THE USE OF BENTONITE CLAYS IN WATER TREATMENT PROCESSES. A LITERATURE REVIEW

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Nowadays, there is a growing need for environmentally safe, inexpensive, and yet effective substances, preferably of natural origin, which can effectively remove contaminants of various genesis from water. Natural clay minerals, which are found in abundant deposits throughout Ukraine, certainly fall into this category. Bentonite clays attract particular attention among naturally occurring clay minerals; because of their structural formula consists mainly of the mineral montmorillonite – a layered aluminosilicate containing crystalline water. Montmorillonite possesses a high sorption capacity for cations and organic substances due to its unique crystalline structure, which allows for isomorphous substitutions within tetrahedral and octahedral lattices. There are two large deposits of bentonite clays in Ukraine: the Cherkasy and Zakarpattia (Gorb) deposits. Both deposits are used for the extraction of bentonite clays, primarily for use in the production of cement, ceramics, and bricks. However, the use of bentonite clays in water treatment appears to be more promising, where they can be effectively used to remove a wide range of contaminants in such water treatment sectors as: drinking water treatment; industrial wastewater treatment; municipal wastewater treatment; remediation of groundwater and surface water; removal of oily substances from water, etc. Bentonite clays are rarely found in their pure form like all natural minerals. Therefore, they must undergo preliminary preparation, which includes both physical methods (grinding, drying, sieving) and chemical methods (thermal and chemical activation) prior to their use in sorption processes. The purpose of these procedures is to impart the necessary properties to the surface of bentonite clays to improve their sorption capacity.

Keywords: *activation of bentonite clay, bentonite clay, deposit, montmorillonite, sorbent, water treatment.*

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1. Introduction

Industrial development is leading to an expansion in the scope of application of various sorbent materials of natural origin, in particular natural clay minerals.

This applies, first and foremost, to minerals of the smectite series, particularly bentonite clays, the main variety of which is montmorillonite. Its composition is expressed by the formula $(Al_{1.67}Mg_{0.33})[(OH)_2Si_4O_{10}]Na_{0.33}(H_2O)_n$. Montmorillonite is one of the most common minerals in soils, is the main component of bentonite clays, and is found in many sedimentary rocks. It forms through the weathering of volcanic rocks – tuffs, ash, and volcanic glass. Montmorillonite contains many various impurities: quartz, feldspars, calcite, pyrite, organic matter, kaolinite, illite, mixed-layer clay minerals, etc (Dong-Hwa et al., 2025; Seonggyu et al., 2025).

Fig. 1 shows schematic representation of the crystal structure of montmorillonite.

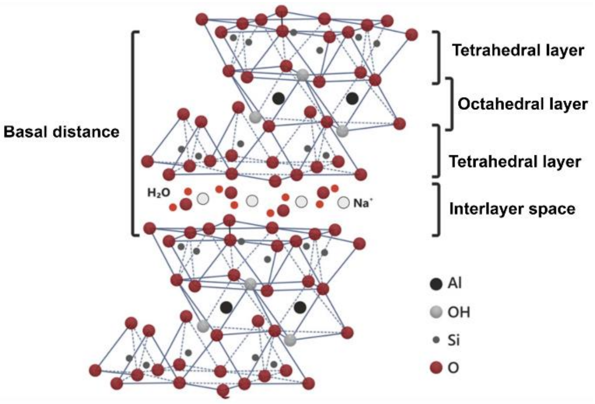

Fig.1. *Schematic representation of the crystal structure of montmorillonite*

Smectites are hydrated aluminosilicates, consisting of two tetrahedral lattices and a single octahedral lattice located between them.

A negative layer charge is formed, which is compensated by interlayer cations, ensuring the high sorption properties of bentonite clays due to isomorphous substitutions within the octahedral and tetrahedral lattices. The charge of montmorillonite is predominantly localized within the octahedral lattices, leading to effective sorption of cations and organic components (Laguta et al., 2025).

