DOBRUDZA COAL BASIN – EXPLORATION FOR UNDERGROUND COAL GASIFICATION AND CO_2 STORAGE

Aleksey Benderev, Klara Bojadgieva
aleksey@geology.bas.bg; klaratb@geology.bas.bg
Geological Institute, Bulgarian Academy of Sciences, Acad. G. Bonchev str. Bl.24, 1113 Sofia, Bulgaria

ABSTRACT
The article is presenting the EC funded integrated project UCG&CO2 STORAGE focused on evaluation of the potential of deep lying coal seams (>1200m) for underground coal gasification and the subsequent storage of CO_2 in Dobrudza coal field (NE Bulgaria). The results of the geological, tectonic and hydro geological exploration are analyzed to obtain the data required for model development and validation on the next stage of project followed by a future technological application. A review of the current environmental state of the studied region is made.

Introduction

Coal gasification is the process of producing a gas from burning coal, called syngas. This is a gas mixture of carbon monoxide, carbon dioxide and hydrogen. Underground coal gasification (UCG) is an in-situ process carried out in non-mined coal seams using injection of oxidants to burn the coal and bringing the product gas to surface through production wells drilled from the surface. Compared to the traditional coal mining and gasification, the UCG has less environmental and social impact.
The earliest records of the idea of gasifying coal underground belongs to two German engineers – the brothers Werner and Wilhelm Siemens (1868). At the beginning of the 20th century the British scientist Sir William Ramsay prepared the first UCG experiment near Durham, UK but was not able to start this experiment due to the outbreak of the war in 1914 [1]. The Soviet UCG program was launched in 1928 but the real testing of the UCG methods did not started until 1933. Of the previously Soviet projects, Angren in Uzbekistan is continuously in operation since 1961(Fig.1). Coal at Angren is fairly shallow, at an average 250 m depth and of about 10 m thick seam. It is the only project that has been running over several decades allowing monitoring of long term behavior and environmental impact [2].

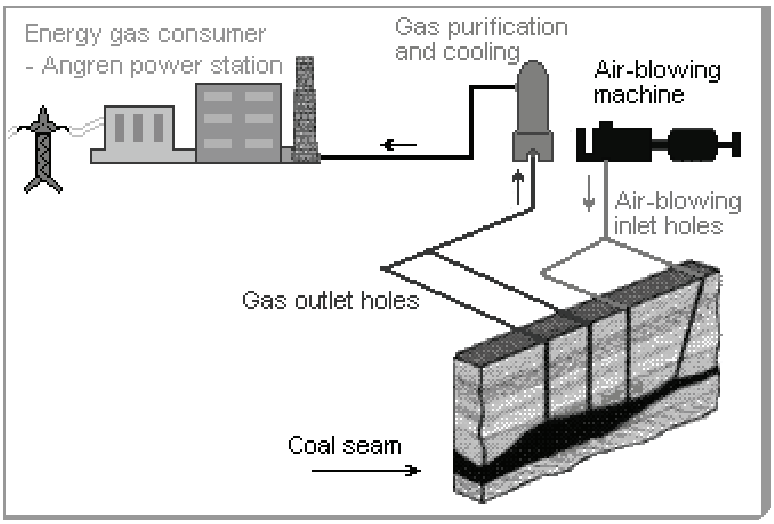

Figure 1. Scheme of Angren facility

Nowadays such experiments are carried out all over the world – in Europe, United States, Canada, Australia, China and South Africa. About 50 small scale installations have been tested till now. A successful UCG experiment needs to produce gas of a combustible quality from non-mined coal in a controlled manner that allows the experiment to be reproduced. Gasification of shallow deposits, however, has a number of disadvantages, particularly regarding environmental issues. Contamination of groundwater by undesired by-products of the process as well as the leaking of gas to the surface has been observed in several projects, particularly in the US and the former Soviet Union [1]. Recently, the attention of the scientific community has been turned to deeper deposits, Fig.2. They are better shielded against potable groundwater horizons and many of the deeper deposits would not be feasible to be mined by conventional underground mining.

Major problems of UCG in deeper lying deposits comprise considerably higher drilling costs and establishment of a sufficiently permeable connection between the gasification chamber and the production well [2].

UCG has numerous economic and environmental benefits. Compared to above ground gasification, UCG is much cheaper, does not disturb land by mining, leaves ash in its natural location and allows an operating UCG plant to increase its syngas production at minimal capital cost. UCG seems to be the most suitable technology to be used in conjunction with CO_2 storage, providing a reduction of greenhouse gas emissions compared to surface exploitation.

