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## THE ENERGY TECHNOLOGICAL BACKGROUND OF INVOLVING SALTY COALS INTO ENERGY BALANCE OF UKRAINE. 1. COMPOSITION OF WATER EXTRACTS AND THE PROSPECTS FOR THEIR UTILIZATION

Coal with high content of alkaline and alkaline earth metals (salty coal (SC)) occupies its definite place in an energy reserve of Ukraine. Deposits of SC are located in central industrial regions, the coal has high fuel indexes and can soon definitely get its share in blended fuels which will meet the standards of Ukraine and will be qualified for use at modern Thermal power plant (TPPs). In order to determine the rational ways of involving salty coal in the burning processes, the world practices widely use the detailed studies of the impact of natural mineral substances on the processes of slagging, sticking and corrosion in case of the burning of such coal.

**Purpose.** To determine the composition of natural water-soluble minerals in coal which cause a number of burning problems using non-destructive methods, a comparative analysis of the composition of mineral phases in SC from various deposits in Ukraine, to assess their slagging ability, and overview the prospects of utilizing flushing water generated during coal desalting.

**Methodology.** Applying the technological regimes of desalting developed by the authors, water extracts of SC have been obtained, which are investigated using a non-destructive X-ray diffraction method of dry substances (device DRON 4M), the composition of mineral phases of SC extracts is studied with the MATCH! program. Total content of salts and their removal efficiency are estimated using the 4805 Conductivity TDS/Temp indicator/EZODO.

**Findings.** The composition and peculiarities of the mineral phases from extracts of salty coals of different domestic deposits are determined. The fouling factor of SCs of different deposits in Ukraine was calculated from the chemical composition of ash; a comparison was made with the data of world sources. It is shown that even with a close value of the sodium oxide content in the ashes, salty coals of different deposits differ significantly regarding the assortment (from 2 to 5 varieties are found) of native water-soluble minerals and their ratio. It is shown that in aqueous extracts from two samples of salty coals it is the sulfate is the prevailing mineral, not halite.

**Originality.** For the first time, a comparative semi-quantitative analysis of the native mineral phases in dry water extracts of SC from three Ukrainian deposits was performed; data on the conditions for efficient coal desalting was summarized. The contamination factor for SC from various deposits in Ukraine is determined, comparison with world sources data is performed. Prospects for disposal (storage) of flushing waters generated during salty coal preparation for energy use are considered.

**Practical value.** The detailed study of dry water extracts and obtained composition of mineral phases allowed predicting: 1) the formation of low fusible eutectics in the process of burning of domestic salt coals and the determination of special process conditions that prevent slagging; 2) the behavior of mixed fuels of SCs with coals marked with significant presence of refractory compounds; 3) the choice of such mineral impurities including industrial wastes that reduce the risk of slagging and corrosion when burning domestic salty coals.

**Keywords:** *salty coal, fouling factor, water extract, native mineral, chlorides, sulphates, disposal of flushing waters*

**Introduction.** Nowadays in Europe and other developed countries the tendency is gaining momentum to reduce utilization of coal in the power industry, up to complete refusal of using coal, motivated by the need to significantly reduce greenhouse gas emissions. The Paris Agreement [1], also signed by Ukraine, obliges the participating countries of "...holding the increase in the global average temperature to well below 2 °C above pre-industrial levels," but with "... differentiated responsibilities and respective capabilities, in the light of different national circumstances..."

Taking into account national interests and significant coal reserves (explored reserves amount to 56.2 billion tons, and projected resources are estimated at above 117 billion tons) [2] in Ukraine, which, at the current mining rate, can secure the country for more than 400 years, the strategic plans (the New Energy Strategy of Ukraine until 2035) closely rely on coal. The plans foresee to utilize 12 million t.o.e. of this fuel resource, backing the production of electric energy at coal-fired power plants and Combined heat and power plant at relatively unchanged level in the long run. In total, in 2017, 55.8 billion kWh were generated from coal, and in 2035 it is planned to generate 63 billion kWh of electricity.

The use of coal at the TPPs and CHPs is also justified for reasons of the state's energy security, in order to compensate for the peak loads in the grid, since renewable sources are not able to completely cover such peaks.