The properties of bentonites are also influenced by charge localization. High sorption capacity and swelling capacity are associated with the absence of charge in the tetrahedral lattice. The appearance of a small fraction of tetrahedral charge, however, leads to a decrease in sorption capacity and reduced swelling. The sorption characteristics of bentonitic clays are also influenced by the average charge per layer – a decrease in sorption capacity occurs with an increase or excessive decrease in the charge per layer. As a result, the bond between layers is quite weak, and the thickness of the interlayer space is quite large. Thus, various ions, as well as water molecules, can freely penetrate the interlayer space, leading to swelling of the mineral (Gamble et al., 2025).

Various methods of their modification are used to regulate the mechanical, adsorption, ion-exchange, and catalytic properties of clays.

A well-known method of chemical modification of bentonite involves replacing calcium and magnesium ions with alkali metal ions. Clay enriched with alkali metal ions exhibits high swelling capacity, plasticity, and binding capacity (Pakkanen et al., 2025).

The acid activation method is widely used to produce active adsorbents and catalysts based on clays. The chemical composition of the clay changes during acid activation, and its structure is altered, accompanied by the formation of additional porosity, an increase in sorption volume, and specific surface area.

Currently, following methods of physical treatment of clay minerals have been developed: thermal treatment, ultrasonic, electromagnetic treatment, and mechanical activation (Lan et al., 2025; Umirov et al., 2025).

Currently, the modification of bentonite clays with homo- and hetero-nuclear metal polyhydroxy complexes is the most effective and widely used method. (Fahad et al., 2024; Ishanova et al., 2025; Linlin et al., 2024).

2. Review of bentonite clay deposits

Bentonite clay deposits in Ukraine are in two regions: Cherkasy and Zakarpattia. Polymineral clayey rocks, on the other hand, are distributed evenly throughout the country in the form of sedimentary rocks. Bentonite clays are primarily supplied to meet the needs of brick and cement plants.

It should also be noted that Ukraine fully meets its own needs for clay raw materials.

The Cherkasy bentonite clay deposit is located in the Lysyanskyi District of Cherkasy Region. It was discovered in 1954, thoroughly explored between 1958 and 1960, and has been mined using open-pit methods since 1974. Since 2004, the principle of selective clay extraction has been implemented, which allows for a significant improvement in product quality. It is proposed to grant the deposit the status of a geological monument of regional significance. It is the largest in Europe and one of the largest in the world. It should be noted that bentonite clays from this deposit were used to address the aftermath of the accident at the Chernobyl Nuclear Power Plant (Shabalin et al., 2021).

The Zakarpattia (Gorbske) bentonite clay deposit has been explored on multiple occasions. In 1964–1966, the "Kyivgeologiya" Trust conducted geological exploration work in the northwestern section of the Gorb deposit with the aim of identifying reserves clays suitable to produce clay powder, in accordance with the GPU (1964). The bentonite clays of the Gorbske deposit are suitable according to the results of the studies conducted: in the oil refining industry – for the purification of petroleum products and a catalyst in cracking processes; in the food industry – for purifying vegetable oil and fining wines; in the porcelain and earthenware industry – as plasticizers. The overburden consists of Quaternary loams and sandy clays, with a thickness ranging from 2.5 to 8.0 m, averaging 4.0 m. Mineralogical composition of the Gorb clays is following: montmorillonite formations with admixtures of beidellite, sometimes kaolinite.

The clays are similar to bentonites in terms of chemical composition: SiO_2 – 48–58.4 %; Al_2O_3 – 16–24 %; Fe_2O_3 – 4.4–18.8 %; CaO – 0.4–1.12 %; MgO – 0.2–0.6 %, but they are classified as bentonite-like due to weak swelling in aqueous solution. Analyses of drilling fluids were conducted in the drilling fluid laboratory of the Ukrainian Scientific Research Geological Exploration Institute (UkrSRGEI). It can be stated that drilling fluids prepared from clay of the upper (I) horizon, meet the technical specifications after treatment with alkaline reagents. The fluids prepared from clay of the lower horizon, even after treatment with reagents, do not meet the technical specifications, mainly due to sand content (over 3 %) according to the research data (Nikolaichuk et al., 2015).

