Development and creation of an innovative scientific and educational cluster for the integrated use of coal and its products

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Abstract. The article proposes to implement a cluster approach to training, development and creation of high-tech industries in the field of processing of coal raw materials with obtaining end products with high added value. The main technological processes used are: preparation and burning of coal water slurry, based the finely dispersed coal preparation waste as well, liquefaction of demineralized coal and coal slime using a complex of high-energy influences (cavitation, ultrasonic and electric pulse), processing of waste from coal processing plants, bottom ash wastes as a basis for filling mixtures in the dead underground workings and open-pit mines. The implementation of the proposed cluster approach will allow the current scientific and practical problems facing the region in the field of coal mining and processing to be solved.

1. Introduction

One of the effective methods for increasing the rate of knowledge diffusion and training with the concentration of high-tech industries is the organization and creation of innovative clusters. The result is a synergistic effect of technological, technical, economic and institutional factors.

For Kuzbass, where one of the main sectors of the national economy is the coal industry, the rational use of mined coal and its products is one of the main tasks for the successful development of the region. Considering the significant transport costs when delivering coal to its customers both to the West and the East, coal companies have put a lot of effort and invested heavily in the construction of new coal processing plants (CPP). According to statistics, almost all coal of coking grades is currently being processed in Russia (in 2014, 94.2 million tonnes were extracted – 90.0 million tonnes per year), respectively, for power-generating coal these figures are 345.1 million tonnes per year and 110.0 million tonnes per year.

The processing technology at CPPs is characterized by the use of closed water slurry schemes to produce coal concentrates with the required moisture content without thermal drying of small classes of coal. The products at CPPs are: concentrate with an ash content of 5.5-10%, industrial product with an ash content of 25-38% (usually for coking coal grades) and a rock with an ash content of more than 70%.
At the same time, finely dispersed coal preparation waste (FDCPW) of the 0-0.5 (1) mm class, usually represented by filter-press residual matter – filter cake (FC), appeared in the composition of the rock being shipped to the dump. The output of the filter cake is from 5 to 10% by weight of the processed coal at the CPP. Given the high humidity and ash content of this product, its implementation on the market without preliminary processing is not economically feasible.

A feature of the CPP filter cake is also that this product contains extremely toxic flocculants, which entails environmental pollution around their storage sites. As a result, coal enterprises suffer economic losses due to the need to use a significant amount of vehicles (the specific cost of transporting the filter cake is about 10 rubles per tonne·km, as well as paying the cost of waste storage, and the surrounding territories get serious environmental problems.

In addition, significant environmental problems arise in settlements located near central heating and power plants (CHPP) and boiler houses associated with the storage of huge quantities of bottom ash wastes (BAW) that remain in ash dumps and residual tanks for decades. As a result, such a notion as “dirty coal” appeared in the mass media and political space, the use of which as a technological and in fuel raw materials must be reduced, and if possible, completely abandoned. At the same time, possible social, economic and political consequences are not taken into account, especially for regions such as Kuzbass.

Thus, the most urgent tasks in the extraction, processing and use of coal and its products, in our opinion, are:

• processing and efficient use of finely dispersed coal preparation waste and low-grade coal and industrial product;
• processing and use of the BAW by CHPPs and boiler facilities;
• reclamation of disturbed lands during the operation of coal mines and open-pit mines.

2. Results and discussion
To solve the set tasks it is proposed to use a cluster approach, when on the same platform it is proposed to combine both modern innovative technologies, which allow individual technical problems of processing and using coal and its products to be solved, including deep processing, and to gain new knowledge in their study and implementation.

