PHYSICS AND CHEMISTRY
OF SOLID STATE
V. 27, No.1 (2026) pp. 86-94

Section: Chemistry

DOI: 10.15330/pcss.27.1.86-94

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ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 27, № 1 (2026) С. 86-94

Хімічні науки

PACS: 75.75.Fk

ISSN 1729-4428 (Print)
ISSN 2309-8589 (Online)

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Magnetic composites Fe_3O_4 based for the purification of polluted water

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Fe_3O_4 magnetic nanocomposite were synthesized from different techniques: Fe_3O_4 nanoparticles were synthesized by co- precipitation of salts in a carbon matrix (biochar, activated carbon) with the formation of Fe_3O_4/BC and Fe_3O_4/AC nanocomposites; and co-precipitation of $FeCl_2$/$FeCl_3$ with oleic acid, with formation of OL/Fe_3O_4 nanocomposite. Characterization techniques including XRD confirmed the spinel structure of composite matrix, with crystallite size around 20 nm. X-ray fluorescence analysis shows the presence of iron and oxygen elements, as well as impurity elements present in oleic acid and biomass carbon, respectively. The adsorption properties of all samples investigated for methylene blue (MB) dye removal. Adsorption tests were conducted at room temperature with magnetic separation of the spent adsorbent and photometric control at 665 nm. It found that magnetic composites effectively remove the dye, with AC/Fe_3O_4 achieving up to 96.6% removal at a concentration of MB 10^{-5} g/L.

Keywords: water purification, adsorption, magnetic nanoparticles, nanocomposites, X-ray analysis.

Received 11 September 2025; Accepted 04 February 2026; Published 20 February 2026.

Introduction

The current environmental crisis is becoming increasingly serious [1]. One of the most pressing problems today is the pollution of water resources with toxic substances. Pollution of water bodies leads to the gradual degradation and destruction of aquatic and coastal ecosystems. The use of water that does not meet regulatory requirements is dangerous to public health [2, 3]. One of the main causes of surface water pollution is the discharge of untreated or insufficiently treated wastewater. Discharges from enterprises and domestic sewage undergo a treatment process and are subject to control before being discharged into water bodies [4].

However, due to high costs, outdated equipment, and the technological complexity of implementing new treatment methods, insufficiently treated wastewater ends up in water resources. Adsorption is one of the most effective methods of wastewater treatment, based on the ability of certain materials to adsorb pollutants on their surface. The adsorption method of water treatment is highly effective, but the cost of adsorption materials can be a problem. The current task is to find effective and inexpensive adsorbents. Agricultural waste is a cheap and readily available material with great potential for reducing the cost of wastewater treatment.

The key factors in evaluating adsorbents are cost and adsorption capacity, which depend on the degree of processing and availability of materials. Several factors influence the adsorption process, including surface area, various functional groups, and porosity of the adsorbent material [5, 6]. Synthetic adsorption materials, in particular polymer resins and chelating agents, demonstrate high efficiency and selectivity in purification processes. However, their disposal after use poses a significant environmental problem due to the low biodegradability of these materials. In this regard, a promising direction is the development of sorbents based on natural biocompatible materials, in particular the use of agricultural waste as a raw material for the creation of environmentally safe adsorbents [7].

Biomass from crop residues is the starting material for the synthesis of coal adsorbents through carbonization. Carbonization is one of the most effective methods of modifying biowaste. This method involves the creation of biochar, which can compete with activated carbon. In turn, activated carbon is widely used not only to remove pollutants from wastewater streams, but also to adsorb pollutants from drinking water sources such as groundwater, rivers, lakes, and reservoirs [8]. Biochar is a solid product with a high carbon content, whose adsorption properties are optimal for wastewater disinfection. Due to its high surface area to volume ratio, it can be used for many environmental applications. The carbon structure of biochar is determined by size, key components of lignocellulosic raw materials, and decomposition at high temperatures [9].

The porous structure of coal allows it to adsorb inorganic and organic chemicals in both gaseous and liquid phases [10]. Biochar improves flocculation, adsorption, and oxidation processes during municipal wastewater treatment, which has a positive effect on sludge treatment, odor reduction, and nutrient recovery [11]. Coal is characterized by a large surface area. The large surface areas of adsorbent materials can be used to create additional sites for both physical and chemical capture of pollutants in wastewater [12]. In addition, a large surface area can maximize the interaction between pollutant particles and the adsorbent material, which increases the adsorption capacity [13, 14].