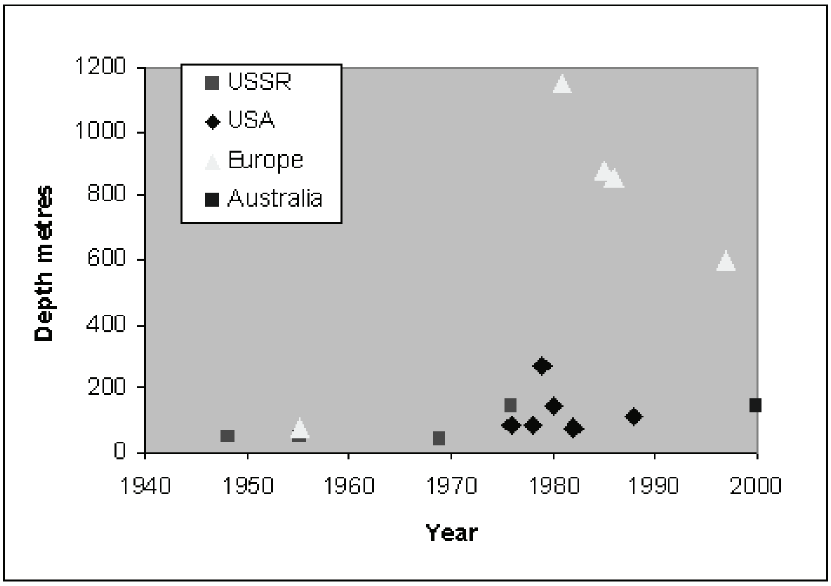

Figure 2. Distribution of UCG according to deposit's depth
[Best Practices in Underground Gasification by Burton, Friedman & Upadhye, 2006]

Groundwater contamination and surface subsidence are possible environmental impacts of UCG. Every coal field has specific geological structure and hydro geological conditions that should be examined in details in order to define the possibility for UCG technology application.

The first integrated project in Bulgaria focused on UCG and CO_2 storage is currently carried out in Dobrudza coal deposit (NE Bulgaria). The full title of the project is: Study of Deep Underground Coal Gasification and the Permanent Storage of CO_2 in the Affected Areas. It is financed by the EC Research Fund for Coal and Steel. The coordinator is Overgas Inc. company, Sofia, Bulgaria. Leading institutes from the UK, Portugal, Germany, Bulgaria and Greece participate in it. Duration of the project is 30 months beginning from July'2010.

Dobrudza coal field has not been exploited till now because the coal is deposited at great depth (1200-1400) m, a thick Upper Jurassic- Lower Cretaceous aquifer (600-800) m is lying above it and the area is strongly tectonically disturbed. The project aims to assess the possibility of exploitation of the deep seated black coal by studying the geological and hydro geological conditions, modeling the process of coal combustion, syngas extraction and CO_2 storage.

The expected outcomes of the project are:

- Development of geological model for the central part of the Dobrudza Coal Deposit (DCD)

- Development of geo-mechanical and cavity models for UCG spaces and CO_2 storage
- Development of hydro-geological model of the DCD
- Engineering, drilling and completion requirements for UCG & CO_2 storage
- Environmental assessment of UCG - CO_2 storage
- Economic assessment of UCG and CO_2 storage. Review of regulatory requirements and assessment of overall feasibility of process

Geological background

Geological and geophysical explorations in the basin were performed during a long period between 1960 and 1986 and the lithologcal structures, genesis and tectonic development of the basin have been studied. These results are summarized in a monograph compiled by a group of authors [4]. A geothermal study has been conducted using geophysical data taken from a large number (over 100) of deep wells drilled along a set at spacing of 1000 m and at less than 500 m in the center of the basin. Temperature data recorded under unsteady thermal regime are available for 83 wells and under recovered thermal regime – for 37 wells [5].
Dobrudza coal deposit is the deepest in the country situated in NE Bulgaria at about 4-5 km from the Black sea coast. It was discovered in 1962 during oil and gas exploration. The coal deposit is a part of Varna depression superimposed on the Moesian plate. It is situated in Vranino horst which is a part of vast Paleozoic subsidence, built of slightly folded Carboniferous layers berried under the Mesozoic sediments. The area of the horst is about 420 km^2. It is bounded by faults and the blocks bordered the horst are lowered along the faults by more than 1000m. Fig.3. The horst is mostly faulted in the area of coal deposit.

