Fabrication and Detailed Characterization of Perlite Mineral Supported a New Magnetic Nanomaterial.

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Abstract

Today, the possibilities offered by nanotechnology are undeniable. Nanotechnology has permeated all aspects of our daily lives. Nanotechnology, as an interdisciplinary field, also provides unique products in a variety of engineering fields. These products are more appealing than macro products due to their unique properties such as surface area, volume, conductivity, optical, and magnetic. Magnetite (Fe_3O_4), the most powerful magnetic mineral on the planet, has many properties such as nano size, surface area, morphology, and ferromagnetism at room temperature, and thus Fe_3O_4 -based products are being developed for appropriate studies. There are very few materials created by modifying perlite Fe_3O_4 , a mineral abundant in nature. In this study, Fe_3O_4 was modified with the mineral perlite to create magnetic nanomaterials. To that end, Fe_3O_4 /Perlite magnetic nanomaterials were created using a co-precipitation method, followed by Fe_3O_4 /Perlite@ SiO_2 magnetic nanomaterials created using a sol-gel method, and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nanomaterials created using a sol-gel method. The structures of the synthesized magnetic nano materials were clarified by various characterization devices such as BET, FTIR, SEM, SEM-EDX, TGA-DTA, and XRD. The characterization findings revealed that the syntheses and surface coatings of Fe_3O_4 /Perlite, Fe_3O_4 /Perlite@ SiO_2 and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nanomaterials were successfully performed. Furthermore, in light of these findings, Fe_3O_4 /Perlite, Fe_3O_4 /Perlite@ SiO_2 and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano materials were discovered to be in crystalline cubic spinel form, mechanical and thermal stability, and mesoporic size. Since synthesized perlite-supported magnetic nano materials have potential in many applications, such as sustainable technologies, environmental safety technologies such as water reclamation and pollution removal, adsorption technologies, etc., they are brought to the attention of related fields.

Highlights

- Fe_3O_4 /Perlite magnetic nano materials were fabricated from Fe^{+2} , Fe^{+3} and Perlite by co-precipitation method.
- Core@shell (Fe_3O_4 /Perlite@ SiO_2) was carried out by the sol-gel method.
- Fe_3O_4 /Perlite, Fe_3O_4 /Perlite@ SiO_2 and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano materials were successfully fabricated.
- Perlite provided thermal stability to the structure.
- Fe_3O_4 /Perlite, Fe_3O_4 /Perlite@ SiO_2 and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano materials have mesoporous structure.
- These magnetic nano materials could be a promising candidate for sustainable technologies.

1. Introduction

Nanotechnology, which deals with materials on a scale of 1 to 100 nm, is a rapidly growing branch of science with significant applications in materials science. Nano materials have recently received a lot of attention because of their fascinating structural (magnetic, optical, electrical, and so on) behavior. Nano materials research has been a popular topic over the last two decades. Nanostructured materials such as nanofilms, nanotubes, and nanocomposites have been developed for use in a wide range of applications. With dizzying recent advances in materials science, nano materials with advanced compositions, adjustable surface charges, shapes, morphologies, well-characterized dimensions, and physicochemical properties are now produced/synthesized. Nano materials are widely acknowledged as the foundation of nano engineering and nano science. Because of their complementary properties and unique structure in comparison to other materials, nano materials are promising materials (Kalambate, Huang et al. 2019).

Non-toxic magnetite (Fe_3O_4) is a widely used magnetic nano material in materials science that is of academic interest because of its availability, reusability, and ease of isolation under an external magnetic field, as well as its bio-physicochemical compatibility. Fe_3O_4 is an iron oxide with a cubic inverted spinel structure. It contains Fe cations in the interstitial tetrahedral and octahedral sites, as well as cubic closed packed oxygen anions (Abdullah, Shameli et al. 2017). Fe_3O_4 with exceptional properties Magnetism has a lot of surface energy. Agglomeration of Fe_3O_4 is caused by high surface energy. However, Fe_3O_4 has a high level of chemical activity. Fe_3O_4 oxidizes in the air due to its high chemical activity. Agglomeration and oxidation reduce the magnetism and dispersibility of Fe_3O_4 . In order to obtain yield from bare Fe_3O_4 , it must be functionalized with various materials. Functionalization provides Fe_3O_4 with areas of chemical coordination/conjugation and chemical stability (Shen, Li et al. 2018).