Biochar differs from activated carbon in that it is produced at lower pyrolysis temperatures (below 700°C) and does not undergo activation. The effectiveness and affordability of biochar as an adsorbent for wastewater treatment is determined by its physicochemical characteristics and pore structure [15].

A current trend in the production of effective bioadsorbents is the development of coal-based nanocomposites. The technology for producing biochar-based composites uses coal as a framework for embedding new materials to create a surface with new properties on which pollutants can be sorbed [16]. In this process, biochar acts as a porous carbon matrix on which metal oxides are deposited [17].

Adding various elements to biochar increases its functionality, allows for the adjustment of surface characteristics, provides useful physicochemical qualities, and opens up broader application prospects [18]. Magnetic biochar is obtained by combining biochar with magnetic material. This gives the carbon material magnetic properties, which can increase the effectiveness of the composite for treating contaminated water [19]. The technology for manufacturing magnetic nanocomposites based on biochar offers a possible way to reuse biomass waste, which is a direction for environmentally sustainable economic development.

The following methods are most commonly used for the synthesis of magnetic biochar [20]: impregnation-pyrolysis; chemical co-deposition; solvothermal co-deposition; mechanochemical activation; reductive co-deposition.

The use of magnetic nanoparticles is promising for cleaning both wastewater and soil cover, which poses a threat to local ecosystems [21]. In a study [22], researchers demonstrate methods of obtaining magnetic sorbents that mainly allow controlling the shape, morphology, magnetic properties, and size of particles. Since magnetic carbon sorbents enhance their adsorption capacity when magnetite nanoparticles are added to carbon matrices, these materials have great potential for removing malachite green and other dyes.

Magnetic composites based on coal can be used as effective and environmentally friendly adsorbents. Compared to conventional biochar, magnetic biochar is more effective in removing water pollutants, including Pb(II), Cd(II), Cu(II), Zn(II), tetracycline, methylene blue, phosphates, and pesticides [13]. Magnetic ferrite nanoparticles are often used as a magnetic material for the production of magnetic biochar and demonstrate high activity in removing various types of environmental pollutants: metals and non-metals (Hg, Cr, Pb, Cu, U, As), dyes (methylene blue, Congo red, methyl violet), pharmaceuticals, and other pollutants [11, 23, 24]. A study [25] noted that of all the adsorbents used, biochar and magnetic nanoparticles demonstrated the greatest ability to remove malachite green – 95.73 and 82.18, respectively.

Given that purification processes are carried out in an aqueous environment, a key advantage of using magnetic ferrite nanoparticles for the synthesis of magnetic carbon, in particular Fe_3O_4 magnetite, is its magnetic properties [26], which allow it to be extracted from solution and separated with a magnet after adsorption [11]. Biochar without additional processing has good adsorption properties, but it can only be separated from water using traditional filtration, sedimentation, and coagulation processes. These processes are expensive, inefficient, and require significant technological interventions in the water treatment system, which significantly limits their application [13]. Separation of magnetic biochar with a magnet simplifies the process of separating the adsorbent from purified water and allows the spent adsorbent to be effectively used for regeneration or as a secondary raw material. Biochar inhibits the aggregation of magnetic nanoparticles [26]. Various metal oxides can be used to synthesize coal-based magnetic nanocomposites. However, Fe_3O_4 has a relatively high adsorption capacity and low synthesis cost.

I. Materials and methods

1.1. Synthesis of Fe_3O_4 magnetic nanocomposites

Soybeans were used for experimental research. Straw was obtained from the harvested soybeans by drying them under natural conditions. A laboratory setup was used for pyrolysis, which included a high-temperature stainless steel reactor with gas outlet pipes to a pressure gauge and a needle valve for gas release. The reactor was installed in an electric furnace with the ability to control the temperature from room temperature to 700°C. The temperature was controlled using a thermocouple. The accuracy of temperature control at high temperatures was ± 10°C. To enable accurate temperature control, the reactor and furnace were wrapped in several layers of foil. Soy straw was loaded into the high-temperature reactor. The pyrolysis reaction took place without oxygen access at a temperature of 480 °C. Reaction time: 1 hour. After the temperature reached more than 200°C, the gaseous reaction products were released through a needle valve. The result was biochar. The yield of biochar from 16.8 g of dry biomass was 5.126 g, which is 30.5%.

