemnega uplinjanja premoga v Velenju, ki je PUP tehnologija metoda vzporednih vrtin ELW v kombinaciji z modificirano CRIP metodo za vžig in podzemno uplinjanje.

Geometrija poskusa in obratovalni parametri za PUP Velenje so ocenjeni na podlagi modularne uplinjevalne sheme podjetja Carbon Energy Pty Ltd (CEPL), ki je bila narejena v okviru testa v Bloodwood Creeku, Avstralija.

1 INTRODUCTION

Coal will remain a leading energy source in the coming decades, and it is expected that the development of clean technologies allowing for and preserving its competitiveness compared to other energy sources will be accelerated. The recent period has witnessed a spread of so-called clean coal technologies (CCT), which includes underground coal gasification (UCG), a combination of the technologies of excavation and transformation of coal into useful energy. The seam of lignite in the Šaleška Valley is one of the thickest in the world, which gave rise to the development of innovative quarrying methods and other technologies, such as UCG, which is gaining popularity throughout the world. In spite of the lack of tests with lignite, attempts have been made to introduce it in Slovenia ell. The Velenje Coal Mine is one of the few in the world to research the UCG methodology for the application of the test on lignite. The method is particularly interesting for those coal deposits in which conventional excavation methods cannot be used, for various reasons.

In fact, the Velenje Coal Mine launched CCT activities in 2009 when a special task group within the R&D department was established. At the end of the same year, the CCS (Carbon Capture and Storage) activities started. The method was introduced by the Georis Research Organization. A project called "Pilot Methodology Fixation of CO_2 using the Fly Ash" applied for Slovene Government and EU funds in 2010and was started in February 2011.

The aim of this paper is to research the UCG method, adjust it, and patent it for the exploitation of thick lignite and coal seams, similarly to the globally known Velenje excavation method, which is known to be the most productive long-wall excavation method in the process of underground coal mining in thick seams.

Many countries still have deposits of low calorific value coal that have thus far not been exploited for various reasons, one of the most important of which is the cost of lignite transportation over long distances, as well as dust and gas emissions in direct use of coal or combustion in thermal power plants. Because of high transportation costs and low calorific value, a practice was established to use the lignite in thermal power plants for production of electricity and heat, which were constructed in the vicinity of the source or deposit. The research was therefore focused on clean technologies for the commercial production of various lignite and coal products, similar to the lignite in the Velenje basin. Not many UCG tests have been performed on lignite and hard coal (most of them were made on soft coal). The reason for this lies in the questionable economic viability of lignite exploitation, while hard coal is not usually exploited for UCG purposes.

UCG technology enables the use of coal energy in an economically viable and environmentally-friendly manner. The UCG process further opens the possibility of exploiting natural coal with minimized environmental impact, because the emissions of gases and solid remains after the combustion of the coal have been significantly reduced compared to the conventional coal-based thermal power plants. UCG technology is a process in which coal is gasified underground, producing various gases that are purified on the surface and used in the gas-steam assembly, where it is converted into useful electricity and heat.

The primary purpose of the underground gasification of coal was to alleviate some of the heavy workload from the miners working underground. This was followed by the oil crisis, while at present, we are facing the period of economic growth and problems related to the provision of energy sources. Another reason is the current energy, financial, and environmental crises, considering that there are sufficient coal deposits all over the world that could be exploited using the UCG method, which would guarantee a reliable supply of energy products in the future. Therefore, the number of underground coal gasification R&D programmes and the number of underground coal gasification tests are constantly growing. Also expanding are the various possibilities of the application of UCG for different purposes, all in favour of the development of this technology. It is essential to maximize the use of experience and know-how obtained from the tests carried out in the past, which would also provide efficient commercial UCG technology. The UCG project in the Velenje Coal Mine, which took place from 2011 to 2015, shows an additional possibility of using the Velenje lignite for supplying electricity and heat to the Šaleška Valley and Slovenia, as an alternative to the Šoštanj Thermal Power Plant.

The previous reports provided a preliminary assessment of UCG based on the results of the pilot testing carried out in the scope of the Rocky Mountain 1 test in the USA, where coal was gasified using the Controlled Retraction Injection Point method. The recent literature provides no data on the actual method of implementing the UCG method for commercial purposes. Of all the companies exploring the possibilities of introducing the UCG method for commercial purposes, only the company Carbon Energy from Australia presented a plan on how to move from pilot testing to commercial procedures and what amount of coal deposit would be gasified.

