THE TECHNICAL AND ECONOMIC ASPECTS OF THE MINE METHANE UTILIZATION DURING THE DECONTAMINATION OF THE COAL FIELDS OF UKRAINE

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The article represents the information about the volume and resources of the mine methane escaping in to atmosphere during the development of the coal mines in Ukraine. It is shown that the methane utilization is preferable in autonomous mine power stations where mine methane is processed into thermal and electric energy using the up-to-date co-generation technologies. Different co-generation technologies are compared as regard to their capital outlays, profits and period of payback. The preference of applying of the mine methane co-generation technology is demonstrated on the basis of the plants with gas engines. The technical and economic assessment is given for mine ventilation stream used as a heat resource and mine methane while supplying it to the mine power system furnaces. The possibility of improving the efficiency of co-generation plants is demonstrated through producing a cooling agent supplied to a mine in the summertime to create comfortable conditions for workers. The further development of the technique and technology is demonstrated for concentration of mine methane and supplying it to gas- main pipelines.

Like in any other country working coal in sizeable volumes, the urgent problem in Ukraine is an energetic and technological processing of mine methane the reserves of which proceed 10 trillion cubic nanometers. However, at the present, practically the whole mine methane escapes into atmosphere during the coal fields development and that, on one hand, is an irreplaceable loss of valuable power and chemical raw products and, on the other hand, threatens with greenhouse effect initiation. Due to the preliminary degassing, the mine methane escapes via surface degasification wells (the CH_4 content is more than 95 %), intra-mine degasification flights (the CH_4 content is within 20-90 %) and also with return air. The share of the mine methane emission is approximately 10 % of the total methane emission of anthropogenic origin. Today about 70 % of this methane escapes from the mines through the air systems.

Let's consider the main orientations of the energetic and technological processing of methane from the coal fields. We'll compare them according to the integral factors as follows: capital outlays per 1 kilowatt of rated capacity, profit per 1000 cubic nanometers of pure methane, period of payback and rate of the equipment use.

In our judgment, one of the most perspective orientations is methane utilization in the mine power systems designed for deep processing of immature (with ash content up to 60 %) and waste coal and mine methane on the site of their production through the thermal and electric energies generation and their implementation on the basis of thermal power-consuming technologies. High efficiency of the mine power systems is explained by applying of the co-generation principle with electric and thermal energies generation. The ratio of thermal and electric energies is 6 : 1 and this requires great heat demand – about 100 – 200 mWt - for effective work of a power system. The latter condition dictates rationality of power systems location nearby with big towns with substantial consumption of heat for house heating and hot water supply [1]. The mine power systems can utilize both methane from degasification wells which is delivered to the gas burners of furnaces and from return air which is delivered to the furnaces of the steam-boilers with circulating boiling bed (CBB), which forms a part of mine power systems. A power system consisting of 4 boilers with CBB furnaces and with efficiency of each boiler at a range of 120 tons of steam per hour requires 188 cubic nanometers per second (with excess air ratio a = 1.2) and this can be compared with a debit of a mine ventilation flow.

Let's analyze the usage of return air from technical and economic point of view on the example of the mine named after Skochinsky (Central Donbass). Basic data are as follows: temperature of mine air – 27.2 ^{0}C; methane content in return air – 0.5 %; methane caloric value – 8555 kcal/nm^3; relative humidity – 100 %; air consumption – 170 nm^3/s. The usage of methane-contained air of return ventilation flow for blowing in to CBB furnaces will save about 60 thousand tons of coal per year. Substitution of a part of coal by mine methane will provide an annual profit in amount of $ 878 thousand during 8400 working hours of a power system per year. It is to be noted that mine ventilation flow is also an additional resource of heat and this can give significant saving of coal. At annual temperature being +8.2 ^{0}C in the region of Central Donbass and temperature of return air being 27.2 ^{0}C, the saving of coal will be 11.3 thousand tons per year and this can provide the annual profit in amount of $ 165 thousand. Thus, if mine ventilation flow is used as an air resource for a power system producing thermal and electric energies the total annual saving of coal will be 71.3 thousand tons and annual profit will be in amount of more than $ 1 million.

