

Investigation of arsenic removal parameters by a new nano-hybrid adsorbent produced from red mud and fly ash

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Abstract

Two common waste materials, red mud and fly ash, were used to produce a new nano-hybrid adsorbent by heat treatment with alkali addition. The new zeolitic structure formation of the hybrid adsorbent was revealed using the BET surface area, XRD, and SEM analyses. This hybrid adsorbent was utilized to remove arsenic from synthetic and real waste waters by batch and column adsorption experiments. The parameters such as the pH, contact time, and effect of the co-existing ions were investigated. Slightly acidic media favored arsenic adsorption by the hybrid adsorbent, the same as the individual use of fly ash and red mud. The effects of ions such as Fe^{3+} , Cu^{2+} , Cl^- , SO_4^{2-} , and PO_4^{3-} were investigated as the co-existing ions. It was found that arsenic adsorption increased with cationic ions and decreased with anionic ions according to their valance charge. The intra-particle diffusion model showed that adsorption took place at three different rates depending on time. The hybrid adsorbent was formed as a pellet and utilized in a column for treatment of arsenic containing real waste water. The hybrid adsorbent derived from mineral wastes was more successful than their individual usages.

Keywords: *Red Mud, Fly Ash, Wastewater, Arsenic, Hybrid.*

1. Introduction

Mining operations are the primary activities in any industrial process, and the major sources of pollutants include overburden waste disposal, tailings, dump leaches, mine water seepage, and other process wastes disposed nearby the industries [1]. There are three main sources for waste generation in mining industry including mining, mineral processing, and metallurgical extraction. The composition of mine wastes is related to the processing type and technological limitations or mineralogical factors and economic conditions that may not have allowed full extraction of valuable minerals [2, 3].

The conversion of waste materials into useful products is interesting for both the environmental and economic perspectives. Recovery and recycling is the best method for decreasing the amount of waste materials, saving the raw materials, and thus decreasing the environmental contamination. Therefore, the development of

innovative and environmentally friendly technologies is extremely important [4].

A wide range of industrial and mining wastes or by-products, which are available in large quantities, are under investigation as alternatives to commercial adsorbents. Industrial wastes are one of the potentially low-cost adsorbents for waste water treatment; however, they require an additional processing to maximize their utilization [5].

Adsorption is a promising process for various pollutant removals from wastewater because it is easy to design and operate, and is of low cost [6]. The main cost of an adsorption process mainly occurs from adsorbent, and therefore, utilization of low-cost adsorbents have been investigated. There are many industrial and mining wastes that have been used as low-cost adsorbents such as red mud [7] and fly ash [8]. They are the most attractive materials due to their abundance,

ultrafine particle size, and high adsorbing capability. In the literature, red mud has been used in several ways such as acid activated [9, 10], iron oxide activated [11], sea water activated [12], and thermal treated [13-15]. However, there are many interesting studies based on mixing red mud with other industrial wastes and producing new materials that are highly effective or selective adsorbents. Among these studies, there is an interesting one that underlies the present work; it focuses on the synthesis of magnetic adsorbents from industrial waste materials [16]; environmentally friendly magnetic zeolites have been produced by the hydrothermal activation of red mud and fly ash, and applied to remove reactive orange 16 from solution. However, there is no study showing the characterization of the hybrid adsorbents produced from fly ash and red mud and adsorption characteristics towards arsenic ion.

In the present work, an alternative method is proposed to synthesize a new adsorbent from waste materials. The interesting aspect of the proposed synthesis is that the precursors employed for it are waste materials such as red mud and fly ash. The new hybrid adsorbent was utilized for remediation of arsenic containing wastewaters.

2. Materials and method

2.1. Materials

The waste material red mud was taken from the tailing dam of the Seydişehir ETİ Aluminium production plant located in Seydişehir-Konya, Turkey. The d_{80} particle size of the material was measured to be 0.011 mm and the d_{50} size was 0.003 mm. The other waste material, fly ash, was received from the power plant of the Soma Electricity Production Company located in Soma-Manisa, Turkey. The waste material was obtained from electrostatic filters. The d_{80} particle size of the material was measured to be 0.011 mm and the d_{50} size was 0.004 mm. The chemical analyses of both waste materials are shown in Table 1. The real waste water sample was obtained from the ETİ Boron Concentration Plant (Kütahya, Turkey), and the chemical analysis results of the waste water sample are given in Table 2.

Analytical-grade HCl, NaOH, FeCl₃, CuCl₂, NaCl, N₂SO₄, Na₃PO₄, and Na₂HAsO₄·H₂O were obtained from Merck Co for use in the experiments.

Table 1. Chemical analysis of waste samples.

Red mud		Fly ash	
Content	Amount, %	Content	Amount, %
Fe ₂ O ₃	39.60	Fe ₂ O ₃	4.42
Al ₂ O ₃	16.50	Al ₂ O ₃	18.36
SiO ₂	18.00	SiO ₂	36.40
Na ₂ O	12.80	MgO	10.34
CaO	1.28	CaO	29.85
K ₂ O	0.27	K ₂ O	1.78
TiO ₂	5.50	C	0.15
SO ₃	0.29	S	2.81
LOI	5.74	LOI	34.49

Table 2. Chemical analysis of real waste water.

