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SCIENCE PRINCIPLES FOR THE CONCEPT – PROJECT OF COMBINED COAL AND GAS AND ELECTRICAL BLOCKS

Coal industry is large source of electrical and thermal energy in the worldwide. Conventional technologies of coal extraction have shortages as lower efficiency of total coal potential energy use (not more 6–8%), high labor and material capacity and negative influence to our environment. Especially these shortages are undergone the underground coal mines.

New technology has proposed by professors Yu. F. Vasyuchkov and B.M. Vorobjev in 1996. According to the technology a hard raw coal must be converted in the gas fuel through gasification procedure and take place coalbed methane recovery from a coal field and mix of these two gas streams for use the one into the combine cycle unit for power (electrical and thermal) generation. For gassy coal fields the complex consists of three main blocks e.g. mining operation (recovery of coal and coalbed methane) and transfer of the coal in gas fuel with preparation and cleaning procedures and power generation. The not gassy coal fields may include the same blocks but on the surface the unit for surface coal gasification must be.

A new approach to the coal-electricity could be suggested for both independent recover of combusted gasses and active collieries with conventional technologies use. A new technological concept of coal-electricity can be implemented at operating coal mines with conventional coal extraction technology where a coal being mined. In this case one system of wells (boreholes) drilled from the surface or from underground workings is intended for methane recovery from developed panels. The panels may be situated in pre-mining areas and areas which are to be mined by conventional mining methods.

The second system of wells is intended for gasification procedure of the coal seam with receiving of mixture of combustible gases e.g. for transfer of a hard coal seam in

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a gas fuel. Further gas fuel is moving to preparation and cleaning units to power generation station.

The technology may be resulted to serious advantages in efficiency of total coal potential energy use as more as 28–30% and decreasing of labor and material productivity as more as 40–50% and cutting down of carbon dioxide content in the gas fuel as more as 8–10 times and nitrogen oxides in 4–5 times compared to conventional technologies of coal extraction. Electrical efficiency of this local coal and gas and electrical complex will achieved as more as 56%.

Therefore, for an attraction of large investments a concept-project (CP) must be developed. To-day the theoretical methods of this design is absent. Our report proposes some discussion and scientific principles for the project development.

There are several main parts of CP. The parts are: a productive capacity of the complex appraisal (1) and the main technical parameters calculation (flow ratę of gas fuel and efficiency of an energy błock etc) (2) and economical including capital outlays assessment of profitability of LCGEC (3).

So, the first scientific principle of CP is search for the optimal solutions about the main parts of the one including the productive capacity.

The second scientific principle requires use the mathematical optimization methods because of very big changeableness of a caloric value of the gas fuel giving in the combine cycle unit. The same methods must be used for a place definition of mining and gas production and power generation blocks. This principle requires the deep analysis of theory and methods of intensive extraction coalbed methane from a coal measure what is discussed lower.

The third science principle is based on methods of minimization use for those functions which show the connection between productive capacity of the complex and economical expenditures on construction and exploitation of the one.

The Coalbed Methane (CBM) is an ecologically clean product. The gas of high quality (95–100%) is distributed in the coalfields as zones: methane zone is distributed lower zone of gas weathering, which includes of nitrogen-methane and methane-nitrogen zones. Just the methane zones serve as sources of CBM. The gas is in coal seams of middle and high ranges of metamorphism (rank), except of very high metamorphism anthracites of the coal basin. Thus for commercial recovery of CBM may be used methane zones of coal seams with rather high gas content and corresponding rank of the coal.

In methane – content coal seams methane bearing capacity arises from a 40 to 45 m^3/t. However most of methane-content coal seams demonstrate gas-content as low as 10–20 m^3/t. Coalfields of the world contain more than 100 trillion m^3 of clean methane that is equal to 126 tones of clean coal with calorific value about of 30 MJ/kg. China, USA, Russia, Australia, Ukraine, Canada, Poland are those countries where there is very much coalbed methane potential.

Coalbed methane from methane zones of the coalfields may be utilized through three possible ways: from mine return air – methane flows and from coalbed methane coal seams using extracted mechanized systems and from methane filling mine gobs.

With use of CBM serious problems spring up in connection with Iow volume rate of CBM extraction from low-permeability coal seams. The economic efficiency of CBM extraction depends of the solution of the following problems:

- low of flow rates of CBM extraction from the coal seams and respectively for power generation;
- small methane recovery volumes to a guarantee of big power stations;
- much number of exploited wells in a single time and a large total length of extracted pipe-lines.

The main gas-dynamic properties of coal seams influencing on gas well productivity of CBM include: filtration and diffusion gas-permeability and porosity and methane content or gas pressure of coal seams.

