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PHYSICOCHEMICAL PROPERTIES OF AYDARKUL BASALT AND ITS EVALUATION AS A PROMISING RAW MATERIAL FOR BASALT-CELLULOSE COMPOSITE CATION EXCHANGERS

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Abstract

This article presents a comprehensive analysis of the physicochemical properties of basalt samples from the Aydarkul deposit in the Republic of Uzbekistan. The chemical composition of the samples was studied using XRF, mineralogical composition via XRD, functional groups by FTIR, morphology with SEM, and thermal stability through DTA/TGA methods. The research established that the basalt is a high-silica aluminosilicate composed mainly of SiO_2, Al_2O_3, Fe_2O_3, CaO, and MgO oxides. Mineralogical analysis revealed the predominance of plagioclase and quartz phases. Thermal analysis confirmed the material's stability at high temperatures. These findings allow for the recommendation of Aydarkul basalt as a promising mineral raw material for producing ion-exchange composite filter materials.

Keywords: *basalt, Aydarkul, XRF, XRD, FTIR, SEM, DTA, TGA, aluminosilicate, filter material*

Introduction:

In recent years, the rapid development of global industry, limited water resources, and the growing anthropogenic impact on the environment have sharply increased the demand for high-efficiency filter and sorption materials (Fu, F., & Wang, Q., 2019; Crini, G., & Lichtfouse, E., 2019; Kyzas, G. Z., & Matis, K. A., 2020; Hubbe, M. A., Hasan, S. H., & Ducoste, J. J., 2021; Mohan, D., Pittman, C. U., & Bricka, M., 2020). Particularly, filter materials used in the oil and gas, chemical, metallurgical, mining, food, and drinking water preparation sectors are subject to high standards, including

mechanical strength, chemical stability, heat resistance, and a well-developed porous structure (Crini, G., & Lichtfouse, E., 2019; Hubbe, M. A., Hasan, S. H., & Ducoste, J. J., 2021; Mohan, D., Pittman, C. U., & Bricka, M., 2020). For this reason, the development of new composite materials based on natural mineral raw materials is currently one of the important scientific directions in the fields of materials science and chemical technology (Fu, F., & Wang, Q., 2019; Kyzas, G. Z., & Matis, K. A., 2020; Mohan, D., Pittman, C. U., & Bricka, M., 2020). Among natural minerals, basalt is considered one of the most promising rocks due to its favorable physical-mechanical and chemical properties (Teixeira, F. G., et al., 2021; Fiore, V., Scalici, T., Di Bella, G., & Valenza, A., 2020; Abdurakhmanov, S. A., Rashidova, R., Mamatkarimova, B., & Sattarov, L. K., 2015). Basalt is of magmatic origin, and its composition primarily consists of a complex of aluminosilicate minerals containing mainly silicon, aluminum, iron, calcium, and magnesium oxides (Abdurakhmanov, S. A., Rashidova, R., Mamatkarimova, B., & Sattarov, L. K., 2015). This mineral composition gives basalt important operational properties, including high strength, low porosity, abrasion resistance, and stability at elevated temperatures and in aggressive chemical environments (Teixeira, F. G., et al., 2021; Fiore, V., Scalici, T., Di Bella, G., & Valenza, A., 2020). Therefore, basalt is widely used in the production of building materials, mineral fibers, thermal insulation materials, composite materials, catalyst carriers, and various filter media (Teixeira, F. G., et al., 2021; Fiore, V., Scalici, T., Di Bella, G., & Valenza, A., 2020; Abdurakhmanov, S. A., Rashidova, R., Mamatkarimova, B., & Sattarov, L. K., 2015). In global practice, significant attention is being paid to the use of basalt-based materials in mechanical and sorption treatment systems for water and industrial solutions (Fu, F., & Wang, Q., 2019; Kyzas, G. Z., & Matis, K. A., 2020; Mohan, D., Pittman, C. U., & Bricka, M., 2020; Kamolov B. S., Kurbanov A. A., Sattorov L. K., 2023). Furthermore, the physicochemical characteristics of basalt and the possibility of improving the quality and functional properties of basalt-based products have been investigated in studies conducted on Uzbek mineral resources (Abdurakhmanov, S. A., Rashidova, R., Mamatkarimova, B., & Sattarov, L. K., 2015). One of the primary requirements for raw materials used in filter-material production is their ability to maintain physical and chemical stability during long-term operation. In this regard, basalt has significant advantages over many synthetic materials because of its high mechanical strength, thermal stability, and resistance to aggressive operating environments (Teixeira, F. G., et al., 2021; Fiore, V., Scalici, T., Di Bella, G., & Valenza, A., 2020). Studies of basalt-based filter materials have also demonstrated their suitability for filtration processes under different operational conditions (Kamolov B. S., Kurbanov A. A., Sattorov L. K., 2023). Their main advantage lies in the strong spatial lattice structure formed by Si–O–Al bonds within their composition. This structure contributes to high thermal stability, chemical resistance, and mechanical strength (Kyzas, G. Z., & Matis, K. A., 2020; Mohan, D., Pittman, C. U., & Bricka, M., 2020). As a result, their cation-exchange capacity, sorption activity, and selectivity can be significantly enhanced (Wang, J., & Guo, X., 2021; Foo, K. Y., & Hameed, B. H., 2020). In particular, pseudo-second-order kinetics has been widely applied to describe sorption processes and to evaluate the contribution of surface interactions to adsorption behavior (Ho, Y. S., & McKay, G., 2019). Basalt deposits located in the Jizzakh, Navoi, Samarkand, Kashkadarya, and other regions of the republic are distinguished by their mineral composition, chemical stability, and favorable strength characteristics. Previous investigations have focused on basalt production, processing technologies, product-quality improvement, and the development of basalt-based filtering and thermal-insulating materials in Uzbekistan (Abdurakhmanov, S.A., Rashidova, R., Mamatkarimova, B., & Sattarov, L. K., 2015).