Elements	Amount, mg/L
As	81.66
B	550.0
Ca	375.7
Cr	0.02
Fe	0.19
Ni	0.56
Cl	653.0
NO ₃	5.0
SO ₄	511.6

2.2. Preparation of hybrid adsorbent

The hybrid adsorbent preparation was done by means of the modified zeolitic process [16]. Briefly, 1 g of red mud (RM) and 1 g of fly ash (FA) were mixed and ground in an agate mortar, and then 4 mL of 0.5 M NaOH was added. The well-mixed wet mud was placed in a crucible, to which heat treatment was applied at 400 °C for 2 h in a muffle furnace. After cooling down, the hybrid red mud-fly ash (RMFA) adsorbent was ground and used for the experiments.

2.3. Batch adsorption experiments

The adsorption of arsenic from aqueous solution using the synthesized hybrid adsorbent was achieved according to batch experiments. The effects of solution pH, contact time, and competitive ions on the As adsorption were investigated. The experimental conditions for the pH tests including 20 ppm initial arsenic concentration, 5 g/L solid concentration, and 30 min contact time were kept constant. In these tests, red mud and fly ash were also tested separately as adsorbents for comparison with the hybrid RMFA. The pH values for the solutions were adjusted using 0.1 M HCl/NaOH solutions. In order to examine the effect of contact time on the adsorption of arsenic by the hybrid adsorbent, the experiments were operated between 30 min to 24 h. 100 ppm of As solution was used in order to examine the effect of foreign ions in the solutions. The foreign ions were determined as Fe³⁺, Cu²⁺,

Cl⁻, SO₄²⁻, and PO₄³⁻; they were added artificially (100 ppm). These tests were conducted in 2 h, and the residual As concentrations were analyzed.

2.4. Column adsorption experiments

The column adsorption test was applied for remediation of real waste water. For this purpose, firstly, the hybrid RMFA was pelletized via a pelletizing machine by adding some water. After drying in an oven, it was placed in a column. The continuous flow experiments were developed using a 4 cm internal diameter with 40 cm height, filled with 40 g of the pellet hybrid adsorbent attaining a height in the column of 12 cm. A porous glass wool was attached at the bottom of the column to prevent the loss of materials. The wastewater solution was fed through up and down at a 0.5 mL/min flow rate. The samples were collected periodically and the residual arsenic concentrations were determined.

The arsenate stock solution was prepared by dissolving Na₂HAsO₄·7H₂O in distilled water to a concentration of 1 g/L As(V). Fresh diluted stock solution was prepared before every series of experiments. After adsorption, the suspension was filtered through a 0.20 µm pore size disk filter, and the supernatant solution was acidified with HNO₃ before analyzing to prevent precipitation. The results of the experiments were evaluated as qm using the following equation:

$$q_m = \frac{(C_i - C_e) * V}{M} \quad (1)$$

where qm (mg/g) is the amount of adsorbed ion on the adsorbent, C_i is the initial ion concentration (ppm), C_e is the final/equilibrium ion concentration (ppm), V is the volume of the suspension (L), and M is the amount of adsorbent (red mud) (g).

2.5. Desorption test

For desorption of arsenic, 1 M NaOH solution was employed in order to regenerate the hybrid adsorbent applied to 100 ppm of arsenic solution. The regeneration was applied for 2 h. Then the hybrid adsorbent was washed with distilled water until its pH reached 7. Then it was dried and used for the next adsorption cycle.

2.6. Analytic methods

The arsenic concentration was determined by the molybdate blue method procedure [17], and double checked for several times by ICP-AES. The other chemical analyses were done by ICP-AES. Prior to analysis, the samples were dried at

105 °C for 24 h. The specific surface area of the samples was analyzed using Micromeritics Gemini VII 2390t BET with nitrogen gas. The TG-DTA analysis was performed using DTA/TG Seiko II Exstar G300 between 20 and 900 °C. The microstructure and surface morphology of the samples were examined using HR FESEM Zeiss Auriga Scanning Electron Microscopy (SEM). The particle size of the materials was analyzed by Malvern Mastersizer 2000. The zeta potential measurements were carried out using a Zeta-meter 3.0 equipment in suspensions with 0.01 wt% solid content using HCl and NaOH as pH regulators and 10⁻³ M NaCl as an electrolyte.

3. Results and discussion

3.1. Characterization

The XRD analysis of the hybrid adsorbent is shown in Figure 1. The waste material red mud contains hematite, sodalite, gibbsite, rutile, quartz, and calcite, while fly ash consists of anhydrite, lime, and calcite minerals. The XRD analysis of the hybrid RMFA shows hematite, quartz, rutile, calcite, and zeolite-L. Zeolite-L has been found in the newly formed mineral due to the alkaline-thermal process of the mixture of the two waste materials [18, 19].

The thermal behaviors of red mud, fly ash, and the hybrid adsorbent are shown in Figure 2. In the TG curve of red mud, the total mass loss at 100-900 °C was found to be 8.23%, and more than half of them (4.9%) are caused by the evaporation of physical water caused by dehydroxylation of boehmite and goethite [20, 21]. For fly ash, the mass loss was measured to be 1.2% at 100-900 °C due to the removal of physical adsorptive water. The TG analysis of the hybrid adsorbent was found to be more than fly ash and less than red mud. The total mass loss was found to be 6.2% and half was lost up to 300 °C (2.6%); the mass loss was recorded between 300 and 700 °C due to transformation of calcium carbonates to calcium oxides.

