Scientific, technological, economic and environmental role of coal and carbonate mineral resources in the strategic development of the fuel, energy and chemical complexes of Russia and the Far East

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Abstract. When implementing the organizational and technological model of innovative production, the following combined areas of mineral processing and new products are planned at the first stage: 1) processing of carbone-carbonate mineral raw materials: calcium carbide, carbon dioxide (in gaseous, liquid or solid state); 2) acetylene, plant growth regulators (REGGROST), plant protection products (TAKAR). Products of fuel and non-fuel purposes at the second stage: 1. synthetic ethyl alcohol (ethanol), antifreeze, ethylene glycol, dichloroethane, synthetic drying oils, acetone, etc.; 2. carbamide (urea), ammonia, nitrogen in the gaseous and liquid state, methanol, gasoline, etc.

1. Introduction

Until the middle of the last century, coal resources were the basis of the world and Russian energy economy. Since the 1950’s there has been a steady decline in the production and use of coal due to an increase in the level of oil and gas consumption. Currently, the share of coal in the global energy balance is on average about 30%. According to some calculations, the current level of oil and gas production will stay the same until the middle of the XXI century, and after 2050 the world’s demand for coal resources will sharply increase.

Today, coal should be considered as power engineering raw material and it is necessary to use it on a large scale only in a complex way, dividing its potential chemical energy in approximately equal parts between energy production (electricity and heat) and chemical production. By organizing the power engineering of solid fuel based on a large-scale power industry (thermal, and possibly nuclear), we will overcome the oil and gas crisis expected to take place already in this, XXI century. Negative trends in the field of raw materials for oil and gas production – reduction of resources when it is necessary to maintain high export deliveries – require a wide and rapid introduction of new coal technologies focused on environmental and energy saving and the integrated use of coal of all kinds.

The process of coal gasification is multipurpose with respect to the composition of the produced gas. The importance of the issues of technological, economic and environmental dynamics of coal industry development, which is a complex production and economic system associated with high costs, the presence of competing energy carriers (oil, gas, nuclear fuel) is increasing due to the need to
improve the mining technology, coal combined processing and use, secure the competitive expected and industrial reserves.

2. Materials
The urgency of the problem increases even more due to the strategic importance of fossil and brown coals with their geological reserves significantly exceeding such main energy sources as oil and natural gas, as well as nuclear fuel, potential hydro resources, for the power industry of Russia and the world as a whole. The share of coal, according to the World Coal Institute, accounts for about 90% (according to other estimates, 60-80%) of the energy potential of all minerals of organic origin suitable for mining. In Russia, according to available estimates, comparable geological reserves of coal in the subsoil are also several times higher than similar reserves of oil and gas fuel. In the “Strategy for the development of fuel and energy resources of the Far Eastern economic region until 2020” the following tasks were set: “...to explore ways to overcome the crisis situation by developing the Far Eastern deposits of coal, oil, gas based on progressive methods of extraction and deep chemical processing of primary raw materials, as well as the introduction of economy mode...” [1,5].

In the Far Eastern region and, especially, in the Primorsky Krai there are favorable conditions for the introduction of methods for the deep processing of coal as a valuable chemical raw material into motor and liquid fuels. The main positive factor for the region is the presence of significant coal reserves, which makes it possible to count on a raw material supply in the long run. On the other hand, considerable experience has been accumulated so far and a whole range of technologies have been developed for processing coal into liquid fuel both in our country and abroad. Technologies for the production of liquid fuels from coal are complex but effective. One of the areas of works in this area is based on the gasification of coal to produce successively synthesis gas and liquid fuels. Gasification and synthesis of gas from liquid fuel and chemical products are effective for the processing of high-ash, hard-to-wash coals.

In the current period, the priority areas for the development of the coal industry in Primorsky Krai and the Far Eastern region of Russia in the first half of the 21st century should be the increase in the competitiveness of coal and the quality of consumer properties of coal products using modern technologies for its extraction and washing, as well as deep chemical processing. This determines the following strategy for the development of deposits and the enterprises diversification:

• reassessment of the resource base – the selection and further exploration of deposits and reserve areas with favorable mining and geological conditions for the development of reserves;
• improvement of coal mining and processing technologies with the use of high-performance technical means;
• complex processing of coals based on innovative waste-free technologies: technologies for production fuels with new consumer properties (synthesis gas, methanol, gasoline, diesel fuel, etc.), production of non-fuel products based on coal chemistry technologies (phenolic resins, higher hydrocarbons, etc.) [2-5].

