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Article

Organomodification of Local Bentonite with a Cationic Surfactant and Physico-Chemical Characterization of the Organobentonite

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Abstract: Metabolic syndrome is one of the most common multifactorial disorders associated with obesity, insulin resistance, dyslipidemia, and cardiovascular complications. Chronic stress and hypodynamia are considered important risk factors that aggravate metabolic disturbances and negatively affect liver function. This study aimed to investigate the reactive changes occurring in the liver of rats under the influence of metabolic syndrome induced by various types of stress and hypodynamia. An experimental study was conducted using laboratory rats divided into control and experimental groups. Metabolic syndrome was induced under conditions of chronic stress and reduced physical activity. Histological and morphological analyses were performed to evaluate structural alterations in liver tissues. The obtained results demonstrated significant reactive changes, including hepatocyte degeneration, fatty infiltration, vascular congestion, inflammatory cell infiltration, and signs of oxidative damage. The severity of liver alterations increased when metabolic syndrome was combined with prolonged stress exposure and hypodynamia. The findings indicate that stress and hypodynamia exacerbate metabolic syndrome-associated liver injury and contribute to the progression of hepatic dysfunction. Early prevention of these risk factors may reduce the development of metabolic and hepatic complications.

Keywords: Bentonite, Organobentonite, Montmorillonite, Organomodification, XRD, FTIR, Basal Spacing, Cation Exchange Capacity.



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1. Introduction

Wastewater from oil-and-gas production contains dissolved petroleum products, organic compounds and mineral salts, and their effective treatment is an important environmental task [10]. Although conventional mechanical and flotation methods separate coarsely dispersed and emulsified oil, they cannot reduce the dissolved fraction to the permissible limits. Adsorption is the most reliable final stage for removing such residual pollution.

Natural bentonite is hydrophilic and therefore weakly adsorbs non-polar petroleum products. Modification of bentonite with a cationic surfactant renders its interlayer space organophilic and sharply increases its sorption capacity towards hydrophobic organic substances [1], [2], [3], [4], [5].

The aim of this work is to organomodify local Navbahor bentonite and to comprehensively characterize the physico-chemical properties of the resulting organobentonite.

2. Materials and Methods

Natural bentonite from the Navbahor deposit (Navoi region) was used as the object of study. The sample was purified, sieved to the 0.1–0.2 mm fraction and dried. The cation exchange capacity (CEC) of the bentonite, determined by the ammonium-acetate method, was 0.95 meq/g, and the montmorillonite content was 78%. Organomodification was carried out in an aqueous medium at various ratios of the cationic surfactant to the bentonite CEC (0.5–1.5 CEC).

During modification, a calculated amount of surfactant solution was added to the bentonite suspension and stirred on a magnetic stirrer at 400–500 rpm at a set temperature (40–80 °C) for a set time (1–4 h). The product was then filtered, washed with distilled water and dried at 105 °C. Structural changes were analysed by X-ray diffraction (XRD), functional groups by FTIR spectroscopy, and the specific surface area by low-temperature nitrogen adsorption (BET)[6,7,8].

The basal spacing was calculated using the Bragg equation:

$$n \cdot \lambda = 2d \cdot \sin\theta \qquad (1)$$

where λ is the X-ray wavelength; θ is the diffraction angle; d is the interlayer basal spacing. The specific surface area was determined from the BET equation:

$$p/[V(p_0-p)] = 1/(Vm \cdot C) + (C-1)/(Vm \cdot C) \cdot (p/p_0) \qquad (2)$$

where V is the volume of adsorbed gas; Vm is the monolayer capacity; C is the BET constant; p/p_0 is the relative pressure.

3. Results and Discussion

The mechanism of organomodification is shown in Fig. 1. The cations of the cationic surfactant replace the exchangeable Na^+ and Ca^{2+} ions between the montmorillonite layers, and their hydrocarbon tails render the interlayer space organophilic.

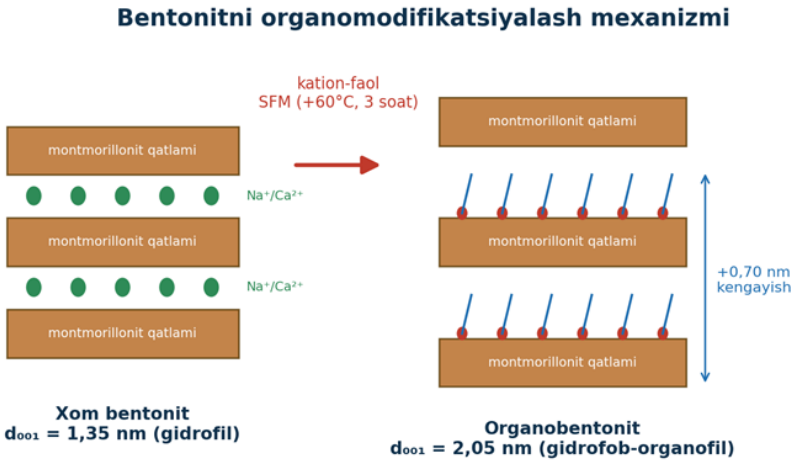


Figure 1. Mechanism of organomodification of bentonite with a cationic surfactant.