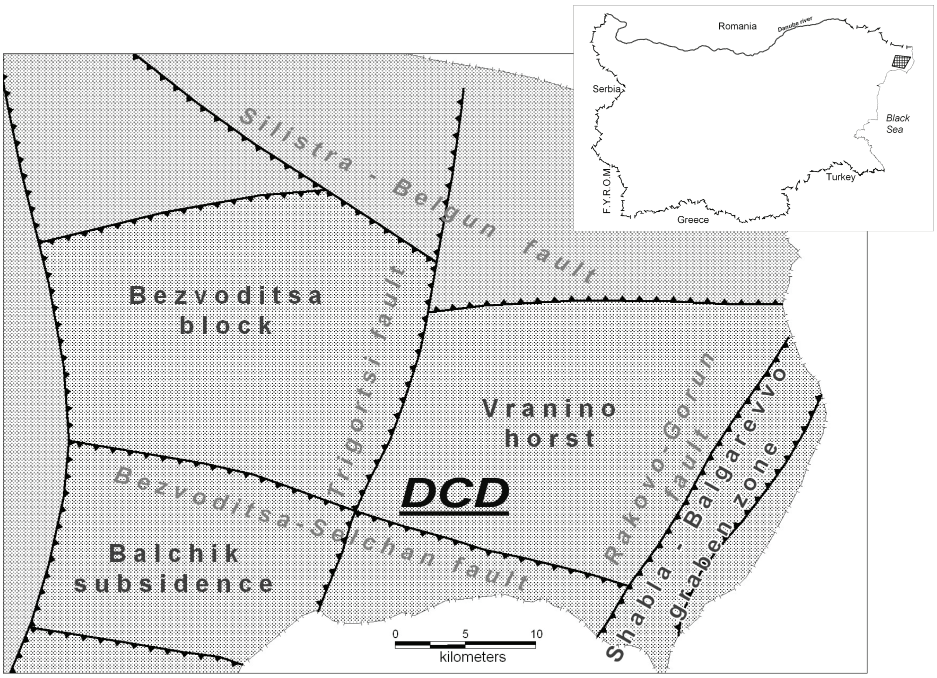

Figure 3. Location of Vranino horst and major faults in the studied area

The coal layers are found in Upper Carboniferous which has a total thickness of 1000 m. They are covered by Permian to Quaternary rocks. The prevailing slopes of Carboniferous layers are 10-15^o. They are faulted by almost vertical tectonic fractures in sub- meridian direction and amplitude of 100m. Rocks of Permian to Middle Jurassic age varying in thickness and permeability are deposited between the Carboniferous and the aquifer of highest water capacity - Upper Jurassic – Lower Cretaceous. Above the most shallow part of the deposit are found 20-50 m thick Middle Jurassic water permeable sediments while in its northern and eastern part the sediments are of Perm-Triassic and Lower Jurassic age, their thickness reaches several hundred meters and are of low permeability [6].

This complex tectonic and geological structure could create paths for water movement and gas migration during the process of coal exploitation. It would be a subject to modeling under different assumptions for existing water conduits.

Dobrudza coal deposit is one of the most perspective areas in Bulgaria for exploitation in terms of coal quality. Coal seams with production capacity are located in Makedonka, Krupen and Gurkovo formations, Table1, [4, 6]. These formations contain 27 coal seams in total of them 16 are with production capacity and total thickness of 31,5 m (seems with thickness above 0,8 m are considered productive).

The coal quality depends on the rate of coalification and chemical composition. The rate of coalification observed in the coal seams is changing in vertical and horizontal direction and ranges over a large interval – from sub-bituminous A to bituminous low volatile matter.

Table 1

Coal formations	***Formation thickness, m***	***Number of coal seams, (incl. exploited), m***	***Total average coal seam thickness (incl. exploited) m***
Gurkovo	*250*	*11 (3)*	*11,2 (7,0)*
Krupen	*60*	*4 (4)*	*7,25 (6,25)*
Makedonka	*180*	*12 (9)*	*16,9 (15,8)*
Mogilishte	*530*	*41 (1)*	*21,5 (2,5)*

The main organic coal components (Table 2) and the caloricity values, varying in the interval (31,7 – 34.0) MJ/kg define the good prospects for coal exploitation.

