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MINERAL-BASED MAGNETIC NANOCOMPOSITE SORBENTS

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The article is devoted to the synthesis of mineral-based magnetic nanocomposite sorbents and the study of the influence of modification by magnetite and molybdenum disulfide on the structural-sorption and surface properties of native saponite clay. Modification of native saponite clay with nanoscale magnetite increases the specific surface area and changes pore's distribution of the original clay from monomodal to bimodal. Next modification of magnetic saponite by micro-sized and nano-sized molybdenum disulfide results in blocking of the secondary porous structure (bimodality disappears of magnetic saponite), but it is increasing the specific surface area. It was found that the sorption activity of modified and unmodified saponite in the region of low concentrations of cationic and anionic dyes (Methyl blue and Congo red) is almost the same. The study of Congo red dye adsorption from highly concentrated solutions showed significant differences in the sorption activities of modified and unmodified saponite samples: the largest sorption capacity characteristic of ternary composites (saponite modified by magnetite and by nano-sized molybdenum disulfide). These ternary composites had in 62 times more activity than native saponite clay and 10 times more than magnetic saponite. It is established that all the samples are characterized by basic properties, but the sample of native saponite modified by magnetite and nano-sized molybdenum disulfide has the largest number of active centers (both acidic and basic character). Thus, it is shown that the modification of the native saponite clay significantly affects not only the texture-sorption but also the surface properties of the native saponite clay.

Keywords: *saponite, magnetic mineral sorbents, nanocomposites, acid-base properties, sorption, dyes.*

Introduction

Smectites are one of the largest and most important classes of the phyllosilicate clay-mineral group. The smectite group includes Montmorillonite Sodium, Montmorillonite Calcium, Bedellite and Vermiculite, and elongated smectites involve Neutronite, Saponite and Hectorite. The basic structural unit of smectite clay is a layer consisting of two mid-tetrahedral layers with a central octahedral layer of aluminum oxide. The general molecular formula of the smectite group is $(Ca,Na,H)(Al,Mg,Fe,Zn)_2(Si,Al)_4O_{10}(OH)_{2-x}H_2O$. One characteristic of smectite clays is the replacement in the octagonal and tetrahedral layers. In the octahedral layers, Aluminum is changed by Magnesium and Ferrum; in the tetrahedral layers, Silicium is replaced by Aluminum. If the octahedral positions are mainly filled with Aluminum, then such smectite mineral is Bedelite; if this places are pledged with Magnesium, then such mineral is Saponite (Fig. 1); if spots are occupied by Ferrum it is Nontronite; and finally if the clay mineral is filled with Lithium, then it is Hectorite (Polyakov 2012 and Murray 2007).

Saponite is a natural sorbent that has high adsorption, ion exchange, catalytic and filtration properties. Saponite has a high cation exchange capacity and high selective activity for many inorganic (Mykhailenko 2015, Macblek 2000, Liansheng 2018 and Saeedeh 2014) and organic substances (Polyakov 2012, Liansheng 2018, Dontsova 2018 and Makarchuk 2017). For the first time in the world, industrial deposits of saponite clay were discovered in Ukraine, in the northern part of the Khmelnytskyi region (Tashkiv deposit). It is also the most well-known, studied and promising industrial saponite deposit in the world. Thus, the development of various commercial products

(Kumaresan 2019 and Chanturiya 2018) based on saponite, including sorption materials, is an actual problem.

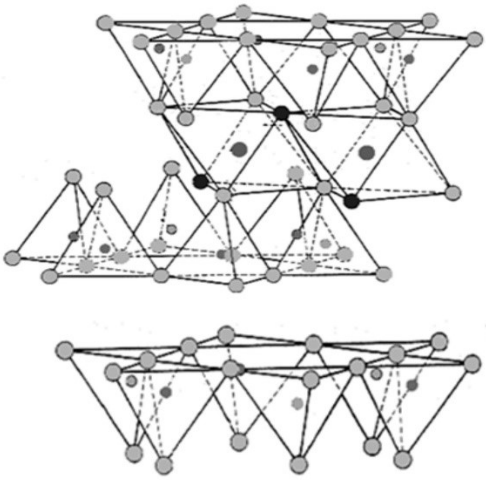

Fig. 1. Spatial structural formula of saponite: ○ – oxygen, ● – OH-groups, ● – Mg, • – Si, • – Al.

Recently, the creation of magnetic composite sorbents based on clay minerals have become most popular (Mykhailenko 2015). The advantage of magnetic adsorbents is that their removal can be easily realized with a magnetic field. Adsorbents with magnetic properties have already been successfully used for the purification of various wastewaters, the collection of oil from the reservoirs surface and in medicine (Macblek 2000, Liansheng 2018, Saeedeh 2014 and Fatemeh 2018). Their advantages include fast recovery, low cost and high mechanical strength. The next improve the sorption properties of mineral-based magnetic sorbents, we propose further modification by the third phase, for example, by photocatalytic particles of transition metal chalcogenides (Dontsova 2018). In addition to varying the sorption properties, modification allows to change the structure of the clay mineral, which leads to an increase in the material porosity, specific surface area, the number of active centers, etc., and, as a result, to improve of its sorption properties.