Because it is natural, perlite, an industrial and glassy volcanic mineral, is environmentally friendly. It can expand up to 35 times its internal volume at high temperatures (850–1100°C). It has a low density as well as a low thermal conductivity. It contains a high concentration of silica (more than 70 percent). Perlite has an adsorptive character due to the presence of silanol atoms. Depending on the pH of the solution medium, it can be charged (+) or (–). It can be used as a filler in a variety of processes and materials due to its chemical ineffectiveness in many environments. It is used in a variety of industries, including dam cleaning, the food industry, clear water extraction, the iron and steel industry, construction, the metal industry, and agriculture (Acemioğlu 2005). Perlite, an aluminosilicate, is a low-cost mineral with an amorphous structure and high availability. Low cost, environmental friendliness, lack of toxic, fire-resistance, high surface area, high water content (in addition to water, Al_2O_3 and SiO_2 , also K_2O , Na_2O , Cao, MGO, TiO_2 , MnO_2 , SO_3), chemical inertness, and lightness perlite are some distinguishing characteristics. Mechanical and thermal stability are high in perlite-based composites (Jafarirad, Pooresmaeil et al. 2021).

Functionalizing magnetic nano materials with silica (SiO_2) facilitates operation while also contributing to the advancement of magnetic nano materials in materials science. SiO_2 prevents magnetic dipolar attraction and agglomeration in Fe_3O_4 , allows Fe_3O_4 to be easily dispersed in liquid media, and protects Fe_3O_4 in acidic media. Silanol groups activate the surface of SiO_2 -coated magnetic nano materials for

various functional groups and solidify the surface. The silica layer provides a chemical-inert surface for magnetic nano materials in biological systems because of these benefits. Because of its relatively mild reaction conditions, low cost, and lack of surfactant, the sol-gel method is preferred in many techniques for coating Fe_3O_4 with SiO_2 (Deng, Wang et al. 2005).

Sulfanilamide is a simple organic sulfur compound. This organic compound contains two NH_2 and one SO_2 groups (Ece 2021). Sulfanilamide is used in the prevention and treatment of bacterial infections as an antimicrobial antifolic agent. Because of their pharmacological activity, sulfanilamide and its derivatives have received a lot of attention in biology (supramolecular) and medicine (antiviral, antifungal, antitumor, anti-inflammatory). They are successfully used in clinics due to their excellent pharmacological activity (Wang, Wan et al. 2010).

The manufacture of magnetic nano materials supplemented with perlite is almost non-existent in the literature. Perlite was added to Fe_3O_4 in this study. The surface of the Fe_3O_4 /perlite was then coated with SiO_2 . Sulfanilamide was eventually used to modify Fe_3O_4 /Perlite@ SiO_2 . BET, FTIR, SEM, SEM-EDX, TGA-DTA, and XRD analyses were used to characterize Fe_3O_4 /Perlite, Fe_3O_4 /Perlite@ SiO_2 , and Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano materials. The materials developed in this study were presented to the materials science community in order to capitalize on their biological, chemical, and physical advantages.

2. Materials And Methods

2.1. Chemicals and reagents

Iron (II) chloride tetrahydrate ($\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$), Tetraethyl orthosilicate (TEOS, $\text{Si}(\text{OC}_2\text{H}_5)_4$) was supplied from Alpha Aesar, Iron (III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) from Merck, ammonia (NH_3) from VWR chemicals, Sulfanilamide ($\text{C}_6\text{H}_8\text{N}_2\text{O}_2\text{S}$) and ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) from Sigma-Aldrich. The chemicals and reagents used in this study are of standard analytical purity. Perlite (+ 355, -500 mesh) powder was obtained from Bitlis-Turkey perlite mine.

