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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ

БАЯНДАМАЛАРЫ

ДОКЛАДЫ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН

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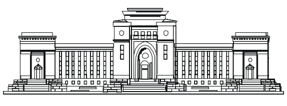

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HIGH-ASH COALS - POTENTIAL RESOURCES FOR FERROALLOY PRODUCTION

Abstract. The paper provides a brief overview of data on the structure of electricity generation in the Republic of Kazakhstan according to the proven world reserves of coal, the annual volume of coal production and its distribution by industry in the Republic of Kazakhstan. Based on the comparative analysis of qualitative and technological characteristics of the carbonaceous raw materials of various coal deposits of Kazakhstan, selected were the high-ash deposits most attractive in terms of being put into production of complex ferroalloys. Represented are the results of the proximate analysis and chemical composition of the representative samples of high-ash coals of Borly and Saryadyr deposits of Karaganda and Teniz-Korzhunkol coal basins, respectively. Based on the results of X-ray diffraction (XRD), established were the base minerals in the representative samples of high-ash coals. Presented are the physicochemical properties and processing characteristics, the aggregate thickness of commercial seams, the quantitative estimation of reserves of coal deposits, as well as the primary consumers. Presented also are the results of studies of the mineral and petrographic composition of the high-ash coals of Borly and Saryadyr deposits showing increased content of leaning microcomponents in pure carbon (21-24% fusinite, 22-35% semi-fusinite), which, in addition to the low content of fusible components (5-10% leptynite, 15-36% vitrinite) will substantially exclude the caking of these types of carbonaceous raw materials at high temperatures.

Key words: high-ash coal, qualitative characteristics, X-ray diffraction (XRD), petrographic composition, complex ferroalloy.

Introduction. Today, the energy industry is one of the important constituents of the global economic progress. This being said, the electric energy industry is of particular importance for the economy of Kazakhstan, since the key sectors of the country, such as metallurgy and oil and gas production require high energy consumption. Accordingly, the competitiveness of the heavy industry of Kazakhstan and the quality of life of people in many respects depend on the reliable and high-quality energy supply.

In the structure of energy production in Kazakhstan, the coal generation dominates, accounting for 70.4% of the total production of electricity in the country [1-3]. The gas power plants produce 19.4% of electricity, the hydroelectric plants produce 9.7%, while the wind and solar power plants produce 0.4% and 0.1% of electricity in the country, respectively [4,5].

In the fight against climate change, in many countries there is a tendency to switch to renewable energy sources and the government of Kazakhstan is not an exception here, setting ambitious goals for the transition to alternative energy sources [6,7].

However, the cost of coal as a fuel for power generation in many countries remain competitive, and its share of the global heat and power generation account for over 40% of the power supply (and 38% of generation) [8-10].

Total proven coal reserves in the world as at the beginning of 2018, amount to 1,035.0 billion tonnes. At the current level of annual coal production in the world, this amount of coal reserves is sufficient for about 150 years, but given the wide spread of renewable energy sources application in developed countries, the developing countries may be supplied with coal for a much longer period [11-14].

The Republic of Kazakhstan is one of the largest energy producers, which ensures it a significant international presence. Undoubtedly, one of the most crucial tasks for most raw stuff exporting countries, including Kazakhstan, is the wide diversification of the economy. In this regard, global companies are paying more attention not to the increase of reserves, but to the introduction of modern high-performance technologies in the field of processing, improvement of economic efficiency, and rational use of non-renewable energy sources.

In terms of coal extraction, Kazakhstan ranks second among the CIS countries. The coal reserves amount to 162 bln. tonnes. To date, 10 basins are found and more than 300 of coal and lignite deposits are explored.

The annual volume of coal production in the country amounts to over 100 million tonnes. Of these, about 51% is consumed by coal heat and power plants, 31% is exported outside of the country, 13% goes to heating needs of budgetary organizations and the population, and 5% is for industrial enterprises.

Most of the coal deposits are located in Karaganda, Pavlodar, Kostanay, and Akmola regions.

More than half the world's coal reserves are of high-ash.