Thus, an innovative scientific and educational cluster for the integrated use of coal and its products, has been developed and is being implemented at SibSIU, including:

• processing of coal and coal slimes;
• technology and equipment for coal processing, including its crushing and classification;
• technology and equipment for the preparation of slurry water-coal fuel (SWCF) based on coal, industrial product, and FDCPW;
• technology and equipment for hydrotransportation of the obtained “liquid” coal through the pipeline and its storage in containers;
• technology and equipment for producing briquette fuel based on coal and FDCPW;
• technology and equipment for producing coal oil granulate and, on its basis, coal-water-oil suspension and coal oil briquettes;
• technology and equipment for burning the obtained types of fuel in a boiler plant with a fuel chamber of layer and swirling-type furnace;
• bench installation for deep processing of coal-water-oil suspension to obtain a synthetic oil product;
• technology and equipment for producing a hardening filling on the basis of CPP and BAW rock, ash from CHPP, also from boiler houses, including those obtained during the combustion of SWCF;
• technology and equipment for producing slurry based on rock and BAW for filling the mined territories during their reclamation;
• a modern coal-chemical laboratory with a collective use center, where all types of analysis of coal and their products are carried out.

It is the implementation of the proposed integrated cluster approach that allows ambitious scientific and practical tasks to be set, a search for solutions to be offered to students and graduate students, employees of design organizations and industrial enterprises, and representatives of the business community. At the same time, the creation of a demonstration technological complex in the block of heavy laboratories of SibSIU within the framework of the innovation cluster will allow the specific narrow technical problems in coal processing and use of the obtained products to be solved with achievement of the required characteristics and environmental effect.

In recent years, a significant number of publications have appeared that describe technologies for the utilization of FC by burning it in boilers with a boiling bed and a swirling combustion system. The main technologies that allow economically efficient and environmentally safe disposal of FDCPW are technologies for producing fuel briquettes and SWCF.

However, at the moment, these technologies are not widely used in Russia due to the following reasons:

• the presence on the market of Kuzbass and other coal regions of a significant amount of relatively cheap raw coal, and transportation of briquettes with high ash content (up to 35-40%) over considerable distances (even to nearby regions) is unprofitable;

• the lack of demand for cheap SWCF from local industrial and municipal enterprises that have boiler houses, CHPPs due to the small experience in the industrial operation of facilities using this technology, including due to significant fluctuations in the quality of FDCPW (ash, humidity);

• the presence of the subjective factor “we will not be the first”, which is commonly found in the management of modern coal and energy companies;

• lack of a legislative framework for the use of coal preparation wastes and BAW in terms of the reliability of long-term forecasts of their value.

Thus, the search and development of technology and a set of equipment for the efficient use of coal and its products is an urgent problem for coal companies both in terms of economics and environment. Taking into account the significant variation in the quality of coal and its products by size, the yield of volatiles (coal grade), moisture and ash content, in order to develop optimal technological solutions for their use, it was decided to create a modern experimental base. A technological complex consisting of four main modules was created at Siberian State Industrial University (SibSIU) together with Scientific and Production Center “Sibekotekhnika”, Scientific and Production Center “Sinoyl” and the branch of Siberian Research Institute of Coal Processing in Prokopyevsk: coal preparation and preparation of fuel, transportation, storage of fuel, and burning of different types of fuel and liquefaction of coal (figure 1).

The coal preparation and processing module with the preparation of various types of fuel contains: a hammer mill, a batch auger mixer, a coarse vibration filter, a drum mini-bead beater and rod mill of discontinuous operation, a vibratory mill of discontinuous and continuous operation, pumping equipment, and tanks for finished fuel storage. The module also has equipment for processing the feedstock using oil granulation and producing briquettes from various feedstock. Thus, the set of mounted equipment for fuel preparation provides the possibility for implementation of various methods for its preparation, based on the type of feedstock (raw coal, coarse slime, FDCPW, coal-oil granules). The fuel transportation and storage module includes: a fuel storage tank, a transportation pump of volumetric type, a pipeline consisting of horizontal, vertical and inclined sections, start-up chambers and reception of calibrating scrapers, instrumentation and automation devices (flow meter, pressure gauges, flow viscometer). The created module allows hydrotransportation studies of various types of water-coal suspensions (coarse and finely dispersed, low and highly concentrated) in turbulent, transitional and laminar modes to be conducted. In this case, the specific pressure losses, the presence of residual matter in the pipeline, the actual rheological characteristics necessary for the calculation of pipeline systems are determined.
The combustion module contains: a fuel combustion chamber with a bed and swirling combustion systems, a hot water boiler with a heat power of 0.25 MW, a two-stage dust collection system, a chimney, draft equipment, a metering pump for injecting fuel into the combustion chamber, a compressor with a receiver for supplying compressed air to pneumomechanical fuel injector, instrumentation kit. To ensure year-round operation of the bench installation, a boiler water cooling system is provided in the air cooling apparatus. The operation of the combustion module makes it possible to determine the efficiency of fuel combustion, the efficiency of the boiler on various types of fuel, the composition of the flue gases.