The hydrogeological conditions of the deposit are favourable for open-pit mining. The mineral deposit is not waterlogged.

3. Review of water purification methods using bentonite clays

Bentonite's versatility makes it suitable for a wide range of water treatment applications. Its ability to adsorb contaminants, exchange ions, and promote flocculation means it can be used in both large-scale municipal projects and specialized industrial processes. The main areas where bentonite plays a crucial role are below.

Drinking Water Treatment.

Drinking water treatment is one of the most important applications of bentonite. Clean and safe drinking water is essential for public health, and bentonite helps ensure that water meets quality standards.

Turbidity Reduction. Bentonite effectively binds suspended solids, facilitating their settling and filtration. As a result, the water becomes noticeably clearer.

Taste and Odor Neutralization. Bentonite removes organic matter, oils, and certain chemical residues, and helps eliminate unpleasant tastes and odours that would otherwise render the water undrinkable.

Removal of harmful substances. Bentonite adsorbs heavy metals and toxic compounds, providing an additional level of safety beyond standard filtration.

Bentonite is considered safe for use in municipal water treatment plants, where it enhances the effectiveness of traditional treatment methods, since it is non-toxic and occurs naturally in large quantities (Muzdybaeva et al., 2026; Xiao et al., 2026).

Industrial wastewater treatment.

Industries such as mining, textiles, electroplating, and chemicals generate wastewater rich in pollutants. This wastewater often contains heavy metals, dyes, solvents, and hazardous organic compounds. Bentonite is particularly valuable in these applications.

Heavy metal adsorption. It immobilizes toxic metals such as lead, cadmium, and chromium, preventing their discharge into rivers and soil.

Removal of organic pollutants. Bentonite removes dyes and chemical residues from textiles, and improved sedimentation. It accelerates the settling of fine particles, making the treatment of industrial wastewater faster and more cost-effective.

The use of bentonite helps industry comply with strict environmental standards while reducing treatment costs compared to chemical alternatives (Hamdan et al., 2026).

Municipal Wastewater Treatment.

Municipal wastewater contains a mixture of organic and inorganic pollutants that must be treated before being discharged back into the environment. Bentonite improves several stages of municipal wastewater treatment.

Improved flocculation. Fine suspended solids aggregate more easily with bentonite, forming larger flocs that settle quickly.

Support for biological treatment. Bentonite makes biological treatment processes more efficient and stable by reducing the pollutant load.

Cleaner final effluent. The treated water has lower turbidity, fewer contaminants, and is safer for discharge into rivers and lakes or for reuse in irrigation.

This makes bentonite an excellent solution for cities facing challenges in managing growing volumes of wastewater (Oncel et al., 2026).

Remediation of Groundwater and Surface Water.

The contamination of rivers, lakes, and aquifers is a global problem caused by industrial spills, agricultural runoff, and accidental discharges. Bentonite is used in remediation strategies due to its immobilizing and sealing properties.

Use of barriers. Bentonite can be used as a lining material to prevent the spread of contaminants in contaminated areas.

Injection methods. Bentonite binds to contaminants such as pesticides, hydrocarbons, and heavy metals, reducing their mobility when injected into aquifers or soil.

Long-term containment. Its ability to swell and form a seal creates natural barriers that limit the migration of contaminants into clean water sources.

Bentonite is widely used in environmental engineering projects to restore contaminated ecosystems as a sustainable remediation agent (Hamdan et al., 2026).

Removal of Oil and Grease.

Certain industries, such as the food, oil refining, and petrochemical sectors, discharge wastewater containing high levels of fats, oils, and greases (FOG). These substances are difficult to treat and can clog pipes or damage infrastructure. Bentonite offers effective solutions.