On the other hand, it remains a known fact that exploitation of the country's coal basins for more than 200 years has already exhausted bulky and accessible coal layers, while the remaining ones have a low thickness (0.8–1.2 m), are located deeper than 1000 m, and, for the most part, are also characterized with high sulfur content. Furthermore, taking into account the problems with coal supplies due to events in eastern Ukraine, it should be recognized that attempts to involve available energy resources, namely, the so-called salty coals (in reserves of about 25 billion tons) [3], remain rather relevant. This type of coal, based on a set of basic indicators (high calorific value, moderately low ash content, small depth of occurrence), is a very promising resource amongst the non-standard energy sources, not only in Ukraine but also in many other countries, including Germany, Poland, Russia, USA, China, and Australia.

**Analysis of the recent research and publications.** The main obstacle in the development and utilization of salty coal (SC) deposits is a high content of fusible alkali metals compounds and chlorine, which hampers the operation of boiler units, cause the development of ash deposits, slagging and corrosion of heat exchange surfaces [3]. In Ukraine, "salty" is referred to the coal that contains more than 2 %  $\text{Na}_2\text{O}$  in ash or more than 0.4 % in terms of coal (dry combustible) mass.

Both domestic and foreign power industry do not have a sufficiently successful experience on industrial utilization of coal with high content of alkaline compounds. In the middle of the twentieth century, attempts were made to develop effective combustion methods for such coals, which identified problems, but did not provide ways for its industrial use [3]. These problems re-

quire further research and experimentation. The work [4] of American researchers presents the main aspects and problems arising from the combustion of coal with high content of Na and Cl in boilers of the thermal power plant.

Concerning the means of reducing the content of salts in coal (water, acid, reagent extraction), the proposed laboratory methods and approaches did not bring them to the industrial realization by a number of environmental and economic indicators [5].

Among the developments in incorporating salty coals into energy balance, which are currently under implementation, specially emphasized could be the research of Chinese scientists [6–10]. In recent years, they have proposed several methods for solving the problem of salty coal use, such as: gasification (the possibility and prospect of gasification of salty coal from Zhundong deposit, in comparison with coal from the Shigouyi coal field [7]); use of various additives allowing Na and Ca to transfer into more refractory compounds [8]; preliminary rinsing with water or treatment with various chemical solutions (leaching) [9]; and combustion in a mixture with other coals [10].

Of the above listed methods, developments ought to be specially considered, being, in our opinion, most prospective in terms of rational use of salty coals, namely with the following options: 1) the removal of harmful impurities with aqueous solutions, which does not require the use of expensive and environmentally harmful reagents (like  $\text{NH}_4\text{OH}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{HCl}$ ,  $\text{HF}$ ); 2) combustion of salty coal in a mixture with other fuels (coal, biomass, and others), which do not contain an abnormally high content of Na and Cl.

As for the first option (removal of salts), it is characterized by a number of factors, such as the duration of contact with water, the coal to water mass ratio, and the conditions under which the contact of coal with water occurs (intensity and nature of mixing, temperature of the medium, particle size, mineralization of water). The studies were conducted of Na and Cl yield at different coal desalting conditions [11, 12] showed the principal promise of this method, which allows to develop an effective and economically feasible technology for cleaning salty coal, when implemented, allow obtaining a high-quality coal (the desalting process does not aggravate the fuel parameters of coal), in which the concentration of Na and Cl will be lower than the maximum permissible value.

This preliminary treatment using well-defined technological regimes provides an energy technological basis for the utilization of domestic coal with high content of alkali metals. And in this part, our developments coincide with the pressing problem of the use of other (renewable) carbon rich materials (biomass). The latter may also contain a lot of fusible salts and require special measures before burning (reducing the content of salts by washing, dipping, pelleting or torrefication).

Regarding the second option, recent publication of the test results for joint burning of salty coals [10] from Zhundong deposit in Xinjiang province (China) with another non-salty coal indicates that, knowing the min-

eral composition of the coal, it is possible to find optimal blend ratios of salty coal and typical hard (bituminous) coal, for which problems of slagging and corrosion are not observed. However, each natural deposit differs from other ones with its individual mineral composition, and this requires special research. Below we compare the salty coals from China's and Ukraine's deposits, using our own and published data (Tables 1, 2).

