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STUDY OF THE CHEMICAL AND MINERALOGICAL COMPOSITION OF THERMAL POWER PLANT WASTES

NAZHIMOVA NURSULUU

Applicant at Karakalpak State University

SEITNAZAROVA OKSANA

Associate Professor, Karakalpak State University

MALLABAYEV ODILJON

Associate professor, Namangan State Technical University, Namangan, Uzbekistan

Phone.: (0594) 270-7722

*Corresponding author

ABDUKODIROV ELYOR

Associate professor, Namangan State Technical University, Namangan, Uzbekistan

Phone.: (0593) 698-3121

Abstract: The paper presents the results of a comparative study of ash–sludge wastes generated from the combustion of coal and natural gas at the Takhiatash Thermal Power Plant. Using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) methods, the morphological and chemical differences between the studied samples were determined. It was shown that coal-derived ash–sludge wastes are characterized by a porous, heterogeneous structure and a high content of silicon, aluminum, and calcium; whereas gas-derived wastes predominantly contain iron oxides and exhibit a denser and more homogeneous structure. The obtained results indicate the potential applicability of these technogenic materials as sorbents, catalysts, and additives in construction composites.

Keywords: Takhiatash Thermal Power Plant, ash–sludge wastes, coal, natural gas, SEM, EDX, morphology, utilization.

Introduction. Ash–sludge wastes from thermal power plants represent a significant technogenic resource formed as a result of fuel combustion and require scientific analysis for the development of rational utilization strategies [1–3]. Under the conditions of intensified energy production and the transition to more environmentally friendly types of fuel, the issues related to the management of ash–sludge wastes have become particularly relevant [4–8]. The Takhiatash Thermal Power Plant (TPP), being one of the largest energy facilities in the northwestern region of Uzbekistan, operated on coal fuel for an extended period. However, in recent years, natural gas has become the primary energy source. This transition has led to changes in the nature and composition of the generated wastes, necessitating a detailed comparative study of their morphological and chemical characteristics.

Ash–sludge wastes generated from coal combustion (CCW) accumulate in large quantities and often pose serious environmental challenges due to the extensive storage areas and dust formation. At the same time, they can be considered a promising raw material for secondary use, particularly in the production of construction materials, sorbents, and adsorption-active systems [9–12]. Wastes resulting from natural gas combustion (NGW) are produced in smaller amounts; however, their accumulation has also become a noticeable factor contributing to the technogenic impact on the environment [12–18].

In this regard, a comprehensive study of the composition and structure of ash–sludge wastes of different origins is of particular importance, as it enables the assessment of their potential technological value. The analysis of the physicochemical properties, morphology, and elemental composition of these wastes constitutes a key stage in determining the optimal pathways for their processing and integration into economic circulation.

The aim of the present study is to conduct a comparative investigation of the morphological and elemental features of ash–sludge wastes from the Takhiatash Thermal Power Plant, generated during the combustion of coal and natural gas, using modern analytical techniques—scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and CHNS/O elemental analysis. The obtained results make it possible not only to identify the structural and chemical differences between the two types of ash–sludge wastes but also to determine potential directions for their application as sorbents or components of composite materials.

Experimental Section

Objects of Study.

Two types of ash–sludge wastes generated at the Takhiatash Thermal Power Plant were selected as the objects of study: coal combustion wastes (CCW) and wastes produced during the operation of the plant on natural gas (NGW). Coal-derived ash–sludge represents large-scale technogenic formations, with quantities reaching hundreds of thousands of tons, accumulating in storage sites and exerting a significant impact on the environment. In contrast, ash–sludge from natural gas combustion is generated in much smaller volumes, approximately 15–20 tons per year.

However, in recent years, the Takhiatash Thermal Power Plant has predominantly operated on natural gas, leading to a gradual increase in the volume of gas-derived ash–sludge. Their accumulation is becoming increasingly significant, creating both environmental and economic challenges. In this context, the study of the properties and the development of effective processing methods for both types of ash–sludge is a relevant task aimed at reducing technogenic impact and integrating these wastes into economic circulation as secondary material resources.

Scanning Electron Microscopy (SEM) on the JEOL JSM-IT200 Microscope

The scanning electron microscopy (SEM) method was employed for a detailed investigation of the morphology of ash–sludge wastes, including particle shape, size, and agglomeration. The JEOL JSM-IT200 microscope provides high-resolution imaging, enabling the study of the surface structure of ash–sludge and the identification of potential porous or glassy phases.

CHNS/O Elemental Analysis Using the FlashSmart Analyzer (Thermo Scientific)

The FlashSmart elemental analyzer was used to determine the mass fractions of carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) in the ash–sludge samples. This method is critically important for assessing the residual content of unburned carbon in the ash–sludge, which can influence their physicochemical properties and potential applications.