Materials and research methods:

Natural basalt samples from the Aydarkul deposit, located in the Jizzakh region of the Republic of Uzbekistan, were used as the object of this research. Aydarkul basalt has high mechanical strength, chemical stability, and an aluminosilicate mineralogical composition, making it a promising local mineral raw material for producing filter materials and functional composites. For analysis, the basalt samples were first crushed to

a size of 5–10 mm in a mechanical crusher. They were then ground in a laboratory ball mill, and a fraction smaller than 100 μm was separated to ensure particle uniformity. The ground samples were dried to a constant weight at 105 °C and stored in hermetically sealed containers. Subsequent physicochemical analyses were carried out on these prepared samples.

X-ray fluorescence (XRF) spectrometry was employed to determine the elemental and oxide composition of the basalt samples. This is a non-destructive instrumental method that allows for a high-precision assessment of the chemical composition of rocks and silicate materials. Measurements were performed using standard calibration samples. The content of the main oxides–SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, and K_2O – was calculated.

X-ray diffraction (XRD) analysis was conducted to determine the mineralogical and phase composition. The analysis was performed on a diffractometer operating with Cu–Kα radiation (λ = 1.5406 Å).

Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify the functional groups and chemical bonds of the samples.

Based on the FTIR spectra, vibrations corresponding to OH-hydroxyl groups and Si–O–Si, Si–O–Al, Al–O, and Fe–O bonds were analyzed. This data allowed for further confirmation of the aluminosilicate structure and mineralogical composition of the basalt.

Scanning electron microscopy (SEM) was used to study the microstructure and morphology of the basalt samples. The particle shape, size, degree of aggregation, porosity, and surface morphology were evaluated through SEM analysis.

Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were performed to assess the thermal stability of the basalt. The analyses were conducted in an air atmosphere within the temperature range of 25–1000 °C at a heating rate of 10 °C/min.