Table 2

Group/ Formation	***Vitrinite***	***Exinite***	***Internite***	***Mineral impurities***
Gurkovo	*48*	*15*	*25*	*12*
Krupen	*53*	*14*	*19*	*14*
Makedonka	*52*	*14*	*20*	*14*

Hydrogeological background

The regional distribution of aquifers and the existing connection between them are one of the main subjects of this study. The hydro geological factor is of crucial significance in the discussed region due to the existence of deep seated Upper Jurassic- Lower Cretaceous aquifer used for water supply in the region. For this reason no contamination related to coal exploitation is admissible.

The Dobrudza coal deposit is a part of Varna artesian basin. Its recharge zone is at about 80 km to the west in the region of North Bulgarian Uplift and the drainage zone is in the Black sea aquatory. The main aquifers discovered in the basin are of Neogene, Paleogene and Upper Jurassic- Lower Cretaceous age. They are regionally traced and of high water capacity, while the aquifers of Dogger, Triassic and Carboniferous are of smaller water capacity.

Upper Jurassic - Lower Cretaceous aquifer is of highest thickness and water capacity in the region. According to the published data [4] its top lies at a depth from 300 to 700 m in the region of Dobrudza deposit. Its total thickness is about 600-800m. The reservoir is mainly built of limestone and dolomite a is a natural drainage zone of the existing aquifers.

The transmissivity coefficient for different aquifers discovered in the region varies in a wide interval – from very low (less than 0,08 m^2/24h in Carboniferous) to about 15 000 m^2/24h – Neogene and Upper Jurassic- Lower Cretaceous, Fig.4.

The analysis of the existing hydrogeological data resulted in defining of four hydro-stratigraphic units as a base for developing the regional model - Upper Jurassic- Lower Cretaceous aquifer, Perm-Triassic aquitard, Carboniferous aquifer and Devonian aquifer.

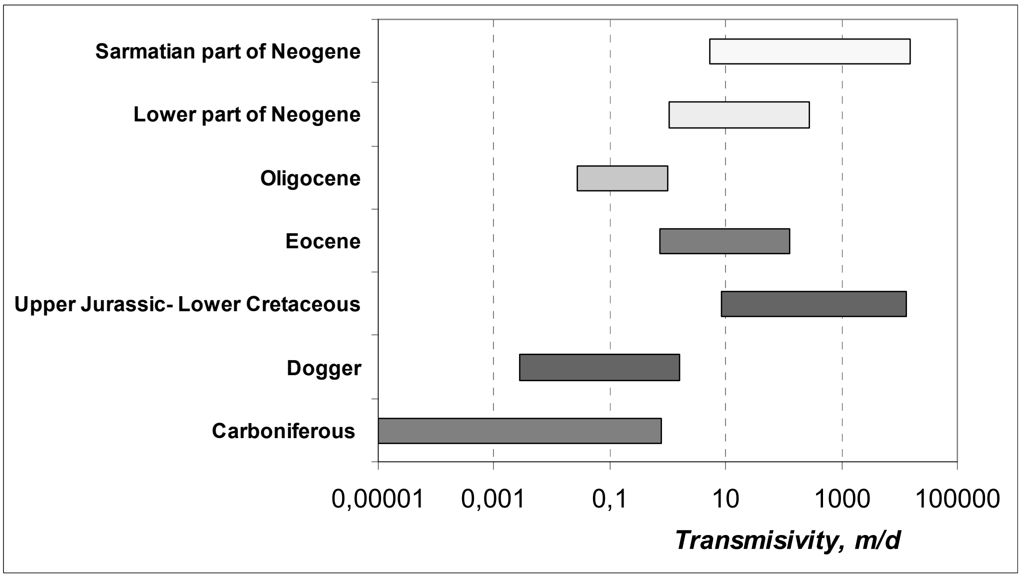

Figure 4. Transmissivity variation in different aquifers

The dominant role of Upper Jurassic- Lower Cretaceous aquifer in the hydrodynamic regime of the region is confirmed also by the hydro chemical analysis. The highest value for the total dissolved solids is calculated for the Carboniferous while the lowest one - belongs to the karst aquifers - Upper Jurassic-Lower Cretaceous aquifer and Neogene (Sarmatian part), where water movement is very intensive, Fig.5a. Although Upper Jurassic-Lower Cretaceous aquifer is deep seated it has a similar chemical composition with the shallower Neogene aquifers, Fig.5b. The other aquifers are characterized by a stagnant water regime and contrast chemical composition. Carboniferous and Upper Jurassic-Lower Cretaceous aquifer are probably not connected as they differ a lot in their chemical composition.