2.2. Fabrication processes

2.2.1. Fabrication of Fe_3O_4 /Perlite magnetic nano material

Fe_3O_4 /Perlite magnetic nano material was fabricated by co-deposition. Each stage of the reaction was carried out under inert medium (argon gas). At 80°C , 6 g perlite was filtered in 100 mL ethanol for 30 min, sufficiently expanded volume, left in a mixture of 2 mmol $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and 4 mmol $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ distributed in 100 mL deionized water, and mixed at 80°C for 30 min at 1000 rpm. For co-precipitation to occur, a drop of 10 mL of 8m NH_3 solution was added to the reaction system. After continuing the reaction for 30 min, the reaction system was turned off and allowed to cool. Magnetic nano particles of brownish black Fe_3O_4 /Perlite (Perlite/Fe = 9) were obtained. To remove unreacted chemicals, the resulting Fe_3O_4 /Perlite

magnetic nano particles were washed several times with distilled water and ethyl alcohol. Magnetic separation was used to isolate Fe_3O_4 /Perlite magnetic nano material. The product was dried (Ahmed, Hamed et al. 2020).

2.2.2. Fabrication of Fe_3O_4 /Perlite@ SiO_2 magnetic nano material

Fe_3O_4 /Perlite@ SiO_2 magnetic nano material was fabricated by sol-gel method. Each stage of the reaction was carried out under inert medium (argon gas). 1 g of Fe_3O_4 /Perlite magnetic nano material placed in the reaction bottle were sonicated in 100 mL of ethanol and 50 mL of deionized water. Drop by drop, 30 mL 8M NH_3 and 4 mmol TEOS were added to the mixture. The reaction system was turned off after 12 h of mixing in room temperature. The resulting Fe_3O_4 /Perlite@ SiO_2 magnetic nano material was cleaned with ethanol and deionized water. Magnetic separation was used to isolate Fe_3O_4 /Perlite@ SiO_2 magnetic nano material. The product was dried (Ece 2021).

2.2.3. Fabrication of Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano material

Each stage of the reaction was performed in an inert medium (argon gas). 1 g of Fe_3O_4 /Perlite@ SiO_2 magnetic nano material was added to a reaction bottle with 200 mL of ethanol and sonicated. The reaction bottle was then filled with 2 g Sulfanilamide and refluxed for 15 h. The reaction system was turned off, and the system was allowed to cool. The Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano material that resulted were washed with ethanol and deionized water, respectively. Magnetic separation was used to isolate Fe_3O_4 /Perlite@ SiO_2 @Sulfanilamide magnetic nano material. The product was dried (Ghorbani-Choghamarani, Shiri et al. 2016). The fabrication processes of magnetic nano materials are schematically presented in Fig. 1, and the magnetization abilities of magnetic nano materials are presented in Fig. 2.

2.3. Characterizations

The characterization of magnetic nano adsorbents was carried out by scanning electron microscopy (SEM) and energy-distributed X-ray spectroscopy (EDX) analysis, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction Spectrometer (XRD), differential thermal analysis (DTA), thermal gravimetric analysis (TGA), Brunauer-Emmett-Teller (BET) surface area analysis. The synthesized magnetic nano materials were characterized by SEM (ZEISS, EVO 50 Series, Carl Zeiss AG, Jena, Germany) for morphological structure analysis. The basic element components of magnetic nano materials were determined by EDX (Bruker, Quantax EDsingle bondXS, Bruker AXS GmbH, Karlsruhe, Germany). The surface properties of magnetic nano materials were analyzed using the FTIR spectrometer (Bruker, Vertex 70v, Bruker Optics Inc., Billerica, USA). FTIR spectra were obtained using the transmission technique (analysis range: $4000 - 400 \text{ cm}^{-1}$ wave numbers). The phase structure and crystallization of magnetic nano materials was characterized by the XRD (D/MAX 2200, Rigaku Corp., Japan) and