Results and Discussion

XRF analysis of the chemical composition of Aydarkul basalt

The chemical composition of basalt is one of the most critical indicators that determines its areas of technological application. Specifically, in the production of filter materials for water purification, the quantity of silicon, aluminum, iron, calcium, and magnesium oxides within the mineral composition directly influences the material's mechanical strength, chemical stability, and surface activity. For this reason, the elemental composition of the Aydarkul basalt samples was determined using X-ray fluorescence (XRF) analysis. Six samples, taken from various locations within the Aydarkul deposit, were selected for analysis. Each sample was dried, crushed, and formed into a pressed tablet under laboratory conditions. Their chemical composition was then analyzed using an XRF spectrometer. The analysis results are presented in Table 1.

Table 1. *Average chemical composition of Aydarkul basalt samples (XRF analysis)*

Sample	SiO_2, %	Al_2O_3, %	Fe_2O_3, %	CaO, %	MgO, %	Na_2O+K_2O, %
A-1	50,8	14,2	9,6	8,9	6,3	3,9
A-2	49,7	13,8	10,1	9,1	6,7	4,1
A-3	51,2	14,8	8,9	8,5	5,9	3,7
A-4	47,5	12,0	10,5	9,3	7,1	4,2
A-5	48,9	13,1	9,2	8,7	6,0	3,8
A-6	50,1	14,0	9,8	8,9	6,5	4,0
Medium	**49,7**	**13,65**	**9,68**	**8,90**	**6,42**	**3,95**

Source: results of the author's XRF analysis

As the table data indicates, silicon dioxide (SiO_2) constitutes the largest proportion of the Aydarkul basalt's composition. Its content ranges from 47.5% to 51.2%, with an average value of 49.7%. This high proportion of silicon dioxide indicates the aluminosilicate nature of

the basalt and is a key factor ensuring its high mechanical strength, heat resistance, and chemical stability.

The second primary component is aluminum oxide (Al_2O_3), the content of which was observed to vary between 12.0% and 14.8%. Aluminum oxide forms strong spatial bonds within the silicate structure, enhancing the material's hardness and corrosion resistance. Concurrently, Al_2O_3 contributes to the formation of active centers on the surface, which increases the efficiency of subsequent chemical modification processes.

The average content of iron oxide (Fe_2O_3) was 9.68%. In addition to determining the natural color of basalt, iron oxides also have a certain influence on its magnetic properties, catalytic activity, and electronic structure. Furthermore, the presence of iron oxides can enhance its ability to interact with heavy metal ions.

Calcium oxide (CaO) and magnesium oxide (MgO) constituted an average of 8.90% and 6.42%, respectively. These oxides are considered the main components of plagioclase and pyroxene minerals, ensuring the mineralogical stability of basalt. Calcium and magnesium oxides positively affect the material's hydraulic properties and, in some cases, ion-exchange processes.

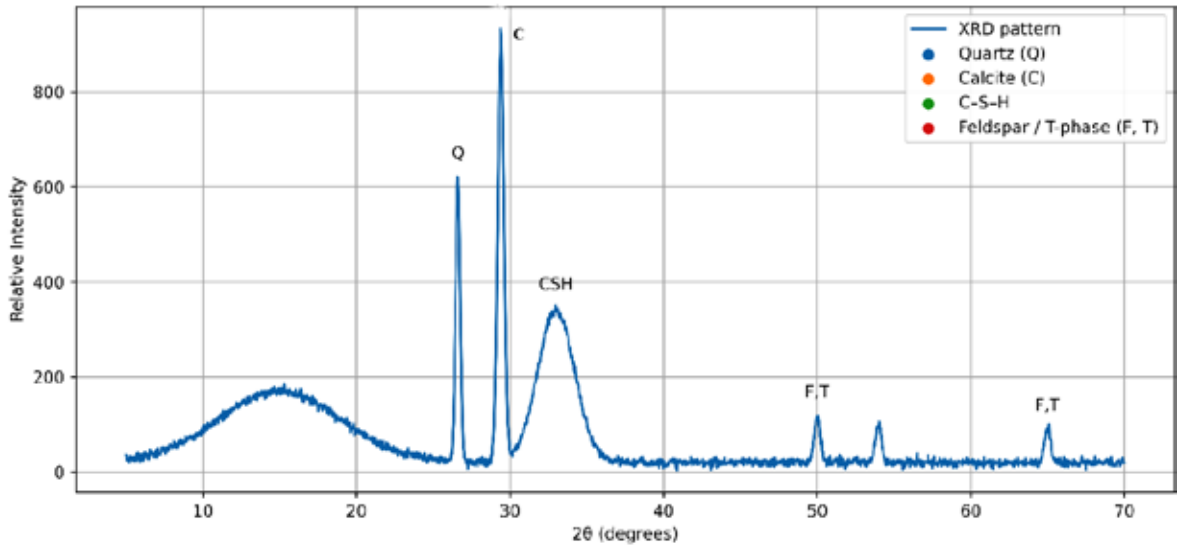
The total amount of alkali metal oxides ($Na_2O + K_2O$) is around 3.5–4.2%, which indicates that the chemical composition of the basalt is relatively stable. Their quantity has a certain effect on the vitrification properties of the mineral and its structural changes at high temperatures.

