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CHANGES IN THERMAL PLASTICITY OF LOW GRADE COALS DURING SELECTIVE EXTRACTION OF METALS

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As the world oil market tends to be highly volatile, the coal becomes a primary source of organic raw materials for chemical and metallurgical industries. Fossil coals can accumulate high amounts of elements and mixtures quite often reaching commercially valuable concentrations. Reserves of scandium and other rare elements in coal deposits in Siberia alone are sufficient to satisfy the expected global demand for several decades. This study is intended to solve complex tasks associated with extraction of metal oxides using the developed enrichment method to ensure the required thermal plasticity determining the quality and properties of metallurgical coke.

Laboratory experiments have been conducted for the enrichment of high-ash coals containing the highest concentrations of metals. Thermal plasticity values have been determined with the help of Gieseler plastometer . Using modern technologies and equipment individual deposits can be turned into profitable production of enriched coking coals with concurrent extraction of rare metals. It has been proven that the highest commercial potential lies with the extraction of scandium and some other rare metals in the form of oxides from the coal..

***Key words*:** coal, coke, enrichment, rare metals, scandium, thermal plasticity, coal chemistry, selective extraction.

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Introduction. In present-day economic environment when oil prices are dropping coal becomes the primary source of raw materials for metallurgical and welding industries. Therefore technologies associated with non-energy use of fossil coals need further advancing. It is known [9, 11, 12] that fossil coals are capable of accumulating significant quantities of elements and mixtures in concentrations valuable for processing in commercial scale. In domestic coal deposits high concentrations of germanium, gold, platinum, scandium and other metals have been identified. Siberian coals, especially those deposited in Kuzbass Basin, have higher metal concentrations as compared to the global coal clark. With the modern technologies of processing and concentration of elements with the use of high-capacity machinery, a profitable enterprise for rare metal extraction can be formed on the basis of some deposits. The analysis shows that the highest potential lies with extraction of Ge, Sc, Au and a complex of lithophile rare metals (Ta, Nb, Zr, Hf, Y, lanthanides) from the coals [2]. On the other hand, abnormal concentrations of scandium and yttrium are found in some brown coal deposits in Kansk-Achinsk Basin, placing them among the elements with the highest potential in terms of extraction from coals in the process of enrichment [6, 8, 10].

There are technological and economic preconditions for quality improvement of coals mined in Russia by means of their deep processing and enrichment during selective extraction of different metals, while obtaining additional valuable coal chemical products and raw materials, for instance for metallurgical applications.

It is known that concentration of rare-earth and rare metals in coal determines its thermal plasticity, which eventually affects the properties of coking coals and their behavior during coking process [4, 14-17].

This paper reviews a technology for selective extraction of certain metal oxides from low rank coals of Siberian cluster with the highest metal concentrations when characteristic changes are observed in thermal plasticity of coal material after concentration of each chemical element (metal) has been changed.

Experiment Method and Procedure. Existing enrichment technologies for low quality coal with high content of volatile components and sulfur are not suitable for metallurgical applications using conventional carbon-composite methods, but may be applicable in the process of coal enrichment for concurrent extraction of high quality oxides of various metals when treated with organic solvents.

Laboratory experiments have been conducted for enrichment of low rank coal with a high yield of volatile components with the highest concentration of metals in its composition [3, 4]. Bituminous and anthracite coal with low thermal plasticity has been used as a base (raw) material. Five samples have been collected from each coal batch from several coal fields. The table below shows concentrations of most valuable elements for extraction (scandium, yttrium, samarium, ytterbium).

Samples (80-100 g) have been treated under the developed technological method [3-5] with organic solvent in order to extract carbonaceous material for further metal recovery from the oxides.

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Concentration of Certain Rare Elements in coal samples from different batches

Coal basin, Mining field	Element concentration, g/t			
	Sc	Y	Sm	Yb
Kuznetsky	3.9	15.4	2.6	1.3
Minusinsky	8.2	13.76	2.2	1.1
Western Siberian	16.0	17.0	2.5	2.1

At the first stage solvents with coals of different types have been prepared in order to determine extraction rates for certain metals. After demetallization the properties of enriched coal and its fitness for metallurgical applications have been assessed. At the extraction stage solution was kept at a constant temperature and heating rate. Throughout the entire process a slurry was purged with oxygen-air mixture to extract components and remove solvent from extraction mixture by evaporating after which enriched coal was obtained in solid form. Therewith most metal oxides were turned into extract. At the final stage the mixture went through compounding process, when extracted and residual coals were blended to obtain enriched coal with high level of thermal plasticity. Organic solvent was removed by evaporating and then recovered for repeated use at the stage of slurry preparation.

The existing standard methods for coal enrichment in vertical shaft furnaces (blast furnaces) using solvents with components containing hydrogen donator require that the carbon bearing material is highly resistant to loads and has high thermal plasticity [4].

Along with a need to find a solution for metal extraction there is also a need to get high-strength coke after enrichment of metal bearing coals. Coke is produced by carbonization of coal mixture consisting of coking coals of different types which are ground in coke oven battery. During coking process the coking coal is softened and melted at the temperature of 300-550°C, while volatile substances are released producing gas which causes swelling due to which particles stick together forming a mass of low-temperature coke. After that with the temperature increase up to ≈ 1,000°C the coke gets compacted becoming a hard coke (a coke cake). Thus adhesive properties of thermoplastic coal strongly affect such parameters as strength of coke and diameter of particles after coking.

