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"Comprehensively analyzing the structural framework and chemical properties of natural and synthetic zeolites"

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Abstract: Much of the current consumption of zeolites is in adsorption, catalysis, ion exchange and environmental cleaning, and the larger surface reactivity and new, porous, structures peculiar to zeolites. The experiment examines the structure of natural and synthetic zeolites, as well as their chemical properties, comparing the two via the techniques of physicochemical characterization. They were used on synthetic zeolites created by hydrothermal pathway and natural zeolites in order to compare the differences in the crystallinity, pore structure, chemical composition, thermal of the mineral that produces zeolites. This was done with different types of analysis including, biological surface, and energy-dispersive X-ray spectrophotometry (EDX). The findings showed that synthetic zeolites were purer with evenly spacing pores and better surface area as compared to natural zeolites which were found to be more thermal resistant and also cheaper. The paper has revealed the significance of structural and chemical properties in the evaluation of the industrial potential of zeolites and the role of environmentally friendly approaches of their synthesis in the future.

Keywords: Zeolites, Natural Zeolites, Synthetic Zeolites, Structural Analysis, Chemical Properties, Hydrothermal Synthesis, XRD, SEM, FTIR, Adsorption Studies

Introduction:

Zeolites are crystallized primarily a compound of silicon, aluminum and oxygen elements in a structure referred to as a three-dimensional framework. Interconnected pores and channels of molecular dimensions are interwoven with these materials, selectively adsorbing, exchanging ions and reacting in catalytic reactions. Zeolites have a unique porous structure and surface activity, which has rendered them one of the most important materials in environmental engineering, petrochemical sector, agriculture, water purification technology and gas separation technologies.

In 1756, and later in the names given to this mineralogist term by others, this mineralogist term was named zeolite when he found that certain minerals could give out steam when heated. The word takes its name based on the Greek words of zeo or boil and lithos or stone. Ever since then, the investigation of the structural chemistry of zeolites, the process of their production and the industrial application has been a popular topic of discussion among the scientific community.

Zeolites have the tetrahedrally-shaped units of SiO 4 and AlO 4 in their structure which are joined with the assistance of oxygen atoms. The framework itself is substituted with aluminum giving the framework a negative charge that is neutralized by exchangeable cations (sodium, potassium, calcium and magnesium). It belongs to the most significant properties of zeolites that can make them effective in adsorption and purification.

Zeolites structure design provides highly ordered and microporous channels and cavities that selectively adsorb molecules, according to size and polarity. The size-selective separation enables zeolites to be applicable in industrial separation, catalytic cracking in petroleum refining, and environmental remediation technology. Additionally, zeolites are also thermal stable, highly chemical resistant and with a large adsorption capacity hence can also be utilized in the technology advanced applications.

The zeolites are further categorised into two namely natural zeolites and synthetic zeolites. Natural zeolites are naturally formed during volcanoes, and sedimentation processes in geologic time, that is, millions of years. They normally occur in volcanic rocks and alkaline lakes. Some of the natural zeolites commonly found are, clinoptilolite, mordenite, chabazite and analcime. The economy of the natural zeolites is viable since they are not only abundant but also cheap to mining. They have extensive applications in waste water treatment, soil conditioning, animal feed through additives and Odor control systems. However, natural zeolites are usually impure, and include quartz, feldspar and clay

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minerals, which may reduce their performance and limit their industrial use.

Synthetic zeolites on the other, are produced under controlled conditions either in the laboratory or in the industrial setting by utilizing silica and alumina sources in alkaline media. The most popular means of the production of synthetic zeolites with a controlled pore structure and chemical composition is the hydrothermal synthesis technique. Synthetic including high purity, uniform crystal size, huge surface area and specific pore structure applied to a specific use. All these qualities make synthetic zeolites highly useful in the use of catalysis, gas adsorption, production of detergents and chemical separation industries.

Zeolites have both positive and negative effects on their industrial and environmental activities, which are determined by their structural and chemical properties. The efficiency of adsorption, catalytic acidity, ion exchange capability and thermal stability are all dependent on such parameters as crystallinity, pore size distribution, surface area and silicon to aluminum ratio and elemental composition. As a result, these properties are important to know in order to select zeolite materials to be utilized in particular applications.