As seen from Table 1, core samples from the Novomoskovsk deposit and Bohdanivsk deposit (Ukraine) and coal samples from the Zhundong deposit (China) [6–10] are similar in technical characteristics, H/C atomic ratio, but differ significantly by the content of heteroatoms (O, N, S). Chinese coal appears to be more oxidized, but Ukrainian coal is more sulfuric. The chemical composition of the ash in the presented samples is also different. As seen from Table 2, Novomoskovsk salty coal has higher content of alkaline (sodium and potassium oxide) and amphoteric (aluminum oxide and iron oxide) components, while the Chinese coal has a higher content of calcium oxide. All of these oxides play a significant role in the formation of certain types of sticky or slag deposits at different parts of the combustion unit equipment.

The chemical composition of coal ash is used to determine the fouling factor (f), which is calculated by the formula [9]

$$f = \frac{B}{A} \sum Alk \%;$$

$$B = \sum Fe_2O_3, CaO, MgO, Na_2O, K_2O \%;$$

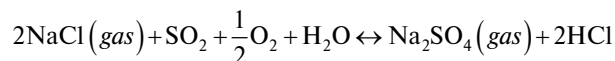
$$A = \sum SiO_2, Al_2O_3, TiO_2 \%;$$

$$\sum Alk = \sum Na_2O, K_2O \%.$$

The ratio of basic oxides to acid oxides (B/A) is considered as a contamination indicator in forecasting the trends for slagging. Comparing the fouling factor, we see that the most prone to slag are some samples of coal from the Novomoskovsk deposit, whose fouling factor varies widely (6.9–25.3 %), whereas for the Zhundong (China) deposit it is 10.7–16.5 %, where the main role in slagging belongs to Na, K, Ca. The fouling factor for coal from the Bohdanivsk deposit (0.8–4.6 %) is considerably less important, due to significantly lower Na content in ash.

It is known that one of the most fusible components in salty coal is halite (sodium chloride (NaCl) – 39.34 % Na, 60.66 % Cl,  $t_{melt} = 801 \text{ }^\circ\text{C}$ ,  $t_{boil} = 1465 \text{ }^\circ\text{C}$ ). When settling at the working surfaces and on the fly ash particles, it substantially increases their stickiness, creating conditions for the formation of the primary slag layer. According to research data, potassium is almost completely bound to refractory silicates that are insoluble in water and are not sublimed during coal combustion.

Under temperatures typical for combustion chambers, sodium chloride in fuel is almost completely sublimated and reacts with sulfur oxides to form sodium sulfate (strong solid thenardite)



Portions of sodium chloride and sodium sulfate, while in a vaporous state, condense on the heating surfaces and fly ash particles and increase their stickiness. The latter reduces ash viscosity and the start temperature of slagging.

Table 1

Characteristics of salty coals from Ukrainian and China deposits

Deposit	Element analysis, %					Proximate (technical) analysis, %			H/C
	$C^{daf}$	$H^{daf}$	$N^{daf}$	$S^{daf}$	$O^{daf}$	$W^a$	$V^{daf}$	$A^d$	Atomic ratio
Bohdanivsk (Ukraine)	70.1–78.0	4.9–5.7	1.3–1.7	1.6–5.9	13.4–15.2	7.0–11.0	41.2–42.6	8.6–14.6	1.0–1.3
Novomoskovsk (Ukraine)	66.3–75.8	4.5–5.2	1.0–1.5	0.9–5.8	8.1–10.6	5.9–9.2	40.9–46.4	7.1–14.8	1.1–1.4
Zhundong (China)	60.9–76.4	4.6–5.2	0.5–0.8	0.1–0.5	18.1–33.14	5.9–10.9	33.5–43.3	4.1–10.1	0.9–1.4

Table 2

Chemical composition of SC ash from deposits in Ukraine and China

Deposit	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	K <sub>2</sub> O	CaO	TiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>
Bohdanivsk (Ukraine)	1.85–6.80	0.45–2.52	2.59–24.44	30.36–52.14	0.09–1.20	4.15–20.25	0.20–2.50	4.07–19.22	0.12–0.80	5.89–17.08
Novomoskovsk (Ukraine)	3.47–12.48	1.52–4.43	11.11–20.67	13.32–32.97	0.07–0.38	7.20–18.56	0.62–1.88	7.84–13.68	0.18–0.72	7.50–34.50
Zhundong (China)	2.70–9.60	3.20–11.14	7.50–11.52	13.90–23.00	0.05–0.54	11.32–18.58	0.25–0.86	10.95–50.00	0.29–0.65	6.50–18.26