The consumption of mineral and energy resources inevitably leads to the generation of enormous waste accumulated in dumps of overburden rock, slag, ash residues, etc. The man-made formations carry a very aggressive impact on the natural environment, therefore, the interest in its recycling is not only due to commercial objectives, but also to the increased environmental requirements.

The disposal of high-ash coal and overburden, unused in energy production, with the minimized loss of all elements and, moreover, the production of merchantable metallurgical products out of them is a prospective and timely technological challenge. In this regard, relevant is the development of new sustainable technology of complex processing of natural and man-made raw materials leading to obtaining effective complex alloys.

Currently, in the Karaganda and Tengiz-Korzhunkol coal basins, different types and grades of coal are produced. Some of the deposits feature a high ash content; such coal with up to 35% ash content can be used in the electric power industry and national economy and; whereas the higher ash content coal practically does not find application and are stored in dumps.

However, a favorable technical composition (50-65% ash, 18-25% volatiles, up to 20-30% solid carbon) of high-ash coals will allow drawing them into the metallurgical treatment for the production of complex alloys. In this regard, the high-ash coals are the potential resource able to expand the raw materials base.

The carbothermic silicon and aluminum recovery processes are accompanied by formation of considerable amounts of suboxides. Therefore, to prevent the transition of silicon and aluminum suboxides to the gas phase, and to increase the yield of metal in the technology of smelting of complex alloys, it is necessary to pay attention to the physicochemical properties of the furnace burden and processes occurring in the upper layers of the furnace, i.e. on the furnace throat.

In this connection, to obtain an objective picture of the complex use of raw materials, it is necessary to study in detail their material composition and technological properties. To identify the suitability of application of high-ash coals, it is necessary to proceed from their physicochemical and technological characteristics. In this regard, the original raw materials were examined to determine their principal physical and chemical properties.

The study of the mineral composition of raw materials for solving technological problems involves the identification of all the minerals of the sample with a quantitative assessment of their ratio and the characteristic of intergrowth using a complex of methods [15,16].

Experimental part. Therefore, to conduct the mineralogical and petrographic studies, we used the representative samples of high-ash coals of Borly and Saryadyr deposits.

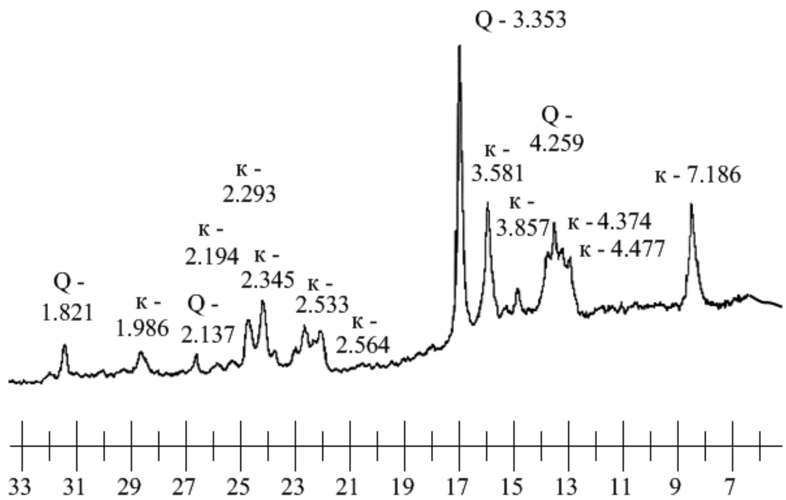
The preliminary preparation of each sample included operations of averaging, reduction, and selection of representative samples for mineralogical, complete chemical, and X-ray analysis.

The results of the proximate analysis and chemical composition of the representative samples of high-ash coals are shown in table 1.