The scheme of the test conducted in Bloodwood Creek, Australia, by Carbon Energy, which is the best source of data, could be used as the basis for conducting a pilot test in Velenje. The presented method of exploiting the coal deposit is the only source from which it is possible to obtain the estimate of gas flows. Reference [1] provides the foreseen operational period of the assembly and the geometry of the anticipated coal deposit where the gasification is planned to be carried out. Based on this, the necessary flows of reagents and the amount of products or obtained syngas can be assessed. In other deposits with different dimensions or cross-sections, different feeding flows will have to be taken into account, proportionally to the cut-off ratios. These ratios will have to be taken into account in the future estimates of underground coal gasification. To ensure the full use of the oxygen for the even combustion of coal in the entire cross-section, certain operational (optimal, if possible) conditions must be met, which can only be determined on the basis of pilot testing. Additionally, the combustion and the initial gasification phase also require a special operational regime, which is not mentioned in the available literature.

The basic unit for determining the energy facility, related to the underground coal gasification, is one combustion cavity. Several combustion cavities represent one set, and several sets are linked into a module. The economic viability analysis is based on the module and volume of coal in it, which can be gasified (length × width × height (thickness)). Carbon Energy, which has been conducting the UCG tests using the CRIP method, proposed a module with the dimensions of length 600 m, width 180 m, and thickness 8 m with four injection, three production, and six combustion wells. The geometry of the gasification module enables good control of the size and height of gasifying coal seams thicker than 3 m, *[5].* If the seam is limited with the overburden and the footwall, the thickness of gasification is determined. Such a model, or several modules, would be used in the UCG testing in Velenje, which would be carried out in cooperation with one of the Australian companies, e.g. Carbon Energy, Linc Energy or another. These companies have already carried out the first UCG tests for commercial purposes or demonstrated the UCG technology in several-month test gasification processes. The gas that is created is used for energy purposes or for obtaining synthetic diesel fuel.

The minimum size of the facility will be determined on an economic basis, considering the investment and operational costs, with simultaneous production of modules. Based on the available coal deposits, depreciation and lifespan of the facility, and the foreseen energy prices, optimal production, and profitability of UCG will be determined.

The positions for determining the value of investment in the thermal power plant that would be using syngas, a product of UCG, for its operation, have also been taken into account. A syngas-powered thermal power plant is an additional opportunity for the Slovene energy segment, further development of the Šaleška region in terms of a reliable and environmentally acceptable energy producer, and for research and development activity.

2 FINDINGS AND RECOMMENDATIONS

The factors having a substantial impact on the implementation of UCG are:

- The geological features of the coal deposit site:
  - thickness, depth and inclination,
  - gas and fluid permeability.
- Coal characteristics:
  - type of coal (the content of humidity, ash, volatile substances, carbon, etc.),
  - chemical structure (hydrogen, sulphur).
- Overburden properties:
  - geology,
  - hydrology,
  - geo-mechanical properties,
  - drilling possibility.

- Operational conditions:
  - composition and speed of injected gas,
  - operating pressure,
  - drilling.
- Resulting (production) gas:
  - desired volume,
  - composition, calorific value,
  - flow speed.
- Process efficiency:
  - thermal,
  - chemical,
  - source.
- Environmental interaction
  - thermal,
  - chemical,
  - use of source and the related settlement of the surface, *[6].*

The principal differences between underground and surface gasification simultaneously represent the strengths and weaknesses of either process:

- on the surface, reactions take place in a closed reactor, where temperature and pressure can be measured and controlled, as well as the feeding of coal and oxidants into the reactor. This allows for the precise and controlled structure and quality of products,
- underground, the form and location of the reaction zone are constantly changing, and it is not possible to measure and control the operational conditions in the same manner as on the surface. During the UCG process, the coal burns, cavities are created and thermal deformations also in the surrounding vitrified clays. The reaction zone can shift into different parts of the coal deposit, and the movement cannot be foreseen or controlled. Part of the gas products can escape from the reactor zone into the environment; in contrast, the water flows into the reaction cavity from the surrounding areas cannot be fully controlled because the properties of the seam keep changing. Water inflow can be best controlled with the control of the operating pressure, *[6].*

The other advantages of the UCG over the conventional mining and further use in thermal power plants are:

- The economic advantages:
  - The cost of the UCG process is low, because there are no costs of coal excavation, transportation, and ash deposit,
  - CAPEX is also reduced, since there is no need to purchase and install the reactor/boiler on the surface,

- Greater flexibility of the syngas use: production of electricity, chemicals, fuels, also hydrogen H_2.