The purpose of this work is the synthesis of ternary magnetic nanocomposite sorbents based on saponite clay by modification of micro-sized and nano-sized molybdenum sulfide; their characterization and study of sorption properties.

Experimental

The saponite of the Tashkiv field, Khmelnitsky region was used as a clay mineral. $FeCl_3{\cdot}6H_2O$ and $FeSO_4{\cdot}7H_2O$ reagents were used for nanoscale magnetite synthesis. Synthesis of the magnetic fluid and magnetic saponite sorbent was performed according to (Makarchuk 2017). Additional modification was performed by micro-size and nano-saze molybdenum (IV) sulfide (MoS_2). For this purpose, freshly prepared non-dried $SapFe_3O_4$ and the corresponding molybdenum sulfide were introduced into the distilled water and stirred vigorously for 30 minute. Then the suspension was filtered and the obtained precipitate was dried for 24 hours at 80 °C. Thus, the four sorption materials were obtained: native saponite (Sap), magnetic saponite sorbent ($SapFe_3O_4$), modified magnetic saponite sorbent by micro-sized MoS_2 ($SapFe_3O_4m$) and modified magnetic saponite sorbent by nano-sized MoS_2 ($SapFe_3O_4n$) (Table 1).

Table 1. Composition of composite sorbents based on saponite clay

Sample	*Phase composition*	*Mass content, % wt.*
Sap	Saponite clay	100
$SapFe_3O_4$	Saponite clay Fe_3O_4	93 7
$SapFe_3O_4m$	Saponite clay Fe_3O_4 MoS_2 (micro-size)	92 7 1
$SapFe_3O_4n$	Saponite clay Fe_3O_4 MoS_2 (nano-size)	92 7 1

Nanocomposite mineral-magnetic sorbents were characterised by scanning electron microscopy (SEM-106I, Ukraine) and by the method of low-temperature adsorption-desorption of nitrogen (Quantachrome Autosorb Nova 2200e, USA).

Studies of sorption properties were carried out on model dye solutions: Methyl blue (MB) and Congo red (CR). The concentration of the dyes was determined by spectrophotometric method (721 UV/VIS Spectrophotometer, China) (Hashem 2012).

The adsorption of organic dyes from aqueous systems were calculated according to equation:

$$a = \frac{x}{m}, mg/g\ ,$$

where a – adsorption x mg of dye per 1 g of sorbent, mg/g;

x – the amount of adsorbed dye from 100 cm^3 solution, mg:

$$x = \frac{(C_0 - C_r)\cdot 100}{1000}, mg,$$

where C_0 – initial dye concentration in the model solution;

C_r – residual dye concentration, mg/dm^3.

To compare the adsorption properties of the composite sorbents, the degree of removal (Re, %) of the pollutant was calculated:

$$Re = \frac{(C_0 - C_r)}{C_0}\cdot 100.$$

SEM characterization of obtained sorbents

SEM images of Sap, $SapFe_3O_4$, $SapFe_3O_4m$, $SapFe_3O_4n$ are presented in Figure 2. As can be seen from Figure 2, on the surface of the $SapFe_3O_4$, $SapFe_3O_4m$, $SapFe_3O_4n$ samples, there are additional white dots compared to SEM image of saponite. This is due to the presence of surface modifiers. The chemical analysis of the surface by scanning microscopy showed a relative increase in ferrum content in $SapFe_3O_4$ sample compared to saponite, and in the samples $SapFe_3O_4m$ and $SapFe_3O_4n$ the molybdenum and sulfur are appear (Table 2). Therefore, the point chemical analysis confirms the deposition of magnetic fluid and MoS_2 modifiers on the surface of saponite clay.