According to the data from VTI (Moscow), the temperature of the start of slagging for salty coal from the Novomoskovsk deposit is within the range of 750–850 °C (with the ash content within 7.6–12 %), whereas for non-salted Donbas coals it falls in the range of 1000–1020 °C. It is worth focusing also on calcium compounds, since their content in fuel largely determines the tendency for slagging and the ability to form solid, hard-to-remove deposits on heating surfaces of the convective path. Such deposits usually begin to form when the content of CaO in the ash exceeds 15–20 %. Ca compounds with oxides of sulfur, carbon and iron when subjected to the contact with water tend to form gypsum and cement-like deposits which are difficult to remove. According to research data, potassium is almost completely bound to refractory silicates that are insoluble in water and are not sublime by coal combustion.

Based on the above, the purpose of our work was to study the native mineral composition obtained from water-soluble mixtures of salty coal deposits in Ukraine. Unlike the chemical composition of ash, the composition of native mineral components can be determined only by non-destructive physical methods (for example, X-ray diffraction) [13]. But the content of alkali compounds in the coal is too small ( $\leq 2\%$ ), which does not allow investigating its composition by physical methods. That is why in our work we used the extraction, drying and analysis of water soluble compounds of salty coal, which allows us to reliably determine the composition of the impurities and to consider the prospects of using the washing waters of the investigated domestic coal.

**Experiment.** For the experiment, 5 samples (core samples) of salty coal were selected: two samples from the Bohdanivsk deposit, two samples from the Starobilsk deposit and one from the Novomoskovsk deposit (Table 3).

The coal was air dried at the room temperature, crushed and sieved to particle size of  $< 200$  microns. To obtain concentrate of minerals that determine behavior of salty coal in thermochemical processes, water extracts (WE) were used of the salty coal (SC) samples coming from the above deposits. Water extractions obtained from salty coal were optimized by the following parameters: time duration, temperature and ratio of solid and

water phases [11]. Samples of salty coal were mixed with distilled water in a special container with coal to water mass ratio – 1 : 3, and then stirred at a speed of 1000 rpm. at 35 °C temperature for 5 minutes. The water-coal slurry was then passed through a filter to a separate coal solid phase. The filtered coal was washed again for 1 minute. Subsequently, the resulting water extracts (both primary and secondary) were analyzed for total salt content using Conductivity/TDS/Temp Indicator Ezodo4805 (Table 4).

In other units, the salt content in the water extracts will be from 2.6 to 6.8 g/liter for the primary rinsing, and from 1 to 2.3 g/liter after secondary rinsing. It is seen that the first leaching removes the main proportion of salts – from 67 to 81.5 % of the total content.

To remove water from water extract, evaporation was used during the day at a temperature of 40–50 °C, until air-dry mixtures were obtained, which were further analyzed using a diffractometer DRON-4M (Cu (Co)  $K\alpha$ -radiation). The shooting of powder diffractograms (DFG) was done at the angles of 15–60° Theta stepwise, at every 0.04°. Interlayer depths in minerals were determined with an accuracy of 0.002 nm. The semi-quantitative phase analysis of diffractograms was performed using the MATCH\* software. The obtained results are presented in Figs. 1–5. The generalized characteristic of certain minerals is summarized in Table 5.

Fig. 1 shows the diffractogram of dry matter in water extract from the Novomoskovsk salty coal. It is seen that at least 4 varieties are present in the minerals from water extract, where the predominant substance is halite (81 %), and tenardite, gypsum and melanterite are presented by residual quantities (15, 10 and 8 % respectively).

Mineral composition of water extract from the Starobilsk salty coal No. 1413 (Fig. 2) appeared simple: in it, there prevails sodium chloride (about 85 %), in the residual quantity is gypsum  $\text{CaSO}_4 \cdot \text{H}_2\text{O} \sim 14\%$ . In water extract composition of another sample from Starobilsk salty coal No. 1416, a larger range of minerals was found: halite – 8 %, magnesium chloride – 20 %, melanterite ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ) – 25 %, gypsum – 33 %, and, judging from the reflexes with  $d = 3.05; 3.45 (48); 2.10$ , it is possible to note the presence of  $\text{CaCl}_2 (2-3\%)$ . Attention should be drawn to the very high content of gypsum, which must be taken into account when firing such coal, and when using the flushing water in case of industrial leaching.