Surface morphologies of red mud, fly ash, and the hybrid adsorbent were investigated using the SEM and EDX analyses. Figure 3a shows that red mud consists of aggregated particles of 0.01 mm size. The fly ash sample occurs as spherical shaped smooth particles (Figure 3b). The surface morphology of the hybrid adsorbent did not resemble the precursor materials such as the spherical structure of fly ash. There are newly-occurring nanoparticles detected (Figure 3c), which have 25 to 100 nm size having a

laminar type that indicates the new zeolitic formation.

The EDX analysis of the hybrid adsorbent is shown in Figure 3d, and comparison of the three samples is shown in Table 3. The hybrid RMFA has the composition of both samples, which indicates the good mixing of the samples. High Na content is induced by NaOH addition in the alkali process.

Table 4 shows the porous properties and surface area of the three adsorbents. The hybrid adsorbent has a higher surface area (compared with red mud and fly ash), which is responsible for its higher adsorption capacity. FT-IR analysis was applied to identify the characteristic functional groups

responsible for the adsorption. Figure 4 shows the FT-IR spectrum of the hybrid adsorbent. In the spectrum, the main bands recorded at the wave number of 795.2 cm^{-1} are attributed to O-Si-O and O-Al-O. Moreover, the broad band observed between 2800 and 3700 cm^{-1} is a sign of -OH stretching. The strong adsorption peak at 3598 cm^{-1} can be assigned to -OH symmetric stretching vibration, and the peak at 1644 cm^{-1} is attributed to water molecules in the zeolite structure. The characteristic bands of the hybrid adsorbent show that the alkali-thermal process is successful [21-23]. Figure 5 shows the zeta potential of the hybrid RMFA. The pH_{zpc} (zero point of charge) was determined to be 5.6.

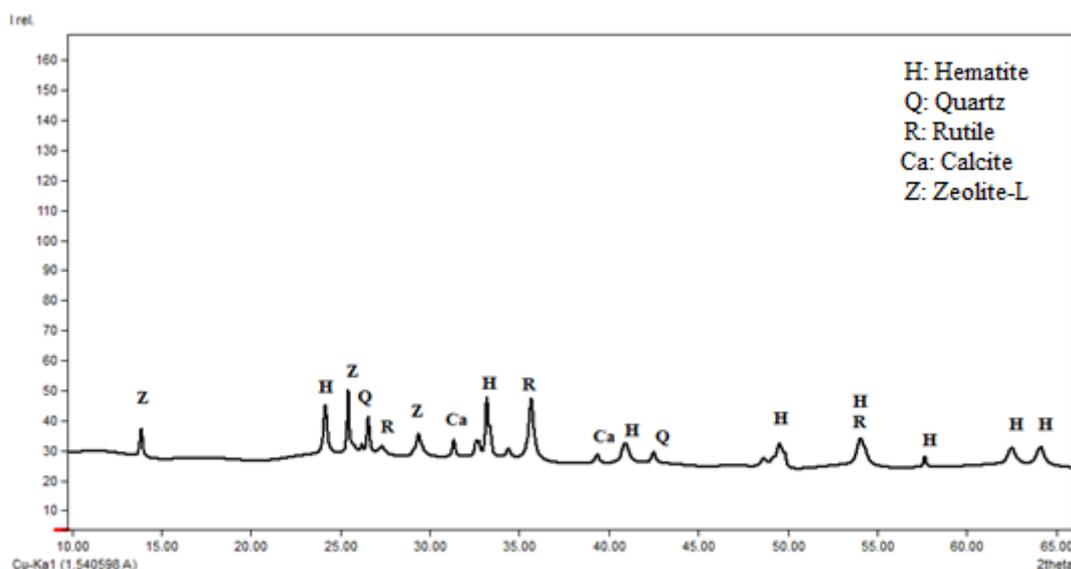


Figure 1. XRD analysis of the hybrid adsorbent.

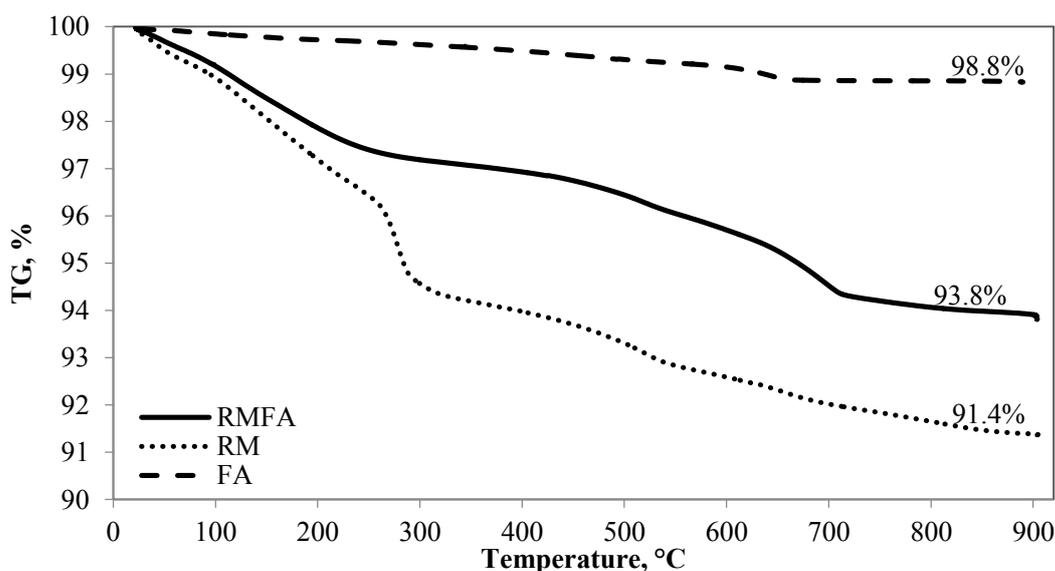


Figure 2. TG Analysis of red mud, fly ash, and hybrid adsorbents.