The operation of the bench installation is carried out both remotely and locally. In addition, an automation system was mounted by the processes of preparation and fuel burning, which allows work of creating a technological complex in automatic mode to be performed.

Alongside with a bench installation, a coal chemistry laboratory was also created.

Testing of the bench installation operation was carried out using FDCPW at CPP “Shchedrakhinskaya” (JSC “Topprom”, Novokuznetsk).
Testing of the bench installation showed the wide possibilities of its use for working out the modes for preparing SWCF from feedstock of various quality, both by size and ash content, as well as burning the resulting fuel with the measurement of the necessary technological and technical parameters. When using a gas analyzer, the level of harmful emissions in flue gases is measured.

Thus, the created bench installation allows the technology for the utilization of finely dispersed coal-enrichment waste to be fully implemented by preparing fuel based on it and then burning it. BAW obtained after burning SWCF at CHPPs and rock from CPP are used to prepare hardening and filling mixtures for filling the mined territories and open-pit mines.

A fundamentally new technological process for processing coal and coal slimes is a method for producing artificial “coal” oil. Coal liquefaction provides an alternative low-cost source of oil and oil products. Liquefaction of coal can also be used as a way of waste recycling in coal production and coal processing. The use of coal for the production of synthetic oil is advisable because of its close chemical composition of natural raw materials. The hydrogen content in oil is 15%, in coal – 8%, and carbon – comparable amounts.

SWCF is a finished product for the use in the electric pulse method of liquefying coal. An important indicator in this case is the coal ash content in SWCF, since during hydrogenation the remainder of non-reactive resin compounds mixed with coal and ash remains. To reduce this residue and increase the conversion of coal, i.e. to reduce the loss of carbon, it is necessary to have the lowest possible ash flow into the process. The method of oil granulation is used for this purpose.

Coal is a poly-conjugated system, mainly of a non-aromatic nature, which includes high molecular weight and low molecular weight organic substances bound by intermolecular interaction (IMI) of different nature and strength, and electrons and radicals, interactions with a carbon substance, contribute to the destruction of IMI and hydrogenation [7]. The objective of the liquefaction process is to carry out the depolymerization reaction of the substance and hydrogenation of the products of depolymerization. These reactions are initiated by special high-voltage pulsed discharges in a mixture of coal, water and an organic solvent. In the discharge channel, the substance heats up to hundreds of thousands of degrees and, accordingly, expands sharply, creating high pressure up to several thousand MPa, causing, among other things, cavitation phenomena. Appearing particles of radicals *O, *H, *OH and free electrons activate the suspension as a whole and contribute to the destruction of long molecules of substances, leading to the appearance of liquid organic products. Atomic hydrogen is involved in the hydrogenation reaction, closing newly formed molecular compounds. In addition, during a high-voltage discharge, additional grinding of coal particles occurs due to tensile mechanical stresses – the product decompresses, i.e. additional pores appear that increase solvent access to coal particles [8].

Water facilitates the occurrence of a high-voltage discharge and is a source of *O, *H, *OH radicals, and hydrocarbons are a supplier of hydrogen. The presence of water and hydrocarbons is necessary as one of the components of a supercritical fluid that is formed locally during cavitation. The process of liquefaction in a supercritical environment occurs best in the presence of organic hydrocarbons and water.

Implementation of the proposed method of liquefaction is carried out on a specially created bench installation of electropulse liquefaction.

3. Conclusion
The developed and created innovative scientific and educational cluster allows the modern approach to training, conducting scientific research, introduction of high-tech industries in the field of processing and use of products of coal enterprises to the market to be fully implemented.

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