Results and Discussion. Figures 1 and 2 show the microscopic images of the studied samples.

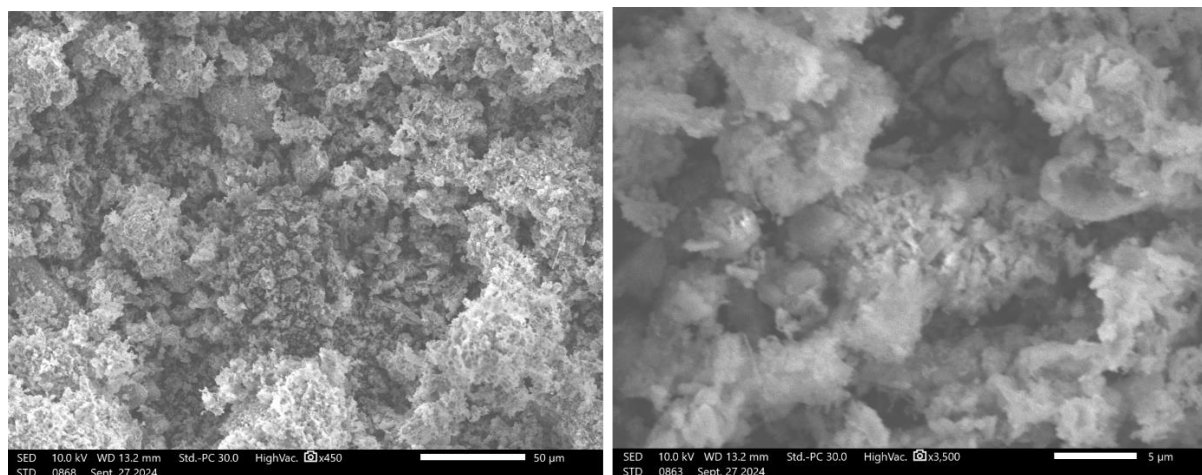


Figure 1. Microscopic images of coal combustion ash-sludge (CCW)

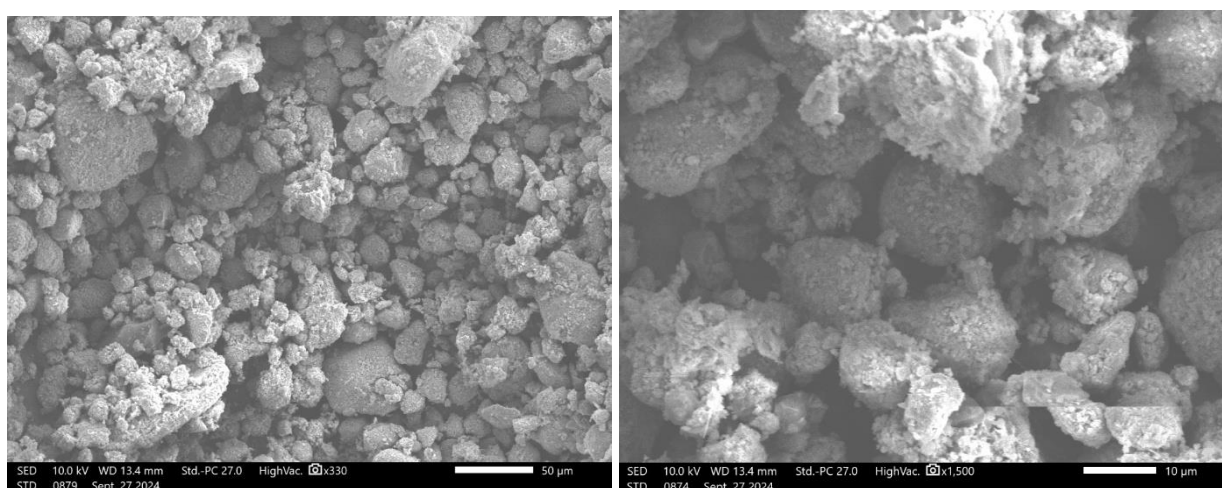


Figure 2. Microscopic images of natural gas combustion ash-sludge (NGW)

