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DEEP CONVERSION AND METAL CONTENT OF RUSSIAN COALS

In today's fuel, energy and metallurgical complex coal is used as an energy source, as well as coke for steel products.During unstable economic situation, the coal becomes the main source of organic raw materials to many industries, especially in the reduction of production and reserves of oil and gas.Coal processing using an integrated approach opens up new opportunities for the coal industry, and new technologies require significant development, technical and economic assessment and broad implementation. In this paper, we discuss the problem with the deep coal processing of Russian industry, solid fuel gasification and producing of synthetic fuel. The article describes the features of the modern coke production, as well as problems of extraction of rare earth and noble metals from waste coal and coal products.Since the 60s the world of deep coal processing technology continues to evolve and improve. Plants of industrial processing of coal were built and successfully work in South Africa, New Zealand, USA, China. With regard to Russia, despite the huge reserves of coal, chemical processing technology has not yet received the same development as in industrialized countries, primarily because of the lack of proper project financing.

The paper shows that there are all the technological and economic preconditions for improving the quality of extracted coal, including in the production and deep processing of low-grade and off-grade solid fuels for disposal of solid waste from coal mining and coal processing with simultaneous extraction of some metals.

According to some experts, in the coming years, the demand for coal is significantly larger view and possibly coal will be the driving force of the world economy.In particular, European experts believe that the global electricity market is on the verge of transition from gas to coal as the preferred fuel for power plants.This trend is reflected in the Energy Strategy of Russia. Emphasis is placed on the need to harmonize the fuel and energy balance of the country through active development of the coal industry to ensure energy security of the country.

Key words: *coal, ash,metal content, deep coal processing,benefication, coke,gasification, rare metals, synthetic fuels*

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Introduction

Huge resources and growth prospects in coal mining call for a science-based approach to coal utilization in various branches of industry [1]. At the present time, the fuel and energy industry of Russia uses coal mostly as a universal energy carrier at heat power stations and as a feedstock for production of blast-furnace coke and coking chemicals. Deep conversion of coal toward manufacture of heating and chemical products is carried out on a limited scale at Russian plants; at the same time, given the permanent fluctuation of free market prices of oil and oil products and the depletion of oil reserves, production of liquid hydrocarbons from coal becomes of concern. Russia holds the largest coal reserves, and the researches in the area of chemical technologies of coal liquefaction are promising, first of all, in terms of the substitution of import oil products by the new domestic-manufacture energy products of the same quality.

Many countries (USA, China, Japan and others), lacking oil and natural gas reserves, in order to ensure energy safety and for energy market price dumping, develop and implement pilot-scale testing of innovation technologies for production of synthetic motor fuel and synthetic crude for organic synthesis using coal products [2]. For instance, after the slump in oil on the world market, the technologies of hydrocarbon gasification liquefaction (the “U.S. Shale Revolution”) and lignite drainage (pilot scale plants in Germany) now enjoy widespread development [3, 4].

The key problem generated by coal combustion at heat power stations using traditional technologies is dumping of millions of tons of ash with, as a rule, high commercial-level content of elements and metals, which, consequently, creates a background for organization of separate production elements from coals at high metal-bearing coal deposits.

It is known that Russian coals contain commercial level concentrations of Ge, U, Au, Sc, Pt, Nb, as well as lanthanides and other elements [5–7]. Thus, development of deep conversion technologies for coals with commercial level content of elements and admixtures is one of the top priority objectives in the domestic coal industry. Reaching the objective requires a comprehensive review of capabilities of multipurpose coal utilization, from the standpoints of both the basic and applied sciences, to find the most rational ways of deep conversion of coal for each coal-mining region in Russia. This article focuses on an integrated approach to the conversion of power-generating and coking coals for different industries.

Power-generating coal application problems

In recent years much attention is given in the world to the improvement of coal product quality under conditions of strengthening of the environmental requirements imposed on package technologies and due to the necessary enhancement in the efficiency of deep conversion of coal and coal combustion products [8]. Transition from coal combustion at power-generating plants to deep coal conversion technologies contributes to the environmental safety and economical efficiency of the entire coal industry. In Europe electric power production from coals is greatly improved due to the use of fluidized bed gasification [9] with the oxygen–air mixture pressure control and the further combustion of coal in melted slag of fluidized bed, or as coal–water slurry in pulverized coal furnaces. With such technologies, coal conversion is more efficient, minimizes loss of fuel during mechanical and chemical treatment, as well as at considerably reduces emissions of nitrogen and sulfur oxides. It seems promising to produce reaction mixes by countercurrent filtration using a technology developed at the Saint-Petersburg Mining University [9], based on selective separation of elements depending on viscosity and density of slurry flow under the action of centrifugal forces.

