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SCIENTIFIC PRINCIPLES OF NATURAL COALS TRANSFORMATION IN SITU

World consumption of energy will increase with very quick rate and achieve 11.7 billion tones per year of the conditional fuel to 2015. Accordingly the Russian Federation will produce 1.775 billion tones per year (moderate variant) in accordance with Energy Strategy of Russia to 2020. These data are very large. In particular the production of natural coal both of the world and Russia will be increased very intensively. In addition the Strategy requires increasing of energy consumption at the expense of forestalling development of the local sources of power generation. The conditions give a challenge to elaborate more the effective order and technologies of coal extraction from the coal fields and saving energy resources for future generations.

The conventional technologies of coal mining consist of the several large stages namely breaking off and transportation both into a mine or open pit and the surface and storing of the natural coal and processing of the one. The technologies have serious shortages which are doing the coal mining less attractive both with economical and social view point. In particular the conventional technology suffers large losses of the coal in the coal measures. In the coal industry practice the standard thickness of a coal seam for mining is as more as 0.7 m. The coal seams losses for the thickness less 0.8 m make up as more as 40–50% of the coal measure reserves sometimes. The losses go in the waste to day. These conditions of the reserves extraction needs in improving. A basis of the activities may be developed of unconventional borehole technologies for the coal mining. The ones must correspond to next requirements:

– The technology may be used for processing of the coal seams with a thickness both less and more 0.8 m.
– The technology must produce the thermal or/and electrical energy manufacturing on the a mine field directly being the local power sources for outside consumers.

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- The direct energy coefficient of the unconventional technology mustn't less as 30% from a total calorific value of the coal.
- Output of the local electrical energy from the unconventional coal block in situ must be included in the global power system of the coal producing region.
- The unconventional technology must garantee both environmental and social advantages as compared with the conventional technologies.

The unconventional technologies of coal mining are based on the next fundamental positions namely **transformation** of the natural coals in liquid or gaseous condition and **transportation** of these products from a coal measure to the surface through boreholes and **processing** of the ones into thermal and/or electrical energy. Besides the hydrogen fuel may be obtained from the products. The main positions may include additional processes which increase of the borehole technology effectiveness of the coalbed methane recovery from the a coal measure for example and use of its in the borehole technology [1].

1. TRANSFORMATION OF THE COAL

In world practice the transformation of the coal into liquid fuel is achieved with through liquation process of the natural coal. The result of the process is based on the Fisher and Tropsh chemical reaction for which reaction of oxygen mono – oxide with hydrogen connection takes place (1926). The reaction is been for high temperature and in presence catalysts that as Fe or Co and Zr or Th. Production of the reaction are methane and water or oxygen dioxide and hydrocarbon. The last matter is a basis of liquid fuel synthesis. Europe is the homeland of the liquid fuel manufactures. In the beginning 20-th years of XX century Germany has had a liquid fuel fabric already. Natural coal has been a raw material for liquid fuel receiving. To 1945 Germany and USA and Japan and China have had of 15 factories producing the liquid fuel for cars and aircrafts from the natural coal.

In the last years (1990) Exxon Co. has started up the plant for liquid fuel production with Co – catalyst and output of 8000 tones per year. In 1993 Shell Co. had started up the plant too with output of 500000 tones per year using Co–Zr catalyst. Here the syngas from the natural coal had serviced raw material for the plant. Companies Chevron, Conoco, BP, ENI, Statoil, and Syntroleum have the projects in a field of the liquid fuel from the coal. Poland Main mining Institute has beginning development to direct liquation of a coal. Several scientific organizations of Poland (Weglowa Co., for example) are investigating the problems of coal mining with the unconventional technologies use including underground gasification of coal seams and the liquation of coals.

The unconventional technology underground coal gasification (UCG) is planned to be in the Nyscheilimskoe coal field placed about 300 km from Alma-Ata. The cost of the UCG station is estimated as more as $ 130 million. The station will produce of 1319 billon m^3 of the substitute natural gas (SNG) with calorific value of 35.6 MJ/m^3. For comparison the station of the USA produced the gas of 3 billion m^3 per year is worth in about $ 500 million.

Experts have acknowledged the coal liquation technology to be profit if a barrel of a oil will be worth of more $ 60. Transformation of the coal to liquid fuel from the one in commercial scale may wait to 2015. Comparison the conventional and unconventional stages is leaded in the Figure 1. The data shows unconventional technology includes processes less as comparison with coal extraction from the coal measures. The hard capacity processes of conventional technology are absent in a composition of the unconventional technology. Besides, influence of the unconventional technology on the environment is been more sparing than the conventional one.