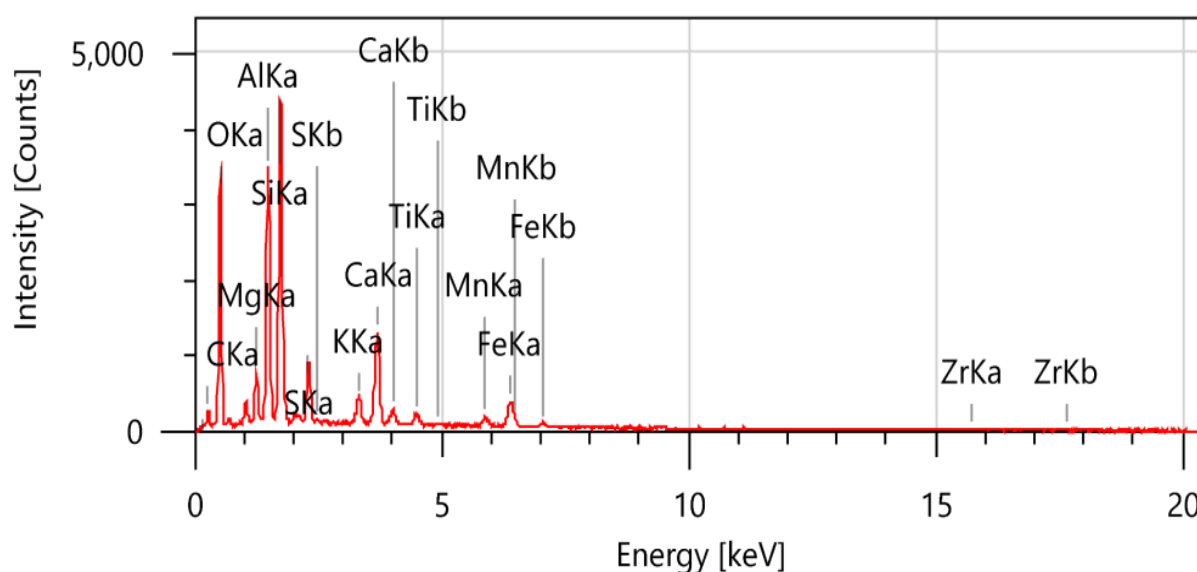
Microstructural Analysis of Ash-Sludge from the Takhiatash Thermal Power Plant.

The analysis of microscopic images of ash-sludge generated from coal combustion (CCW) and natural gas combustion (NGW) revealed significant differences in their morphology and structure.

In the CCW samples, pronounced particle agglomeration is observed, with particles varying in size and shape. The particles predominantly exhibit irregular configurations, with rough surfaces and a well-developed porous structure. Fragment sizes range from a few micrometers to several tens of micrometers, indicating the heterogeneous nature of the system. The presence of microcracks and porous inclusions may suggest residual carbon content and potentially high sorption activity of the material.

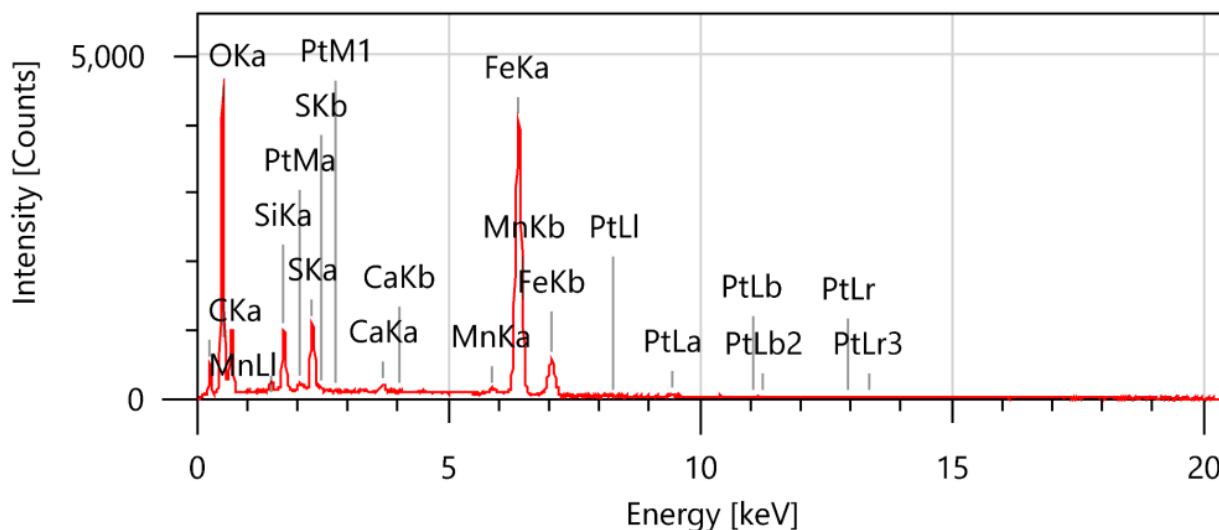
In contrast, the microstructure of NGW is characterized by the predominance of rounded particles that are more uniform in size. The particle surfaces appear smooth, with a lower degree of porosity. This morphology is typical for ash–sludge formed during the high-temperature combustion of natural gas, where gaseous combustion products promote the formation of dense, low-porosity structures.