XRD analysis of the mineralogical composition of Aydarkul basalt

The mineralogical composition of basalt is a key factor that determines its physicochemical properties, chemical stability, and efficiency in various technological applications. For this reason, X-ray diffraction (XRD) analysis was performed to determine the phase composition of the Aydarkul basalt samples. This method is considered one of the most reliable instrumental analysis techniques in materials science, as it allows for a high-precision assessment of the crystal structure and phase state of minerals.

The analysis was conducted using Cu–Kα radiation (λ = 1.5406 Å) in the 2θ range of 10–70°. The resulting diffractograms were compared with the international ICDD (International Centre for Diffraction Data) database to identify the mineral phases.

Figure 1. *XRD diffractogram of Aydarkul basalt*



Analysis of the diffractogram revealed that the bulk of the sample is composed of well-crystallized aluminosilicate minerals. The intense diffraction maxima observed in the diffractogram confirm the presence of plagioclase minerals, quartz, and iron oxide phases, which are characteristic of basalt.

The high-intensity peaks located in the 26–30° region are primarily attributed to the quartz (SiO_2) phase, indicating a high concentration of silicon dioxide. This result is in full agreement with the SiO2 content determined by XRF analysis. Silicon dioxide is the main mineral component responsible for the high mechanical strength, hardness, and abrasion resistance of basalt.

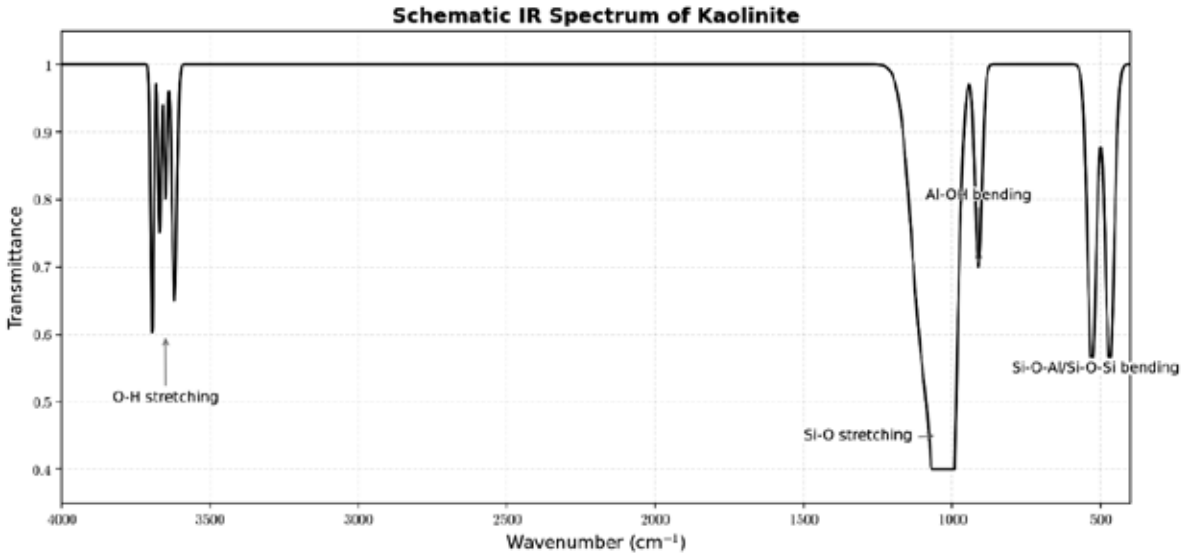
The diffraction maxima recorded in the 31–34° range correspond to plagioclase minerals, which are composed of calcium and sodium aluminosilicates. The predominance of the plagioclase phase further confirms the magmatic origin of the basalt. In addition to ensuring the material's resistance to high pressures, these minerals are crucial for maintaining mechanical stability during the preparation of filter materials.