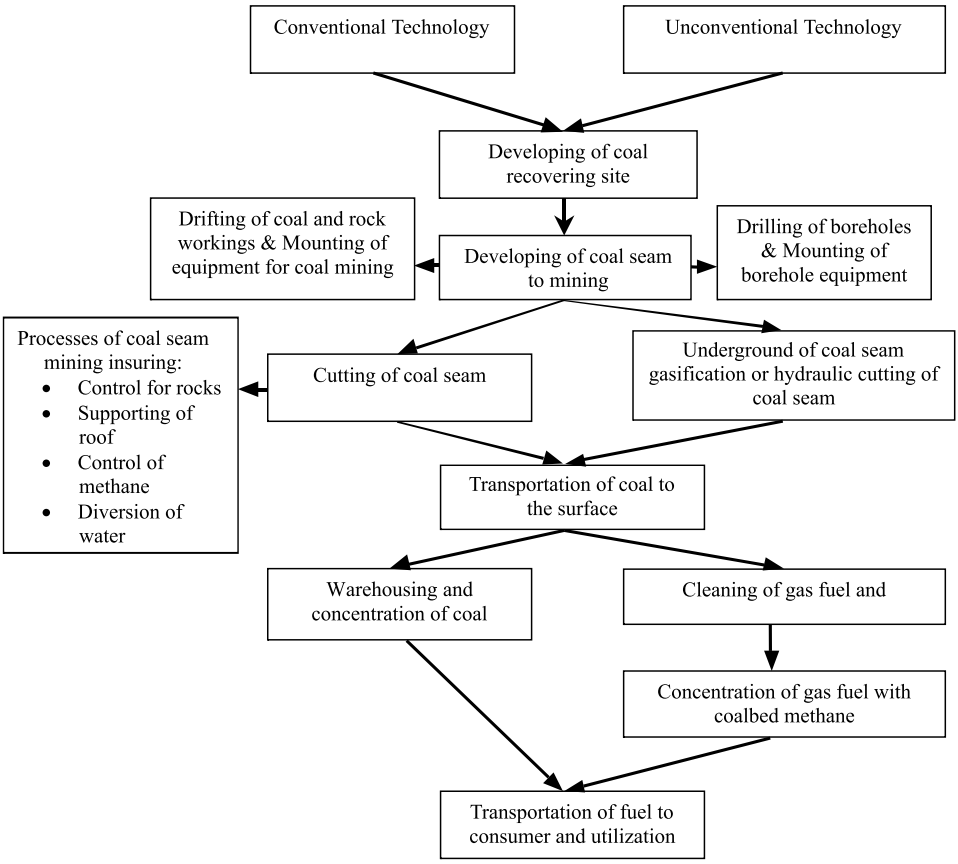


Fig. 1. Comparison of conventional and unconventional technologies

Moscow State Mining University has proposed the innovative unconventional technology which consists of next stages: gasification of the coal seams and cleaning of combustible gas mixture and enriching combustible gases with the coalbed methane and thermal and/or electrical energy production on the surface. Gasification process may be realized both in underground conditions and on the surface.

Very important stage in the unconventional technology is underground combustion of the coal in the coal measures. For the effective process the several oxidants are used in the UCG practice. The main oxidants are oxygen and air and vapor of water as well as vapor and oxygen feeding. Very important index of the UCG process is the calorific value of raw gas or gas mixture produced from the UCG boreholes. The comparison of the calorific values of UCG gases is happened in Table 1 for the different oxidants [2].

Table 1

Gases from the underground coal gasification processes changed the oxidant kind

Components	Air feeding	Vapor and oxygen feeding	Substitute natural gas
CO	27.30	20.20	0.01
CH_4	1.80	11.13	93.01
H_2	10.10	38.94	4.16
CO_2	4.60	28.03	1.81
C_2H_2	–	0.40	–
C_2H_6	0.10	0.61	–
$N_2 + O_2$	56.2	0.29	1.01
H_2S	0.01	0.40	–
Total	100.0	100.0	100.0

The calorific value of the raw gas mixtures after different oxidant feeding in a coal seam are changed very significant. The one of the gas mixture after air feeding is of 4.2 MJ/m^3 and after vapor and oxygen feeding is of 12 MJ/m^3. But the calorific value for substitute natural gas produced in the surface gas generator is estimated like 34–35 MJ/m^3 that is the value is a magnitude about for the natural gas .