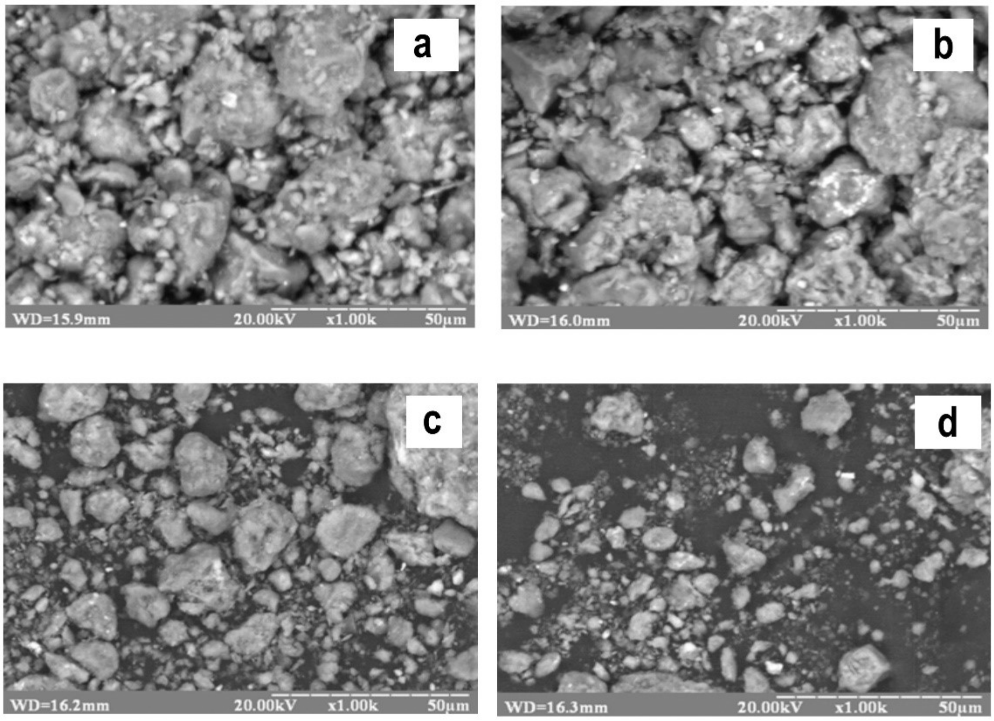

Fig. 2. SEM images of the surface Sap (*a*), $SapFe_3O_4$ (*b*), $SapFe_3O_4m$ (*c*) $SapFe_3O_4n$ (*d*).

Table 2. Point chemical analysis of the surface of the samples by scanning microscopy

Element	*Sap*	*$SapFe_3O_4$*	*$SapFe_3O_4m$*	*$SapFe_3O_4n$*
	Mass content,% wt.			
Mg	5.4	0.4	-	-
Al	4.9	0.7	-	-
Si	24.6	2.5	1.55	1.31
Ca	20.8	2.1	0.9	0.78
Fe	41.3	91.2	3.4	4.1
Mo	-	-	54.8	53.1
S	-	-	39.1	38.9

Structural adsorption characteristics of the sorbents

The specific surface area of all samples was determined by the Brunauer-Emmett-Teller equation, and the porosity was investigated by the Barrett-Joyner-Holland method (Thommes 2015).

Figure 3 shows nitrogen isothermal adsorption-desorption for saponite clay and modified composite sorbents. As can be seen from Figure 3, all the presented isotherms according to the IUPAC classification are of type IV, which is characteristic of mesoporous materials. All samples under study are characterized by an average pore size in the range of 4 nm It can also be argued that modification of saponite by magnetite and molybdenum disulfide has a significant effect on the adsorption and textural characteristics of the composites. Thus, the transition from the native saponite to modified nanocomposite sorbents changes the loop of capillary-condensation hysteresis from H3 through the hybrid type H1+H3 to H1. The transition to a hybrid type of hysteresis loop for magnetic composite sorbent is due to the deposition and partial blocking of cylindrical pores by Fe_3O_4 particles.

Table 3 summarizes the porous structure characteristics of all the samples. As can be seen from the data, the increase of the specific surface area by BET from 35 m^2/g to 53 m^2/g during the transition from the native saponite (4.3 nm) to the magnetic composite $SapFe_3O_4$ is caused by the formation of a secondary structure, what is confirmed by the bimodality (4.3 nm and 12.5 nm). Further growth with the growth of the specific surface area for $SapFe_3O_4m$ and $SapFe_3O_4n$ associated with the formation of a secondary structure of molybdenum sulfide on the SapFe_3O_4 surface. As expected, the surface area of the ternary composite modified with nano-sized MoS_2 is the largest.