Apart from electric power production, gasification is applicable to manufacturing various purpose chemicals. On evidence of the published data and reports, there is only one commercial production of liquid products using Fisher–Tropsch synthesis from coal gasification in Sasolburg, South Africa [10–12]. However, better results are obtained on the pilot plants at the TU Bergakademie Freiberg, and it is planned to implement round 60 projects on coal gasification (Virtucon, Freiberg, Germany [4, 13], where 10 plants are designed exclusively for chemical production.

Earlier, for production of power-plant fuel and process gas, Russia ran more than 300 gas-generator plants with round 2500 gas generators [5]. These stations, using different fuel, generated nearly 30 Bm^3 per year, however, at present, owing to a sharp increase in oil and natural gas production in the world, researches into coal gasification technologies are postponed. The joint investigations in this area by the TU Bergakademie Freiberg and Saint-Petersburg Mining University [14] are interesting and promising from the viewpoint of science and technology. The fluidized bed gasification technology [15] is considered the most efficient method of coal utilization for power generation, and may be the basis for the production of synthetic motor fuels, spirits and other feedstock for organic chemistry.

As an individual trend in gasification, the technology of underground coal gasification and combustion may be assumed [15]. A few years ago, this process began to be used on a commercial scale. For example, Russia had a number of plants, though some of them experienced the emergency stop due to the complicated control of underground coal combustion, and because of low profit and environmental issues. By expert predictions, it is feasible to create profitable production of an ecology-friendly pure gaseous energy-carrier to generate hot water, steam and electric power directly at a coal processing site. Despite difficulties, the feasibility of combination of underground coal combustion in concrete reservoirs with gasification and liquefaction on the spot is still studied.

It is noteworthy that hydrogenization of power-generating coal using the known technologies remains yet to be studied. The products generated on pilot plants, such as artificial liquid fuels, are non-competitive with oil products [16]. The current level of R&D in the area of chemical conversion of coal, considering the available reserves and potential, allows assuming that actual production of synthetic fuel from coal is infeasible in Russia in the years to come, and it is necessary to accomplish a package of fundamental studies to be proved later on experimentally.

Issues of cake and by-product process

The by-product coking industry can produce blast-furnace coke and coking plant gas, as well as a range of valuable chemicals and materials for electrode industry. The layered coking of coal box furnaces, with trapping of chemical by-products is at the highest technical level though there are still trends to improvement of the technology efficiency by means of reduction in heat loss and in emissions of cyanides. In this regard, there is a tendency toward the transition from optimization of the traditional layered coking process in batch-action multi-box furnaces to the new-generation processes meeting such requirements as continuity, full automation and control of the process, environmental safety and resource-saving. The classical technology of coal conversion in the by-product cake industry is economically inefficient today, especially considering strengthening of the environmental standards.

Europe (Germany) [17] develops an innovation technology of crude coke gas processing and utilization, and a structure of a chemical plant of the future. The produced regeneration gas is subjected to thermal decomposition to recover gas with the content of more than 65% of hydrogen and more than 30% of carbon oxide. The main products of such by-product coke industry are blast-furnace cake and process gas usable as energy sources, or in production of basic metals and alloys.

In the recent decade in USA, coal coking technologies without trapping of by-products are extensively introduced. Aimed at efficiency enhancement, cookeries are connected with the plants for utilization and transmission of heat exit gas after coking into the ambient environment [10].

The by-product coke industry in the framework of Russian metallurgy operates four cokeries and seven primary metals plants. Cokeries, when processing crude benzol or resin, recover only aromatic hydrocarbons and naphthalene as individual substances. Expansion of the production range by individual chemical substances and improvement of the production quality can enhance profitability of products and can make them competitive with the foreign manufacture analogs. Most of Russian plants are also faced with the problem when trapping of chemical by-products is off the standards of the environmental and industrial safety. Processing of crude benzol, for instance, is carried out in fractionation workshops using obsolete sulfuric acid purification technology that, under certain conditions fulfilled, may be replaced by more efficient catalytic processes of hydraulic cleaning, alkylation and reforming [12].