In order to improve adhesion of coking coal (coal mixture) it is generally recommended to use the coking method assuming coal mixing with a sintering additive demonstrating high fluidity at the temperature when coal begins to soften and melt. In our study we used such sintering additives as coal tar pitch, petroleum tar, solvent-refined and extraction coals. The same as with coal, adhesive power of these sintering additives in thermoplastic condition greatly affects the coke properties after coking.

For modeling of coal thermoplastic properties in the coke oven battery certain study techniques are used to investigate the coal swelling ability which appears to improve gas permeability properties during coal plasticization. In order to test coals free from metals for plastometric properties the coal sample weighing 100±1 g ground to the size < 1.5 mm was used. The plastic layer thickness was measured using an upgraded Gieseler plastometer [5] (Fig. 1).

The method for thermal plasticity assessment is based on the ability of caking coals to soften when heated in absence of air, become plastic at temperatures in the range from 350 to 470°C and then form coke if further heated in the furnace [1, 13].

Figure 2 shows dependencies beneath increased thermal plasticity of different

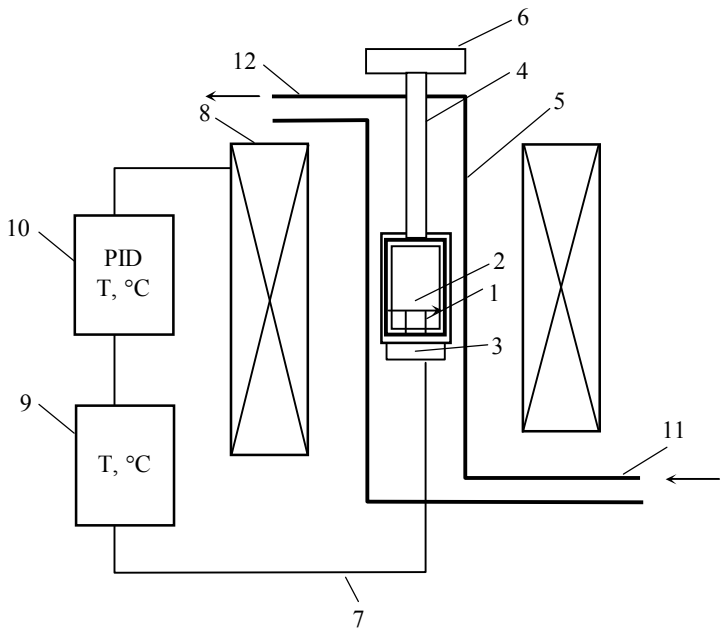


Fig.1. Upgraded plastometer

1 – sample; 2 – material with through holes from the top to the bottom; 3 – tank; 4 – pressure meter rod; 5 – tube; 6 – load sensor; 7 – temperature gauge; 8 – heating element; 9 – temperature sensor; 10 – temperature controller;11 – gas inlet; 12 – gas outlet

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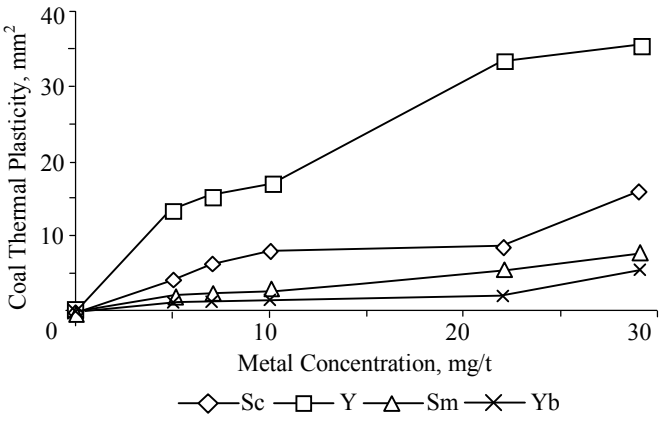


Fig.2 Dependency of Coal Thermal Plasticity on Metal Concentration

samples. The highest change in thermal plasticity is observed during recovery of yttrium and to some extent of scandium. Change in the ytterbium concentration has almost no effect on the coal properties.

For metal winning and concentrating the portions of enriched coals were mixed with metal oxides. The resulting mixture was recovered in the laboratory rotary furnace. At this final stage the following processes take place: recovered mixture is heated for metal oxides agglomeration; then it is loaded to blast furnace and melted in order to separate metals and slag; and mold is drained. When complex technology was used the maximum extraction rate comprised 1.2 mg / 100 g for scandium, 2.5 mg / 100 g for yttrium, 0.54 mg / 100 g for samarium, and 0.15 mg / 100 g for ytterbium.

Conclusions

The problem of supplying Russian industrial sector with nonferrous and rare metals is aggravated by the complicated social and economic situation. Using modern technologies individual deposits can be turned into profitable production for extraction of rare metals. The highest potential lies with extraction of scandium and some rare earth elements from the coals. Reserves of scandium and yttrium contained in Kuzbass coals are sufficient to satisfy the expected global demand for several decades.

The proposed technology for low rank coals enrichment to get coking coals with predetermined thermal plasticity can be adapted for metal bearing coals. Complex treatment of coal mixture with organic solvents at different temperatures allows along with enrichment to concentrate metals in the solvent and then recover them at the subsequent stage. The selected treatment patterns ensure oxide extraction and improve coal properties, in particular thermal plasticity, which can be used to control extraction rate of rare earth metals.

The existing resources are sufficient to establish a large production facility at the deposit field for associated extraction of Y, Sc and other elements and mixtures.

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