The relatively low-intensity peaks observed in the 50–55° and 62–66° regions correspond to iron oxides-mainly the hematite (Fe_2O_3) and magnetite (Fe_3O_4) phases. The presence of iron oxides is characteristic of the natural mineralogical composition of basalt and can serve to increase surface activity during subsequent chemical modification processes. Furthermore, these oxides also have a certain influence on the material' catalytic properties.

FTIR analysis of functional groups in Aydarkul basalt

Fourier Transform Infrared Spectroscopy (FTIR) is a crucial instrumental analysis method for the in-depth study of the chemical nature and surface structure of basalt. This method enables the identification of chemical bonds and functional groups within the material. The presence of hydroxyl (–OH), silicate (Si–O–Si), aluminosilicate (Si–O––Al), and metal-oxygen (Fe–O, Al–O) bonds, which are involved in sorption processes, is particularly significant in the production of filter materials. Aydarkul basalt samples were analyzed using an FTIR spectrometer in the 4000–400 cm-1 range. The resulting spectra allowed for the evaluation of the mineral's primary functional groups and the chemical structure of its silicate framework.

Figure 2. *FTIR spectrum of the Aydarkul basalt*



The results of the spectral analysis revealed a broad absorption band in the 3400––3450 cm^{-1} region. This band corresponds to the stretching vibrations of hydroxyl (–OH) groups. The presence of hydroxyl groups is attributed to water molecules adsorbed on the mineral surface, as well as structural hydroxyls within the silicate minerals.

Furthermore, the preservation of high-intensity Si–O–Si and Si–O–Al bonds shows that the material's silicate framework is not compromised during the modification process. This is a crucial factor for the long-term operational life of filter materials.

The obtained FTIR results showed good agreement with the XRF and XRD analyses. All instrumental analyses confirmed that

Aydarkul basalt is a high-silica aluminosilicate mineral and that its structure is suitable for the production of filter materials.

International studies have noted that the main FTIR bands for natural basalts are observed around 3400, 1640, 1030, 790, and 520 cm^{-1} (Kurbonov A. et al. 2023). The spectral characteristics of Aydarkul basalt are in full agreement with this data, which demonstrates the reliability of the research results.

Table 2. *Main absorption bands observed in the FTIR spectrum of Aydarkul basalt*

Wave number, cm^{-1}	Functional group	Comment
3400–3450	–OH	Hydroxyl groups
1630–1650	H–O–H	Adsorbed water
1030–1050	Si–O–Si	Silicate framework
780–800	Si–O	Quartz phase
650–700	Al–O	Aluminosilicates
500–600	Fe–O, Mg–O	Iron and magnesium oxides

FTIR analysis confirmed that Aydarkul basalt is an aluminosilicate mineral with a highly developed silicate framework. The hydroxyl groups identified in the spectrum indicated the reactivity of the material's surface for chemical modification. The high intensity of the Si–O–Si and Si–O–Al bonds proved that the mineral possesses a robust spatial structure. These results reaffirm the high potential of Aydarkul basalt for the development of basalt-cellulose-based cation-exchange filter materials. SEM analysis demonstrated that the surface of Aydarkul basalt is not smooth but possesses a multi-level relief. The high degree of surface heterogeneity creates favorable conditions for the diffusion and adsorption of heavy metal ions onto the mineral surface.