Table 1 – Chemical composition and proximate analysis of high-ash coals

Field	Content, % wt								
	A^c	V^c	W	SiO_2	Al_2O_3	CaO	MgO	Fe_{total}	P_{total}
Borly	48,90- 53,43	17,01 - 18,50	0,44 - 1,50	50,75 - 62,10	34,50 -39,50	1,50	0,54	1,17 - 1,70	0,01 - 0,03
Saryadyr	44,20	20,70	1,80	61,30	28,70	1,40	1,0	4,60	0,02

In the representative sample of high-ash coal of Borly deposit, according to X-ray analysis conducted by X-ray diffractometer DRON-2,0 (Fe K_α - radiation), the following minerals were found: kaolinite ($Al_2Si_2O_5(OH)_4$) and quartz (α - SiO_2) (figure).



XRD pattern of high-ash coal of Borly deposit. k - kaolinite, Q - quartz

Results and discussion. The comparative analysis of the properties of carbonaceous raw materials of different coal deposits having respective chemical composition of ash for the smelting of complex alloys showed that the most attractive are the high-ash coals (carbonaceous rocks) of Borly and Saryadyr coal deposits of Karaganda and Teniz-Korzhunkol coal basins, respectively. The high-ash coals of these deposits have a high ash fusion temperature, reduced tendency to cake, and relatively low electrical conductivity value [17].

Borly deposit is located in the Karaganda region, 110 km north of the city of Karaganda and 60 km north-east of the railway Karaganda-Nur-Sultan. The deposit represents a gently sloping brachysyncline structure (6.5x2.5 km), the flanks of which are layered by carbonate formations of Famennian Tournasian tiers, while the central portion is a thick stratum sandy-argillaceous rocks of Visean-Serpukhovian age, by analogy with the Karaganda basin, is divided into series (from bottom to top).

1. Ashlyarik (C_1V_{1-2}) 450 m thick;
2. Karaganda (C_1V_{3-s}) 200 m thick;
3. Nadkaraganda (Upper Karaganda) (C^1s-C_2) 100 m thick.

The commercial coal-bearing capacity is attributed to the lower part of the Karaganda series section, where three contiguous carbon formations are identified, comprising of 11 coal seams, including 5 commercial seams. The total thickness of the commercial seams is 37.4 m on average.

The coals of the deposit are bituminous; humic by material composition. The ash content of bulk of coal is 31-44%, of run-of-mine coal is 39-47% (45.4% on average). The ash is refractory and has high abrasive properties. The coals are low-sulfur (0.4-1.1%) and low-phosphor (0.01-0.02%). The coals of seams are attributed to «K» rank; the volatile content is 26-36%, the thickness of the plastic layer is 11-16 mm [18-20].

Due to difficult washability, they are not suitable for carbonization, and high ash coals can only be used as power fuel. The ash has a high content of alumina (26.8% on average).

All coal reserves can be mined using open-pit method at the overburden ratio of 1.7 cu.m./tonne. The coal seams are unhazardous in terms of coal and gas outburst (the methane concentration is 0.03 to 0.1 cu.m/tonne), whereas the coal dust is explosive. The coals are prone to spontaneous ignition. The increased content of Al_2O_3 (38-39%) is in particular peculiar to coals and intermediate rocks of the Lower coal formation.

When quantifying the deposit reserves, the coal seams with a minimum thickness of 1.0 m and a maximum ash content of 55% were allocated to the booked reserves. The primary consumers of coal are the power plants of Karaganda and Akmola regions. As of January 1, 2015, the reserves amount to 342708.0 (thousand tonnes) by category $A+B+C_1$ [21].

The Saryadyr deposit is located in the south-eastern part of the Tengiz-Korzhunkol basin (in Yereimentau district of Akmola region, 30 km from the town of Yereimentau) and is a relatively large depression [18-20].

According to the position in the section, lithological composition, fauna, coal-bearing character, they are classified into three series (from bottom to top):

1. Akkuduk (C_1 V_1 ak) 100 m thick;
2. Ashlyarik (C_1 $V_{1\text{-}2}$ ash) up to 220 m thick;
3. Karaganda (C_1 V_3 - s krg) 400 m thick.

The series are composed of gray-colored sandstone, siltstone, mudstone with sparse and thin interbedded marl and coal seams. The coal-bearing capacity is attributed to Ashlyarik and Karaganda series containing in total 7 coal seams, of which three are commercial. The aggregate thickness of all the commercial seams is 18.3 m.