3. Methods of research
The developed and patented technologies provide for the integrated waste-free processing of coal and carbonate mineral raw materials using several modules that ensure the production at the first stage: calcium carbide, calcium oxide, carbon dioxide; at the second stage: products of processing of calcium carbide, synthetic gaseous and liquid fuels and non-fuel products.

In the new industrial complex for the production of calcium carbide (CaC₂) limestone is pre-roasted (CaCO₃) to produce calcium oxide (CaO) and carbon dioxide (CO₂); the mixture of calcium oxide (CaO) and coal (C) is used to produce calcium carbide (CaC₂). The carbon dioxide (CO₂) formed during the roasting of limestone is captured and carbon dioxide (H₂CO₃) is produced from them with the help of equipment for capturing waste gases. On the other hand, calcium carbide is processed into plant growth regulators (REGGROST) and plant protection products (TAKAR).
Upon production of acetylene from calcium carbide, hydrated lime is formed – Ca(OH)\(_2\), which is used in construction, in agriculture for the production of superphosphate – Ca(H\(_2\)PO\(_4\)), in water treatment systems, etc. The synthesis of carbamide (urea) – CO(NH\(_2\))\(_2\) is possible with the participation of carbon dioxide (CO\(_2\)) by addition of ammonia (NH\(_3\)), or carbamide can be also obtained from calcium carbide using nitrogen (N\(_2\)). At the same time, air mixture separation – rectification of liquid air or ammonia oxidation is used to obtain nitrogen (N\(_2\)): 4NH\(_3\) + 3O\(_2\) = 2N\(_2\) + 6H\(_2\)O. Carbamide (urea) is used to increase the effectiveness of plant growth regulators (REGOST).

Calcium oxide, calcium carbide, acetylene, methanol, urea, fertilizer REGROST and TAKAR are obtained as the main products of coal and carbonate mineral raw materials processing, and the additional products: carbon dioxide, drinking or soda water, slaked lime. On the other hand, the processing of acetylene allows synthetic ethylene, ethyl alcohol, naphthalene, hydrogen, synthetic drying oils (linseed oil), chloroprene rubber to be obtained. In accordance with the polymerization reaction, the following products are also created: ethylene, polyethylene (polymer), propylene, polypropylene in the following directions of acetylene (C\(_2\)H\(_2\)) processing indicated in the previous paper [9-10].

The results of technological research and economic and mathematical modeling of processes make it possible to examine in more detail the configuration and parameters of the systems for restructuring and diversifying coal-mining, energy and industrial enterprises, to coordinate and determine the operating modes of the management and production subsystems, to predict technological and economic indicators of newly created and diversified production complexes.

4. Results and discussion

Figure 1 shows an example of a physical-technological model of the unit for processing coal and carbonate mineral raw materials. Analogous physico-technological models are developed and patented for the majority of the products considered above and have published copyright certificates [8].

The unite works as follows. Lime is fed into the kiln 1 and roasted. During roasting lime is decomposed into lime and carbon dioxide (CO\(_2\)). Lime (CaO) is removed by the product line 14 to the feeder 6, which ensures the selection from the total volume of the part of the lime intended for delivery to the consumer and the part intended for further processing. Part of the lime, intended for further processing, is fed to the second kiln 2, where in the presence of carbon (in the form of coke or coal, with a grain size of 20-25 mm and a sulfur content less than 1%) it is processed into calcium carbide.

Calcium carbide (CaC\(_2\)) is removed by the pipeline 14 to the feeder 7, which selects from the total amount of products a part of calcium carbide intended for delivery to the consumer and a part intended for further processing. Part of the calcium carbide, intended for further processing, is fed into the gas generator 4, where it is brought into contact with water and processed into acetylene. In this case the synthesis of ethanol is carried out according to the well-known scheme obtaining ethylene – C\(_2\)H\(_4\) at the intermediary stage:

\[
\text{C}_2\text{H}_2 + \text{H}_2 \rightarrow \text{C}_2\text{H}_4; \text{C}_2\text{H}_4 + \text{H}_2\text{O} = \text{C}_2\text{H}_5\text{OH}
\]