For particle synthesis, solutions of divalent and trivalent iron chlorides were prepared. For synthesis, stoichiometric ratios of $FeCl_2$ and $FeCl_3$ were selected. 195 ml of iron chloride solution was added to 3 l of water. The solution was placed in a surface mixer and a dropper with ammonia solution was connected. As ammonia was added, the solution gradually changed color from rusty red to black. The pH of the solution was constantly monitored. Ammonia was added until the pH reached 10. The black color indicates the presence of magnetite (Fe_3O_4) nanoparticles. To stabilize the obtained nanoparticles, a solution of surfactant was prepared from oleic acid and concentrated ammonia solution. The surfactant was added to the solution with the synthesized nanoparticles. Subsequently, diluted HCl (8%) was added to bring the pH to neutral. The magnetic particles were separated using a magnet. After washing 3 times with water and 3 times with alcohol, they were dried.

The magnetic composite was synthesized in two ways:

1) Biochar was impregnated with a solution of magnetite nanoparticles with oleic acid. Contact time was 20 hours (adsorption of nanoparticles by carbon). After synthesis, the magnetic carbon was separated using a magnet. After three rinses with water and three rinses with alcohol, it was dried.

2) Magnetic particles were synthesized directly in the carbon matrix of activated carbon. 2.5 g of activated carbon was added to the synthesis solution (stasiometric mixture of $FeCl_2$ and $FeCl_3$). Left to settle for 3 days at a temperature below 20 °C. Separated the AC using filter paper. Added the impregnated AC to 250 ml of H_2O and began to synthesize magnetite nanoparticles on the surface of the AC by gradually adding ammonia (NH_4) solution. The synthesis was carried out by heating the solution to 35°C and stirring at 600 rpm. After synthesis, the magnetic composite was separated using a magnet. After washing 3 times with water and 3 times with alcohol, it was dried.

1.2. Characterization techniques

The X-ray diffraction analysis has been performed using a Shimadzu XRD-7000 X-ray with $Cu_{K\alpha}$ monochromatic radiation source (λ = 1.5418 Å). The crystal phases were identified using the Match! 3.0/FullProf software. To investigate the elemental composition of the synthesized adsorbents, analysis was performed using an Expert 4L X-ray fluorescence analyzer.

1.3. The adsorption experiment

To study the adsorption efficiency of methylene blue by coal-based magnetic nanocomposites, model solutions with known concentrations of methylene blue were prepared.

The samples were prepared as follows:

a) To three model solutions of MB (volume 100 ml) with the following concentrations: $1\cdot10^{-5}$ %, $1\cdot10^{-6}$%, $1\cdot10^{-7}$ %, 0.3 g of Fe_3O_4/BC composite was added.

b) To model solutions of MB (volume 100 ml) with the following concentrations: $1\cdot10^{-5}$ %, $1\cdot10^{-6}$ %, 0.3 g of Fe_3O_4 composite (pH = 7) was added.

c) To model solutions of MB with the following concentrations: $1\cdot10^{-5}$ % (100 ml), 10^{-6} % (50 ml), 0.3 g of Fe_3O_4/AC composite (pH = 10) was added.

d) To model solutions of MB with the following concentrations: $1\cdot10^{-5}$ % (100 ml), $1\cdot10^{-6}$ % (50 ml), 0.3 g of Fe_3O_4/AC composite (pH = 7) was added.

e) 0.3 g of AC composite was added to the model solution of MB with a concentration of $1\cdot10^{-6}$ % (50 ml).

Adsorption processes took place at room temperature (18 °C). The temperature was chosen to simulate the purification process under natural conditions without external heating. The spent adsorbent was separated from the solution using a magnet.

The adsorption efficiency of methylene blue was determined by measuring the intensity of the color before and after the reaction. The measurements were performed on a Shimadsu UV-1900i UV-VIS spectrophotometer.

Solutions of known methylene blue concentration were used to control the amount of adsorption. Control samples were selected to simulate different pollution intensities – $1\cdot10^{-5}$ %, $1\cdot10^{-6}$ %, $1\cdot10^{-7}$ by volume.

These concentrations were also selected based on previous experiments and the ability to effectively determine absorption spectra using a Shimadsu UV-1900i spectrophotometer.

Methylene blue solutions with concentrations of $1\cdot10^{-5}$ %, $5\cdot10^{-6}$ %, $1\cdot10^{-6}$ %, and $1\cdot10^{-7}$ % were used to calibrate the spectrophotometer. Calibration was performed according to the peak at a wavelength of 665 nm.