Table 3

Characteristics of the samples of salty coals

Deposit	Ash $A^d$ , %	Volatiles $V^{daf}$ , %	Moisture $W$ , %	$\text{Na}_2\text{O}$ in ash, %	Sulfur S, %
Bohdanivsk No. 19	11.2	41.1	9.6	3.60	2.7
Bohdanivsk No. 25	5.3	42.8	12.7	6.92	1.2
Starobilsk No. 1416	11.8	47.4	14.3	3.39	5.4
Starobilsk No. 1413	7.3	43.7	20.3	6.57	2.8
Novomoskovsk	11.5	44.1	8.1	9.40	2.1

Table 4

Characteristics of water extracts from the SC

Deposit	Overall salinity	
	Primary extract TDS, ppm	Secondary extract TDS, ppm
Bohdanivsk No. 19	4680	2290
Bohdanivsk No. 25	5030	1900
Starobilsk No. 1416	2640	950
Starobilsk No. 1413	5570	2340
Novomoskovsk	6840	1550



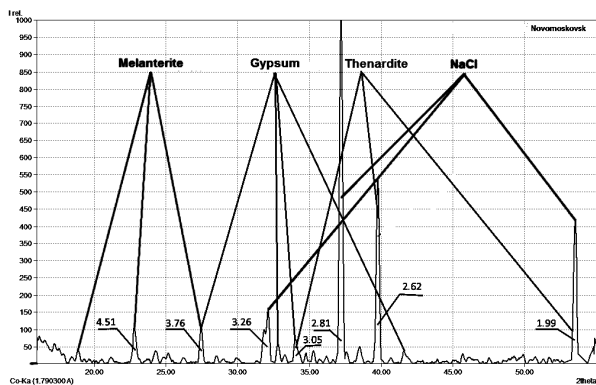


Fig. 1. The diffractograms of the water extract of salty coal from the Novomoskovsk deposit

After analysis of the diffractograms of water extract of salty coal from the Bohdanivsk deposit, we noticed relatively simple composition of the minerals in the case of salty coal from wells No. 19 (Fig. 3, a), where the predominant substance is gypsum (91 %), and the content of halite is only 9 %. Instead, the water extract of coal from well number 25 (Fig. 3, b) showed at least 4 minerals: halite – 17 %,  $\text{CaCO}_3$  – 29 %,  $\text{MgCl}_2$  – 35 %, anhydrite ( $\text{CaSO}_4$ ) – 19 %.

The results on presence of significant quantity of sulfates in water extracts were rather unexpected, assuming the data on the solubility of salts (Table 4). However, they confirmed the results from the 1990s, where, in WE from the Novomoskovsk SC, besides halite ( $\geq 75\%$ ), sulfates, gypsum and glauberite, were also found.

Finally, the study showed that despite similar values of salinity index – an elevated ( $\geq 2\%$ )  $\text{Na}_2\text{O}$  content in the ash, the so-called salty coals essentially differ from each other by mineral composition of water-soluble substances, even within one deposit. When burning coal, this will be significant, since fusible eutectics of minerals will require special approaches to the organization of the process. A detailed study on the mineral composition of salty coal will certainly be necessary upon the selection of fuel blends adapted for combustion in existing boilers.

Concerning the further fate of salty coal rinsing water, we consider it to be a secondary (and quite likely, valuable) resource rather than the waste, as these waters contain not only chemical elements and compounds (sodium, magnesium, calcium, chlorine anions, sulfate ions), but also the biologically active trace elements can be found. This reasonable thought is based on the data obtained on the wide variety and high content of a number of valuable (essential) trace elements (Cu, Zn, Mn,