The discussion of the properties of zeolites is presented through the application of different methods of characterization and analysis. In the case of crystallization structure and phase identification, the most common method is the X-ray diffraction (XRD). The scanning electron microscopy (SEM) will reveal information as well as the distribution of particles. finds application in the identification of functionalities and structures of vibrations in zeolites. Surface area and pore features are established via Brunauer Emmett Teller (BET) analysis and composition proportions of elements, as well as silicon/aluminum proportions, are evaluated with the assistance of energy-dispersive X-ray spectroscopy (EDX).

Emerging environmental problems of raiding worry and growing body of industrial waste have in recent years prompted researchers to discover the process of synthesizing zeolites in a sustainable, inexpensive fashion. Final substitute raw materials which have been researched to be utilized in the manufacturing of zeolites are agriculture. These sustainable practices can help not only ease waste disposal challenges, but also produce low-cost and environmentally friendly zeolitic products.

Little comparative studies are available on the structural and chemical properties of natural versus synthetic zeolites when the conditions were similar even though much research has been carried out on zeolites. Morphological variations, crystallinity and chemical composition variations need to be compared closer to identify the effect of these variations on the mechanism of functioning of these materials and their application in industry.

That is why the present paper is given to the exploration and comparison characteristics of natural and artificial zeolites with the usage of the most advanced methods of analysis. The study will endeavor to determine their crystallinity and morphology, as a way of determining how suitable they are to various industrial and environmental uses. It is hoped that the findings of this research will be used to develop a more efficient zeolitic substance, as well as more effective synthesis processes in future technology.

Related Works:

The scientific research has concentrated on Zeolites due to their outstanding structural, chemical and adsorption features that makes them target of excellent industrial and environmental applications. To understand the structural behavior and efficacy of zeolites in its performance, a group of scientists have studied synthesis, characterization and functional applications of natural and synthetic zeolites.

Donald W. Breck provided an in-depth discussion of the structure and structure of zeolites, in his landmark textbook,The crystalline aluminosilicate structure behind the zeolites, along with the crystalline aluminosilicate structure and its molecular sieving, ion-exchange and catalytic activity was described in this paper. Breck emphasized that the pore size, and framework structure affect significantly the adsorption and separation processes in the industry.

Colin S. Cundy and Paul A. Cox (2003) took an interest in the history of zeolites and on how they are produced hydrothermally. Their paper outlined how the synthesis conditions such as temperature, pressure, alkalinity, and crystal morphology influence the zeolite formation and crystal morphology. The study found that hydrothermal synthesis can be used to synthesize zeolites with intended pore structure and improved crystallinity that can be utilized in the industry.

Edith M. Flanigen (2001) talked about the history of the zeolites and molecular sieves and their industrial significance. The study has highlighted how the synthetic zeolites are useful in catalysing the petroleum refining process and the detergent making process. Flanigen also conducted the topology of the structure, and the adsorption selectivity of zeolitic materials related.

Frederick A. Mumpton (1999) studied natural zeolites used industrially and in agriculture. This research found natural zeolites are capable of having a high ion-exchange capacity and adsorption capacity to be applied in soil conditioning, waste water purification, animal feed additives and as Odor controlling agents. One of the commercially important natural zeolites was also identified to be clinoptilolite.

Xavier Querol et al. (2002) examined the zeolites preparation made out of coal fly ash and they indicated that the appropriate exploitation of wastes is critical when developing materials in a friendly manner. Their findings indicated that fly ash based zeolites possessed a high adsorption capacity, and could serve as cost effective alternatives to zeolites that are normally produced. The experiment was a significant contribution to sustainable zeolite synthesis research.

In their research, Shaobin Wang and Yong Peng (2010) investigated the effectiveness of natural zeolites in water and waste water treatment. They found out that natural zeolites are effective in the ion exchange and adsorption of heavy metals, ammonium ions and organic polluters in contaminated water. The authors concluded that the zeolites are environmentally friendly and economical adsorbents.

The principles of synthesis and identification of zeolites were written by Ryszard Szostak (1998). The paper provided detailed information concerning the crystallization phenomena, the type of structure classification, and methods of obtaining zeolite structures. controlled synthesis factors in the synthesis of pure zeolite products.

vibrational spectrums using the FTIR spectroscopy, Wiesaw Mozgawa (2001) conducted a study in order to explore the relationship between these two. The analysis indicated that there is a connection between feature infrared absorption bands of aluminosilicate structure with some framework vibration. The experiment assisted in gaining an understanding on structural ID using the spectroscopic techniques.