II. Results and discussion

2.1. X-ray diffraction analysis

X-ray diffraction patterns of Fe_3O_4 samples synthesized using two types of composite materials (Fig. 1) confirm the formation of a spinel phase. The sample OL/Fe_3O_4 synthesized with oleic acid is identified as a single-phase material belonging to the Fd3m space group [26]. Sharp diffraction peaks indicate good crystallinity of the samples. The AC/Fe_3O_4 sample synthesized with activated carbon forms a characteristic deformation in the corresponding region. This is explained by the fact that the activated carbon sample is rooted in the spinel structure. The synthesis of magnetite with oleic acid is accompanied by the formation of a core-shell structure, where the acid envelops the pure spinel nanoparticles.

The particle size was determined by peak 311 according to the Scherrer formula, with a size around 15-20 nanometers.

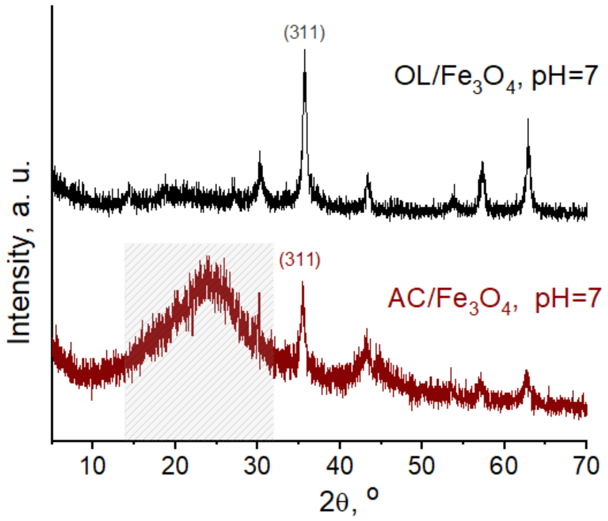


Fig. 1. X-ray patterns of ferrites composites.

2.2. X-ray fluorescence analysis

To investigate the elemental composition of the synthesized adsorbents, analysis was performed using an Expert 4L X-ray fluorescence analyzer, with results presented in the table 1. The Modification with oleic acid results in the emergence of new elements, indicating potential changes in surface sorption properties. The biochar composite exhibits the most complex elemental composition, characterized by an exceptionally high calcium content – a typical biochar component originating from the parent biomass.

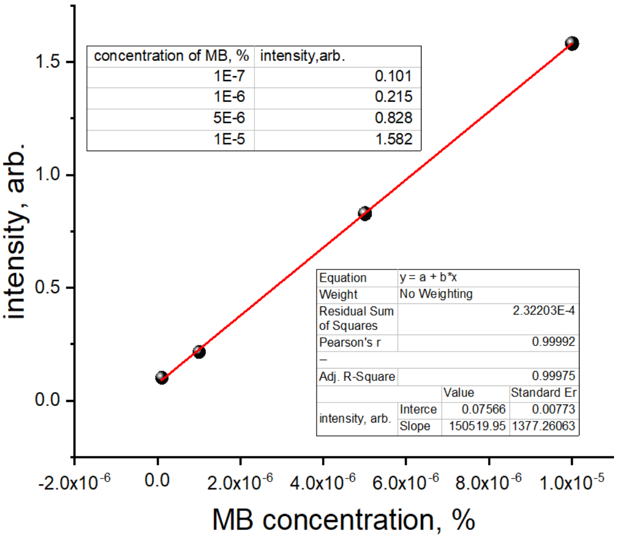
Table 1.

X-ray fluorescence analysis results of adsorbents composition.

Element	**Fe_3O_4/OL pH7**	**Fe_3O_4 / BC**
	matrix %	
8O	**32.027**	**32.653**
12Mg	-	0.51075
13Al	0.893	0.83025
14Si	3.594	4.5855
15P	0.092	0.13175
16S	0.077	0.08275
19K	0.981	0.7125
20Ca	3.253	3.51025
22Ti	0.12	0.1165
24Cr	-	0.015075
25Mn	0.142	0.131
26Fe	**58.635**	**57.359**
28Ni	-	0.126
29Cu	-	0.02375
30Zn	0.066	0.0635
38Sr	0.0454	0.02265
39Y	-	0.003125
40Zr	0.0366	0.011175
42Mo	-	0.004125
47Ag	0.0184	0.00585

2.3. The adsorption experiment

The analyses resulted in a calibration graph. A linear regression was constructed from the experimental data obtained, which made it possible to evaluate the sorption results of the synthesized composite sorbents based on carbon and magnetic nanoparticles. Figure 2 shows the relationship between the absorption intensity and known concentrations of methylene blue.



concentration of MB, %	intensity,arb.
1E-7	0.101
1E-6	0.215
5E-6	0.828
1E-5	1.582

Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares			2.32203E-4
Pearson's r			0.99992
–			
Adj. R-Square			0.99975
		Value	Standard Er
intensity, arb.	Interce	0.07566	0.00773
	Slope	150519.95	1377.26063

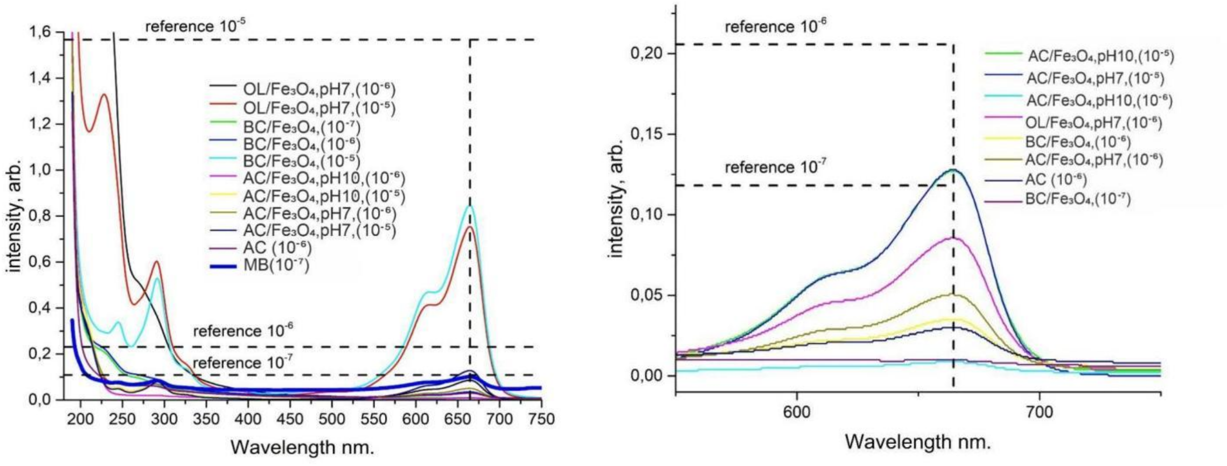
Fig. 2. Alibration graph of the dependence of the intensity of absorption spectra at a wavelength of 665 nm for control solutions of methylene blue with concentrations of 10^{-5}, 10^{-6}, $5 \cdot 10^{-6}$, 10^{-7} g/L.

To evaluate the effectiveness, we consider the intensity of light absorption at a wavelength of 665 nm – the maximum absorption (λ max) characteristic of the dye under study, which allows us to accurately determine its concentration in the solution after the adsorption process (Figures 3).

The intensity of light absorption at the maximum absorption characteristic of methylene blue is directly proportional to the concentration of the dye. Low light absorption intensity indicates low color intensity. Accordingly, low absorption intensity indicates the effectiveness of the adsorption process. The reference points show the initial concentrations of methylene blue in the model solutions. The concentrations of methylene blue in the test samples were determined using a calibration curve. The dye concentration and percentage removal before and after adsorption are shown in Table 2.

The percentage of dye removal is evaluated as the main indicator of the effectiveness of cleaning the model solution from methylene blue. Figure 4 shows a histogram demonstrating the percentage of methylene blue removal by each of the studied adsorbents.

The best results are observed when the dye is adsorbed by magnetic nanocomposites based on activated carbon. The significant difference between the effectiveness of biochar and activated carbon is due to different methods of nanocomposite synthesis. Magnetic particles synthesized directly in coal work best. The maximum removal rate of 96.58% was demonstrated by the AC/Fe_3O_4 adsorbent, pH = 10 (10^{-5} g/L). The effectiveness of this adsorbent is explained by the synergistic effect of the adsorption properties of coal, in particular its large surface area and porous structure, and the adsorption properties of Fe_3O_4 nanoparticles. The lowest removal rate was observed with the BC/Fe_3O_4 adsorbent (10^{-5} g/l). It is predicted that a coal-based



(a) (b)

Fig. 3. (a) Adsorption spectra of test samples; (b) Adsorption spectra of test samples at wavelengths of 560-750 nm.

Table 2.

Adsorption efficiency of the materials studied.