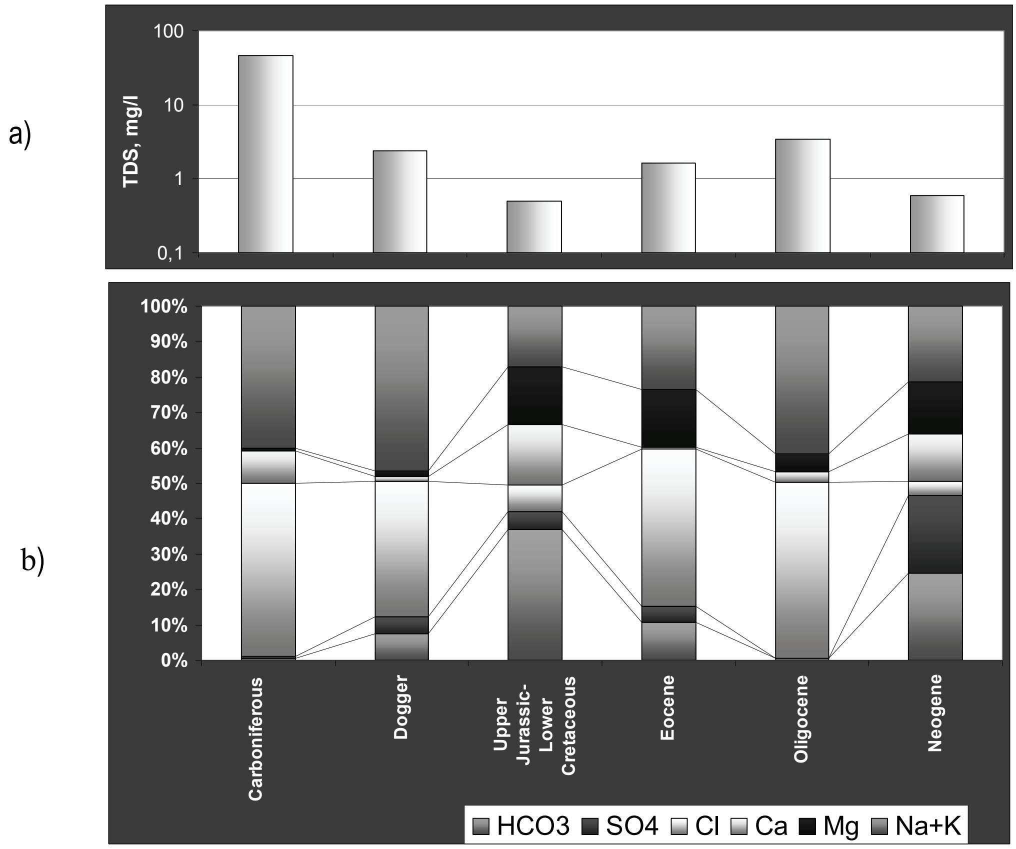

Figure 5. Results from hydrochemical analysis, a) TDS variation b) chemical composition

Current environmental state in DCD

In climatic aspect the area of DCD is located in the Northern Black Sea Sub-region and is predominantly influenced by the Black Sea. The region is characterized by relatively high annual and seasonal temperatures, shorter periods of snow and lower annual precipitation.

Peculiarities of climatic and relief features in the region influence considerably on the dispersion of air pollutants as well as on the transfer of polluted air masses. No significant sources of pollution exist in the discussed area. The only pollution could be associated with the populated areas where solid fuel is used for heating during the winter season.

Surface runoff is almost absent in the discussed region. It is associated with the flat terrain, high karstification of Miocene limestone and the location of aquifers deep below the surface. The dominating processes of rapid rainfall infiltration define the high values of underground flow. Temporary surface streams as a result of intensive rainfall and snow melting are formed very rare. They flow along wide valleys to the north direction and drain into Shabla-Ezerets and Durankulak lakes. A small part of the area drains to the east towards the Black Sea where the Gulf "Tauk Liman" is situated, Fig.6.