Moreover, if the reaction is carried out at a pressure up to 23 atm and a temperature up to 75-80°C, the yield of ethanol will be up to 90%, and at pressure up to 80 atm and a temperature up to 280-300°C, the yield of ethanol will reach 95%. And the synthesis of dichloroethane is carried out according to the scheme:

\[
\text{C}_2\text{H}_2 + \text{H}_2 = \text{C}_2\text{H}_4; \text{C}_2\text{H}_4 + \text{Cl} = \text{CH}_2\text{Cl}\text{-CH}_2\text{Cl}.
\]
Figure 1. Technological model of the unit used for processing coal and carbonate raw materials: 1 – lime kiln; 2 – calcium carbide kiln; 3 – carbon dioxide synthesis reactor; 4 – gas generator; 5 – the first gas sampling unit; 6, 7 – feeders; 8 – the second gas sampling unit; 14 – product pipeline; 19 – ethylene synthesis reactor; 20 – acetone synthesis reactor; 21 – ethanol synthesis reactor; 22 – dichloroethane synthesis reactor.

Ethylene glycol is obtained by acetylene hydrolysis. The synthesis of acetone is carried out according to a known scheme at a temperature of about 460°C. Acetone is delivered to the consumer, and gaseous $\text{C}_2\text{H}_2 + \text{H}_2\text{O} \text{ (vapour)} = \text{H}_3\text{C} - \text{C} - \text{C} \text{H}_3 + \text{CO}_2 + \text{H}_2$ products – process waste is disposed on-site (CO$_2$ is used in the production of carbon dioxide and hydrogen is used in the synthesis of ethanol and/or dichloroethane). Of course, hydrogen combustion is also possible, i.e. use as an energy carrier in the process of burning or acetone synthesis, but this is not the most expedient way of using it (the corresponding links are shown by a dotted line).

5. Conclusions
The results of technological research and mathematical modeling of processes make it possible to consider in more detail the configuration and parameters of the systems for restructuring and diversifying coal mining and energy enterprises, to coordinate and determine the operating modes of the control and production subsystems, to predict technological and economic indicators of the newly created or restructured industrial complexes [5, 6, 7].
Optimization of production costs is carried out in this case on the basis of the following criteria:

\[
P = \sum_{\mu} \sum_{J} (C_{JI} - S_{JI})V_{JI} \rightarrow \text{max},
\]

where \( P \) is the total profit of the coal mining and energy enterprise from the sale of products; \( m \) – the number of coal grades; \( n \) is the number of ways of processing and use; \( V_{JI} \) – the natural volume of the \( J \)-th grade of coal processed and used by the \( l \)-th method; \( S_{JI} \) is the prime cost of the \( J \)-th grade of coal processed and used by the \( l \)-th method; \( C_{JI} \) – the price of the \( J \)-th grade of coal and \( l \)-th type of fuel.

At the same time the following restrictions are applied:

\[
C_{JI} \leq C_{JI} \leq C_{JI},
\]

restrictions are established according to the market research;

\[
0 \leq V_{JI} \leq \text{minimum} \ (v_{JI}^\text{tech}; v_{JI}^\text{cons.}),
\]

where \( v_{JI}^\text{tech.} \) – the maximum possible volume of production; \( v_{JI}^\text{cons.} \) – the maximum possible amount of sales.

The calculations results of the economic parameters of combined processing of coal and carbonate mineral raw materials were carried out in the conditions of JSC “Spassktsement”, Partizanskaya State District Power Plant and other industrial enterprises in Primorsky Kraiy.

When calculating the technical and economic indicators of the competitive production placement, the following indicators were highlighted: return on investments, prime cost, return on sales, payback period, profitability index [10].

We consider it expedient to conduct joint R&D works with FEFU Engineering School, Institute of Mining of the Far Eastern Branch of the Russian Academy of Sciences and Siberian State Industrial University to increase the efficiency of development and use of the fuel, energy and chemical complexes of Russia in the following areas:

1) development of a physico-technical and economic-technological model of technologies and technical equipment for deep chemical step-by-step processing of coal and carbonate mineral raw material;

2) application of electrothermal and develop plasma environmentally friendly resource- and energy-saving technologies for processing coal and carbonate minerals using several modules (subsystems) to obtain competitive fuel and non-fuel products;

3) development of the statement of work (SoW) for the performance of R&D works, NPD, feasibility studies with the solution of the following tasks: consideration of alternative options for enterprises placement in the newly designed mining and chemical complexes in Russia and abroad; to develop innovative technologies and complexes of technical equipment for the industrial processing of coal and carbonate mineral raw materials using plasma reactors with a capacity of 500; 1000 kW.

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