The seams of Karaganda series Nadyozhniy and Sputnik-II have a very complex structure and relatively volatile. The Pyatimetroviy seam is stable and simply structured.

The coals of the deposit in terms of its quality are the best in the basin, especially the coals of Pyatimetroviy seam, which ash content for run-of-mine coal is 25%. On average, the ash content at the deposit ranges from 30 to 40%, sulfur content 0.6-0.8%, phosphorus 0.62-0.03%, volatile content on dry ash free basis is 38-45%.

The coals are humic, bituminous, hard-cleaning, ranked «G» (gas), unsuitable for carbonization and may be used as power fuel.

The environmental conditions are favorable for open-pit mining at the overburden ratio of 7.3 cu.m/tonne, and 4.9 cu.m/tonne at the site of primary development. The coal seams are classified as unhazardous in terms of sudden coal and gas outbursts. The coal dust is explosive.

As of January 1, 2015, the reserves amount to 164727.0 (thousand tonnes) by category $A+B+C_1$, and 94799.0 (thousand tonnes) by category C_2.

The principal consumers of coals are power plants are and the population [21].

As is known, during the extraction, the coal seams are accompanied with rock layers (carbonaceous rocks) with high ash content of more than 40%, which does not always find use and are stored in dumps. The carbonaceous rocks have unstable chemical composition. The composition varies sharply from layer to layer and even within one layer, whereas for the production of complex alloys it is important that the carbonaceous materials have uniform chemical and mineralogical composition. The problem of their unstable composition can be solved by stacking and fractionation.

Accordingly, the representative samples of high-ash coals of Borly and Saryadyr deposits were subjected to mineralogical and petrographic studies.

High-ash coal of Borly deposit is classified as humic coal, bituminous (K_{en}) (humolites are a group of coals formed due to transformation of higher plants residues in bog conditions). The color is gray to black. The lustre is matt to mirror.

The petrographic composition of high-ash varieties of coals and coal-bearing rocks is shown in table 2. The petrographic composition of coals of Borly and Saryadyr deposits shows the increased content of leaning microcomponents in pure carbon (21-24% fusinite, 22-35% semi-fusinite) which, in addition to the low content of fusible components (5-10% leptynite, 15-36% vitrinite) will substantially exclude the caking of these types of carbonaceous raw materials at high temperatures.

The material and petrographic composition shows the significant presence of mineral impurities, consisting primarily of fine mica-clay materials closely interrelated with the organic portion of coal.

Table 2 – Petrographic composition of coals of Borly and Saryadyr deposits

Sample name	Overall composition of coal, %							Composition of coals with minerals, %					Pure coal composition, %								Total	Total caking components in pure coal, %	Total leaning components in pure coal, %	Vitrinite reflectance
		minerals												inertinite										
	pure coal	clay minerals	iron sulfides	carbonates	silicon oxides	other	total	vitrinite	inertinite	liptinite	minerals	total	vitrinite	semi-fusinite	macrinite	fusinite	sclerotinite	inertodetrinite	micrinite	liptinite				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Run-of-mine coal of Borly deposit	39	56	traces	–	5	–	100	6	31	2	61	100	15	35	6	24	–	13	2	5	100	20	80	0,95
Run-of-mine coal of Saryadyr deposit	59	36	traces	shares	5	–	100	21	32	6	41	100	36	22	6	21	–	5	traces	10	100	46	54	0,74

Conclusions. The results of study of the mineralogical and petrographic composition of high-ash coals of Borly and Saryadyr deposits show an increased content of leaning microcomponents in pure carbon (21-24% fusinite, 22-35% semi-fusinite) which, in addition to the low content of fusible components (5-10% leptynite, 15-36% vitrinite) will substantially exclude the caking of these types of carbonaceous raw materials at high temperatures. These high-ash coals have a high fusion point, a favorable petrographic composition, low tendency to caking and a relatively low value of electric conductivity. In general, high-ash coals of Borly and Saryadyr deposits by their physical and chemical properties and qualitative indicators are the complex metallurgical raw materials and meet the requirements for the smelting of complex aluminum-, silicon-, manganese-containing alloys.