Brunauer-Emmett-Teller (BET, Quantachrome, Nova 2200E, Quantachrome GmbH & Co. KG, Odelzhausen, Germany). TGA and DTA were performed for the creation of magnetic nano materials and the determination of quantitative differences of surface-bound functional groups. TGA and DTA thermograms were obtained with a TG/DTA simultaneous measuring device (SHIMADZU, DTG-60, Shimadzu Europa GmbH, Duisburg, Germany) at a heating rate of 10°C/min in the range of 25-1000°C. Surface area measurements of magnetic nano materials were performed at 77 K according to the nitrogen adsorption/desorption method of BET (Quantachrome, Nova 2200E, Quantachrome GmbH & Co. KG, Odelzhausen, Germany).

3. Results And Discussions

3.1. Characterization of magnetic nanomaterials

Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were characterized in detail by BET, FTIR, SEM, SEM-EDX, TGA-DTA and XRD analysis techniques.

3.1.1. SEM analysis

SEM images of the surface morphologies of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are presented in Fig. 3. Figure 3a shows that the regular/homogeneous appearance of Fe₃O₄/Perlite magnetic nano materials similar to a wooden stick/leaf is smooth, with dense, wide and deep cavities/pores. Figure 3b depicts that Fe₃O₄/Perlite@SiO₂ magnetic nano materials have irregular and rough shapes when compared to Fe₃O₄/Perlite magnetic nano materials, resulting in fewer dense, wide, and deep cavities. It is believed that SiO₂ surrounds Fe₃O₄/Perlite magnetic nano materials with light-colored spherical beads, revealing the material's core-shell layered structure. It is observed in Fig. 3c that the dense, wide and deep cavities on the surface of Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are close to disappearing, and the residue of irregularity and smoothness dominates the surface in the form of lighter spherical beads thanks to the surfactant functional group (Sulfanilamide). The results confirm that SiO₂ coated Fe₃O₄/Perlite, then sulfanilamide coated Fe₃O₄/Perlite@SiO₂.

3.1.2. SEM-EDX analysis

The SEM-EDX analyses of the basic element components of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. As expected in Fe₃O₄/Perlite and Fe₃O₄/Perlite@SiO₂ magnetic nano materials, Al, Ca, Fe, K, Mg, Mn, Na, O, S, Si, Ti elements were observed. Similarly, in Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano material, Al, C, Ca, Fe, K, Mg, Mn, N, Na, O, S, Si, Ti elements were observed. The results confirm the successful fabrication of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials.

3.1.3. FTIR analysis

The FTIR spectra of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials are presented in Fig. 7. In all three materials, the peak around 564 cm^{-1} is a square peak indicating the presence of Fe_3O_4 caused by the Fe-O bond (Ece 2021, Kutluay 2021). Peak around 800 cm^{-1} is a symmetrical stress peak showing the Si-O-Si bond. A wide and sharp peak around 1082 cm^{-1} is an asymmetric stress peak indicating the presence of a Si-O-Si bond. Peak around 1652 cm^{-1} is a bending stress peak indicating the presence of an O-H bond. The peak around 3330 cm^{-1} is the tensile peak of single bond OH groups of different structures, such as H-OH, Al-OH, and Si-OH, adsorbed to the surface. The peaks observed in the FTIR spectrum of $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano material at 1490 cm^{-1} indicate the presence of the N-H bond. The symmetrical and asymmetric stretching peaks of $\text{O}=\text{S}=\text{O}$, which are expected to be seen at 1140 cm^{-1} and 1325 cm^{-1} , are covered by other peaks, respectively. The peak observed at 1410 cm^{-1} shows C = C aromatic, and the peak observed at 2910 cm^{-1} shows CH_2 vibrations. The findings are consistent with the literature (Ahmed, Hamed et al. 2020, Ece 2021). The results obtained confirm that $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials were successfully fabricated.