- Environmental advantages:
  - Most of the ashes remain underground, significantly reduced emissions of H_g and other heavy metals, SO_x and NO_x, which reduces the amount of gas purification,
  - Reduced CO_2 emissions.
- Treatment of CO_2:
  - Reduced CO_2 separation costs,
  - Possible storage of CO_2 in the cavities and the surrounding vitrified clays, *[7]*, *[8]*, *[9]*

Obstacles to the commercial development of the UCG:

- Operational risks due to untested large-scale UCG processes and many problems that arose during the tests conducted in the USA and Western Europe.
- Unreliability of the process from the point of view of environmental impact,
- Public acceptability,
- Lack of precise criteria or recommendations for the selection and characterization of the site/deposit to be gasified,
- Not enough experts with multidisciplinary know-how, *[10].*

All UCG tests have been conducted at different operating conditions, using various types of coal, at various depths and different seam thicknesses, and over different time periods. Due to such a diversity of conditions in which the UCG tests have been carried out, the results are too dispersed to allow for reliable conclusions. Nevertheless, it can be claimed that all types of coal can be gasified, using specific UCG methods determined on the basis of the specific conditions. This article lists brief general recommendations and findings from the UCG tests conducted all over the world, relating to the testing performed in Velenje.

The recommendations for the selection of a suitable site for the UCG, issued by the providers of tests or their national authorities, differ and are very general, depending on the country or its legislation, as well as the geological and hydrogeological conditions of the coal deposit.

Based on the experience from the conducted tests, published literature and some UCG demonstrations, certain recommendations can be drawn to be used as guidelines by potential investors, contractors, legislative bodies and others in devising and implementing the UCG tests. Such experience was used to compile data on how the differences in the geology, hydrogeology, coal composition, surrounding vitrified clays and underground waters, as well as the implementation of the gasification process, transportation of impurities and economic viability of the process impact the environment and population health.

The tests have been carried out over extended periods, using different coals at different depths, i.e. in different conditions, which means that it would be very dangerous to generalize the results, which must instead be considered to be specific for a certain site or test. Over time, some techniques such as seismic research, drilling into coal seams, use of computers for data analysis and some other techniques have changed considerably and affected the interpretation of results.

Nevertheless, some general principles theses, and findings can be deducted from test results:

- The geological characterization of the potential site is crucial for the successful technical implementation of the test and its minimum environmental impact.
- The losses of gas in the tests conducted in shallow coal deposits are in general much bigger than in the case of deeper deposits.
- The same applies to the pollution of water, which is also more likely in deposits closer to the surface, where most of the aquifers are located.
- Lower-type coals (lignite, sub-bituminous coal) are less permeable and more reactive than higher-type coals (anthracites), which is a welcome feature in the establishment of links between the wells.
- Lower-type coals are softer, which can affect the stability of wells in the coal seam.
- The depth of the coal deposit is a key parameter affecting the operating pressure in the reaction cavity, particularly when the entire process must be conducted in such a manner that the pressure in the cavity is slightly below the hydrostatic pressure and that the water flows into the cavity during the process, and not vice versa, i.e. from the cavity to the surrounding aquifers.
- The calorific value of the syngas can be maximized by blowing oxygen-enriched air into the reaction cavity.
- The cavity “closure” procedure has also been introduced. This means that the reaction cavity is cleaned, i.e. rinsed with water after the test to avoid the potential leakage of certain contaminants.
- Preliminary simulations can help in the planning of the required devices on the surface and in preparing the environmental impact assessment, *[6]*.

What all recommendations have in common is the fact that the size of the source or coal deposit should be suitable for long-term exploitation, which guarantees the better economic viability of the process. The geological conditions must be suitable for constant coal gasification, and the environmental impacts must be minimized to an acceptable level.

The UCG process requires a multidisciplinary approach to the production of syngas, comprising a broad range of different aspects. Additionally, there were certain limitations in all tests. The tests conducted were mostly small-scale, and none of them provided a commercially accessible technology that would be able to meet all the environmental requirements, *[10]*.

In spite of the fact that many findings have been made in all tests and that several technologies have been developed, with recommendations and monitoring techniques, the UCG methodology is still not commercially recognized or accessible. It is expected that a commercially accessible UCG technology would be developed in the next few years when the currently ongoing and scheduled tests all over the world are completed.