In a photo-purification and separation of gases, Michael W. Ackley, Sanjay U. Rege and Himanshu Saxena (2003) carried out an exploration regarding the use of natural zeolites. They discovered that the zeolites possess an excellent selectivity to the gases by adsorption due to their microporous nature and the ability to exchange ions. It has stated on industrial importance of zeolites in harvesting of gases.

Andreas A. Zorpas and Vassilis J. Inglezakis (2012) also examined adsorption energy and ion-exchange in adsorption systems. They worked out the thermodynamic behaviour of adsorption and emphasized the significance of the surface properties and the pore geometry to adsorption efficiency.

Adam Derkowski et al. (2007) looked into the production of zeolitic materials using fly ash using simplified processes of their production. The synthesis experiment discovered the zeolites that were synthesized had strong adsorbency and potential cleanup applications to the environment. The paper also revealed economic and environmental benefits of heavy exploitation of industrial wastes to the manufacturing of zeolites.

Jasenka Peric, Marina Trgo, and Nataoska Vukojevic Medvidovic (2004) in their work experimented with the natural zeolites in the extraction of the heavy metals that consisted of Zinc, copper and lead. It displayed that they found out that zeolites had a high adsorbent capacity of the toxic metal ions and they could be applied to purify the wastewater.

Miguel A. Hernandez, Fernando Rojas and Victor H. Lara (2000) have carried out nitrogen adsorption studies to explain. They stressed on the significance in calculation of adsorption capacity and the molecular transport property.

Adebayo S. Kovo et al. (2009) prepared zeolite A with natural material of kaolinite and evaluated its structure. This experiment also discovered that kaolinite would serve well as a raw material in the production of zeolites and it could also give well crystallized zeolite structures that can be utilised in industries.

Sudaryanto Babel and Trihadiningrum A. Kurniawan (2003) in removing the heavy metals in the wastewater. Their study has revealed that zeolites were highly efficient and cost-effective adsorbents due to the porous texture, ion-exchange and efficiency of adsorption.

Generally, the reviewed literature indicates that natural and artificial zeolites possess amazing structural and chemical characteristic that enables them to be used in a greater number of industrial and environmental activities. This is because previous scholars have highlighted on the role that crystallinity, pore structure, surface area, and chemical composition plays in determining the performance of the zeolites. However, the direct comparative study of natural and synthetic zeolites, conducted under equal experimental conditions has limited research. Therefore, the present paper is planned to conduct an in-depth similarity of their structural and chemical characteristics with the aim to be able to understand their application and productivity in the industry.

Objectives of the Study:

- To explore the structural features of natural and synthetic zeolites by employing the use of modern characterization methods.
- To examine the chemical composition and elemental characteristics of natural and synthetic zeolites, and compare them.
- To assess how the structural and chemical properties of zeolites affect the industrial and environmental uses.

Material and methods:

To investigate and compare the structure and chemical properties of natural and synthetic zeolites, the present piece of work was carried out, with the assistance of various different methods of analysis and characterization. The natural zeolites samples were removed and not purified before being tested, in the natural mineral fields. The sample taken was subsequently washed clay materials and surface contaminations. Drying of the samples that had been washed was done in a hot air-oven at 105 C in order to dry the samples. The dried zeolite was crushed; fine particles were sieved to get similar sized particles to proceed with the experiments. To increase purity and remove the unwanted mineral impurities, the natural zeolites samples were subjected to the acid activation solution 1 M of hydrochloric acid. Some hours were taken in the samples in the acid solution and the neutral pH was achieved. The characterization studies were further maintained in airtight containers to be utilized on the dried samples.

The hydrothermal method of synthetic zeolite samples was done in the laboratory. The actual materials that were used to complete the synthesis were the analytical grade in order to make an alkaline solution sodium hydroxide was dissolved in distilled water. This was followed by the addition of silica gel and sodium aluminate slowly after unmistakable mixture to cause the gel mixture to become homogeneous. A molar composition of the prepared gel was regulated to obtain a good crystallization of zeolite framework. The mixture underwent processing towards a mixture that was viewable in exposed to 120 C under the same conditions of 24 hrs in a completely static hydrothermal regime. After doing crystallization process, the synthesized product the pH was brought to neutral. The amount obtained was dried up to 100 C and to fine powder to be further characterized.

