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INVESTIGATION OF THE SORPTION PROPERTIES OF SAPROPEL IN INDUSTRIAL WASTEWATER TREATMENT AND PROSPECTS FOR ENSURING ENVIRONMENTAL SAFETY

Gulnoza Zayniddin qizi Khomitova ¹, Matluba Mukhtarovna Amonova ²

¹ PhD Student, Bukhara State Technical University, Bukhara, Uzbekistan

² Doctor of Technical Sciences, Associate Professor, Bukhara Innovative
Education and Medical University, Bukhara, Uzbekistan

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Abstract

This article investigates the treatment of textile and printing industry wastewater using a sorbent based on local sapropel. The aim was to evaluate stabilization of the cation-anion composition and the deep purification of highly mineralized wastewater contaminated with organic dyes generated during the washing of printed fabrics. Physicochemical analysis showed that the initial wastewater contained 608 mg/L sulfate and had a total hardness of 14.4 meq/L; it was also characterized by a reddish color and a sulfurous odor associated with 32.3 mg/L hydrogen sulfide. Treatment with the sapropel-based sorbent reduced sodium from 215 to 105 mg/L, sulfate from 608 to 298 mg/L, total hardness to 7.78 meq/L, and hydrogen sulfide to 14.23 mg/L. Decolorization and deodorization were also achieved. The results demonstrate the sorption potential of humic and mineral components of sapropel and support further development of this local material for industrial wastewater treatment. Because ammonium, nitrate, and oxidizability did not decrease, an additional polishing stage should be evaluated when deeper removal of nitrogenous and oxidizable contaminants is required.

Keywords: modified sapropel, total hardness, composite sorbent, ion-exchange adsorption, demineralization, sulfate removal, humic acid, sorption activity, wastewater, environmental safety

Introduction

The rapid development of the modern textile and printing industries is closely associated with the generation of large volumes of technologically complex wastewater. Chemical reagents used in fabric dyeing and washing lead to the accumulation of high

concentrations of mineral salts, organic dyes, and potentially toxic compounds. Excessive sulfate, chloride, and metal-ion loads can disrupt the natural balance of receiving waters and increase anthropogenic pressure (Ayangbenro & Babalola, 2017; Bahemmat et al., 2016).

Conventional mechanical and biological treatment methods do not always provide the desired efficiency in the deep demineralization of highly mineralized wastewater containing organic coloring substances. Therefore, the development of inexpensive sorbents based on locally available raw materials has important scientific and practical value for environmental safety and water recycling (Adeeva et al., 2013a; Adeeva & Kovalenko, 2012).

Sapropel, an organogenic sediment, has attracted considerable attention in this field. It is rich in humic acids, mineral components, and bituminous substances and can interact with complex cation-anion mixtures through ion-exchange and adsorption mechanisms. Previous studies have demonstrated sorption by carbon-mineral and humic materials derived from sapropel (Adeeva et al., 2013b; Chechevatov et al., 2017; Kovalenko & Adeeva, 2010; Platonova & Adeeva, 2018; Platonova et al., 2016). The aim of this study was to assess the treatment of colored textile wastewater using a modified composite sorbent based on local sapropel and to evaluate changes relevant to technical water recycling.

Materials and Methods

The study object was wastewater generated during the washing of printed fabrics in textile and printing production. Samples were characterized before and after treatment with the sapropel-based sorbent. The comparative analytical dataset included major cations and anions, total, carbonate, and noncarbonate hardness, pH, hydrogen sulfide, fluoride, oxidizability, dry residue, clarity, qualitative salinity, color, odor, and sediment formation. Ion concentrations are reported in mg/L and meq/L, and equivalent percentages are expressed relative to the corresponding total cation or anion equivalents. Treatment performance was evaluated by direct comparison of the initial and treated samples.

Results and Discussion

The chemical composition of wastewater generated during the washing of printed fabrics is important for developing effective treatment and recycling strategies. The concentrations of the identified cations and anions, total hardness, pH, oxidizability, and other physicochemical characteristics were examined. The initial results are presented in Table 1.

Sodium (Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), and ammonium (NH₄⁺) were the dominant measured cations, with concentrations of 215, 124, 100, and 21 mg/L, respectively. Their reported equivalent shares in the total cation composition were approximately 37%, 25%, 33%, and 5%, respectively.

The data show that magnesium and sodium were present in relatively high concentrations and, together with calcium, contributed substantially to total hardness. Total hardness was 14.4 meq/L; carbonate and non-carbonate hardness were 6.4 and 8.0 meq/L, respectively.

Sulfate (SO₄(2-)), bicarbonate (HCO₃-), and chloride (Cl-) were the most abundant anions. Sulfate reached 608 mg/L and represented approximately 51% of the total anion equivalents. Bicarbonate and chloride were measured at 390 mg/L (26%) and 204 mg/L (23%), respectively. Total cation and anion equivalents were both 24.92 meq/L, indicating a balanced ionic analysis.

The pH was 6.90, indicating an almost neutral medium. Hydrogen sulfide reached 32.3 mg/L and explained the sulfurous odor. Oxidizability was 32.23 mg O₂/L, indicating the presence of oxidizable or reducing substances. The wastewater was clear after filtration, slightly saline, reddish, and associated with a black precipitate. The combination of high mineralization, color, sulfide, and oxidizable matter makes direct discharge environmentally undesirable.