For process of methane increasing in the raw gas mixture (enriching with methane or methaning of the mixture) next reactions must be taken place

$$CO + 3H_2 = CH_4 + H_2O + q \quad (1)$$

$$CO_2 + 4H_2 = CH_4 + 2H_2O + q \quad (2)$$

For realizing of the condition (1) requires that a ratio of H_2/CO must be as more as 3. A practice has shown the ratio has achieved as more as 3.7 in the real outlet gas mixture after methaning process.

So, the regime of substitute natural gas if most attractive with view point of gas quality. But last word for SNG use in commercial scale belongs the economic comparison.

2. DISINTEGRATION OF COAL MASS

Next important question consists in hardness and durability of a coal mass in situ. Any treatment of a coal seam is met with these characteristics of the coal mass. For example, UCG process is directly connected with fire channel developing and width of the one into the coal mass. If the channel is developed very difficult the total effectiveness of the one will be low. Other example consists in unconventional or borehole technology use for extraction of the raw coal to the surface in hard form. This technology may be used in the coal seams with thickness less 0.8 m for example. In further breaking of coal may be used both with energy (power) aims and for hydrogen production and methaning process.

For durability control in the coal mass the methods of the one decreasing or weakening of the coals must be developed. The methods have a name as disintegration of the coal mass. These methods may be based on physical and chemical treatment (PCT) of the coal seam or microbiological (MBT) ones. The PCT method is wide known in Russia and USA and has published in the monongraph [3]. The method MBT may be developed on base pumping process in the coal seam with microbiological suspensions that is to say water and mineral solution with that kinds of the microbiological cultures as Thiobacillus ferrooxidans, Thiobacillus thiooxidans, Thiobacillus thioparus, Thiobacillus neapolitanus, Thiobacillus organoparus as well as Silicate bacteriums. The cultures have shown high leaching ability to the mineral as alumininum and silicium and quartz. In particular the alumininum and siliciums have lost of 9–50% of itself mass for 105 days of bioleaching process and quartz has lost of 0.7–1.4% for 28 days.

Microbiological treatment of the coal seam will call the pores and fractures increase in the one. This increasing Δm (%) is estimated from the equation

$$\Delta m = \rho_c \cdot A_w / \rho_m \tag{3}$$

where:

ρ_c – density of the coal, kg/m^3,
A_w – content of mineral part in an unity of a volume of the coal, %,
ρ_m – density of the mineral, kg/m^3.

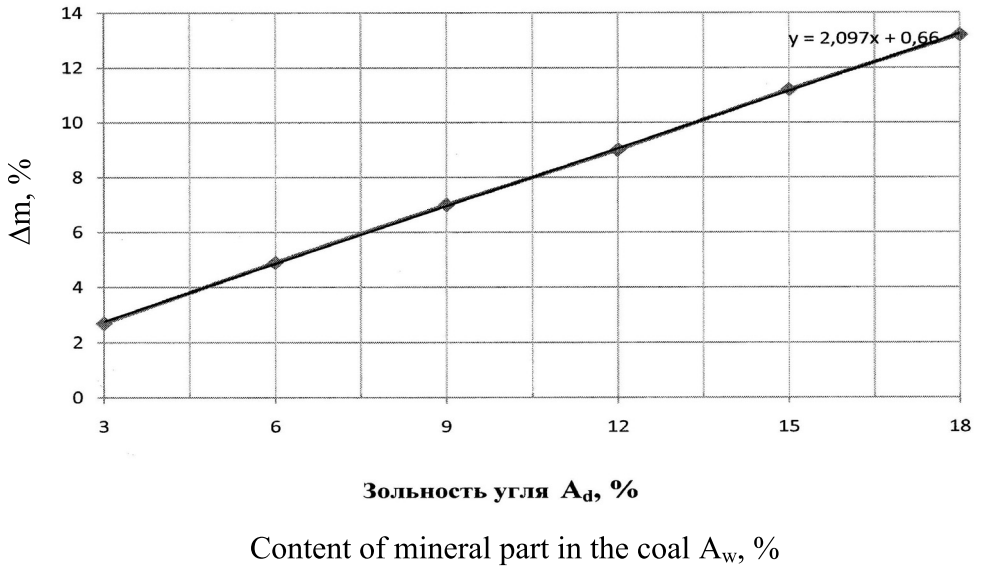
Magnitude A_w may be calculated from the equation

$$A_w = 1{,}129A_d + 0{,}935S - 0{,}2 \tag{4}$$

where:

A_d – ash content of the coal, %;
S – content of sulfur in the coal , %.