Thus, coal-derived wastes (CCW) are characterized by higher heterogeneity, a loose texture, and well-developed porosity, whereas gas-derived wastes (NGW) exhibit a more compact and homogeneous structure. These differences directly influence their physicochemical and adsorption properties, determining the potential directions for the further use of the studied ash–sludge as sorbents and composite materials.



Element	Line	Mass%	Atom%
C	K	8.05±0.22	13.88±0.37
O	K	42.42±0.48	54.88±0.62
Mg	K	2.32±0.07	1.97±0.06
Al	K	10.40±0.13	7.98±0.10
Si	K	14.75±0.17	10.87±0.12
S	K	3.46±0.08	2.23±0.05
K	K	1.94±0.06	1.03±0.03
Ca	K	7.36±0.13	3.80±0.07
Ti	K	1.14±0.06	0.49±0.03
Mn	K	1.47±0.09	0.55±0.03
Fe	K	5.57±0.16	2.07±0.06
Zr	L	1.11±0.08	0.25±0.02
Total		100.00	100.00
Spc_004			Fitting ratio 0.0289

Figure 3. Results of energy-dispersive X-ray (EDX) analysis of the coal combustion waste sample



Element	Line	Mass%	Atom%
C	K	9.18±0.17	20.48±0.37
O	K	28.14±0.27	47.12±0.46
Al	K	0.43±0.03	0.43±0.03
Si	K	2.80±0.07	2.68±0.07
S	K	3.24±0.07	2.71±0.06
Ca	K	0.45±0.03	0.30±0.02
Mn	K	0.70±0.06	0.34±0.03
Fe	K	53.68±0.45	25.75±0.21
Pt	M	1.37±0.09	0.19±0.01
Total		100.00	100.00
Spc_005		Fitting ratio 0.0156	

Figure 4. Results of energy-dispersive X-ray (EDX) analysis of the natural gas combustion waste (NGW) sample

Energy-dispersive X-ray (EDX) analysis enabled the determination of the elemental composition of ash–sludge generated from coal combustion (CCW) and natural gas combustion (NGW), revealing significant differences between them.

In the CCW sample (Figure 3), oxygen (42.42 wt.%) and silicon (14.75 wt.%) predominate, indicating a significant presence of silicate compounds, primarily quartz and aluminosilicates. A considerable amount of aluminum (10.40 wt.%) confirms the presence of mullite and kaolinite phases, which are typical for coal combustion products. Calcium (7.36 wt.%) and sulfur (3.46 wt.%) may be associated with the formation of sulfate and carbonate compounds. The presence of magnesium, potassium, titanium, and manganese in the range of 1–2 wt.% indicates minor mineral phases such as magnesian and potassium silicates, and titanium and manganese oxides. Small amounts of iron (5.57 wt.%) and zirconium (1.11 wt.%) were also detected, which may be present in oxide or zirconate forms. Thus, the composition of CCW indicates a predominantly silicate–oxide

nature of the ash–sludge, formed during high-temperature coal combustion and containing residual carbon inclusions (8.05 wt.%).

In the NGW sample (Figure 4), a markedly different elemental composition is observed. The iron content increases to 53.68 wt.%, indicating the predominance of iron oxides (possibly Fe_2O_3 and Fe_3O_4) formed during the high-temperature combustion of natural gas. At the same time, the concentrations of silicon (2.80 wt.%) and aluminum (0.43 wt.%) are significantly lower, reflecting a minimal presence of silicate phases. The oxygen content (28.14 wt.%) is also lower than in the coal-derived sample, while the carbon content rises to 9.18 wt.%, which may be associated with residual carbon compounds and products of incomplete combustion. The presence of platinum (1.37 wt.%) is due to the use of a platinum coating during sample preparation for analysis.

Conclusion. The conducted study demonstrated that ash–sludge wastes from the Takhiatash Thermal Power Plant, generated during the combustion of coal (CCW) and natural gas (NGW), differ significantly in terms of morphology and chemical composition.

CCW is characterized by well-developed porosity, a heterogeneous structure, and high contents of silicon, aluminum, and calcium, indicating a silicate–aluminosilicate nature and making it promising for use as a sorbent and mineral additive. In contrast, NGW consists predominantly of iron oxides and carbon, exhibits a denser and more homogeneous structure, and may be suitable for catalytic and adsorption applications.

The obtained data confirm the feasibility of the rational processing of both types of ash–sludge and their integration into economic circulation, contributing to the reduction of environmental impact and the efficient utilization of technogenic resources.

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