Although large-scale, the modern by-product coking industry is characterized by the low level of research and technology, and something new is introduced only if no considerable investment is required. In connection with this, an emphasis is laid on mathematical modeling of physicochemical processes, which can assist in reaching the objective of enhanced efficiency through rational production management by means of automated monitoring. For instance, the Saint-Petersburg Mining University has developed ANSYS and ROCKY models and program packages that enable reduction in heat loss and harmful emissions from chimney flues of coke furnace batteries.

Thus and so, the strategy of Russian by-product coking industry, as one of the trends, involves implementation of new flow charts for trapping and processing of coke gas, withdrawal of unprofitable products, and accomplishment of a special technical-and-economical project on development and arrangement of coke production without chemical processing and with generation of furnace gases and power energy, with concurrent liquefaction.

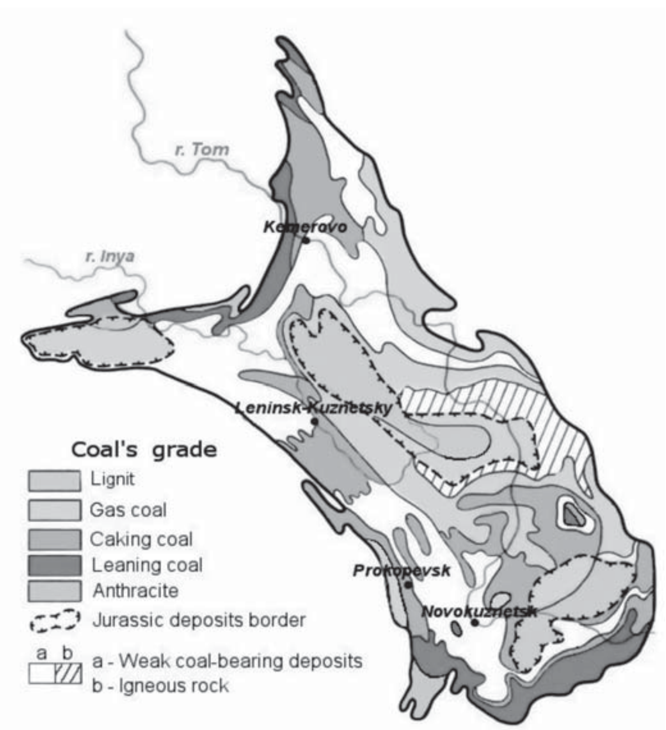

Fig. 1. Kuznetsk Coal Basin and grade composition of local coals

Integrated treatment of metal-bearing coals and waste

Coal fields in Siberia are among the largest sources of coal in the world [18]. For example, the Kuznetsk Coal Basin features a wide variety and uniqueness of grade composition of coal (**Fig. 1**), a mature infrastructure, availability of coal processing plants, such as dressing, semicoking, coking, underground and ground-based gasification, as well as the developed chemical industry. It is known that introduction of new processes in integrated conversion of coal into highly reactive and pure solid, liquid and gaseous fuels will allow a wide range of valuable multipurpose chemical products and construction and electrode materials. There are technologies to expand the range of coke-chemical products starting to be deficient at the present time (pure benzol, naphthalene, anthracene, feedstock for production of medicated substances, coal-tar asphalt, etc.).

The Kuznetsk Coal Basin appeals for the first turn the metallurgical industry as it produces round 70% of coking coals in Russia. Though being yet the major supplier of coking coals, the region needs new coal mines to be constructed, operating mines to be modernized and plants on assortment, treatment and preparation of charge coal for coking to be expanded in order to rival the same industry branches in China. For economic strengthening and efficient utilization of coking coals in Russia, it is expedient to enlarge production of marketable blast-furnace coke of new quality with the concurrent expansion of the conventional line of coke chemistry products (benzol, phenol, naphthalene, polyaromatic compounds, basic nitrogens, coal-graphite materials, etc.).