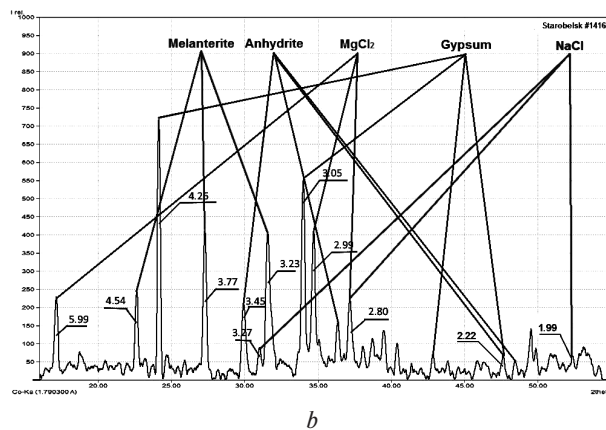
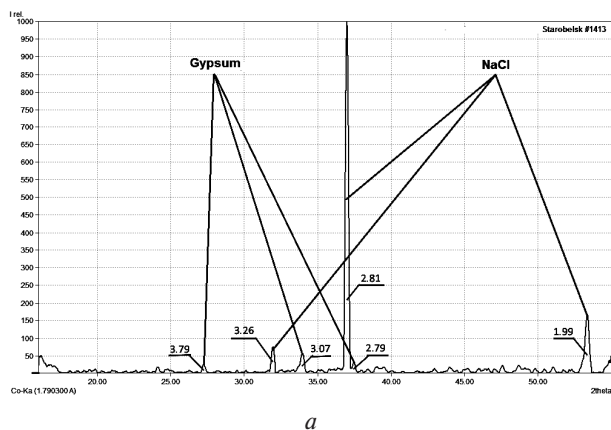


Fig. 2. Diffractograms of dry matter in WE of salty coal from the Starobelsk deposits: a – No. 1416; b – No. 1413

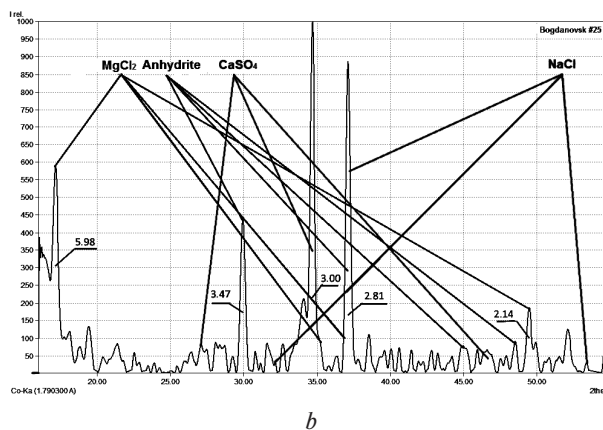
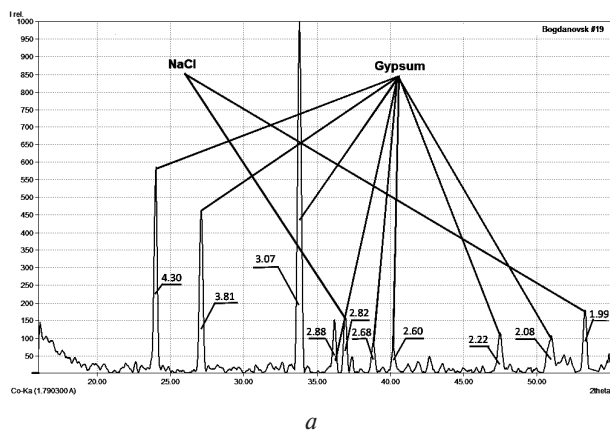


Fig. 3. Diffractograms of dry matter in WE of salty coal from the Bohdanivsk deposits: a – No. 19; b – No. 25

Characteristics of minerals found in water extract probes of salty coals

Mineral	Formula	MM, a.m.u.	Density, g/cm <sup>3</sup>	T <sub>mel</sub> , °C	Solubility in 100 g H <sub>2</sub> O (at 20°C)
Halite	NaCl	58.4	2.17	801	35.85 g
Magnesium Chloride	MgCl <sub>2</sub>	95.2	2.316	707	35.3 g
Calcium Chloride	CaCl <sub>2</sub>	110.9	2.51	772	74 g, 159 g (at 100 °C)
Calcium Sulfate (Anhydrite)	CaSO <sub>4</sub>	136.1	2.96	1420	0.2036 g, 0.067 g at 100 °C (precipitates)
Semi-dry Gypsum	CaSO <sub>4</sub> ·0.5H <sub>2</sub> O	145.1	2.67–2.73	Decomposed at 163 °C	Slightly soluble (as gypsum)
Gypsum	CaSO <sub>4</sub> ·2H <sub>2</sub> O	172.2	2.32	Decomposed at 128 °C	0.206 g (20 °C); 0.212 g (30 °C)
Tenardite	Na <sub>2</sub> SO <sub>4</sub>	142.0	2.68	883	19.2 g (20 °C); 42.3 g (100 °C)