Now let's consider ecological aspects of the mine ventilation flow utilization in the CBB furnaces, which are the integral part of any power system. While processing every 100 m^3/s of mine return air containing 0.5 % of methane the emission of greenhouse gas will be reduced by 208 thousand tons of CO_2 equivalent per year [2]. Therefore, the greenhouse gas reduction in the given case will be 353 thousand tons of CO_2 equivalent per year if the credit rate for reduction of CO_2 emission is $ 1.5 per ton, and it can provide additional profit at the rate of $ 530 thousand per year. Besides, due to the substitution of a part of coal, which is burnt in the furnaces of a power system, by mine methane contained in ventilation flow, emission of sulfur dioxide, nitrogen oxides, and dust into environment will be reduced by 16,5 %.

At the recent time attention of the West is directed in large part to the technologies of methane oxidation in mine ventilation flow. There are two basic technologies available: thermal oxidation of methane and catalytic oxidation. Both include reversing-stream reactor with a set of electric heating elements. But technology of thermal oxidation requires temperature in the order of 1100 ^{0}C, whereas using technology of catalytic oxidation the temperature of methane ignition will be several hundreds degrees lower and capacity of electric heating elements will be decreased due to catalyst [3]. Technical and economic calculations show that utilization of mine ventilation flow in reversing-stream reactor will require capital outlays in amount of $ 250 per kWt and profit will be \$ 37.8 per 1000 cubic meters and period of payback will be 6.4 years if debit of the flow is 100 nm^3/s with 0.5 % content of methane. And if take into account such ecological effect as reduction of CO_2 emission ("credit" will be equal to \$ 1.5 per ton) then period of payback can be diminished to 3.7 years. Relatively low profit is explained by dependence of the plant efficiency on the volume of methane in return air. At standard 0.5 % content of methane in return air the plant efficiency is 75% and at 0.3 % content of methane the efficiency of a plant is 50 %. Taking into account the fact that considered technologies of methane oxidation in return air have been used only in pilot projects, today it is problematic to judge about their reliance and further development.

Utilization of mine methane from degasification wells can also be used in autonomous power systems on the basis of gas turbines or gas engines. Our analysis demonstrates superiority of plants with gas engines over the plants with gas turbines due to their higher efficiency (37.0 % versus 28.5 % for plants with gas turbines) and, therefore, lower gas consumption (0.286 nm^3/kWt?h versus 0.380 nm^3/kWt?h for plants with gas turbines). The capital outlays for the aggregates with gas turbines are high enough because of their expensiveness (about \$ 500 per 1 kWt) and period of payback for them is more than 4 years. The superior advantage of the plants with gas engines is also the fact that they don't need any fuel compressor to provide the necessary parameters of gas because their working pressure is only 0.05-0.5 mPa versus 2.0-2.5 mPa in plants with gas turbines. The common drawbacks for plants both with gas turbines and gas engines is dependence of available capacity at output shaft on air temperature at input. But even by this factor, plants with the gas engines have superior trajectories over the plants with gas turbines. The fact is that a plant with gas turbine losses 1 % of capacity per each following degree if air temperature at input proceeds 27 ^{0}C, whereas a plant with gas engine losses only 0.4 % of its capacity per each following degree at air temperature being increased at input by 1 ^{0}C above 35 ^{0}C. Besides, plants both with gas turbines and gas engines loss their output capacity with percentage of methane content being lower than fixed limit.

According to above stated, it is recommended to use plants with gas engines as a drive for electric generators in aggregates with thermal capacity up to 20 mWt. Technical characteristics of such aggregates can be significantly increased due to use of co-generation principle in the way it was realized in the mine power systems (co-generation on the basis of steam turbines). However, unlike the mine power systems, power plants with gas engines work with ratio 1 : 1 of generated thermal and electric energies and such ratio is more preferable. At the same time, simultaneously with electric power generation the heat demand of industrial enterprises (process steam and hot water) or of housing estate (heating and gas and water supply) is covered. Thermal energy with needed technical characteristics can be provided by a boiler-utilizer, which uses the heat of exhaust and systems of cooling and lubrication. Efficiency of co-generation plants with gas engines reaches 90 % and it is practically impossible for any other technologies applied in power engineering. Table 1 demonstrates figures of different methods of electric and technological processing of mine methane, which are under comparison in our work.