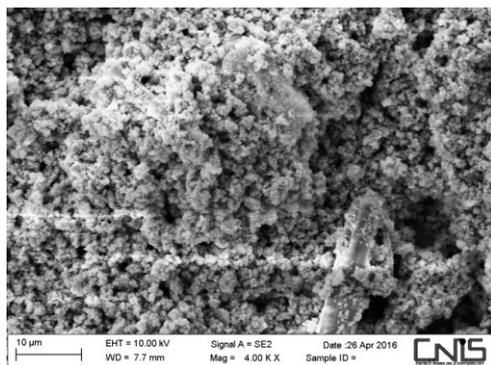


Figure 3a. Morphology of red mud.

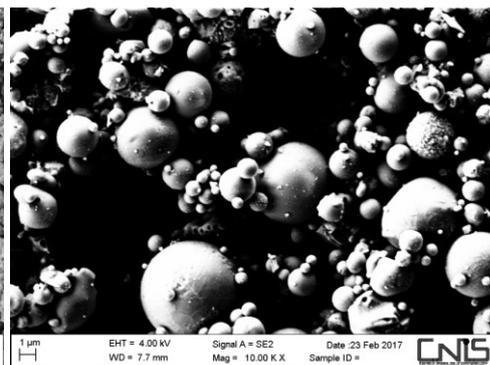


Figure 3b. Morphology of fly ash.

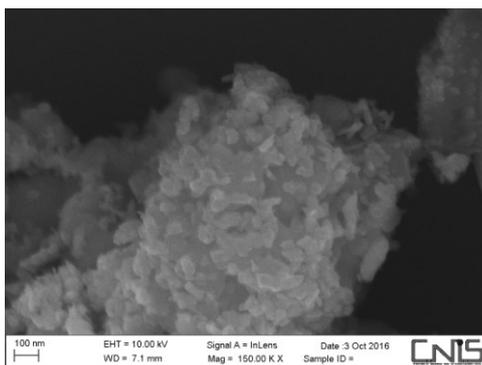


Figure 3c. Morphology of the hybrid adsorbent.

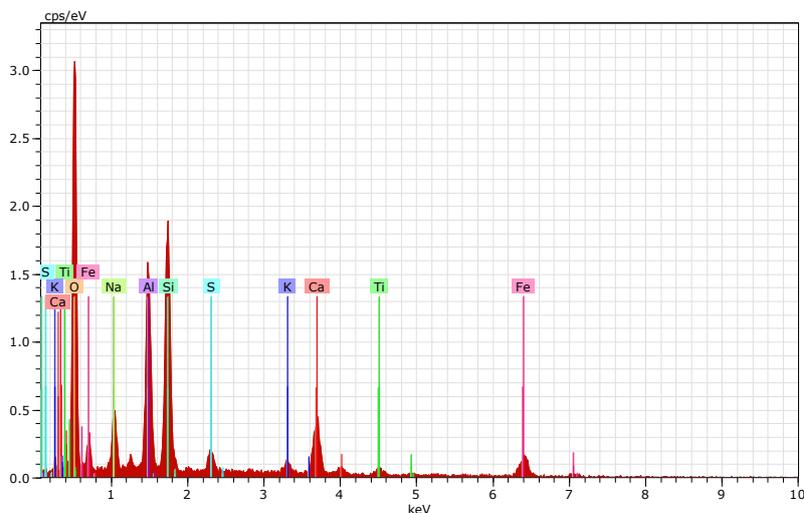


Figure 3d. EDX analysis of the hybrid adsorbent.

Table 3. EDX analyses of waste materials and the hybrid adsorbent.

Elements, wt%	RM	FA	RMFA
Fe	24.84	2.60	10.27
Al	10.75	9.60	10.68
Si	10.89	19.62	13.12
S	0.30	4.23	1.41
Ti	2.59	-	1.47
Ca	0.79	15.18	3.33
Mg	0.30	0.73	0.43
Na	9.33	0.26	11.66
O	40.43	43.98	47.75
C	-	0.52	-

Table 4. BET Surface area and pore size analyses.

Parameters/ Materials	BET surface area, m ² /g	Average pore width, nm	Cumulative volume of pores, cm ³ /g
Red mud	17.98	15.26	0.069
Fly ash	1.25	11.81	0.003
Hybrid RMFA	31.87	38.31	0.013

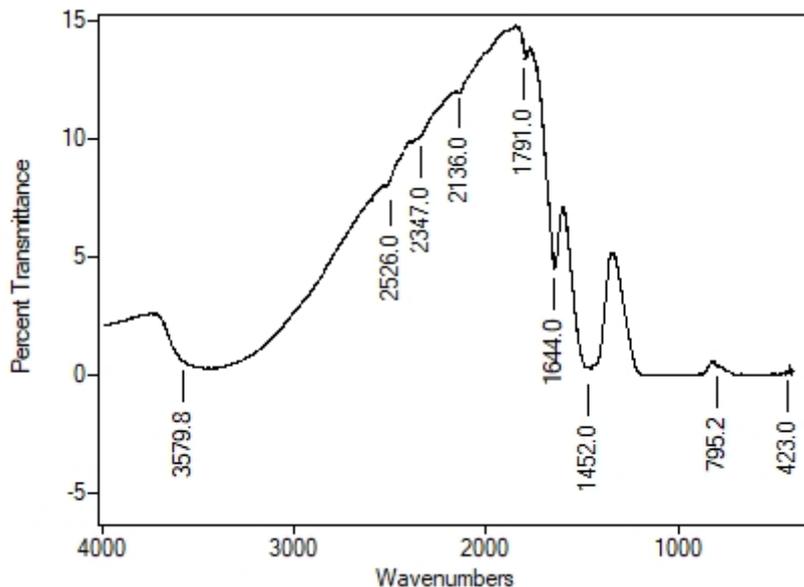


Figure 4. FT-IR spectrum for the hybrid adsorbent.