A structure of the coal seams is characterized with fracture (crack) and pore systems in a very large range of its meanings. Last model of this structure looks as systems of pore's blocks of the coal seam shared with cracks in situ. Accordance to this model the methane emission from seam derives from both cracks and pores blocks concurrently but an emission from the blocks is a main spring of CBM. The filtration permeability characterizes the cracks and the diffusion permeability characterizes the blocks.

In the cracks coalbed methane is in free gas condition and in pores of the blocks the methane is in bounded condition. A distribution of gas-content in situ is of 5–15% for free gas and of 85–95% for bounded gas. The free gas is transferred in a coal in connection with filtration laws. Our investigations have shown that a regime of methane filtration in the coal seam has a place after gas pressure decrease into the coal seam to less 1 MPa.

The bounded gas is in the coal seam in sorbtion and/or dissoluble conditions. The dissolved gas is defined as molecular hard solution of methane in the organic structure of coal. This is new phenomenon which has been researched and scientific discovery has been done by us [1]. During of CBM extraction from wells at first the free gas is emitted but then, after decrease gas pressure to 1 MPa and less, the bounded gas is emitted more. The connected methane is emitted from the blocks to cracks in accordance with the diffusion laws.

Thus the CBM productivity of well depends on a coal resistance to transfer of CBM through both cracks (macro pores) in the regime of filtration and micro pores in regime of diffusion. But the regime depends on filtration and diffusion permeability of a coal.

The filtration permeability depends on sizes and amount of pores and cracks. Porosity of coal seams is low and is changed from 1–3% (anthracite) to 8–12% (bituminous coals). For comparison: oil sandstones porosity is estimated as high as 20–35%. From data [2] a permeability of oil-gas rocks is changed from 1 to 3,000 mD or more often – from 50 to 1,000 mD. Most productive gas wells work in the roeks with a permeability of 10–20 D.

The permeability of coal seams were determined in our investigations within the range of 0.001–1000 mD. More often the permeability takes place as the interval of 0.01–10 mD. The investigations of other authors in USA, Australia, Russia prove these figures are too. Thus the permeability of coal seams is less than the permeability of oil-gas fields in 1,000–10.000 times. The leaner transfer of methane in coal seams is described by traditional equations of filtration as Darcy law.

Diffusion permeability of coal seams is estimated through efficient coefficient diffusion (ECD) of gas – methane in a coal [3]. For coals the middle meanings of ECD are estimated in interval from (1–3)10"10 (anthracite) to (6.6)10"8–10"9 m^2/s (middle and low rank coals). The ECD and the initial gas content of a coal seam have influence on the time and level of extraction of methane from a seam. More than 75–80% of captured gas from a seam is bounded methane. In situ the distribution of methane content into a coal seam from a wall of a coal working or from the wall of the single crack during extraction process can be described next equation:

$$a_x = a_0 \mathrm{erf}\left[\frac{x}{2\sqrt{D_e \tau}}\right], \ \mathrm{m^3/t} \tag{1}$$

where:

- a_0 – initial gas content of coal, m^3/t;
- x – distance in situ from flow end (crack or wall of mine working), m;
- D_e – ECD, m^2/s;
- τ – time of gas flow, s;
- erf – integral of probability.

The total volume of CBM extraction from the coal seam in diffusion regime is calculated as:

$$V_\tau = \frac{8 \cdot \rho \cdot F \cdot D_e \cdot k \cdot \tau \cdot (\pi - 4k^2 D_e \tau)}{m_0(\pi - 2k\sqrt{\pi D_e \tau})}, \ \mathrm{m^3} \tag{2}$$

where:

- p – density of a coal in situ, t/m^3;
- F – active area of gas-flow out in situ, m^2;
- k – coefficient of gas methane distribution in the coal seam at initial moment of time;
- m_0 – porosity of coal.

For conditions of thick coal seam k_{12} of a mine named after Kostenko and meaning as more as De = 5–10~9 m^2/s good correspondence (92%) has got between calculated and actual gas-output of extraction well N° 2 after hydro fracturing of this seam with an hydrochloric acid treatment. Thus, there is good correspondence the scientific theory of intensification methods of coalbed methane extraction and practice data.

To increasing permeability and gas-production of degasification systems may use of several methods – by means of hydrofracturing on a base water, by cavitation procedure and by physical and chemical (P&C) method as well as unloading coal seams. The method of hydrofracturing has tested and is described in Russia in 1961–1993 [4] and in USA after 70th of last century [5].

(P&C) method is founded on a treatment of a coal seam by water-acid mixture with addition of active-moistened (surface – active) substances (SAS) in regimes of hydro fracturing or filtration and foUowing dewatering of the seam and recovery of CBM with high methane output to the surface through wells [6].