The dependence of pore and fracture volume increasing of coal from the content of mineral part of coal is shown in the Figure 2. Here, magnitude Δm is calculated as a loss of the total ash content. So, the direct connection between the pore and fracture volume of coal increasing and mineral content of coal decreasing is taking place after bioleaching or physical and chemical treatment of the coal.



Content of mineral part in the coal A_w, %

Fig. 2. Increasing of the pore and fracture volume Δm of the coal from bioleaching level of mineral its part

Scientific accompanied task consist in substantiation of the uniformity and large dimensions of zones having the treatment of the coal mass.

3. TECHNOLOGICAL SCHEME OF BOREHOLE LOCATION

Next important principle consists in optimal technological scheme developing. The scheme defines both technical and energy effectiveness gas fuel use and economical effect and competitive ability of the unconventional technology.

Besides, the coalbed methane use as a part of the one is obligatory. Modern achievements in coalbed methane recovery have shown the flow rates of gas boreholes may achieve of 5–7 m^3 per minute and more in the USA, Australia, Poland. Therefore progressive technologies of coalbed methane extraction must be included in the unconventional methods. Especially, if the developed and developing countries have large reserves of coalbed methane in it territories. For example, the reserves of coalbed methane have estimated as more as 13,000 billion m^3 in Kuznetsk basin of Russia only. In additional the technological scheme must provide coal extraction without supporting of working out are in situ. This problem may be decided on the basis of chamber and pillar system use for a coal seam mining. The parameters of a working chamber are calculated this way that dimensions of its permit to support of a roof of the coal seam without breaking down. For example, the wide of working area between the pillars must be as less as 4–6 m for the rocks with moderate hardness. This parameter may be changed in connection with the different coal seams conditions. The principles of transformation in situ the coal seam in gas fuel may be formulated next way (Tab. 2).

Table 2

Principles of natural coal transformation in gas fuel

No	Principle	Methods of realizing	Being experience
1.	Transfer of coal in liquid (gas or liquid) condition	Thermal (Underground coal gasification, Surface coal gasification), Liquation	Existence (available) experience
2.	Developing of coal massif to transfer	Hydraulic and physical and chemical and microbiological treatment of coal mass	Hydro fracturing and physical and chemical treatment experience in Russia and USA
3.	Substantiation technological scheme of boreholes location for maximization of coal reserves extraction	Modeling of location of pillar and chambers into coal seam and minimization coal losses into coal measure	Wide numerical modeling of geotechnical tasks in coal mining industry
4.	Cooling of raw gas generator mixture (RGGM)	Building of coolers	Industrial experience
5.	Cleaning of RGGM from incombustible gases	Moving off incombustible components from RGGM as CO_2, N_2, S, and SO_3	Cleaning of gases in the chemical industry
6.	Enrichment of cleaning gas moisture (CGM) that is to say gas mixture methaning	Recovery of coalbed methane from the coal seam with integration of its into CGM	Recovery of coalbed methane in Russian Federation and USA through surface boreholes
7.	Control of enriched gas mixture (EGM) quality	Sensors and systems of control for flow rate and composition of EGM	Wide use of system for parameters control of technological processes
8.	EGM use in power generation on vapor and gas cycle generators (VGG) or combined cycle units (CCU)	Combined cycle unit permits to achieve of coefficient effectiveness of 55% and more	Industrial use of VGG and CCU in the developed countries

Very important question of the unconventional technologies use for the future in the commercial scale consists in hydrogen production during transformation the coal in the fuel gas. Moscow state mining university has received the patent of Russian Federation for hydrogen production in structure of the unconventional technology. Main principle of the method is deeper cleaning of the generator or raw natural gas mixture from the incombustible and other pollutants.

4. CONCLUSION

1. Modern coal extraction conventional technologies suffer shortages and high losses of the coal into the coal measures
2. In the future a recovery of natural coals must be increased and the losses of the valuable energy resources will increase too.
3. Unconventional technologies on the basis of borehole methods will become attractive more and more.
4. Scientific principles of natural coal transformation in the gas fuel are formulated in the present report.
5. Level of development of modern techniques and technologies is ready to wide industrial use of the unconventional technologies in a practice.

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