Further studies will have to analyse the set goals and results of the UCG research carried out in Slovenia. Based on the comparison of the recent findings in the area of UCG, research activities will have to be defined that had been essential for devising the UCG technology and those that gave no valuable contribution to the development of the technology but were nevertheless conducted for other purposes. Research activities that might have been overlooked but are now crucial for the introduction of new technology into an environment will have to be proposed.

Based on the findings of the analysis of previous work performed in the UCG area in Slovenia, future research will have to indicate the key findings and propose the activities that should be carried out in the scope of research needed for the implementation of the first UCG test in Slovenia. The global UCG Association, *[11]*, has been informed of the work in UCG, as shown in Figure 1.

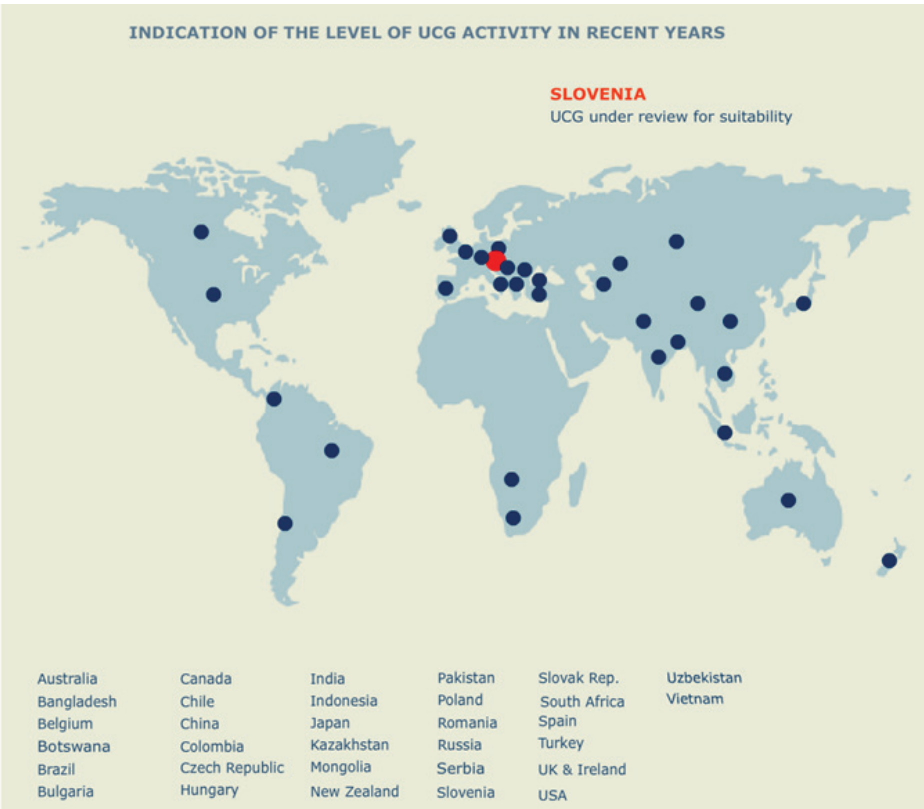

Figure 1: *Development projects and UCG tests, [11]*

Potential contractors for the UCG project are:

- CRIP: Carbon Energy (CEPL) in Australia, Gazprom Promgaz in Russia, Xinao in China, several companies - the USA,
- VLW: Sasol in South Africa,
- εUCG: Ergo Exergy Technologies Ltd. in Canada, Laurus Energy in Canada, Linc Energy Ltd. in Australia, Cougar Energy in Australia, Solid Energy New Zealand (SENZ) in New Zealand, Eskom in South Africa,
- general or UCG combinations: UCGEL (UCG Engineering Ltd.) in Great Britain, British Coal Gasification (BCG) Energy Ltd in Great Britain, Seamwell International in Great Britain, Alberta Ingenuity Centre for In Situ Energy in Canada, Glowny Instytut Gornictswa in Poland.

These contractors have rich experience in UCG, including at the level of pilot and semi-commercial tests. Based on such experience, some are already able to manage the UCG process and further technologies to exploit the produced gas.

Since the other gasification technologies or UCG methods are not known in detail, contact will have to be established with the providers of other technologies, such as Ergo Exergy Ltd. or Linc Energy Ltd. and partners in the projects HUGE1 and HUGE2.

If the UCG test were carried out in Velenje, domestic Slovene contractors could participate in all phases of the project. In particular, domestic know-how can be used in the construction of wells, preparation of all necessary infrastructure facilities on the surface, monitoring of production gas and monitoring of the quality of the underground water. The representatives of domestic institutions could gain new knowledge/findings about the UCG technology from potential foreign UCG contractors.