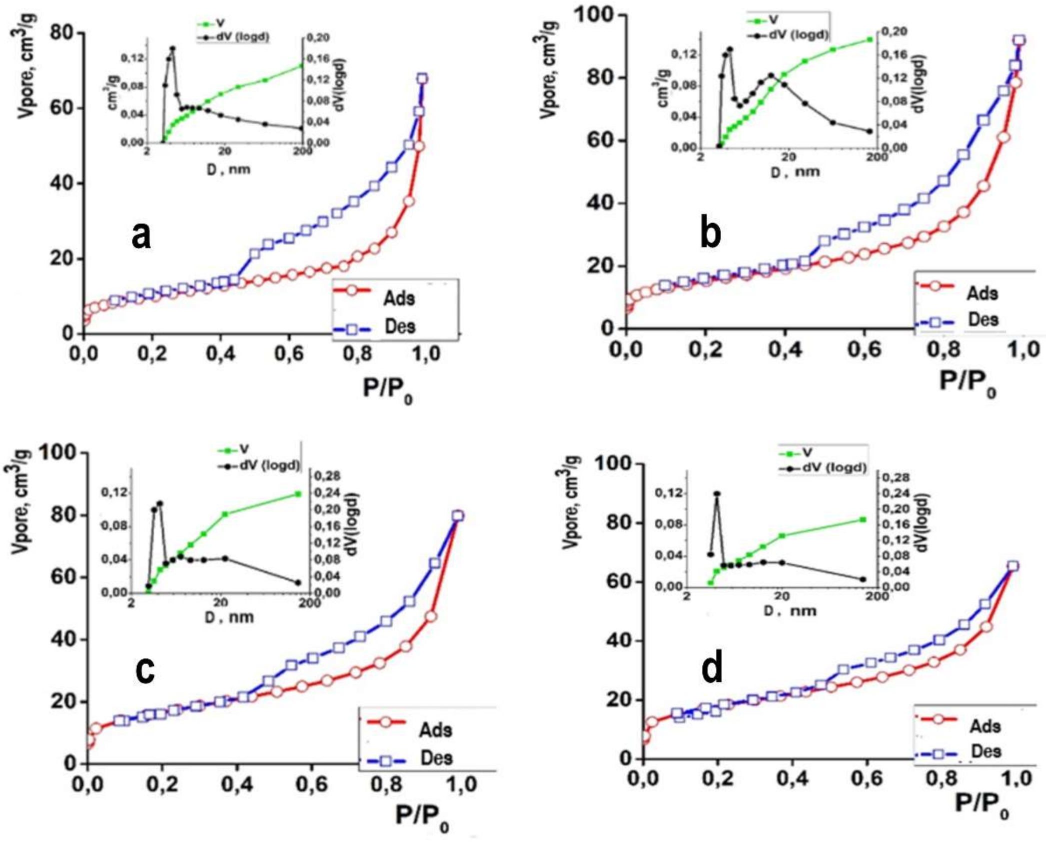

Fig. 3. Isotherms of adsorption-desorption of nitrogen on Sap (*a*), SapFe_3O_4 (*b*), SapFe_3O_4m (*c*) and SapFe_3O_4n (*d*).

Table 3. Characterization of the porous structure of saponite-based samples

Characteristic	Sap	SapFe_3O_4	SapFe_3O_4m	SapFe_3O_4n
Specific surface S, m^2/g	35	53	57	61
Mesopore volume V_{total}, sm^3/g	0,12	0,12	0,11	0,08
The prevailing pore diameter d, nm	4.3	4,3; 12,5	3,6	4,1

Sorption properties of magnetic nanocomposites and saponite clay

Sorption properties of sorbents were studied with CR and MB model solutions (initial concentration of dyes is 100 mg/dm^3). The pH of all model dye solutions was in the range of 7.

The kinetic of CR removal from model solutions by all sorbents are shown in Figure 4. The obtained dependences evidence that the removal of dyes from water solutions by composite sorbents is better than native saponite clay, the degree of CR removal is for Sap – 47 %, SapFe_3O_4 – 95 %, SapFe_3O_4m – 96 %, SapFe_3O_4n – 98 %.

The sorption properties of the composite sorbents (SapFe_3O_4, SapFe_3O_4m, SapFe_3O_4n) and the native saponite clay (Sap) were analyzed by form the adsorption isotherms of Congo red and Methyl blue from model solutions. The adsorption isotherms were plot at low and high dyes concentations.

At low dye concentrations SapFe_3O_4n and Sap had shown the best sorption capacity (Fig. 5). SapFe_3O_4m and SapFe_3O_4 had slightly lower rates. The obtained sorption capacities of all sorbents do not differ much, that is, these sorbents are equally effective at removing dyes at low concentrations. Thus, the dye sorption capacity in low range of concentrations was in according to the following order: SapFe_3O_4n > Sap > SapFe_3O_4m > SapFe_3O_4.

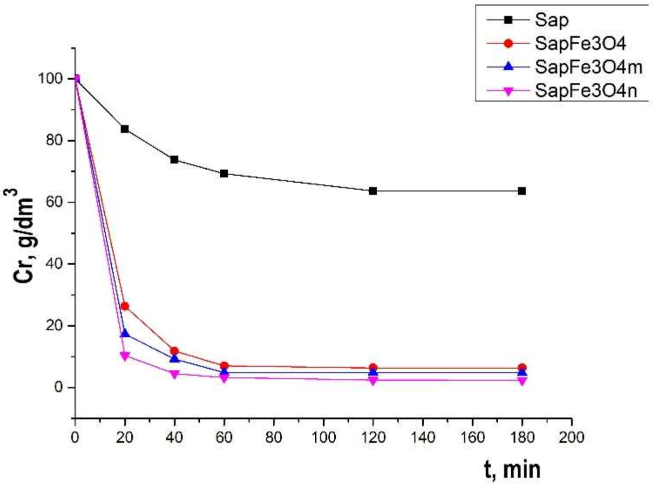

Fig. 4. The dependence of CR residual concentration on the adsorption process duration.