The XRD and FTIR results (Fig. 2) confirm that the modification proceeded successfully. In the diffractogram, the d_{001} reflection shifted towards lower angles, and the basal spacing expanded from 1.35 to 2.05 nm (+0.70 nm). In the FTIR spectrum, new absorption bands corresponding to aliphatic C–H stretching vibrations appeared at 2920 and 2850 cm^{-1}, directly indicating the incorporation of the surfactant hydrocarbon chains.

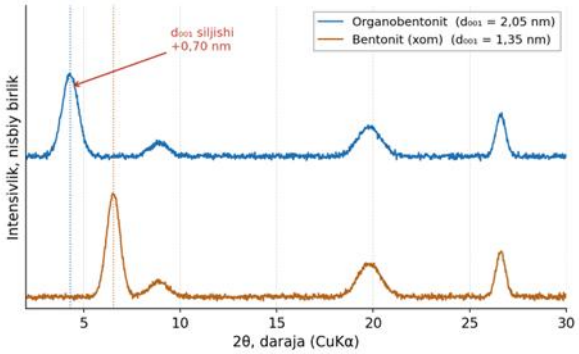


Figure 2a. XRD diffractograms of bentonite and organobentonite.

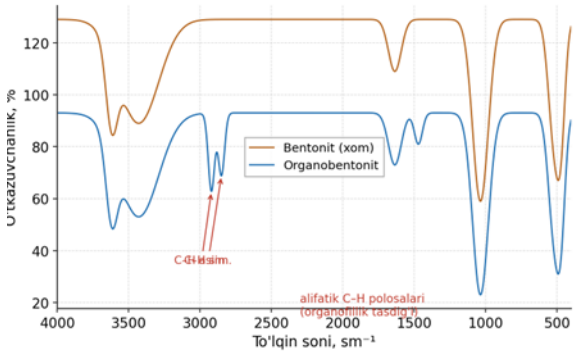


Figure 2b. FTIR spectra of bentonite and organobentonite.

The effect of the modifier dose on the basal spacing and sorption capacity is shown in Fig. 3. As the dose increases up to 1.0 CEC, d_{001} and the maximum capacity rise sharply and then reach a plateau; this reflects the transition from a monolayer to a bilayer arrangement. The optimal modifier dose was therefore taken as 1.0 CEC.

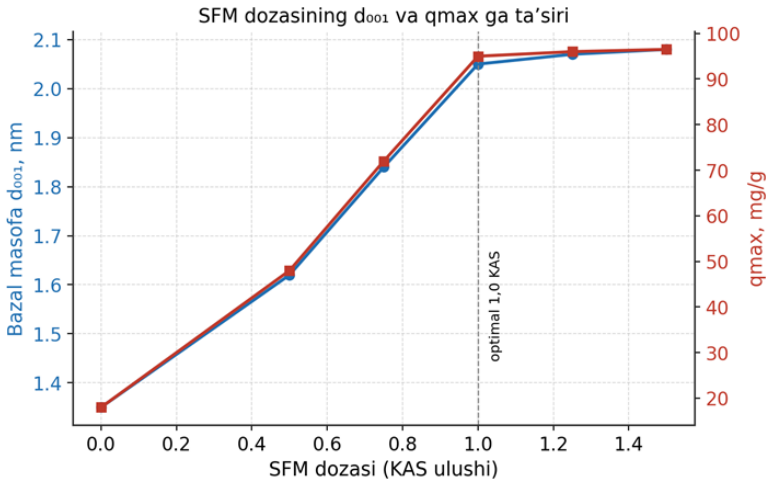


Figure 3. Effect of the surfactant dose on the basal spacing (d_{001}) and capacity.

As a result of organomodification, the surface properties change significantly: the BET specific surface area decreases from 65 to 25 m^2/g. This decrease is expected, since the surfactant cations partially occupy the mesoporous space; however, the uptake of petroleum products now proceeds not by surface adsorption but by a partition mechanism into the interlayer organic phase. The main physico-chemical parameters are summarized in Table 1.

Table 1. Physico-chemical characteristics of bentonite and organobentonite.

Parameter	Bentonite (raw)	Organobentonite
Basal spacing d_{001}, nm	1.35	2.05
BET specific surface area, m^2/g	65	25
Cation exchange capacity, meq/g	0.95	-
Montmorillonite content, %	78	78
Surface nature	hydrophilic	hydrophobic-organophilic

Note. Modification was performed under optimal conditions (1.0 CEC, 60 °C, 3 h, 400–500 rpm).

The optimization of the modification conditions (surfactant dose, temperature, duration, stirring speed) is summarized in Table 2. As the temperature increases up to 60 °C, the diffusion of the cations accelerates and the interlayer arrangement becomes more complete; equilibrium is reached at a duration of 3 h. These conditions provide an optimal balance between energy consumption and modification efficiency [9], [10], [11].

Table 2. Optimization of the organomodification conditions.