In the future, they are a potential source of raw materials for the sustainable development of not just the fuel and energy sector, but also the expanded mass production of complex ferroalloys. The development of technology of producing complex ferroalloys using high-ash coals will define the role of coal deposits of Kazakhstan as a long-term (for centuries) resource base of ferroalloy production in Kazakhstan.

The industrial commissioning of complex ferroalloys production will ensure:

- the involvement of dump high-ash coals – of little use in the energy sector – in production, with simultaneous solution to the problem of their disposal and, as a consequence, improvement of the environmental conditions of communities of coal mining regions of Kazakhstan;
- the involvement of unsuitable manganese ores in metallurgical conversion to produce standard grades of manganese ferroalloys, such as ferromanganese and silicomanganese without additional and complex enrichment operations;
- the complete exclusion of the use of expensive carbonization in the process flow;
- ensure the competitiveness of output products and increase the export potential.

The involvement of high-ash coals in the production of complex ferroalloys is an adequate response to the global and domestic challenges of the time and in the foreseeable future will allow balanced and sustainable development of the ferroalloy industry in Kazakhstan.

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ЖОҒАРЫ КҮЛДІ КӨМІРЛЕР – ФЕРРОҚОРЫТПА ӨНДІРІСІНІҢ ӘЛЕУЕТТІ ШИКІЗАТ БАЗАСЫ

Аннотация. Жұмыста Қазақстандағы электр энергиясының өндіріс құрылымына қысқаша шолу жасалған. Көмір генерациясы басым рөлге ие, оның үлесіне елдегі электр энергиясын өндірудің жалпы көлемінің 70,4%-ы келеді. Әлемде және Қазақстанда дәлелденген көмір қоры, көмір өндірудің жылдық көлемі және оны Қазақстан Республикасындағы салалар бойынша бөлу туралы мәліметтер келтірілген. Елдегі негізгі көмір кен орындарының орналасқан жері туралы ақпарат келтірілген.

Көмір қабаттарын қазып алу кезінде әрдайым қолданылмайтын және үйінділерде сақталатын 40% -дан астам күл мөлшері бар тау жыныстары (көміртекті жыныстар) жүреді. Мұндай көміртекті тау жыныстарының теріс жағы – тұрақсыз химиялық құрам. Мұны жинау және бөлу арқылы шешуге болады.

Қазіргі уақытта Қарағанды және Теңіз-Қоржанкөл көмір бассейндерінде көмірдің әртүрлі түрлері мен сорттары өндіріліп жатыр. Кейбір кен орындарында күл мөлшері жоғары, мысалы, 35% дейін көмірді электр энергетикасы мен халық шаруашылығында қолдануға болады, ал күл мөлшері көп болған жағдайда олар іс жүзінде пайдаланылмайды және қоқыстарда сақталады.

Сондықтан энергетикалық салада пайдаланылмаған күлді көмір мен артық жүктемені кәдеге жарату барлық элементтердің шығындарын азайтып, сонымен қатар олардан нарықтық сұранысқа ие металлургия өнімдерін шығару перспективалы және уақтылы ғылыми-техникалық міндет болып табылады. Осыған байланысты тиімді кешенді қорытпаларды алу үшін табиғи және техногендік шикізатты кешенді түрде өңдеудің жаңа ресурстарын үнемдейтін технологияларды әзірлеу өзекті болып табылады.

Қазақстандағы әр түрлі көмір кен орындарындағы көміртекті шикізаттың сапалық және технологиялық сипаттамаларын салыстырмалы талдау негізінде жоғары күлді көмірдің ең тартымды кен орындары күрделі ферроқорытпа өндірісіне тарту тұрғысынан таңдалды.

Техникалық талдау нәтижелері және сәйкесінше Қарағанды және Теңіз-Коржанкөл көмір бассейн-дерінің Борлы және Сарыадыр кен орындарындағы жоғары күлді көмірлердің химиялық құрамы келтірілген.