Adsorption of oils and fats. The porous structure of the clay traps hydrophobic compounds, preventing them from floating on water surfaces or on coating equipment.

Separation efficiency. Bentonite promotes the coagulation of oil droplets, ensuring faster separation and removal.

Environmental protection. Industries prevent sewer blockages and lower the risk of environmental contamination by reducing the oil and grease content in wastewater.

This makes bentonite a reliable and cost-effective option for industries that must comply with strict wastewater discharge standards (Belgibayeva et al., 2026).

The Benefits of Bentonite in Water Treatment.

Bentonite offers several advantages over synthetic or chemical alternatives.

Environmental friendliness. Bentonite is non-toxic, biodegradable, and safe for the environment as a natural mineral.

Cost-Effectiveness. It is widely available and relatively inexpensive, making it suitable for large-scale water treatment projects in both developed and developing countries.

Versatility. Bentonite can be adapted for various water treatment needs: from household filters to industrial treatment plants.

Bentonite clays can be used in promising fields such as the production of ceramic membranes for water treatment (Biswas et al., 2025).

Comparison with other materials. Activated carbon is more expensive and less effective against heavy metals, removing organic compounds excellently. Zeolite has similar ion-exchange properties but lacks the same swelling and adsorption capacity as bentonite. Bentonite offers a balanced and cost-effective alternative in many cases.

4. Bentonite clays in sorption processes. Methods for improving the sorption properties of bentonite clays

There is a wide variety of water purification methods, including reagent-based, ion-exchange, electrochemical, and membrane methods; however, adsorption is considered the most effective and simplest method, as it allows for the use of a wide variety of natural sorbents possessing high sorption capacity, cation-exchange properties, selectivity, and the ability to remove harmful impurities. The efficiency of adsorption-based water purification depends on the nature of the sorbent and its sorption surface area and ranges from 80 to 95 % (Kahsay et al., 2025; Lee at al., 2025).

Bentonite clay is one of the most effective and affordable natural sorbents, a finely dispersed clay containing more than 70 % montmorillonite.

Natural clay adsorbents, particularly bentonites, are extremely rare in their pure form and typically contain impurities, associated minerals, carbonates and sulphates, hydroxides, oxides, and others. Consequently, the adsorbents are dried, ground, and sieved to remove these impurities. However, the adsorbents do not possess the necessary activity for an effective adsorption process even after such preparation. Therefore, bentonite is subjected to thermal or chemical activation to improve their adsorption properties.

The following chemical methods of activating clay adsorbents are known soda, salt, alkaline, and acid. Soda and salt activation is carried out by treatment with a 5 % solution of Na_2CO_3 or NaCl, which is used to improve the degree of dispersion and porosity of the adsorbent. This method makes it possible to obtain organophilic mineral adsorbents with a wide range of adsorption activity and varying degrees of selectivity by introducing various organic cations (Kheliel et al., 2025; Taxiarchou et al., 2025).

The replacement of inorganic clay cations with organic ones is accompanied by an increase in its specific surface area and sorption activity, as well as the loosening of its crystal lattice.

Table 1 presents a summary of the comparative characteristics of natural and modified bentonite clays.

Table 1. *A summary of the comparative characteristics of natural and modified bentonite clays (Jock Asanja et al., 2019)*

Parameter	**Natural bentonite**	**Activated bentonite**
Chemical composition	Primarily montmorillonite with impurities	Modified composition (H^+ or Na^+)
Type of cations	Ca^{2+}, Mg^{2+}, Na^+	H^+ or Na^+
Specific surface area	30–100 m²/g	100–300 m²/g
Porosity	Medium	High
Sorption capacity	Moderate	High
Ion exchange capacity	50–100 mg-eq/100 g	Varies depending on activation
pH of the suspension	6–8	Acidic or alkaline
Swelling	High	Depends on the type of activation
Structure	Layered	More open
Heat resistance	Average	High
Catalytic properties	Weak	Enhanced
Applications	Drilling fluids, waterproofing	Sorbents, catalysts, purification