Co, Fe) in salty coal (for instance, from Novomoskovsk deposit), and its chemical components (fulvic acids, humic acids). This is a reason why the aqueous extracts generated during the salty coal washing ensuring, on the one hand, unproblematic combustion of purified coal, should themselves become the object of scientific research by specialists; they could become an additional resource of water with medium mineralization (5–15 g/liter) to reduce the acidity of soils and increase the crop productivity. In view of the above study, for predominant ions, the salty coal washing water could, obviously, be classified as being chloride-sodium-calcium.

Secondly, in case of the need of fresh water (in particular, in the Northern Donbas) and taking into account the climate conditions, partial desalination of washing waters can be offered using the already developed and applicable methods [14], with the production of technical water and, simultaneously, of the salt concentrate to a certain economically and ecologically sound level, for example, to the level of high mineralization water (15–30 g/liter), which may be an additional resource for replenishing brine lakes and estuaries, which are abundant in Ukraine (Rapne lake, Slavyansk city; Solone lake, Arabatska Strilka; Kuyalnyk estuary, Odesa city, and others). The study of biological activity in the saline flushing water can also give additional impetus to identify ways to use this, at first glance, “waste”.

The technical and economic aspects of coal desalting and industrial use of flushing water generated during the enrichment of salty coals still require a wide range of specific inter-disciplinary studies.

**Conclusion.** The developed methods and techniques for desalting Ukrainian coals and studied specific features of the composition of fusible water-soluble compounds in the SC serve the energy and chemical technological basis for the involvement of salty coals to the energy balance of the country.

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## Енерготехнологічне підґрунтя для залучення солоного вугілля до енергобалансу України.

### 1. Склад водних екстрактів і перспективи їх утилізації

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Вугілля з підвищеним вмістом лужних і лужноземельних металів (солоне вугілля (СВ)) займає чинне місце серед резервних джерел енергії в Україні. Поклади СВ розташовані у промислових регіонах, воно має високі паливні показники й може незабаром стати суттєвою частиною сумішевих палив, що відповідатимуть стандартам України та зможуть кваліфіковано використовуватись на сучасних ТЕС. Для визначення раціональних способів залучення солоного вугілля до паливної галузі у світовій практиці широко застосовується детальне дослідження впливу природних мінеральних речовин на процеси шлакування, налипання й корозії при спалюванні такого вугілля.

**Мета.** Визначення складу природних водорозчинних мінералів-вугілля, що призводять до низки проблем при спалюванні, не руйнуючими методами, порівняльний аналіз складу мінеральних фаз СВ різних родовищ України, оцінка їхньої здатності до шлакування та огляд перспектив використання промивних вод, що утворюються при знесоленні вугілля.

**Методика.** Із використанням розроблених авторами технологічних режимів знесолення одержані водні екстракти СВ, що досліджені методом рентгенівської дифракції (прилад DRON 4M), та визначено склад їх сухих речовин за допомогою програми MATCH!. Загальний вміст солей та ефективність їх видалення з вугілля водою оцінено за допомогою приладу 4805 Conductivity TDS/Temp indicator/EZODO.

**Результати.** Визначено склад і особливості мінеральних фаз екстрактів СВ різних вітчизняних родовищ. За даними хімічного складу золи розраховано

фактор забруднення для СВ різних родовищ України, проведено порівняння із даними світових джерел. Показано, що навіть при близькому значенні вмісту оксиду натрію в золі, солоне вугілля різних родовищ за асортиментом (знайдено від 2 до 5 різновидів) нативних водорозчинних мінералів та їх співвідношенням суттєво розрізняється. Визначено, що у водних екстрактах двох зразків солоного вугілля превалюючими мінералами є сульфати, а не галіт.