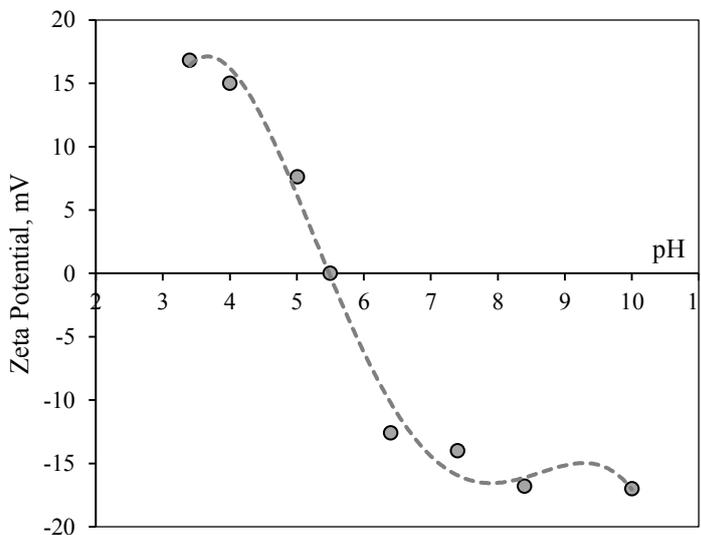


Figure 5. Zeta Potential of the hybrid adsorbent.

3.2. Adsorption tests

3.2.1. Effect of pH

The pH designates the ion speciation and surface ionization, and therefore, it is an important adsorption parameter. For this reason, the adsorption experiments were carried out at different pH values in order to determine the most favorable adsorption conditions using the hybrid adsorbent and its constituent materials, red mud and fly ash. The results obtained are shown in

Figure 6, where the amount of adsorption was plotted against the equilibrium pH. The highest arsenic adsorption was found at pH 5.5 with red mud and at pH 4 with fly ash, individually. The highest amount of arsenic adsorption was obtained by the hybrid adsorbent at around pH 5. Therefore, slightly acidic media yield a high amount of adsorption for all the adsorbent materials. The high arsenic adsorption capability of the hybrid adsorbent is observed due to a high

BET surface area (31.87 m²/g), which is induced from the zeolitic structure of the hybrid adsorbent. The adsorption behavior of As(V) can be explained by the influence of pH on the surface charges of the adsorbents and adsorbates. The As(V) ion is formed as H₃AsO₃ below pH 2.3, deprotonates to H₂AsO₃⁻ as the pH increases to 6.8, transforms to HAsO₃²⁻ between pH 6.8 and 11.6, and becomes AsO₃³⁻ above pH 11.6. The As(V) ions interact directly with the surface of the adsorbents according to their ionization [24]. The hybrid adsorbent consists of iron oxides, which is

negatively or positively charged upon pH. The zero point of charge pH for the hybrid adsorbent was found to be 5.6, and therefore, the surface charge of the adsorbent is positive under pH 5.6 and negative above it. Most probably, electrostatic interactions take place under pH 6 between arsenic and the hybrid adsorbent surface, achieving a high adsorbing capability. On the other hand, not only the electrostatic interactions but also chemisorption are effective because of low adsorption occurrence at acidic pH, where the adsorbent has a highly positive zeta potential.

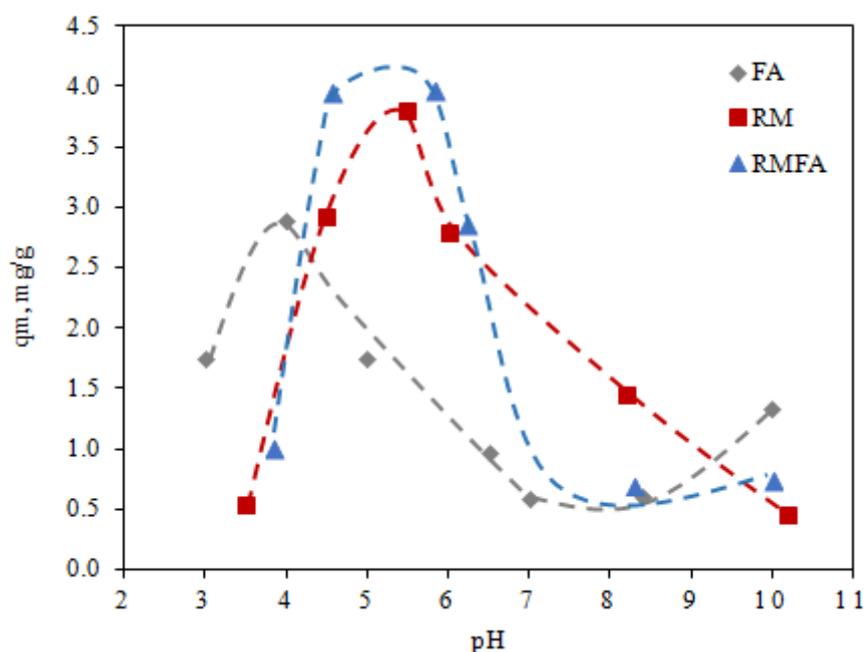


Figure 6. Effect of pH on arsenic adsorption.