The structural properties zeolites were identified by the use of X-ray diffusion

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(XRD). scan range of 5 to 50 (2th) in order to identify crystal phases and an approximation of the degree of crystallinity. The data acquired by diffusion was compared to the standard reference data to determine the phase. The surface morphology and distribution of the zeolite samples was analyzed by scanning electron microscopy (SEM). The technique could provide a very detailed information concerning crystal shape, particle size as well as the texture of surfaces of the materials and structure vibrations do appear in the zeolite structures. The spectra were digitized within the range of 400-4000 cm-1 and common absorption bands inside the frequency range at 400OAl-O, 400O Si-O, common to the two groups were compared. Chemical composition and the distributions of elements in the samples of zeolites were determined by using energy dispersive X-ray spectroscopy (EDX). This was required to identify the ratio of silicon to aluminium and the other constituents, such as sodium, calcium and iron were identified. Measurements of nitrogen adsorption-desorption of the pore size, pore volume and specific surface area of zeolite samples. The zeolite samples adsorption performance was also determined in an aqueous dye adsorption experiment. Zeolite was added to the dye solution and stirred after some predetermined time with a known amount of the known sample of the zeolite. The adsorption was followed with the period of left dye and the solution was filtered after the adsorption process using a UV-Visible spectrophotometer.

$$\text{Adsorption Efficiency (\%)} = \frac{C_0 - C_e}{C_0} \times 100$$

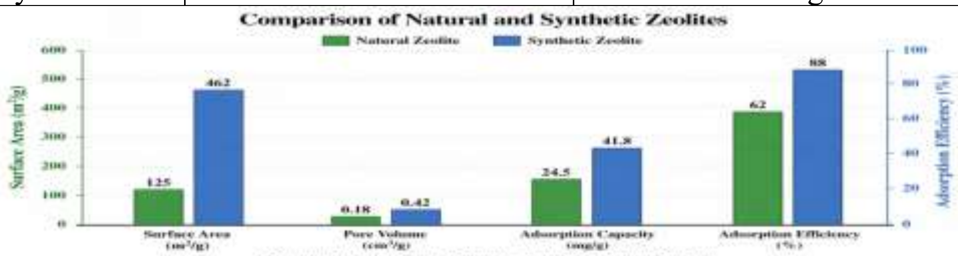
where C_0represents the initial dye concentration and $C_e$represents the equilibrium dye concentration after adsorption.

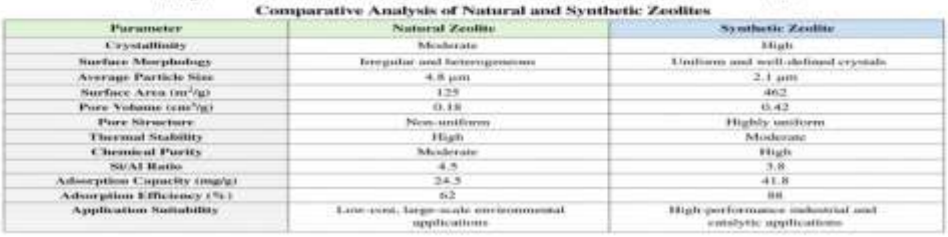
To ensure the accuracy and reproducibility of the results all the experiments were performed in triplicates. Statistically, to identify the significance of the differences between the two structural and chemical property of natural and synthetic zeolites.

Analysis of the study:

Table 1: Structural Characteristics of Natural and Synthetic Zeolites

Parameters	Natural Zeolite	Synthetic Zeolite
Crystallinity	Moderate	High
Surface Morphology	Irregular and heterogeneous	Uniform and well-defined crystals
Average Particle Size	4.8 µm	2.1 µm
Surface Area (m²/g)	125	462
Pore Volume (cm³/g)	0.18	0.42
Pore Structure	Non-uniform	Highly uniform
Thermal Stability	High	Moderate
Purity Level	Moderate	High





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Pore Volume (cm³/g)	0.18	0.42
Pore Structure	Non-uniform	Highly uniform
Thermal Stability	High	Moderate
Chemical Purity	Moderate	High
Si/Al Ratio	4.5	3.8
Adsorption Capacity (mg/g)	24.5	41.8
Adsorption Efficiency (%)	62	88
Application Suitability	Low-cost, large-scale environmental applications	High-performance industrial and catalytic applications

Analysis of Table 1

The structural analysis could reveal that there existed remarkable differences between natural and synthetic zeolites. Much increased crystallinity in synthetic zeolites was obtained due to controlled hydrothermal synthesis conditions. SEM observations have revealed synthesized zeolites to have uniform and highly ordered crystal structures with irregular morphology of natural zeolites as a result of naturally present mineral impurities. Compared to observed to have much higher number of advantageous in adsorption and catalysis by both synthetic and natural zeolites. Natural zeolites were however more thermally stable due to the presence of mineral phases which were naturally stable.