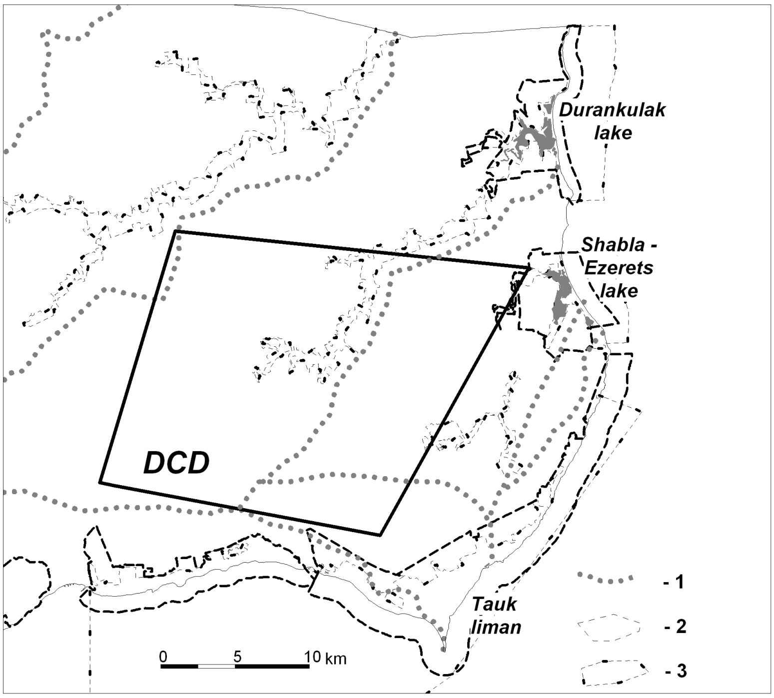

Figure 6. Location of DCD with respect to protected lakes and zones under Natura 2000 *1. water catchments, 2. Protective zone under Habitat Directive 3. Protective zone under Birds Directive*

Karst processes are widespread in the region. The karst it typically platform type with the presence of negative surface karst forms. Significant areas are covered by loess deposits. It should be emphasized that the Sarmatian aquifer is mostly vulnerable as a result of human activity.

Most widespread are the black earths soil varieties and the major part of the region is an agricultural land – mainly non-irrigated and used for cereal cultivation. In a close vicinity of the area are located one reserve, three protected areas, four protected zones included in Natura 2000 under Birds Directive and three under Habitats Directive, Fig.6. Dobrudza coal deposit is a part of the territory of three municipalities inhabited by 43 273 people (towards 2009).

The mentioned above factors characterize the studied area as a non polluted and rarely inhabited region with a fertile soil and intensive crop cultivation. UCG technology will provide minimal disturbance to land and about 25% reduction in CO_2 production as compared to conventional coal-fired power plants. The underground waters are very sensitive to surface contamination and this should be considered in the phase of planning facilities. The close location of protected areas and lakes will require strict quality control of surface and underground waters, discharging in them.

Geological environment and ground water are mostly exposed to the impact of underground coal gasification and CO_2 storage. This assessment would be one of the project outcomes.

Conclusions

- The collected and analyzed geological and hydro geological information outlined the main factors that should be considered in modeling the processes of underground coal gasification and CO_2 storage in Dobrudza coal deposit
- The high caloricity coal values define good prospects for exploitation.
- The accumulated experience in deep coal gasification in the recent years is a good base for promoting the technology in the country.
- Underground coal gasification technology will provide minimal land disturbance practically no contamination of the surface water.

References

1. Klimenko, A. Early Ideas in Underground Coal Gasification and Their Evolution, Energies 2009, 2, 456-476; doi:10.3390/en202004562.
2. Schlüter R., Kempka,T., Nakaten,N. Review of operational UCG-CO2 injection scenarios and the options for CO_2 storage. UCG_CO2 storage project, 2011.
3. Blinderman, M.S.; Anderson, B. Underground coal gasification for power generation: Efficiency and CO2-emissions. Proc. 12th International Conference on Coal Science, Cairns, Australia, November 2–6, 2003; Paper No. 13C1.
4. Hristov ,Z.(Chief editor), Geology of Dobrudza coal basin, Technika, S, 1988 (in Bulgarian), pp.170.
5. Bojadgieva, K., S.Gasharov, S.Veselinov.1998.Geothermal Study of the Hydrogeological Regime in the Region of the Dobrudja Coal Deposit (NE Bulgaria)-Bulgaeian Geophysical Journal, XXIV, 3-4,127-136.
6. Kamenov,B., Z.Nikolov, E.Stefanova 1984. Coal basins and deposits in Bulgaria, In: Coal basins and fields of the countries members of UMIA and Jugoslavia. Ed. UMIA, Moskow, 1984, p.107-161.(in Russian)