Table 3. *Morphological characteristics of Aydarkul basalt based on SEM analysis*

Parameter	Result	Importance for filter materials
Particle shape	Multifaceted	High mechanical stability
Surface texture	Uneven	Increased sorption centers
Micropores	Advanced	Increased specific surface area
Pore diameter	0.5–5 μm	Unrestricted water flow
Microcracks	Available	Enhances ion diffusion
Crystal structure	Well-formed	Thermal and mechanical stability

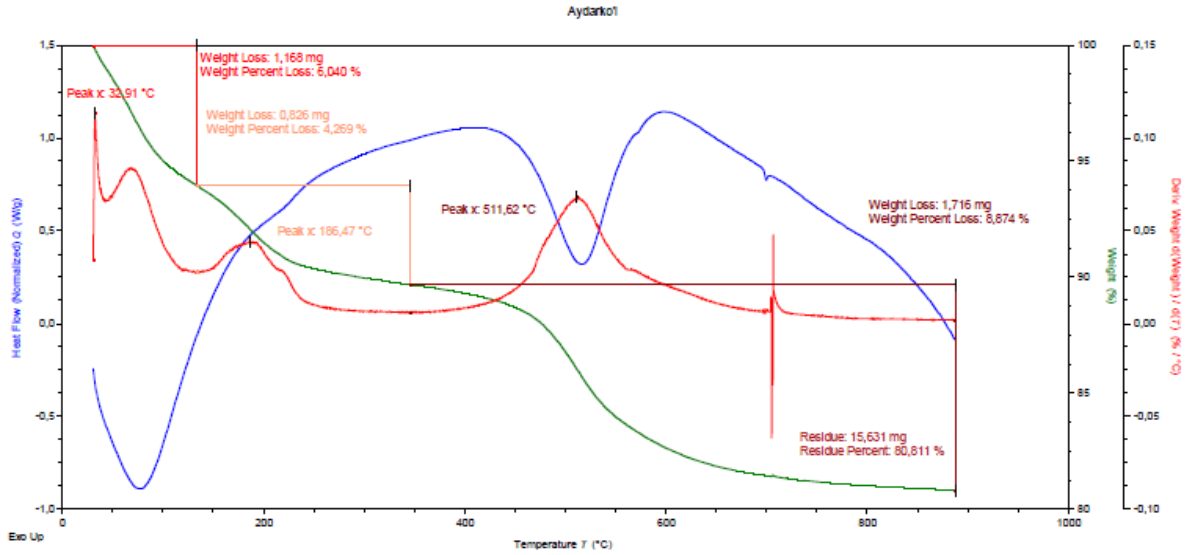
Based on the results of SEM analysis, it was determined that the Aydarkul basalt has a highly developed microporous morphology.

The thermal properties of Aydarkul basalt samples were investigated using differential thermal analysis (DTA) and thermogravimetric analysis (TGA). The samples were analyzed in the temperature range of 25–1000 °C at a heating rate of 10 °C/min.

Analysis of the TGA curve revealed that the total mass loss during the heating process is relatively low, indicating the mineral's high thermal stability. The change in mass occurred primarily in three stages.

Stage I (25–200 °C). In the first stage, the mass loss was approximately 0.8–1.2%. This change is mainly attributed to the evaporation of water molecules physically adsorbed onto the mineral's surface.

Figure 3. *DTA and TGA curve analysis of Aydarkul basalt*



Conclusion:

In this study, the chemical composition, mineralogical properties, functional groups, microstructure, and thermal stability of natural basalt from the Aydarkul deposit in Uzbekistan were comprehensively evaluated using a suite of instrumental analysis methods (XRF, XRD, FTIR, SEM, and DTA/TGA). The obtained results demonstrated the consistency of data across various analytical techniques and scientifically substantiated that this mineral is a local aluminosilicate raw material with high potential for the production of filter materials.

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