Material	After cleaning	Before cleaning	Percentage removal
BC/Fe_3O_4, (10^{-5})	5.1237×10^{-6}	10^{-5}	48.76
OL/Fe_3O_4, pH = 7, (10^{-5})	4.506×10^{-6}	10^{-5}	54.94
AC/Fe_3O_4, pH = 10, (10^{-5})	3.4124×10^{-7}	10^{-5}	96.59
AC/Fe_3O_4, pH = 7, (10^{-5})	3.4788×10^{-7}	10^{-5}	96.52
AC/Fe_3O_4, pH = 10, (10^{-6})	4.4255×10^{-7}	10^{-6}	55.75
OL/Fe_3O_4, pH = 7, (10^{-6})	6.8908×10^{-8}	10^{-6}	93.11
BC/Fe_3O_4, (10^{-6})	2.6985×10^{-7}	10^{-6}	73.02
AC/Fe_3O_4, pH = 7, (10^{-6})	1.7022×10^{-7}	10^{-6}	82.98
AC, (10^{-6})	3.0306×10^{-7}	10^{-6}	69.69
BC/Fe_3O_4, (10^{-7})	4.3591×10^{-8}	10^{-7}	56.41
MB, (10^{-7}) (model pollutant)	1.00×10^{-7}	10^{-7}	0.00

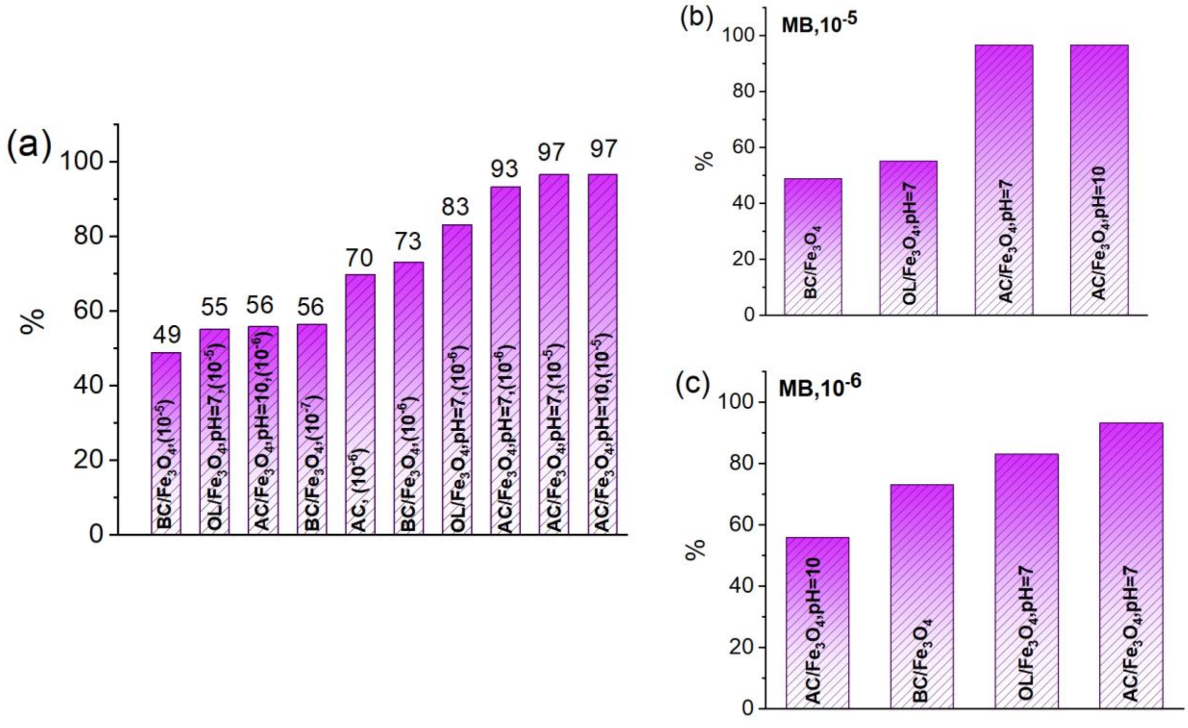


Fig. 4. Percentage of MB removal: (a) increase in the percentage removal of a model pollutant (b) initial concentration of model pollutant (10^{-5} g/L); (c) initial concentration of model pollutant (10^{-6} g/L).

nanocomposite synthesized by depositing magnetite directly into coal will show similar results to activated carbon. Samples tested at a concentration of 10^{-6} g/L generally show better purification efficiency compared to similar materials at a concentration of 10^{-5} g/L. This is a typical pattern for adsorption processes, where lower pollutant concentrations result in more complete saturation of the active centers of the adsorbent.

To study the adsorption properties of the synthesized adsorbents, the research was conducted using model solutions with different concentrations of methylene blue. Hence, it is advisable to compare the purification efficiency within the same concentration range.