The top power-generating plants in Kuzbass are Kemerovo, South Kuzbass, Tom-Usinsk and Belovskaya Hydraulic Power Stations and Kuznetsk, West Siberian and Novokemerovskaya (Kemerovo) Heat Power Plants [19]. These plants supply finely dispersed ash, coal slag and ash-and-slag mix. Annually, these plants generate nearly 3 Mt of waste. **Fig. 2** depicts distribution of waste per coal-based plants.

Low quality (high contents of sulfur, phosphorus, moisture and ash, and fineness) of ROM power-generating coal presents a number of economical and environmental problems, worsens logistics and exportability. For these reasons, it is required for the first turn to develop technologies of primary processing of coals (dressing, grain sizing, utilization of high-ash rejects of coal dressing). It is urgent to raise energy potential of low-grade coals—production of high-calorific solid fuel (thermal coal, heating briquettes, active semicoke) under integrated processing of pyrolysis resins with deficient

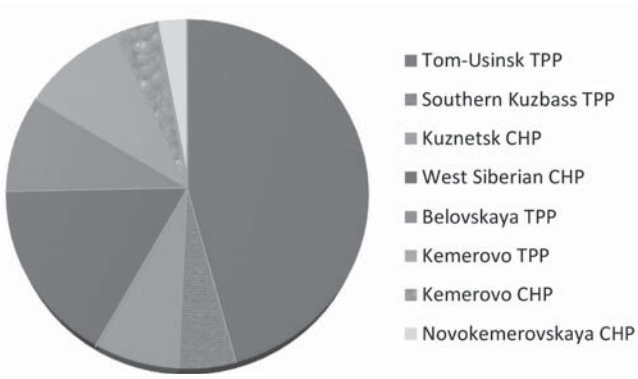

Fig. 2. Ash and slag waste in the territory of the Kemerovo Region

by-product chemical components of engine and boiler fuels, organic binders for briquetting and road construction, electrode materials. Scientists and specialists of the Saint-Petersburg Mining University, based on the immense experience and knowledge in the area of integrated processing of complex ores, in particular, fluidized bed furnace treatment, successfully put the knowledge and skills to use in development of low-grade coal dressing technologies, including elements of X-ray detection and thermal treatment under extreme conditions.

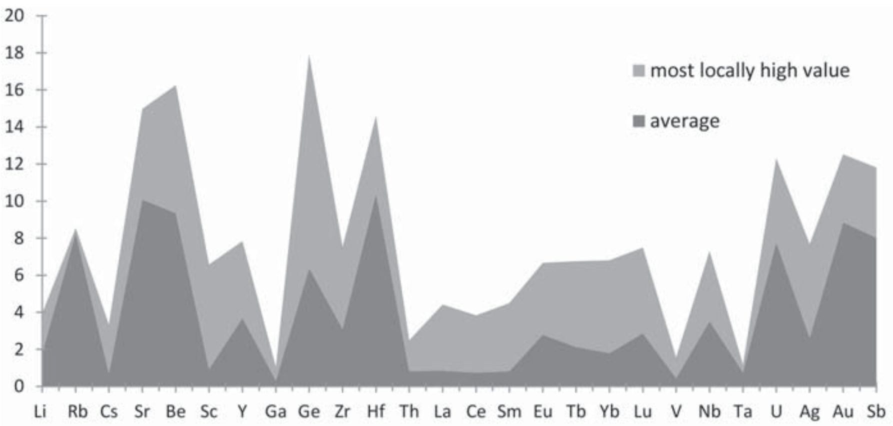

Fig. 3. Diagram of elements in Kuzbass coals. The contents of elements are determined in terms of the concentration coefficient calculated as a ratio of the average and maximum contents

Russia possesses many deposits of low-quality solid combustibles (peat, lignite, mixite coal, oil shale, oxidized black coal) that could be of use in metallurgy in the future. In terms of some processes, it is possible to draw an approximate pattern for integrated processing of low-quality coal and waste. For example, lignite, lacking great power-generating value, can be used as a feedstock in profitable manufacture of valuable extractable products, after simple thermal and chemical pre-modification and intensive mechanochemical treatment. Fixed residue of the extraction is applicable to production of cheap adsorbents and mineral fertilizers.