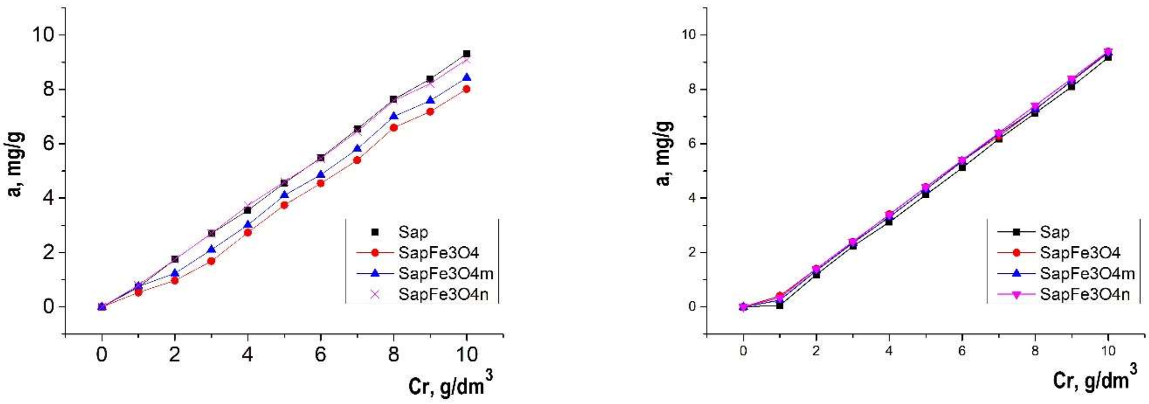

Fig. 5. The adsorption isotherms of dyes: Congo red (a) and Methyl blue (b) (dyes concentrations 1-10 mg/dm^3).

Figure 6 shows that significantly higher sorption activity at removing dyes from model highly concentrated aqueous solutions is exhibited by composite sorbents compared to using the native saponite clay.

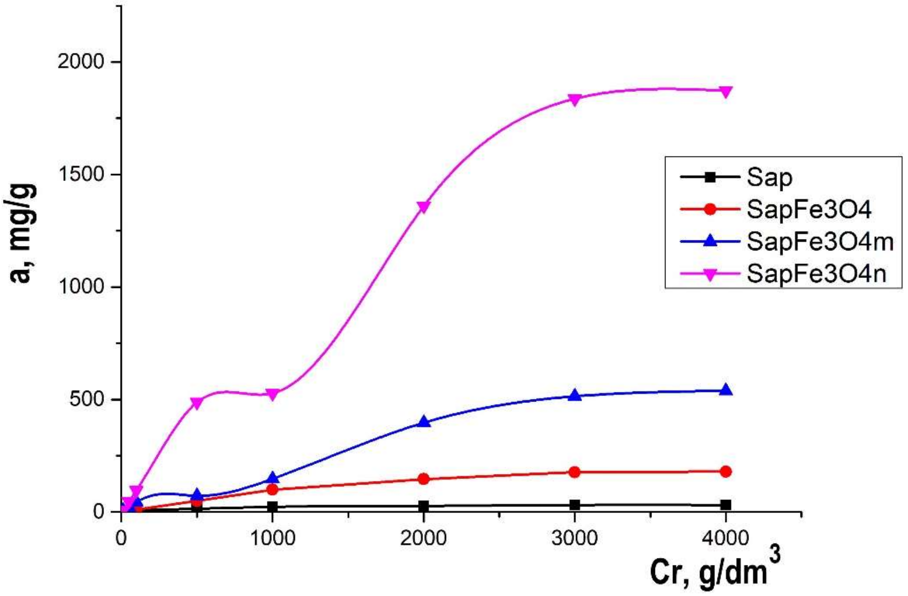

Fig. 6. The adsorption isotherm of Congo red (dye concentrations of 10-4000 mg/dm^3).

Modification of saponite clay with magnetite increases its sorption capacity from 30 mg/g to 180 mg/g, ie, there is a 6-fold improvement in characteristics. Next modification of $SapFe_3O_4$ by micro-size molybdenum disulfide increases the sorption capacity up to 540 mg/g, what is 3 times higher than for $SapFe_3O_4$, and modification of magnetic saponite by nano-size molybdenum disulfide increases the sorption capacity (1870 mg/g) in 10 times comparing to it.

The increase in the sorption capacity of $SapFe_3O_4n$ towards dyes cannot be explained only by changes in texture characteristics. In our view, such a significant increase in sorption capacity may be due either to the appearance of additional surface active centers on the surface of the magnetic composite material or to the emergence of the photocatalytic activity of molybdenum disulfide in the magnetic nanocomposite $SapFe_3O_4n$. In this regard, additional studies were conducted on the acid-base properties of the sorption nanocomposite samples under study.