The most widespread practical application has been the acid activation of clay adsorbents, during which the dissolution of most of the oxides (CaO, MgO, Na_2O, FeO, Fe_2O_3, Al_2O_3, etc.) is observed, resulting in an increase in pore size, a change in the chemical nature of the surface, and the formation of the H-form of the sorbents. Acid activation of clay is carried out using 20 % sulfuric acid in practice. A complete replacement of exchangeable ions and a partial replacement of Al^{3+} and Mg^{2+} ions in the crystal lattices occur under these conditions. At the same time, the crystal structure remains virtually intact. The chemical nature of the adsorbent after acid activation changes to the H-form; micropores disappear, and the adsorbent is significantly enriched with transition pores, which increases the efficiency of the adsorption process (Saleh et al., 2025).

5. Conclusions

Bentonite has proven to be one of the most valuable natural minerals in modern water treatment. Its unique properties, such as strong adsorption capacity, ion-exchange capacity, and effective flocculation, make it highly effective for removing heavy metals, organic contaminants, and suspended solids. Bentonite consistently improves filtration and purification, offering a sustainable solution to global water quality challenges, from municipal drinking water systems to comprehensive industrial wastewater treatment.

Although there are concerns regarding its regeneration and effectiveness in heavily contaminated environments, bentonite's natural abundance, cost-effectiveness, and environmentally friendly characteristics give it a competitive advantage over many other treatment materials. Demand for advanced bentonite application technologies is expected to grow rapidly, looking ahead, given that water scarcity and environmental pollution are becoming critical issues worldwide.

A key advantage of bentonite clays in terms of their application in water treatment is their high sorption capacity, high selectivity when activated, and low cost. All these factors suggest that bentonite clays are promising, effective, and cost-effective sorbents for treating both industrial wastewater and preparing drinking water.

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ЗАСТОСУВАННЯ БЕНТОНІТОВИХ ГЛИН У ПРОЦЕСАХ ВОДООЧИЩЕННЯ. ОГЛЯД ЛІТЕРАТУРИ

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В сучасному світі все більшою мірою зростає потреба у використанні екологічно безпечних, дешевих і в той же час ефективних речовин бажано природного походження, які б володіли здатністю ефективно очищати воду від забрудників різноманітного генезису. До таких речовин можна впевнено віднести природні глинисті мінерали, численні запаси яких сконцентровано на території України. Серед глинистих мінералів природного походження особливу увагу привертають бентонітові глини, структурна формула яких містить, головним чином, мінерал монтморилоніт – алюмосилікат шаруватої будови, до складу якого входить кристалічно зв'язана вода. Завдяки особливій кристалічній структурі, що здатна до ізоморфних заміщень в межах тетраедричних та октаедричних сіток, монтморилоніт володіє високою сорбційною здатністю по відношенню до катіонів та органічних речовин. На території України розташовано два великих родовища бентонітових глин: Черкаське та Закарпатське (Горбське). Обидва ці родовища використовуються для видобутку бентонітових глин з метою їх застосування, переважно, у виробництві цементу, кераміки та цегли. Але більш перспективним виглядає застосування бентонітових глин саме у водоочищенні, де вони можуть ефективно застосовуватися для вилучення широкого спектру забрудників у таких галузях водопідготовки як: підготовка питної води; очищення промислових стічних вод; очищення комунальних стічних вод; ремедіація грунтових та поверхневих вод; вилучення з води маслянистих речовин і т. п. Як і всі природні мінерали, бентонітові глини рідко зустрічаються в чистому вигляді. Тому, перед їх застосуванням у сорбційних процесах необхідно проводити їх попередню підготовку, що включає як фізичні методи (подрібнення, просушування, просіювання), так і хімічні (термічна і хімічна активація), метою яких є надання поверхні бентонітових глин необхідних властивостей для покращення їх сорбційної здатності.

Ключові слова: *активація бентонітової глини, бентонітова глина, родовище, монтморилоніт, сорбент, водоочищення.*