3.2.2. Adsorption kinetics

Figure 7 shows the arsenic adsorption, which takes place rapidly, and over 90% of the arsenic ions are removed in the first hour. The adsorption equilibrium can be achieved within 8 h. To further investigate the adsorption kinetics, the pseudo-first-order and pseudo-second-order models [25, 26] and the Weber-Morris diffusion models [27] were used to represent the arsenic adsorption onto the hybrid adsorbent. These models can be expressed as:

$$\log(qe - qt) = \log(qe - k_1) \times \frac{t}{2.303} \quad (2)$$

$$\frac{t}{qt} = \left(\frac{1}{k_2 \times qe^2} \right) + \frac{t}{qe} \quad (3)$$

$$qt = ki \times \sqrt{t} + C \quad (4)$$

where *qe* and *qt* are the amounts of arsenic adsorbed by the RMFA hybrid (mg/g) at

equilibrium and at time *t* (min), respectively, and *k*₁ (L/min) and *k*₂ (g/(mg min)) are the adsorption rate constants of the pseudo-first-order and pseudo-second-order kinetic models, respectively. The pseudo-second-order kinetic model is based on the assumption that the rate limiting step might be chemisorption involving sharing or exchange of electrons between adsorbent and adsorbate [28]. *ki* is a constant of the Weber-Morris model diffusion rate [mg/(g min^{1/2})], and *C* is a constant for the boundary layer (mg/g).

The kinetic parameters obtained are summarized in Table 5. The kinetic data for arsenic adsorption onto the hybrid RMFA could be satisfactorily fitted by the pseudo-second-order model, with *qe* = 52.94 mg/g, *k*₂ = 0.00033 g/mg·min, and *R*² = 0.99 for As(V). This indicates that the adsorption of As(V) onto the hybrid RMFA involves chemisorption [28].

According to the Weber-Morris diffusion models, the plots of q_t versus $t^{0.5}$ have three linear parts for the adsorption of arsenic by the hybrid adsorbent. As shown in Figure 8, these lines do not pass through the origin, and therefore, intra-particle diffusion is not only the rate controlling step but also the other kinetic models may control the adsorption [27]. The slope values for the first, second, and third linear stages (ki_1 , ki_2 , and ki_3) are given in Table 5. The first linear stage corresponds to the faster external mass transfer

through the boundary layer, following by the slower diffusion stages. The third stage refers to the adsorption equilibrium, which shows a very low adsorption rate (ki_3). The first adsorption stage is represented as a rapid adsorption (zone 1), while the third stage is represented by deceleration. Further, the first zone is attributed to a macropore diffusion process, while the other linear portions can be ascribed to a micropore diffusion process.

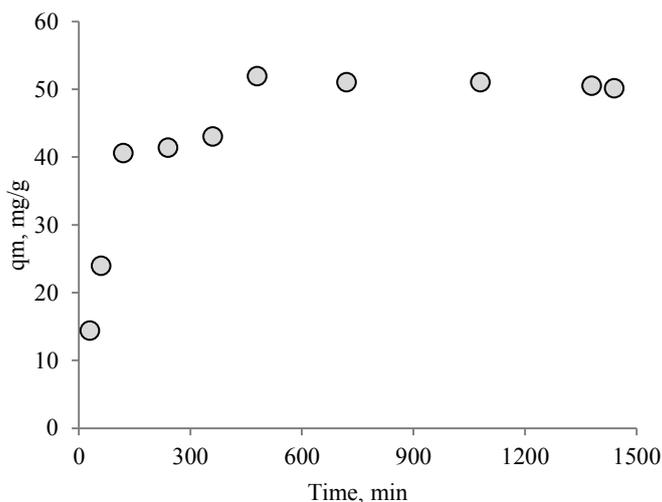


Figure 7. Effect of contact time on arsenic adsorption.

Table 5. Kinetic parameters for the adsorption of arsenic by the hybrid adsorbent.

Pseudo-first-order kinetic model	q_{cal} , mg/g 4.35	k_1 , L/min 0.00199	R^2 0.75
Pseudo-second-order kinetic model	q_{cal} , mg/g 52.94	k_2 , g/mg.min 0.00033	R^2 0.99
Intra-particle diffusion model	ki_1 mg/(g min ^{1/2}) 4.81	ki_2 mg/(g min ^{1/2}) 0.30	ki_3 mg/(g min ^{1/2}) 0.003

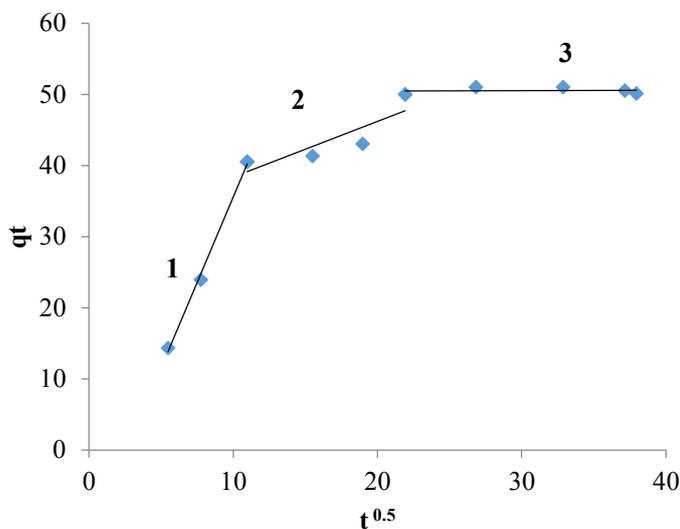


Figure 8. Intra-particle diffusion model.