Acid-basic properties of sorbents

The acid-base properties of all sorbents were investigated according to (Dontsova 2018).

Figure 7 illustrates changes in the pH of the sorbent suspension in bidistilled water for Sap, $SapFe_3O_4$, $SapFe_3O_4m$ i $SapFe_3O_4n$ over time. The value of isoionic point (pH_{iip}) for Sap, $SapFe_3O_4$, $SapFe_3O_4m$ and $SapFe_3O_4n$ is 9.3, 8.4, 7.7 and 9.1, respectively. These values indicate the base properties of the surface for all samples. The saponite is characterized by the highest basicity and the $SapFe_3O_4m$ has the smallest basic properties.

A more detailed study of the acid-base properties of the sorbent samples was carried out by adsorption of the Hammett indicators in the aqueous medium. For this purpose the Hammett indicators used: o-Nitroaniline (pK= –0.29), Fuchsine (pK=2.1), Bromophenol Blue (pK=3.9), Methyl Red (pK=5.25), Bromothymol Blue (pK=6.8), Phenol Red (pK=7.6), Thymol Blue (pK=8.8), Indigo Carmine (pK=12.8). Figure 8 presents the distribution curves of the adsorption centers of the Hammett indicators on the surface Sap, $SapFe_3O_4$, $SapFe_3O_4m$ and $SapFe_3O_4n$. Analysis of the obtained data on the distribution of adsorption centers on the saponite surface indicates the predominance of Brønsted base sites (pK=8.8, pK=12.8) and Lewis acid sites (pK= –0.29), as well as a small number of Brönsted acid sites (pK=2.1, pK=5.25). Surface modification saponite by magnetite leads to reduction of Brønsted base sites (pK=8.8) and increase Brønsted acid sites (pK=5.25), which explains the decrease pH_{iip}, and a higher adsorption affinity for anionic dyes compared to saponite. Number of Lewis basic sites (pK= –0.29) compared to the saponite in $SapFe_3O_4$ increases.

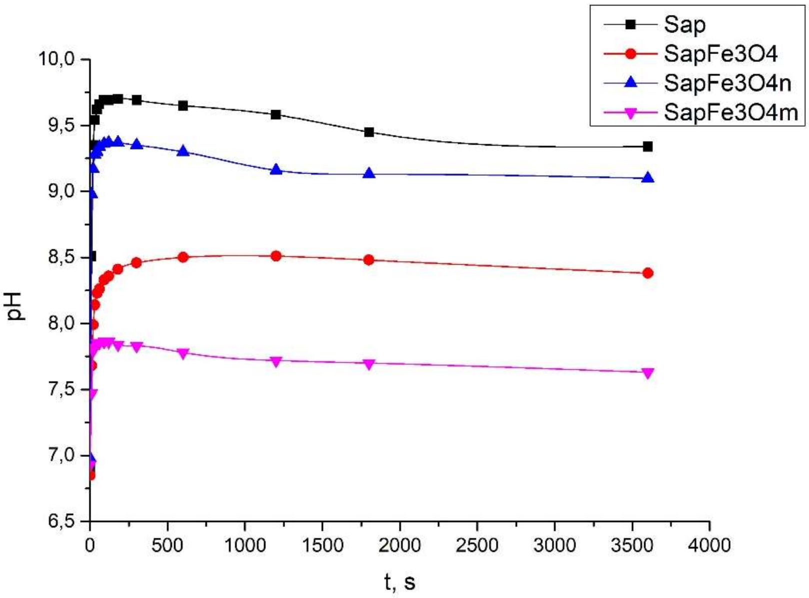

Fig. 7. Changing the pH of aqueous suspensions for Sap, $SapFe_3O_4$, $SapFe_3O_4m$ i $SapFe_3O_4n$ over time.

Next modification of the magnetic sorbent $SapFe_3O_4$ by micro-sized molybdenum disulfide increases the number of Brønsted base sites on its surface (pК=8.8, pК=12.8), but comparing its with $SapFe_3O_4n$ number of centers is decreases. Number of Lewis basic sites (pК= –0.29) compared to saponite in $SapFe_3O_4$ is increasing, but less than $SapFe_3O_4n$.

Next modification of the $SapFe_3O_4$ samples by nano-sized MoS_2 increases the number of Brønsted basic sites on its surface (pК=8.8, pК=12.8) compared with $SapFe_3O_4$, but it is still smaller than the saponite. In addition, re-modification by graphene-like particles MoS_2 leads to an even greater increase in Lewis acid sites (pК= –0.29).