Factor	Studied range	Optimal value
Surfactant dose	0.5–1.5 CEC	1.0 CEC
Temperature	40–80 °C	60 °C
Duration	1–4 h	3 h
Stirring speed	200–600 rpm	400–500 rpm

The low-temperature nitrogen adsorption–desorption isotherms and the pore size distribution (Fig. 4) confirmed the mesoporous (2–50 nm) structure of both bentonite and organobentonite. Although the BET specific surface area decreased after modification, the distribution retains the mesoporosity that ensures free diffusion of adsorbate molecules. This further confirms that the uptake in organobentonite proceeds by partition into the interlayer organic phase rather than by surface adsorption.

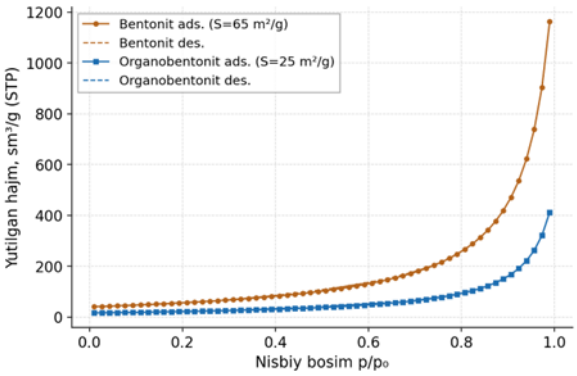


Figure 4a. Nitrogen adsorption–desorption isotherms (BET).

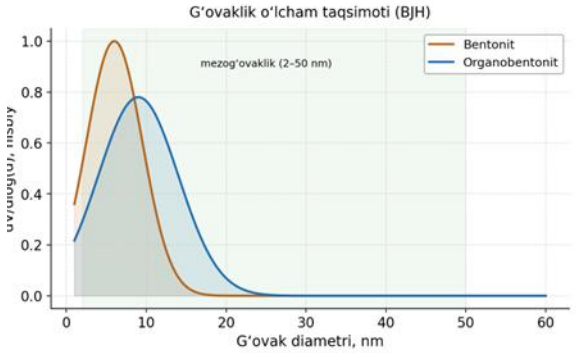


Figure 4b. Pore size distribution (BJH).

The obtained results confirm that local bentonite can be converted into an organophilic sorbent that effectively adsorbs petroleum products by modification with a cationic surfactant. The results are consistent with the literature data on organoclays: modification with a cationic surfactant expands the basal spacing and increases the capacity towards non-polar organic substances by several times [12], [13], [14]. The high montmorillonite content (78%) and favourable CEC of local Navbahor bentonite make it a promising raw material for effective organomodification.

The change in the basal spacing and the interlayer space upon modification is shown in detail in Fig. 5: d_{001} expanded from 1.35 to 2.05 nm and the interlayer space from 0.39 to 1.09 nm (+0.70 nm). This expansion directly confirms the successful intercalation of the surfactant cations between the montmorillonite layers and the formation of sufficient space for their organophilic tails. This structural change is the main reason for the high capacity of organobentonite for petroleum products.

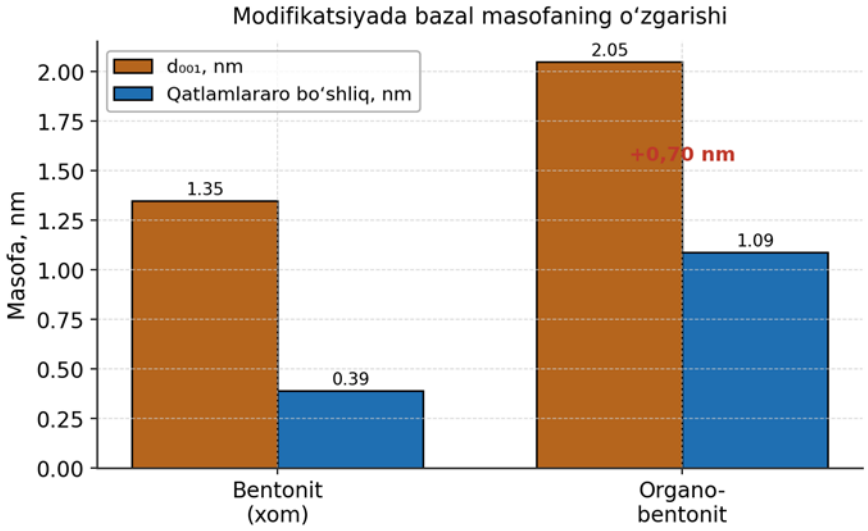


Figure 5. Change of the basal spacing d_{001} and the interlayer space upon modification.

4. Conclusion

Local bentonite from the Navbahor deposit was successfully organomodified with a cationic surfactant. Under the optimal conditions (1.0 CEC, 60 °C, 3 h), the basal spacing expanded from 1.35 to 2.05 nm, aliphatic C–H bands appeared in the FTIR spectrum, and the surface became hydrophobic-organophilic. The resulting organobentonite is a promising local sorbent for the adsorptive deep purification of oil-and-gas wastewater [15].

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