3 CONCLUSION

Each type of energy produced (coal, nuclear, hydro, gas and nonetheless the energy from renewable energy sources) impacts the environment, but people can no longer live without it. The energy sector merely meets the energy needs; it does not generate the consumption. Fossil fuels will continue to be the principal energy source at least until the mid-twenty-first century, according to all forecasts and the indicators of all international professional institutions. Slovenia has a limited amount of renewable energy sources (RES), as established in many studies based on which the goal of 25% energy production based on RES by 2020 was set. It is not possible to achieve a higher percentage, either technologically or economically. Nevertheless, we are aware that we have to strive for investment in the development of RES, which will take decades; in the meantime, we will have to make do with conventional sources, including coal. Among the fossil fuels, coal is the only source that will be available for the longest period on the energy market, mainly due to the enormous volume of deposits.

The strategic objectives of Velenje Coal Mine, a company with highly developed technology, comprise the modernization of coal production which could contribute to better working conditions and higher economic and ecological acceptability, also due to the adaptation to the environmental requirements that Slovenia has to meet in the framework of the European Union, which call for new and comprehensive strategic consideration in the area of energy - from the point of view of production and consumption. Velenje Coal Mine integrated the aspect of sustainable operation in its strategy, which it implements consistently. In spite of the fact that Velenje Coal Mine is an energy company, it is also very successful in the area of energy use efficiency, which also reduces coal costs and consequently contribute to lower prices of electricity and heat produced in the Šoštanj Thermal Power Plant.

According to the long-term plan of lignite extraction in the Velenje Coal Mine, i.e. until 2054, which currently provides one third of electricity produced in Slovenia, the Velenje Coal Mine decided to follow the global trends and set up a project team in charge of clean coal technology development issues. This project comprises the following sets: lignite degasification, capture, transportation and storage of CO_2 and underground lignite gasification. In the 2011-2015 period, the implementation of the CCT project was (among others) financed from the planned costs and assets for the project Razvojni center Energija d.o.o., for which the Velenje Coal Mine was a co-founder and co-owner. Even though it is difficult to predict what will happen in 40 years, the development and the application of the so-called BAT technologies presents the possibilities that these activities would be carried out in any case also when the coal deposits are depleted. The bases are presented for the implementation of the pilot testing of the underground coal gasification project in the coal seam of the Velenje basin, which is an opportunity to exploit the deposits of soft coal in north-east Slovenia.

UCG is gaining ground throughout the world as a leading branch in the production of syngas, mainly thanks to its economic viability, exploitation of coal in the areas not suitable for conventional mining, and production of electricity and heat, as well as clean fuels. Some companies have already made the comparisons between the processes of gasification of different types of coal and the knowledge of the strategy of conducting individual processes, and thus obtained the key parameters for planning and commercializing the UCG process. The developments in the UCG area clearly indicate that the process has potential, because many countries have already decided to undertake preliminary research or studies about the UCG possibilities. UCG is considered to be a viable option for resolving the energy problem in the near future and is being mentioned in the national long-term development plans for the exploitation of natural resources.

However, we should be aware that UCG is, above all, a very risky development research project, including the pilot test and afterwards the pilot device, because the underground transformation of coal involves very high technological risk. It is practically impossible without the support of the state in the form of an appropriate national energy development plan.

Underground coal gasification is a suitable method for producing energy from coal deposits without excavation. Only a handful of UCG tests has been conducted on lignite and other types of coal, which is a huge opportunity for Slovenia, and other countries, from the energy, environmental and business point of view.

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Nomenclature

(Symbols)	(Symbol meaning)
CCT	Clean Coal Technologies
CCS	Carbon Capture and Storage
CEPL	Carbon Energy Pty Ltd
CRIP	UCG method with Controlled Retraction Injection Point
ECC	Energy-chemical combine

ELW	Extended Linked Wells method
EUR	euros
HUGE	Hydrogen Oriented Underground Coal Gasification for Europe
UCG	Underground Coal Gasification
PV	Velenje Coal Mine
IMGE	Institute for Mining, Geotechnology and Environment
SG	syngas
TEŠ	TEŠ Power Plant
UCG	underground coal gasification
VLW	Vertically Linked Wells method
USA	United States of America
εUCG	Ergo Exergy's Underground Coal Gasification technology