During 1961–1991 in Karaganda and Donetsk basins 188 well were drilled from the surface to gas-content coal seams and 405 the coal – seam treatments were done on 23 mine's fields. From total number of the treatments 76% used P&C technology. Total resources from which CBM was extracted by application of C&P method consisted of 33 million tons of coal. Only during 15 years for 68 seam-treatments 9000.5 tons of factory acid and 20.8 tons AMS were injected into coal seams.

In addition, the comprehensive underground tests of C&P method were made too in the same mine of Kharaganda basin. The underground 74 boreholes were drilled in a block of coal seam k_{12} with thickness 7.8 m and sizes along line strike 260 m and across strike line 850 m. These boreholes were drilled from lower coal seam k]0 up to upper coal seam k_{12} through rock layer with thickness of 8–12 m.

The hydro – dynamical curves of an injection process for SAS solutions in coal seams of Karaganda basin are expressed next equation

$$P = a - q^b \tag{3}$$

where:

- p – injection pressure on a head of the well, MPa;
- a – coefficient of geostatic condition of the coal seam, MPa;
- q – rate of flow for the mixtures, l/s;
- b – coefficient counting of the seam's depth.

a is equal of 0.7 to 11.2 and b is equal of 0.502 to 0.159 for a real coal measure. The meanings are real for $5 < q < 95$ l/s.

With rise of a seam's depth the pressure of P&C treatments on the well head is proportional to this depth:

$$p_h = 13.9 + 4.4\ 10^{-2}(H - 437.1),\ \text{MPa} \tag{4}$$

It is proved that the connection takes place for $q = 50$ l/s and $H = 440$ m. The connection coefficient in equation (4) is $r = 0.967$. The resistance of the coal seams to solution injection for $q = 40–60$ l/s is lower on 18% than for water injection. In the event of Iow flow ratę of the mixture through underground boreholes into coal seam (regime of filtration) the injection pressure in the bottom holes p_b has been increased during time τ of the process:
to acid mixtures injection:

$$p_b = 11.7 + 3.6*10^{-2}\ \tau = 0.83 \tag{5}$$

to SAS mixtures (solutions) injection:

$$p_b = 14.8 + 4.7*10^{-3}\ \tau = 0.43 \tag{6}$$

The specific injectivity index K_i is significant characteristic of gas-dynamic condition of coal seams which strong influences on gas-producing capacity of the one. The coefficient is a ratio of injection flow rateȩ of mixture to difference between a bottom and a head of the well. The meanings of the coefficient of P&C treatments processes for five coal seams are shown that specific „injectivity" of the wells linearly increases and that additional opening of seam's crack in situ and the growth of gas-productive capacity from the wells take place.

Really the gas-productive capacity by extracted methane of the coal seams has grown in 2.6–3.2 times as compared with water's hydrofracturing. The main result of the testing is the diffusion permeability of a coal has increased after the C&P treatments in 3.2–3.4 times. An extraction of CBM from the areas of C&P treatments through the surface wells has increased on 15–20% and has been equal to 40–60% of the natural gas-content. The efficiency of decrease of gas emission into mine workings in the treatment zones has attained as more as 50–70%.

Technology of fracturing and P&C treatment to decrease expenditures on drilling and exploitation of extracted wells as well as to decrease electricity production cost on 15–25%.

In an area of gassy coal fields the local power plant is established. An electric capacity of the plant must be 80–100 MWt and more. For commercial supply the plant volume of CBM may be inadequate. For example, the power plant with electric capacity 25 MWt and 40% efficiency must have a guarantee methane supply at a flow rate of 120–140 m^3/min but that may require many boreholes (wells) leading to increasing of expenditures. With growth of electric capacity of the plant this disproportion would increase. Technology of coal-electricity solves this problem and brings other advantages – more complete and cheaper use of coal deposits while providing environment protection.

In internal-combustion engines (ICE) CBM may be used as both a source of electric energy and engine (motor) fuel. In cooperation with specialists of the gas industry of Russia Moscow State Mining University has developed and implemented technology of electricity generation based on ICE and use of the methane-air mixtures with methane concentration of 90% and even more in ICE.

CONCLUSIONS

1. To meet the basie challenges and to reach higher efficiency of power generation and indexes of environmental protection the innovative technological approach to development of „Local Coal-Gas-Electricity Complex" is suggested. The proposed technology of „Mineral" Co. and Moscow State Mining University (Russia) is characterized as:
   economically efficient since maximum energy is recovered from coal measures (coal, methane combustiable gasses) with the highest efficiency in combined cycle electric power generation;
   ecologically clean since minimum of methane and gas emissions to atmosphere and almost zero particulates and without ash;
   socially effective and humanistic since no underground workers and thus no risk of underground disasters.

2. The Integrated LCGEC Technology may be technically and economically investigated at the stage of conceptual (pre-feasibility) study for implementation under specific mining and geological conditions of selected coal mines.
3. Scientific principles of LCGEC concept – project including intensive methods of coalbed methane recovery are proposed.

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