Table 2: Chemical Composition Analysis of Zeolite Samples

Chemical Components	Natural Zeolite (%)	Synthetic Zeolite (%)
SiO_2	64.5	72.8
Al_2O_3	11.8	18.4
Na_2O	2.9	6.5
CaO	5.7	1.2
Fe_2O_3	4.3	0.6
MgO	2.1	0.4
Loss on Ignition (%)	8.7	3.2

Analysis of Table 2

Analysis of chemical composition revealed that alumina structured and helped provide the syntheses with greater stability of the framework and adsorption capacity. The synthetic zeolites were restrained to allow a greater control of silicon-to-aluminum ratio. The natural impurities included calcium, iron and magnesium oxides in high amounts in the natural zeolites. The lower concentration of impurities in synthetic zeolites would indicate high purity and high versatility in the exploitation of synthetic zeolites in industrial applications that require highly efficient adsorbent and catalysts.

Table 3: Adsorption Performance of Zeolite Samples

Parameters	Natural Zeolite	Synthetic Zeolite
Initial Dye Concentration (mg/L)	100	100
Equilibrium Concentration (mg/L)	38	12
Adsorption Efficiency (%)	62	88
Adsorption Capacity (mg/g)	24.5	41.8
Contact Time (min)	60	60

Analysis of Table 3

The adsorption experiment has revealed that the adsorption capacity and the adsorption efficiency of synthetic zeolites was significantly higher than that of natural zeolites. Increased surface area, even distribution of pore and enhanced crystallinity are the reasons why synthetic zeolites perform highly. Natural zeolites were also found to adsorb well, but these zeolites worked quite poorly due to structure irregularities and mineral contaminant. The results further suggest the synthetic zeolites to be more useful in the utilization of the wastewater treatment as well as eliminating the pollutants.

Results and Discussion:

Big differences between the natural and synthetic zeolites as revealed by the results of the structural and chemical characterization existed. The X-ray diffraction showed a sharper and more dominant pattern of diffraction in the synthetic zeolites and they can be more crystalline and purer in phase. Relative to natural zeolites, the x-ray diffraction intensity of the natural zeolites was more widely dispersed because of mixed mineral phases and impurities.

shown that the synthetic zeolites were of high and ordered cubic and crystalline morphology and particle are spread evenly. Heterogeneity of Natural zeolites Surface structure of natural zeolites was caused by natural geologic structures formed. These structural differences had a great effect on adsorption and ion exchange.

The FTIR analyses indicated that the two samples of zeolites had normal vibrations of the aluminosilicate frameworks. Clearly noticeable strong absorption bands at -1 (1000) were indicative of asymmetric vibrations of Si/O/Al that constituted the zeolitic structures. The synthetic zeolites showed a narrower absorption band of the spectrums which was the indication of homogeneity in the structure.

Surface area analysis in BET, has shown that the synthetic zeolites occupied a lot more surface area than the natural zeolites and also the pore volume. This facilitated the porosity and afforded better adsorption locations therefore enhancing adsorption. The adsorption experiments also determined that synthetic zeolites had superior dye removal capacity due to highly-ordered pore systems and the high active surface area of the zeolites.

According to EDX analysis, natural zeolites contained other components of other minerals such as calcium, magnesium and iron oxides but synthetic zeolites were purer with the ratio of silicon to aluminum controlled. The controlled composition was also observed in synthetic zeolites and this proved to be a contribution to the enhanced catalytic and adsorption properties.

Overall, the study findings indicate that synthetic zeolites are even more versatile in the context of excellent adsorption capacity and the catalytic activity and structure of an isotropic material that can be utilized in the advanced industry. However, natural zeolites remain an economic option as an alternative in large scale applications in the environment due to their low prices, natural occurrence, and performing functions satisfactorily in adsorption.

Conclusion:

The effectively studied and contrasted using various techniques of analysis and characterization in the given experiment. It was found that the two types of zeolites exhibited a high degree of crystallinity, morphologies of the surfaces, pore structure, chemical composition as well as adsorption properties. The high crystallinity, crystallinity surface area, well-distributed pores, and improved chemical purity of the synthetic zeolites were synthesized under hydrothermal synthesis conditions. These attributes were also associated with their high adsorption performances and enhanced their industry and catalyst application.