Table 1

Item	Figures / Power plants	Rate of equipment use	Capital outlays, USD/kWt	Profit, 1000 n?[3]	Period of payback, years
1	Plant with gas turbine (without co-generation)	1,0	480,0	37,0	4,25
2	Plant with gas engine(without co-generation)	1,0	313,0	56,0	2,38
3	Plant with gas engine (with co-generation)	1,0	247,0	98,0	1,86
4	Mine power system (with co-generation)	0,6	259,0	92,0	4,00
5	Mine power system (with co-generation)	1,0	259,0	105,0	2,05

Having analyzed the Table 1, it can be concluded that figures for plants with gas engines and mine power systems will be practically the same when using co-generation technologies if rate of equipment use is 1.0. It means that capital outlays can be about $ 250 per 1 kWt, profit – about $ 100 per 1000 nm^3 of pure methane and period of payback – about 2 years. It can be explained by the fact that input and output energy at such plants are the same from thermal point of view (to wit, methane at input and temperature of gas escaping into atmosphere at output). Hence, the choice of this or that co-generation power plant depends both upon the state of the thermal energy market and investment capability for embodying this or that variant. For example, at the mine “Krasnoarmeskaya-Zapadnaya” (Donbass) debit of methane from degasification flight is 120 m^3/min with total content of methane in mixture about 40%. Maximal electric capacity consumed by the mine is 14 mWt and heat capacity of the mine boiler is varied from 28.3 gcal/h in winter to 4.4 gcal in summer. Technical and economic assessment shows that installation of plants with gas engines with total 4 mWt electric capacity and 4.4 gcal/h heat capacity at the ground of the Krasnoarmeskaya-Zapadnaya mine will provide 32 million kWt?h of electric power and 35.2 thousand gcal of heat. Prime cost of generated electric power will be about $ 0.009 per 1 kWt?h and saving of fuel in the mine boiler-house can be 8000 tons of coal per year. It gives annual profit in amount of $ 1mln. and period of payback of the project will be 1.5 year. Besides, harmful emission from the mine boiler-house into atmosphere will be reduced by 30 %.

As the given example shows, the heat demand of coal producers significantly differs and depends upon seasons (winter - summer). Low heat demand in summertime greatly reduces efficiency of electric energy generation. When the heat demand is lack the efficiency can fall from 85 % to 40 %. It is to be mentioned that the depth of working levels of the Ukrainian coal mines reaches 1000 m and more. The temperature of wall rock here is about 45 ^{0}C. Therefore, the measures aimed to the reduction of temperature are quite necessary to be executed at the working areas. The problem can be solved by supplying cold water with temperature +1.5 ^{0}C to the mines and cool air supplied to the working areas via “water-air” heat exchanger. Cold water can be supplied by absorbing aggregates, which in summertime use heat from cooling systems and exhaust from plants with gas engines producing electric power. And mine methane can serve as fuel for the plants with gas engines. Thus, due to the heat from the plants with gas engines a cooling agent (water) is supplied to a mine to reduce temperature at working areas in summertime and in wintertime heat is supplied to the heaters, which make cold air warmer and prevent pit-shaft from frosting-up. And, at the same time, efficiency of the plants with gas engines will be high in any season. Such system has been implemented and is successfully working at the PNIOWEK mine in Poland.