The histogram in Figure 5 demonstrates the efficiency of dye removal from a solution with a concentration. Four magnetic nanocomposites were selected to study the adsorption efficiency at a methylene blue concentration of 10^{-5} g/L. BC/Fe_3O_4 demonstrates moderate purification efficiency. The residual dye concentration is 5×10^{-6} g/l, which represents 48.76 % removal of the pollutant. Similar results are demonstrated by the OL/Fe_3O_4 adsorbent synthesized at pH = 7 – magnetite with oleic acid – 54.9%. Oleic acid acts as a stabilizer for magnetic nanoparticles, preventing their aggregation, but at the same time it can partially block active adsorption centers, which explains the lower efficiency compared to pure AC/Fe_3O_4 composites, which are also characterized by a synergistic effect from the use of coal and magnetic nanoparticles.

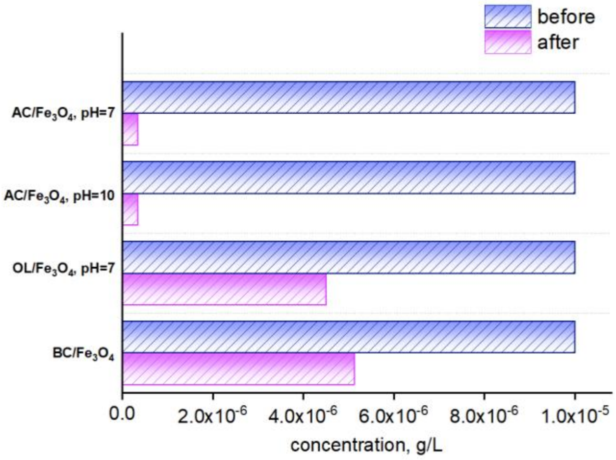


Fig. 5. MB concentration before and after purification (initial concentration (10^{-5} g/L).

Two magnetic nanocomposites based on activated carbon AC/Fe_3O_4, pH = 10 (10^{-5}) and AC/Fe_3O_4, pH = 7 demonstrate the highest efficiency of pollutant removal, 96.58% and 96.52%, respectively. There is no significant difference between the samples synthesized at pH = 10 and pH = 7. Therefore, it can be assumed that pH during synthesis does not affect adsorption efficiency. On the other hand, the question remains open as to how the adsorbent will behave at higher pollutant concentrations, as well as the optimal amount of adsorbent per unit of pollutant time.

To study the adsorption efficiency at a methylene blue concentration of 10^{-6} g/L, five composites were selected (Figure 6).

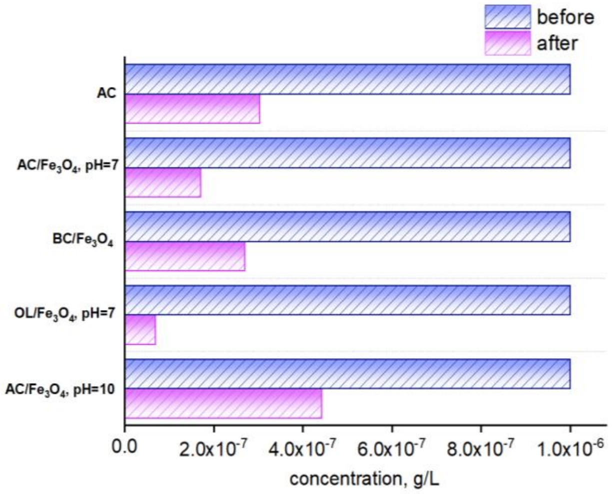


Fig. 6. MB concentration before and after purification (initial concentration (10^{-6} g/L).

The graph shows the results of purifying model solutions with an initial concentration of methylene blue of 10^{-6} g/L. Unlike the previous graph with a concentration of 10^{-5} g/l, here we observe significantly better purification efficiency for practically all materials studied, which confirms the classic pattern of adsorption processes—higher efficiency at lower contaminant concentrations. Pure activated carbon without magnetic additives demonstrates moderate efficiency with a residual concentration of about 2×10^{-7} g/l, which corresponds to a purification efficiency of approximately 80%. This result confirms that the addition of magnetic nanoparticles not only gives the composite magnetic properties for easy separation, but also improves its adsorption characteristics. Figure 7 shows the efficiency of dye removal by a biochar-based nanocomposite from a solution with a concentration of 10^{-7}.