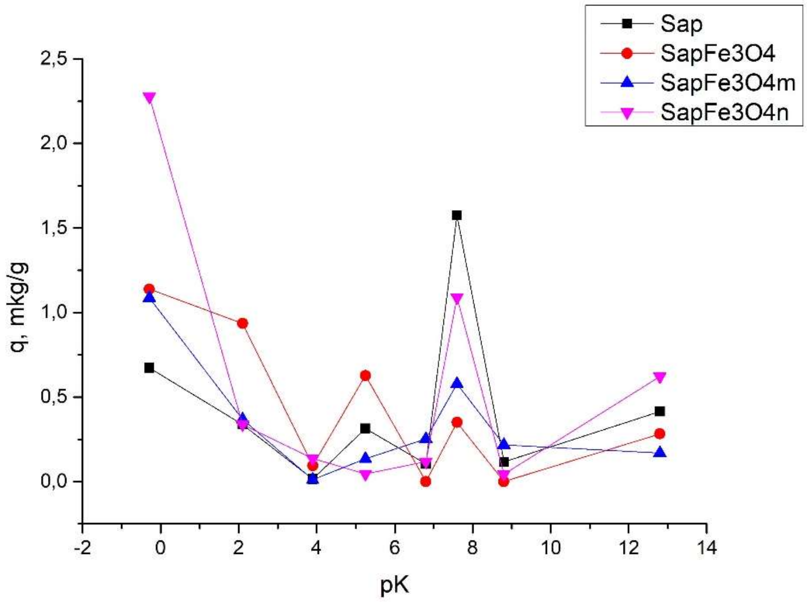

Fig. 8. Distribution of active adsorption sites on the surface of the studied sorbent samples

Thus, in our opinion, it is precisely with the increase of the content of the Lewis basic sites from Sap to $SapFe_3O_4$, $SapFe_3O_4m$ and $SapFe_3O_4n$ that we can associate the increase of the adsorption capacity towards the cationic dye. The increase in sorption activity in relation to the Congo red is due both to the increase in the Brønsted acid sites and, in the case of the ternary nanocomposites $SapFe_3O_4m$ and $SapFe_3O_4n$ presence the photocatalytic activity of molybdenum disulfide in it.

Conclusions

Modification of the native saponite sorbent by magnetite allows not only to give it magnetic properties, but also to significantly improve the structural-adsorption characteristics (increase of the specific surface area from 35 to 53 m^2/g). Next modification of the micro-sized and nano-sized of MoS_2 contributes to a further increase of the specific surface area up to 57 and 61 m^2/g, respectively. The porosity of the native clay changes from monomodal to bimodal pore distribution, which indicates the development of additional porous structure on macropores of saponite as a result of adsorption of nanoscale magnetite.

Studies of sorption properties in the range of low dyes concentrations have shown that all sorbents have approximately the same sorption capacity. Further increase in the concentrations revealed a significant increase in the sorption capacity for the modified sorbents, namely: for $SapFe_3O_4$ the sorption capacity was 180 mg/g; for modified of micro-sized molybdenum disulfide was 540 mg/g. The sorption capacity of nano-sized molybdenum disulfide modified was 1870 mg/g, which exceeds the values of native clay 3.4 times, $SapFe_3O_4$ 10 times and $SapFe_3O_4m$ 62 times.

Defined acid-base properties indicate the basic character of all sorbents. The modification significantly affects not only the textural but also the surface properties of the native saponite clay: the modification significantly increases the number of active sites compared to the unmodified saponite.