In case when any energetic systems are not available working near at hand or construction of new ones are not reasonable due to little heat demand then methane enrichment is considered as more perspective with further marketing it in liquid (filled in vessels) or gas (supplied via gas-main pipeline) states. Such methods of enrichment of mixture containing methane and air as membrane, separation or vortical are under development and have series of drawbacks including low performance and poor extraction of methane. Besides, these methods are tested only in experimental or pilot samples. Extraction of mine methane from methane-air mixtures in the way of fluidization using cryogen requires high capital outlays and power consumption – in order of 0.30 – 0.85 kWt?h per 1 kg of liquid methane. Besides, market of liquid methane in vessels requires special infrastructure and, basically, cannot be work at the commercial level. Thereupon, special attention can be directed to the technology and equipment of BCCK Engineering, Inc. (USA, Texas, Midland) designed for enrichment of methane-air mixture, which provide gas of higher grades meeting the most strong technical standards for marketing gas through gas-main pipelines. Enrichment of methane-air mixture at the BCCK plants is executed by phased extraction of oxygen, carbonic acid, water steam and nitrogen. Oxygen is extracted from the mixture during oxidation of catalyst, carbonic dioxide is extracted in amine contactor through reaction with chemical solvent of the amine diglycol (ADG) type, and dehydration of water steam is provided by the system of molecular sieves. The basic technological process – extraction of nitrogen – is executed in the patented plant Nitech™ , which requires almost twice less power consumption for further gas compression if compare with well-known technology of absorption at pressure fluctuation (APF). It is to be noted that Nitech™ technology is designed for much significant gas consumption than APF technology. After separation, redundant gaseous nitrogen returns to atmosphere and enriched gas containing up to 95 %-99 % of hydrocarbons leaves the plant in two flows: one of the flows, with the pressure of 0.12 atm, contains 25 % of output volume and the second one, with the pressure of 20 atm, contains 75 % of output volume. Both flows of enriched gas pass to the compressor station where they are compressed to the pressure value in the gas-main pipeline.

The lowest level of the designed effectiveness of the BCCK plants is 30000 m^3/day. The sale price of such plant is about $ 1.1 mln (the costs for compressor station are not included). The weight of the plant is about 50 tons. Such plant can work with up to two degasification wells. The company has also designed plants with maximal performance in the order of 300000 – 500000 m^3/day, which can enrich methane-air flows from collector common for several degasification systems. The price of such plant is $ 5.5 mln (the costs for compressor station are not included). Working range of the methane content in the mixture at the plant input is 20 %-95 %. Significant fluctuations of the methane debit are permitted at the plant input (from 25 % up to 100 % of the designed maximum for each plant). Pressure of methane-air mixture is 40 atm at the plant input.

Such plants can work in any climate conditions, they also can be installed on the vehicles; they are easy to assemble and disassemble and transport to any other site. Lifetime of the plants manufactured by the BCCK Engineering Inc., is more than 30 years because they don't contain any rotating parts and elements which can be damaged by corrosion or erosion.

Economic assessment shows that the prime cost of 1000 m^3 of methane enriched at the plant with performance of 500000 m^3/day will be 1.42 USD/$CH_{4\ part}$, where $CH_{4\ part}$ is a methane part (share) in the reference mixture. Thus, for standard $CH_{4\ part}$ = 0.60 the prime cost of 1000 m^3 of enriched methane will be 1.42 : 0.6 = 2.37 USD. As the market price of 1000 m^3 is $ 50, the profit will be $ 47.6 per 1000 m^3 and period of payback will be approximately 2 years if taking into account expenses for compression and gas transportation within 5000 m (the price of pipeline is $ 82 per 1 meter). The technical and economic assessment demonstrates superiority of the BCCK Engineering technology and plants over other well-known technologies of methane enrichment in the coal fields.

The considered orientations of energetic and technological process of methane in the coal fields are the most perspective and should be recommended for implementation. Their high effectiveness and environmentally friendly aspects will assist in solving ecological, social, and economic problems in mining regions of Ukraine.

References:

1. Bulat A.F., Perepelica V.G., Chemeris I.F. Creation of Ecologically Friendly Power Systems With High Performance on the Basis of Unprofitable Coal Mines of Ukraine.// Reports of the National Academy of Science of Ukraine. – 2001. - ? 1. – p.111-117.

2. Sapundgiev H. The Mine Return Air: Potential Resource of Ecologically Clean Energy.// Reports of the 2nd International Conference "Reduction of the Methane Emission". – Novosibirsk: Siberian Department of The Russian Academy of Science. – 2000. – p. 575-581.

3. Carotes P. Reduction of the methane Emission from the Mine Return Air.// Reports of the 2nd International Conference "Reduction of the Methane Emission". – Novosibirsk: Siberian Department of The Russian Academy of Science. – 2000. – p. 533 – 541.