Table 1. Analytical Results for Wastewater Generated during Printed-Fabric Washing

Composition per Liter of Solution				Other Parameters	
Cations	mg/L	meq/L	% of equivalents	Parameter	Value
Na ⁺	215	9.36	37	Total hardness, meq/L	14.40

Composition per Liter of Solution				Other Parameters	
Cations	mg/L	meq/L	% of equivalents	Parameter	Value
K+	ND	0.00	0	Carbonate hardness, meq/L	6.40
NH ₄ ⁺	21	1.16	5	Noncarbonate hardness, meq/L	8.00
Ca ²⁺	124	6.20	25	pH	6.90
Mg ²⁺	100	8.20	33	H ₂ S, mg/L	32.30
Fe ³⁺	0	0.00	0	F ⁻ , mg/L	1.29
Fe ²⁺	0	0.00	0	Oxidizability, mg O ₂ /L	32.23
Total	460	24.92	100	Measured dry residue, mg/L	1,520
				Calculated dry residue, mg/L	1,473
Cl ⁻	204	5.75	23	Clarity	Clear after filtration
SO ₄ (2-)	608	12.67	51	Qualitative salinity	Slightly saline
NO ₂ ⁻	ND	0.00	0	Color	Reddish
NO ₃ ⁻	6	0.10	<1	Odor	Sulfurous
HCO₃⁻ / Total	390/1,208	6.40/24.92	26/100	Sediment	Black precipitate

Note. ND = not detected. HCO₃⁻ – is shown with the anion total in the final row to preserve the original table structure

Table 2. Analytical Results after Treatment with the Sapropel-Based Sorbent

Composition per Liter of Solution				Other Parameters	
Cations	mg/L	meq/L	% of equivalents	Parameter	Value
Na ⁺	105	4.57	33.37	Total hardness, meq/L	7.78
K ⁺	ND	0.00	0.00	Carbonate hardness, meq/L	4.89
NH ₄ ⁺	24	1.33	9.75	Noncarbonate hardness, meq/L	2.89 (calculated)
Ca ²⁺	89	4.45	32.52	pH	7.12
Mg ²⁺	40	3.33	24.36	H ₂ S, mg/L	14.23
Fe ³⁺	0	0.00	0.00	F ⁻ , mg/L	0.72
Fe ²⁺	0	0.00	0.00	Oxidizability, mg O ₂ /L	34.21
Total	258	13.68	100.00	Measured dry residue, mg/L	954
				Calculated dry residue, mg/L	907
Cl ⁻	146	4.11	30.06	Clarity	Clear

Composition per Liter of Solution				Other Parameters	
Cations	mg/L	meq/L	% of equivalents	Parameter	Value
SO ₄ (2-)	298	6.21	45.38	Qualitative salinity	Not saline
NO ₂ -	0	0.00	0.00	Color	Colorless
NO ₃ -	7	0.11	0.83	Odor	Odorless
HCO₃- / Total	198 / 649	3.25 / 13.68	23.73 / 100.00	Sediment	No precipitate

Note. ND = not detected. Noncarbonate hardness was calculated as total hardness minus carbonate hardness ($7.78 - 4.89 = 2.89$ meq/L). HCO₃- is shown with the anion total in the final row to preserve the original table structure.

Treatment with the sapropel-based sorbent produced substantial changes in the ionic composition and organoleptic characteristics. The analytical results after treatment are presented in Table 2.

Sodium decreased from 215 to 105 mg/L, while calcium and magnesium decreased from 124 to 89 mg/L and from 100 to 40 mg/L, respectively. Total hardness fell from 14.4 to 7.78 meq/L. These results are consistent with ion exchange and adsorption by the humic and mineral components of sapropel.

Sulfate decreased from 608 to 298 mg/L, bicarbonate from 390 to 198 mg/L, and chloride from 204 to 146 mg/L. The treated sample remained sulfate-dominated, but the absolute anion load was substantially lower. Hydrogen sulfide decreased from 32.3 to 14.23 mg/L, fluoride from 1.29 to 0.72 mg/L, and the measured dry residue from 1,520 to 954 mg/L. The water became clear, colorless, odorless, and free of visible precipitate.

Not all indicators improved. Ammonium increased from 21 to 24 mg/L, nitrate from 6 to 7 mg/L, and oxidizability from 32.23 to 34.21 mg O₂/L. Consequently, the available data support demineralization, sulfide reduction, decolorization, and deodorization, but they do not demonstrate removal of the total nitrogenous or oxidizable load. A biological, oxidative, or membrane polishing stage should therefore be evaluated for applications requiring more complete purification.

The study is a comparative water-quality assessment. Adsorption isotherms, kinetic constants, optimal sorbent dose and contact time, regeneration performance, and spent-sorbent composition should be determined before industrial scale-up. Compliance must also be verified against the specific standard governing the intended discharge or technical reuse route.

Conclusion

The sapropel-based composite sorbent substantially improved the ionic and organoleptic characteristics of wastewater generated during printed-fabric washing. Sodium and sulfate were reduced by approximately one half, total hardness decreased to 7.78 meq/L, hydrogen sulfide decreased to 14.23 mg/L, and the measured dry residue fell to 954 mg/L. The disappearance of reddish color, sulfurous odor, and visible precipitate confirms the practical potential of the treatment.

Because ammonium, nitrate, and oxidizability did not decrease, the sapropel sorption stage should be considered a component of an integrated treatment system rather than a universal stand-alone process. With optimization, regeneration testing, and validation against reuse criteria, this local raw material may offer an economical and environmentally compatible option for industrial wastewater management.

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Contact: matlubamuxtarovna1988@gmail.com