Although natural zeolites contained mineral impurities and their pore structure was not very regular, it proved to be thermally stable, satisfactorily acted as an adsorbent and was relatively cheap because it can be found in nature and can be easily manufactured. The experiment determined that structural and chemical properties of zeolites are significant determinants of zeolites in the industrial application and the environmental practice.

The adsorption experiments also showed that synthetic zeolites possess greater adsorption capacity owing to the highly ordered arrangement and also the high surface area available. However, even natural zeolites may have the massive applications in the sphere of environmental cleanup and wastewater treatment at relatively low expenses.

Overall, the paper indicates that a good understanding of the relationship between zeolites structure and functional performance is essential. The other feature brought out in the course of the study is that there is need to develop high-performance zeolitic materials that needs to be done using long-term and environmentally friendly synthesis processes. Future research on zeolites that can be applied in advanced industrial and environmental use should focusing on producing more superior green materials in relation to their structure and chemistry by utilization of the agricultural and industrial waste materials.

References:

1. Breck, D. W. (1974). *Zeolite Molecular Sieves: Structure, Chemistry, and Use*. New York: Wiley.
2. Cundy, C. S., & Cox, P. A. (2003). The hydrothermal synthesis of zeolites: History and development from the earliest days to the present time. *Chemical Reviews, 103*(3), 663–702. https://doi.org/10.1021/cr020060i
3. Flanigen, E. M. (2001). Zeolites and molecular sieves: An historical perspective. *Microporous and Mesoporous Materials, 48*(1–3), 9–30. https://doi.org/10.1016/S1387-1811(01)00339-4
4. Mumpton, F. A. (1999). La roca magica: Uses of natural zeolites in agriculture and industry. *Proceedings of the National Academy of Sciences, 96*(7), 3463–3470. https://doi.org/10.1073/pnas.96.7.3463
5. Querol, X., Moreno, N., Umaña, J. C., Alastuey, A., Hernández, E., López-Soler, A., & Plana, F. (2002). Synthesis of zeolites from coal fly ash: An overview. *International Journal of Coal Geology, 50*(1–4), 413–423. https://doi.org/10.1016/S0166-5162(02)00124-6
6. Wang, S., & Peng, Y. (2010). Natural zeolites as effective adsorbents in water and wastewater treatment. *Chemical Engineering Journal, 156*(1), 11–24. https://doi.org/10.1016/j.cej.2009.10.029
7. Szostak, R. (1998). *Molecular Sieves: Principles of Synthesis and Identification* (2nd ed.). Springer.
8. Mozgawa, W. (2001). The relation between structure and vibrational spectra of natural zeolites. *Journal of Molecular Structure, 596*(1–3), 129–137. https://doi.org/10.1016/S0022-2860(01)00741-4
9. Ackley, M. W., Rege, S. U., & Saxena, H. (2003). Application of natural zeolites in the purification and separation of gases. *Microporous and Mesoporous Materials, 61*(1–3), 25–42. https://doi.org/10.1016/S1387-1811(03)00353-6
10. Inglezakis, V. J., & Zorpas, A. A. (2012). Heat of adsorption, adsorption energy and activation energy in adsorption and ion exchange systems. *Desalination and Water Treatment, 39*(1–3), 149–157. https://doi.org/10.1080/19443994.2012.664698
11. Derkowski, A., Franus, W., Beran, E., & Czimerova, A. (2007). Properties and potential applications of zeolitic materials produced from fly ash using simple methods of synthesis. *Powder Technology, 166*(1), 47–54. https://doi.org/10.1016/j.powtec.2006.12.005
12. Perić, J., Trgo, M., & Vukojević Medvidović, N. (2004). Removal of zinc, copper and lead by natural zeolite—A comparison of adsorption isotherms. *Water Research, 38*(7), 1893–1899. https://doi.org/10.1016/j.watres.2003.12.035
13. Hernández, M. A., Rojas, F., & Lara, V. H. (2000). Nitrogen-sorption characterization of the microporous structure of clinoptilolite-type zeolites. *Journal of Porous Materials, 7*(4), 443–454. https://doi.org/10.1023/A:1009653801340
14. Kovo, A. S., Hernandez, O., Holmes, S. M., & Coville, N. J. (2009). Synthesis and characterization of zeolite A from natural kaolinite materials. *Journal of Porous Materials, 16*(2), 159–165. https://doi.org/10.1007/s10934-008-9183-1
15. Babel, S., & Kurniawan, T. A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: A review. *Journal of Hazardous Materials, 97*(1–3), 219–243. https://doi.org/10.1016/S0304-3894(02)00263-7