**Наукова новизна.** Уперше виконано порівняльний напівкількісний аналіз нативних мінеральних фаз сухих водних екстрактів СВ трьох українських родовищ, узагальнені дані щодо умов ефективного знесолення вугілля. Розглянуті перспективи утилізації (захоронення) промивних вод, що утворюються при підготовці солоного вугілля до енергетичного використання.

**Практична значимість.** Завдяки детальним дослідженням сухих водних екстрактів і встановленню складу мінеральних фаз СВ стає можливим прогнозування: 1) утворення низькоплавких евтектик у процесі спалювання вітчизняного солоного вугілля та відповідного вибору спеціальних умов процесу, що запобігатимуть шлакуванню; 2) складу та поведінки сумішевих палив за участі СВ й іншого вугілля, що відрізняється значним вмістом тугоплавких сполук; 3) вибору певних мінеральних додатків (у т.ч. промислових відходів), що знижують ризики шлакування й корозії при спалюванні вітчизняного солоного вугілля.

**Ключові слова:** солоне вугілля, фактор забруднення, водна екстракція, нативні мінерали, хлориди, сульфати, утилізація промивних вод

## Енерготехнологическое основание для вовлечения соленых углей в энергобаланс Украины.

### 1. Состав водных экстрактов и перспективы их утилизации

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Угли с повышенным содержанием щелочных и щелочноземельных металлов (соленые угли (СУ)) занимают вполне определенное место среди резервных источников энергии в Украине. Месторождения СУ расположены в центральных промисловених регіонах, угли мають високі топливні показателі і можуть вскорі стать существенной частью смесевых топлив, которые будут соответствовать стандартам Украины и смогут квалифицированно использоваться на современных

ТЭС. Для определения рациональных способов вовлечения соленых углей в топливную отрасль в мировой практике широко применяется детальное исследование влияния природных минеральных веществ на процессы шлакования, налипания и коррозии при сжигании таких углей.

**Цель.** Определение состава природных водорастворимых минералов-углей, которые приводят к ряду проблем при сжигании, не разрушающими методами, сравнительный анализ состава минеральных фаз СУ разных месторождений Украины, оценка их склонности к шлакованию, а также обзор перспектив использования промывных вод, которые образуются при обессоливании углей.

**Методика.** С использованием разработанных авторами технологических режимов обессоливания получены водные экстракты СУ, которые исследованы неразрушающим методом рентгеновской дифракции (прибор DRON 4M), определен состав их сухих веществ при помощи программы MATCH!. Общее солесодержание и эффективность удаления соли из углей водой оценили при помощи прибора 4805 Conductivity TDS/Temp indicator/EZODO.

**Результаты.** Определен состав и особенности минеральных фаз экстрактов СУ разных отечественных месторождений. По данным химического состава золы рассчитан фактор загрязнения для СУ разных месторождений Украины, проведено сравнение с данными мировых источников. Показано, что даже при близком значении содержания оксида натрия в золе, соленые угли разных месторождений по ассортименту (обнаружено от 2 до 5 разновидностей) нативных водорастворимых ми-

нералов и их соотношению существенно различаются. Показано, что в водных экстрактах двух образцов СУ преобладающими минералами являются сульфаты, а не галит.

**Научная новизна.** Впервые выполнен сравнительный полуколичественный анализ нативных минеральных фаз сухих водных экстрактов СУ трех украинских месторождений, обобщены данные об условиях эффективного обессоливания углей. Рассмотрены перспективы утилизации (захоронения) и использования промывных вод, образующихся при подготовке соленых углей к энергетическому применению.

**Практическая значимость.** Благодаря детальным исследованиям сухих водных экстрактов и установлению состава минеральных фаз СУ стало возможным прогнозирование: 1) образования низкоплавких эвтектик в процессе сжигания отечественных соленых углей и соответствующего выбора специальных условий процесса, которые будут препятствовать шлакованию; 2) состава и поведения смесевых топлив при участии СУ и другого угля, который отличается значительным содержанием тугоплавких минералов; 3) выбора определенных минеральных добавок (в т.ч. промышленных отходов), которые снижают риски шлакования и коррозии при сжигании отечественных соленых углей.

**Ключевые слова:** соленые угли, фактор загрязнения, водная экстракция, нативные минералы, хлориды, сульфаты, утилизация промывных вод

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