Solid carbon-bearing materials, after thermal decomposition during pyrolysis, together with siftings and ashes of power-generating coals, may be gasified with the production of power gas (syngas) for further generation of carbon oxide and valuable chemicals, or in production of hydrogen for hydrogenization, e.g., as a promising ecology-friendly fuel for motor transport or for power engineering [5]. Numerous attempts have been made to obtain a chemistry-based appraisal of coal deposits, though the results dissatisfy the up-to-date requirements, either because of deficiency of data, or due to faulty analyses and research [18].

So, the options of multi-purpose utilization of different nature solid fuels, discussed in terms of Kuzbass coals, are feasible in various coal mining regions, considering their infrastructure and grade composition of coals.

Metal recovery from waste coal under integrated processing

A wide range of R&D in the area of technology intensiveness can be used in production of valuable metals [19]. High-tech science-based recovery of rare and rare earth elements from coals and coal waste is worldwide manageable [20].

Processing of statistical data on coal compositions offers a reliable estimate of average contents of elements and admixtures in coals. Obtained using modern analytical methods, the new data on the contents of some elements in coals enable completing and amending, or even modifying the common view on functionality of coals in various regions.

The studies into the metal content of Kuzbass coals show that these coals contain lithophylic elements typical of alkaline rocks (Zr, Hf, Nb, Y, Ba, Be) and disconnected elements (Sc, Fe, Cr, Ni, Co) (**Fig. 3**). The studies were carried out using the modern methods of direct quantitative estimation of elements in samples without pre-burning and the chemical and physicochemical analyses, such as X-ray phase analyses (diffractometer DIFREI-402), differential thermal analysis coupled with the mass-spectroscopy, optical (ZeissAxio Lab.A1) and scanning electron microscopy (JSM-6460LV JEOL with INCA Oxford).

The resultant average contents of rare elements for the region disagree with the data obtained by the other researchers [22, 22]. On the other hand, it is seen in the figure that the test coals feature low content of heavy and rare metals (Cu, Pb, Zn, Cd, Ga, Se, Te) and of some elements (Li, B, V, Th). The difference lies also in wider spectra of some metals and metal compounds, and in their higher contents. There are also groups of rare and rare earth metals. High concentration of rare earth metals allows forecasting commercial concentrations of REM in some coal fields or coal beds. Coals with the high contents of Ge, Au, Sc, Nb, Ta, Y, Zr and lanthanides are of commercial interest.

At the present time, it is complicated to recover metals during the integrated processing of coals. For instance, recovery of germanium from coking coals is suppressed due to the absence of the recovery technology to be included in the current coking process and adapted to specific coals.

Scandium and its oxides, as one of the most promising elements for recovery, is mainly concentrated in ash, and its concentration is sometimes higher than 0.25%. However, there are no prospects for its recovery at a commercial scale in view of the great depths of coal occurrence.

The decision-making on gold recovery from coals and coal waste is based on the data of exploration and appraisal of coal deposits. As follows from the accomplished research [23–25], it is required to evaluate gold resources of coal beds and dumps and to carry out laboratory and full-scale testis on gold recovery.

With the advanced technologies, some coal deposits allow profitable recovery of rare metals. Dressing of coal with high volatile yield and high metal content was tested. The integrated processing of metal-bearing coals by counter flows of organic acids produced positive effect with the yield of oxides of some rare metals [9].

Conclusion

Coal is considered as not only a power generation source but also as a material applicable in the chemical and metallurgical industries, therefore, new processes of coal conversion are mostly meant for production of different kinds of fuel. Given a decrease in oil and gas production in the world, coal becomes a key source of organic feedstock for the chemical industry and metallurgy. New approaches to complex processing of coal need improvement, technical and economical evaluation and wide introduction.

It is found that there are technological and economic prerequisites to enhance quality of produced coals and to start deep conversion of low-grade and off-standard solid fuels after treatment of solid coal waste, which will offer additional valuable products.

Russian coals contain germanium, scandium, niobium and some valuable lanthanides. Such coals are typical of volcanogenic and sedimentary rocks in Siberia. A variety of abnormal contents of rare elements discovered in coal samples makes it possible to expect commercially significant contents of such elements in some deposits and coal beds. These conclusions are based on the tests of the samples of Kuzbass coals with the commercial contents of precious, rare earth and rare elements, and lanthanides.

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