3.2.3. Effect of coexisting ions

In order to investigate the potential influence of the co-existing ions present in wastewater solutions on arsenic adsorption by the hybrid RMFA, cations and different valance charge anions were used. These adsorption tests were conducted with 100 ppm As and 100 ppm of the co-existing ions under the same experimental conditions as those used for all the other adsorption tests. The results obtained are shown in Figure 9. The simultaneous adsorption of 40.5 mg/g for As(V) was achieved, and it was increased up to 99.9 mg/g in the presence of Fe³⁺. As(V) can be removed through precipitation of ferric arsenate as FeAsO₄.2H₂O (scorodite) [29].

The existence of copper also enhanced As adsorption but when it was compared with the iron ion, it was found to be quite low. Anions had a negative effect on arsenic adsorption. In the presence of anions, the adsorption of arsenic was decreased, according to their valance charges. Overall, the degree of influence of the three anions on arsenic removal decreased in the following order: PO₄³⁻ = SO₄²⁻ > Cl⁻. Tuutijärvi et al. [30] have studied the effects of several competing anions on arsenate adsorption with maghemite nanoparticles. Sulfates and nitrates had negligible effects on arsenate adsorption at pH 3; however, phosphates and silicates had an adverse impact at pH 7.

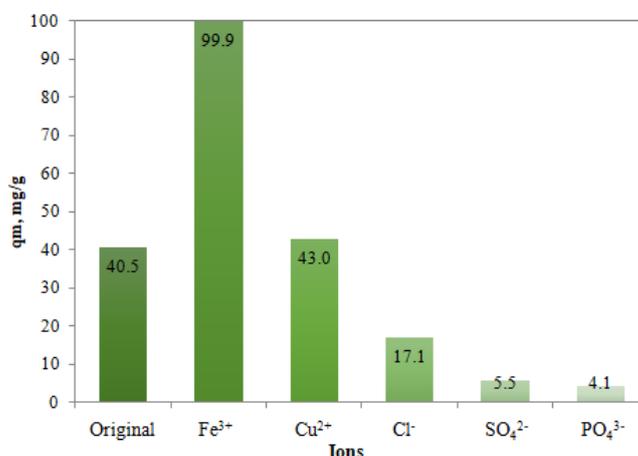


Figure 9. Effect of competitive ions on arsenic adsorption capacity.

3.2.4. Reusability of hybrid adsorbent

As far as the industrial practicability of the hybrid RMFA is concerned, the study of the reusability becomes necessary, which is highly beneficial for cost reduction. On the basis of pH effect on the adsorption, it was considered that an alkali solution could be utilized for desorption of arsenic from loaded hybrid adsorbent. Five consecutive adsorption/desorption cycles showed that the

arsenic adsorption capacity of hybrid adsorbent was decreased from 40.5 to 34.6 mg/g, as shown in Figure 10. The remaining high adsorption capacity indicates that part of the adsorbed arsenic on the surface could be desorbed with the help of a highly alkaline aqueous solution. Therefore, this hybrid adsorbent can be used even after five consecutive adsorption desorption processes without any significant performance loss.

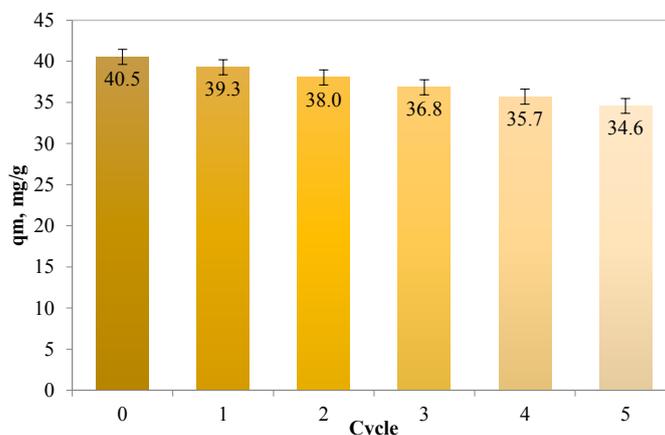


Figure 10. Regeneration and reuse of hybrid RMFA.

3.3. Application with real waste water

The synthetic waste water solutions are insufficient to examine the removal of the single ions needed to be considered in a real ions system. In this work, all experiments indicated that the hybrid RMFA presented good adsorption properties in batch adsorption test but it would be also interesting to carry out an investigation in a real waste water treatment. The real waste water from boron concentration plant contained 81.66 ppm arsenic to be removed. The removal of arsenic from wastewater sample was investigated by column adsorption of the hybrid RMFA pellets. The breakthrough curves for arsenic ions

is presented in Figure 11. The adsorption column was operated to treat 7 L of waste water before the inlet As(V) concentration was attained at the exit. This figure shows how the breakthrough curve has two different regions; the curve has a steep slope, corresponding to the first 2.5 L. After this volume, the slope becomes less steep until the curve reaches the feeding concentrations. The mixed composition of real waste water enhances and prevents the arsenic adsorption at the same time. Obviously, anions such as high concentration of sulfate and chloride (Table 2) have negative effects (as discussed in batch tests), while cations such as Fe and Ca enhance arsenic adsorption.