Рентгендік фазалық талдаудың нәтижелері бойынша (РФТ) жоғары күлді көмірдің өкілдік үлгілеріндегі негізгі минералдар анықталды. Физика-химиялық қасиеттері мен технологиялық сипаттамалары, жұмыс қабаттарының жалпы сыйымдылығы, көмір кен орындарының қорларын сандық бағалау және негізгі тұтынушылар туралы мәліметтер келтірілген. Борлы және Сарыадыр кен орындарындағы жоғары күлді көмірлердің минералогиялық және петрографиялық құрамын зерттеу нәтижелері таза көмірдегі жұқа микрокомпоненттердің (21-24% фюзинит, 22-35% семифюзинит) жоғарылағанын көрсетті, ол ерігіш компоненттердің аз құрамымен (5-10% лейптинит, 15-36% витринит) іс жүзінде көмір шикізатының осы түрлерін жоғары температурада жентектеуді болдырмайды.

Түйін сөздер: жоғары күлді көмір, сапа көрсеткіштері, рентгенфазалық талдау (РФТ), петрографиялық құрам, кешенді ферроқорытпа.

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ВЫСОКОЗОЛЬНЫЕ УГЛИ - ПОТЕНЦИАЛЬНАЯ СЫРЬЕВАЯ БАЗА ФЕРРОСПЛАВНОГО ПРОИЗВОДСТВА

Аннотация. В работе приведен краткий обзор по структуре производства электроэнергии в Казахстане. Доминирующую роль занимает угольная генерация, на долю которой приходится 70,4% от общего объёма производства электроэнергии в стране. Также приведены данные по доказанным запасам угля в мире и в Казахстане, ежегодному объёму добычи угля и его распределения по отраслям в Республике Казахстан. Приведены сведения по расположению основных месторождений каменного угля в стране.

При добыче пластам угля сопутствуют породные слои (углистые породы) с повышенной зольностью более 40%, которые не всегда находят применение и складируются в отвалы. Отрицательной стороной таких углистых пород является нестабильный химический состав. Это можно решить путём штабелирования и фракционирования.

В настоящее время в Карагандинском и Тениз-Коржункольском угольных бассейнах добываются различные виды и сорта углей. Некоторые месторождения содержат высокую зольность, такие угли зольностью до 35% могут быть использованы в электроэнергетике и народном хозяйстве, а с более высоким содержанием золы практически не находят применения и складируются в отвалы.

Поэтому утилизация неиспользуемых в энергетике высокозольных углей и вскрышных пород с минимизацией потерь всех элементов и более того производство из них металлургической продукции обладающей рыночным спросом является перспективной и своевременной научно-технической задачей. В этой связи актуальным является разработка новых ресурсосберегающих технологии комплексной переработки природного и техногенного сырья с получением эффективных комплексных сплавов.

На основе сравнительного анализа качественных и технологических характеристик углистого сырья различных угольных месторождений Казахстана выбраны наиболее привлекательные с точки зрения вовлечения в производство комплексных ферросплавов месторождения высокозольных углей.

Представлены результаты технического анализа и химического состава представительных проб высоко-зольных углей месторождений Борлы и Сарыадыр Карагандинского и Тениз-Коржункольского угольных бассейнов, соответственно.

На основе результатов рентгенофазового анализа (РФА) установлены основные минералы в представительных пробах высокозольных углей. Приведены физико-химические свойства и технологические характеристики, суммарные мощности рабочих пластов, количественная оценка запасов угольных месторож-дений и сведения по основным потребителям. Также приведены результаты исследований минералого-петрографического состава высокозольных углей месторождений Борлы и Сарыадыр показавшие на повышенное содержание отощающих микрокомпонентов в чистом угле (21-24% фюзинита, 22-35% семифю-зинита), что наряду с низким содержанием плавких компонентов (5-10% лейптинита, 15-36% витринита) практически будет исключать спекание данных видов углистого сырья при высоких температурах.

Ключевые слова: высокозольный уголь, качественные показатели, рентгенофазовый анализ (РФА), петрографический состав, комплексный ферросплав.

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