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References

Polyakov, V.E.; Tarasevich, Yu.I. Ion Exchange Equilibriums Involving Singly Charged Cations on Saponite. *Khimiya i Tekhnologiya Vody*, **2012**, 34(1), 18–27.
Murray, H.H. Occurrences, Processing and Application of Kaolins, Bentonites, Palygorskite-Sepiolite, and Common Clays. *Applied Clay Mineralogy*, Amsterdam; Boston: Elsevier, **2007**. https://doi.org/10.1016/s1572-4352(06)x0200-3
Mykhailenko, N.; Makarchuk, O.; Dontsova, T.; et al. Purification of aqeous media by magnetically operated saponite sorbents. *Eastern-European Journal of Enterprise Technologies*, 4(10), **2015**, 13–20. https://doi.org/10.15587/1729-4061.2015.46573
Macblek, F.A.; Bartol P. Magnetic Sorbent for Radiocesium and Radiostrontium Removal from Clay and Soil Suspensions. *J. Radioanalytical and Nucl. Chem*. 246(3), **2000**, 565–569. https://doi.org/10.1023/A:1006740922917
Liansheng W.; Yuanlv Y.; Fuqiang L.; et al. Organo-bentonite-Fe_3O_4 poly(sodium acrylate) magnetic superabsorbent nanocomposite: Synthesis, characterization, and Thorium(IV) adsorption. *Applied Clay Science*, 83-84, **2018**, 405–414. https://doi.org/10.1016/j.clay.2013.07.012
Saeedeh H.; Hossein S.; Saeedeh R. Adsorption of Cobalt(II) from Aqueous Solutions by Fe_3O_4/Bentonite Nanocomposite. *Water, Air, & Soil Pollution*, 226, **2014**, 2212–2219. https://doi.org/10.1007/s11270-014-2212-6
Fatemeh A.; Hossein E. Chemically modified bentonite/Fe_3O_4 nanocomposite for Pb(II), Cd(II), and Ni(II) removal from synthetic wastewater. *Powder Technology*, 110, **2018**, 154–167. https://doi.org/10.5004/dwt.2018.22228
Dontsova, T.A.; Yanushevskaya, E.I.; Nahirniak, S.V.; et al. Directional control of the structural adsorption properties of clays by magnetite modification. *Journal of Nanomaterials*, 2018(Article ID 6573016), **2018**, 1–9. https://doi.org/10.1155/2018/6573016
Makarchuk, O.; Dontsova, T.; Perekos, A. Magnetic nanocomposite sorbents on mineral base. *Springer Proceedings in Physics*, 195, **2017**, 705–719. https://doi.org/10.1007/978-3-319-56422-7_54
Kumaresan, S. & Radheshyam, R. P. Synthesis of saponite based nanocomposites to improve the controlled oral drug release of model drug quinine hydrochloride dihydrate. *Pharmaceuticals*, **2019**, https://doi.org/10.3390/ph12030105
Chanturiya, Valentine A. & Minenko, Vladimir G. Advanced techniques of saponite recovery from diamond processing plant water and areas of saponite application. *Minerals*, **2018**, https://doi:10.3390/min8120549.
Hashem F.S. Adsorption of Methylene Blue from Aqueous Solutions using Fe_3O_4/Bentonite Nanocomposite. *Scientific reports*, 1 (Article ID 549), **2012**, 1−5. https://doi.org/10.4172/scientificreports.549
Thommes M.; Kaneko K.; Neimark A.V.; et al. Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report). *Pure and Applied Chemistry*, 87(9-10), **2015**, 1051–1069. https://doi.org/10.1515/pac-2014-1117

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МАГНІТНІ НАНОКОМПОЗИТНІ СОРБЕНТИ НА МІНЕРАЛЬНІЙ ОСНОВІ

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Стаття присвячена синтезу магнетитвмісних нанокомпозитних сорбентів на основі сапоніту та вивченню впливу модифікування магнетитом та дисульфідом молібдену на структурно-сорбційні та поверхневі властивості нативної сапонітової глини. Модифікування нативної сапонітової глини нанорозмірним магнетитом збільшує питому площу поверхні та змінює розподіл пор вихідної глини від одномодального до бімодального. Наступне модифікування магнетитвмісного сапоніту за допомогою дисульфіду молібдену мікро-розміру та нанорозміру призводить до блокування його вторинної пористої структури (зникає бімодальність магнетитвмісного сапоніту), але збільшується питома площа поверхні композиту. Було встановлено, що сорбційна активність модифікованого та немодифікованого сапоніту в області низьких концентрацій катіонних та аніонних барвників (метиловий синій та конго-червоний) майже однакова. Вивчення адсорбції конго червоного із його висококонцентрованих розчинів показало значні відмінності в сорбційній активності модифікованих та немодифікованих зразків сапоніту: найбільша сорбційна ємність характерна для потрійних композитів (сапоніт, модифікований магнетитом та нанорозмірним дисульфідом молібдену). Цей потрійний композит мав активність у 62 рази більше, ніж нативний сапоніт і 10 разів більше, ніж магнетитвмісний сапоніт. Встановлено, що всі зразки характеризуються основними властивостями, але зразок нативного сапоніту, модифікований магнетитом та нанорозмірним дисульфідом молібдену, має найбільшу кількість активних центрів (як кислотного, так і основного характеру). Таким чином, показано, що модифікування нативної сапонітової глини суттєво впливає не тільки на її структурно-сорбційні, але й на поверхневі властивості.

Ключові слова: *сапоніт, магнетитвмісні мінеральні сорбенти, нанокомпозити, кислотно-основні властивості, сорбція, барвники.*

МАГНИТНЫЕ НАНОКОМПОЗИТНЫЕ СОРБЕНТЫ НА МИНЕРАЛЬНОЙ ОСНОВЕ

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Статья посвящена синтезу нанокомпозитных сорбентов на основе сапонита и изучению влияния модификации магнетитом и дисульфидом молибдена на свойства природной сапонитовой глины. Показано, что модификация сапонита увеличивает ее удельную поверхность и изменяет пористую структуру.

Ключевые слова: *сапонит, магнетитсодержащие минеральные сорбенты, нанокомпозиты, кислотно-основные свойства, сорбция, красители.*