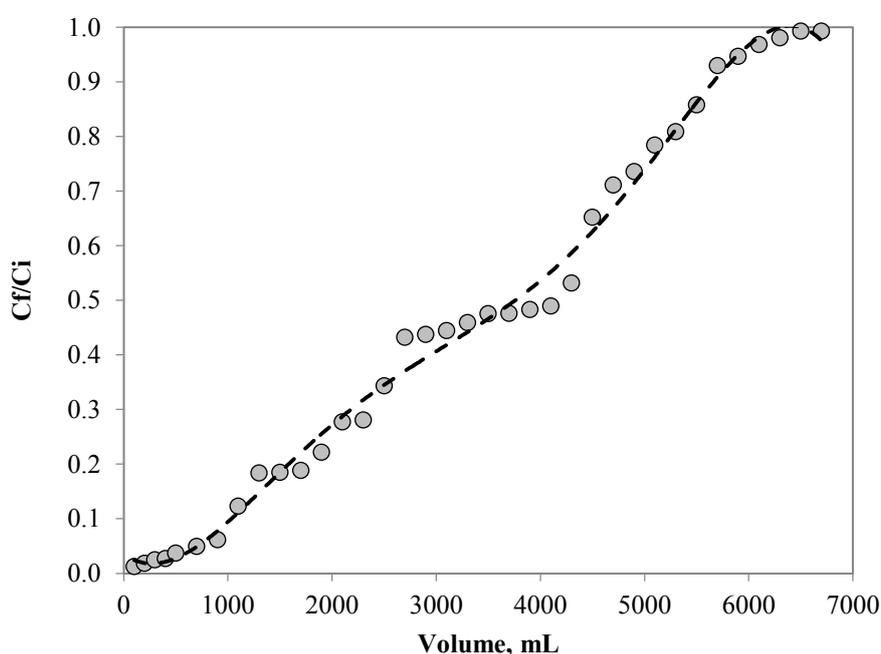


Figure 11. Breakthrough curve of arsenic.

4. Conclusions

In the present work, the adsorption of arsenic onto a new nano-hybrid adsorbent produced from red mud and fly ash was studied. This new hybrid adsorbent had a unique nano-structure, characterized by XRD, SEM, EDX, and TG-DTA analyses and used for removing arsenic containing synthetic and real wastewaters. The results obtained showed that there was a high efficiency for the arsenic adsorption in a slightly acidic medium. Moreover, the hybrid adsorbent gave better results compared to individual usage of red mud and fly ash. The adsorption capacity of the hybrid adsorbent in arsenic concentration of 100 mg/L was found to be 40.5 mg/g. The co-existing ions such as Fe^{3+} , Cu^{2+} , Cl^- , SO_4^{2-} , and PO_4^{3-} had an impact on arsenic removal. It was found that cations had a positive effect on the arsenic

adsorption. The hybrid adsorbent was found to be reusable at the end of the five cycle test with a little capacity loss.

The hybrid adsorbent has a high affinity for arsenic removal from real waste water. As a result, the hybrid adsorbent was found to be an alternative adsorbent for remediation of waste water and could be an economical contribution as it was derived from red mud and fly ash. These wastes are abundant and easy to recover and inexpensive, thus a low-cost adsorbent can be synthesized. The commercial hybrid products of red mud and fly ash could be an alternative solution for environmental problems in both the solid waste management and waste water treatment.

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بررسی پارامترهای حذف آرسنیک توسط جاذب جدید نانو هیبریدی تولید شده از گل قرمز و خاکستر بادی

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چکیده:

در این پژوهش، دو ماده‌ی شیمیایی رایج، گل قرمز و خاکستر بادی، برای تولید یک جاذب جدید نانو هیبریدی به روش حرارتی با افزودن قلیا مورد استفاده قرار گرفت. شکل جدید ساختار زئولیتیک جاذب هیبریدی با استفاده از مساحت سطح BET، XRD و SEM تجزیه و تحلیل شدند. این جاذب ترکیبی برای حذف آرسنیک از آب‌های مصنوعی و واقعی با استفاده از آزمایش‌های جذب دسته‌ای و ستونی مورد استفاده قرار گرفت. پارامترهایی مانند pH، زمان تماس و اثر یون‌های هم‌پوشان بررسی شدند. اثر یون‌هایی مانند Fe^{3+} ، Cu^{2+} ، Cl^- ، SO_4^{2-} و PO_4^{3-} به عنوان یون‌های هم‌پوشانی مورد بررسی قرار گرفتند. مشخص شد که جذب آرسنیک با یون‌های کاتیونی افزایش یافته و با یون‌های آنیونی کاهش می‌یابد. مدل نفوذ درون ذره نشان داد که جذب در سه زمان مختلف متفاوت است. جاذب ترکیبی به عنوان یک پلت فرم تشکیل شد و برای حذف آرسنیک موجود در فاضلاب واقعی مورد استفاده قرار گرفت. جاذب ترکیبی مشتق شده از باطله‌های معدنی از استفاده‌های منفرد آن‌ها موفق‌تر است.

کلمات کلیدی: گل قرمز، خاکستر بادی، فاضلاب، آرسنیک، هیبرید.