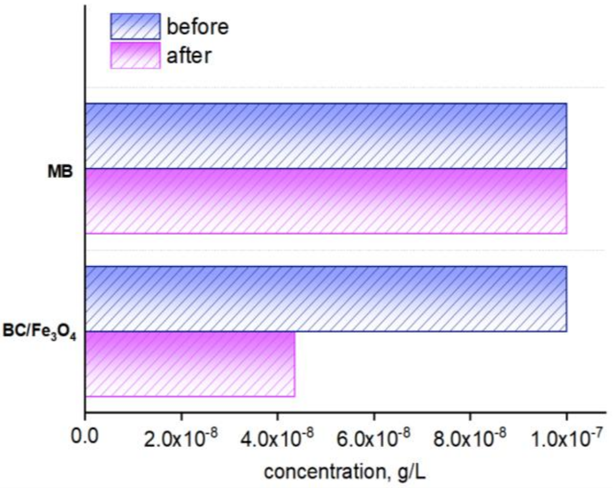


Fig. 7. MB concentration before and after purification (initial concentration (10^{-7} g/L).

The graph shows the results of purifying model solutions with the lowest concentration of methylene blue (10^{-7} g/L) among those studied. The graph compares two materials: a control sample of methylene blue (MB) and a composite (BC/Fe_3O_4). The magnetic nanocomposite based on biochar actively adsorbs the pollutant at low dye concentrations. The residual concentration of methylene blue is about 4×10^{-8} g/l, which corresponds to a purification efficiency of about 56.4093%. This is a good result, considering that at such low concentrations of the pollutant, adsorption processes are complicated due to the limited driving force of mass transfer. This result also requires further study, given the low concentration of the pollutant and the instrument error.

Synthesized magnetic nanocomposites on charcoal demonstrate high efficiency in removing harmful substances from model solutions and can be used for wastewater treatment. The developed materials combine high adsorption capacity with the technological advantages of magnetic separation, making them competitive with traditional water purification methods.

Conclusions

A comprehensive analysis of the problem of water pollution was conducted, and it was established that the adsorption method is one of the most effective ways to treat wastewater. The high adsorption efficiency of synthesized magnetic nanocomposite materials for removing methylene blue from model solutions achieving up to 96.6% for AC/Fe_3O_4 was experimentally confirmed.

Experimental studies confirm the high adsorption efficiency of synthesized magnetic nanocomposites for removing methylene blue from model solutions. It has been established that the method of nanocomposite synthesis significantly affects the adsorption capacity of the material. Composites based on biochar (BC/Fe_3O_4) showed lower efficiency compared to composites based on activated carbon (AC/Fe_3O_4), which is explained by different methods of nanocomposite synthesis.

The introduction of magnetic bioadsorbents into water treatment practices will help reduce the anthropogenic impact on the environment and ensure the ecological safety of water resources.

The results of the work demonstrate the promise of using crop residues to create effective bioadsorbents and modifying them to obtain magnetic nanocomposites with improved performance characteristics. The use of magnetic nanocomposites based on biochar is a promising technology in the field of water purification. Magnetic nanocomposites demonstrate high adsorption efficiency and solve the problem of separating spent adsorbent from purified water. The presented method of water purification using biochar-based nanocomposites complies with the principles of circular economy and sustainable development, transforming agricultural waste into a valuable product.

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Магнітні композити на основі Fe_3O_4 для очищення забрудненої води

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Магнітний нанокомпозити на основі Fe_3O_4 були синтезовані різними методами: наночастинки Fe_3O_4 отримані шляхом спільного осадження солей у вуглецевій матриці (біовугілля, активоване вугілля) з утворенням нанокомпозитів Fe_3O_4/BC та Fe_3O_4/AC; та продукти спільного осадження $FeCl_2$/$FeCl_3$ з олеїновою кислотою з утворенням нанокомпозиту OL/Fe_3O_4. Методи характеристики, включаючи Х-променеву дифракцію, підтвердили структуру шпінелі композитної матриці з розміром кристалітів близько 20 нм. Х-променевий флуоресцентний аналіз показує наявність заліза та кисню, а також домішкових елементів, присутніх в олеїновій кислоті та вуглеці з біомаси. Адсорбційні властивості всіх зразків досліджували на видалення барвника метиленового синього (MB). Адсорбційні випробування проводили при кімнатній температурі з магнітною сепарацією відпрацьованого адсорбенту та фотометричним контролем при 665 нм. Було виявлено, що магнітні композити ефективно видаляють барвник, причому AC/Fe_3O_4 досягає до 96,6% видалення при концентрації MB 10^{-5} г/л.

Ключові слова: очищення води, адсорбція, магнітні наночастинки, нанокомпозити, Х-променевий аналіз.