3.1.4. XRD analysis

The XRD patterns of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials are shown in Fig. 8. In the XRD model of $\text{Fe}_3\text{O}_4/\text{Perlite}$ magnetic nanomaterial, the observed peaks of 30.52° (220), 35.76° (311), 43.50° (400), 51.28° (422), 57.68° (511) and 63.18° (440) indicate the presence of Fe_3O_4 in the structure. In addition, these peaks show the crystalline cubic spinel form. The peak at 24.40° is the diffraction peak of amorphous SiO_2 . The observation of these peaks in the XRD models of $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials shows that the surface coating was successfully achieved, and that Fe_3O_4 and SiO_2 maintain their form in the coatings (Gad and Elbarbary 2021). In addition, the observed peaks of 15.78° , 30.76° and 43.04° in the XRD model of $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano material are diffraction peaks of Sulfanilamide (Muthuselvi, Gayathri et al. 2016).

3.1.5. TGA-DTA

TGA-DTA of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials are presented in Fig. 9. In TGA analysis, the mass loss of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ ve $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials was measured as 2.89%, 4.34%, 10.53%, respectively. The mass loss that occurs below 200°C is due to evaporation of water molecules and solvents adsorbed to the surface, sublimation of sulfanilamide. Mass loss in the range of $200\text{--}600^\circ\text{C}$ is due to the extinction of oxygen-carrying groups. However, thermal decomposition and crystal water

decomposition are thought to occur. The phase change of iron oxides also occurs in this temperature range. At temperatures above 600°C, very little mass loss indicates high thermal stability (Ece, Kutluay et al. 2020). Exothermic peaks in DTA are caused by incineration of combustible species. However, the exothermic peak around 735°C is due to the transformation of SiO₂ (Majouli, Younssi et al. 2011).

3.1.6. BET analysis

3.1.6.1. N₂ adsorption-desorption isotherms

N₂ adsorption-desorption isotherms of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are presented in Fig. 10. While the isotherms given in Fig. 10 were examined, it was concluded that Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials showed type IV-H3 hysteresis cycles according to the IUPAC (International Union of Pure and Applied Chemistry) classification. However, these hysteresis cycles are characteristic of mesoporous materials. The obtained values are compatible with the literature (Bharath, Alhseinat et al. 2017, Cychosz and Thommes 2018).

3.1.6.2. BJH pore size distributions

BJH pore size distributions of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are presented in Fig. 11. When BJH pore size distributions were examined, Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were found to be 9.683 nm, 7.912 nm, 34.692 nm, respectively. According to the IUPAC Classification (2 < mesopore < 50 nm), Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were found to be included in the meso-pore classification. The values obtained are compatible with the literature (Zhu, Fu et al. 2011, Cuong, Wu et al. 2020).

3.1.6.3. DFT pore size distributions

DFT pore size distributions of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are presented in Fig. 12. When examining the dominant pore width, Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were found to have pore width of 3.917 e-02 cc/g, 5.025 e-02 cc/g and 1.022 e-01 cc/g respectively. When pore volumes were examined, Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were found to have pore volumes of 2.271 nm, 1.585 nm and 17.999 nm, respectively (Zhu, Fu et al. 2011, Liu, Zhao et al. 2020).

3.1.6.4. Textural properties of the Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and

Fe₃O₄/Perlite@SiO₂@Sulfanilamide

The textural properties of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are presented in Table 1. When the textural properties of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were examined, it became clear that the BET surface areas of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were 8.09 m²/g, 12.71 m²/g and 5.89 m²/g, respectively.

Table 1

Textural properties of the Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide

Textural properties	Fe ₃ O ₄ /Perlite	Fe ₃ O ₄ /Perlite@SiO ₂	Fe ₃ O ₄ /Perlite@SiO ₂ @Sulfanilamide
BET surface area (m ² /g)	8.09	12.71	5.89
Total pore volume (cm ³ /g)	0.04	0.05	0.10
Mesopore volume/fraction (D-R) (cm ³ /g)	0.04/100%	0.05/100%	0.10/100%
Average pore radius (BJH) (Å)	96.83	79.12	346.92
Surface area (BJH) (m ² /g)	8.61	10.35	7.79
Pore volume (BJH) (cm ³ /g)	0.04	0.05	0.10
Pore radius (BJH) (Å)	15.27	17.04	21.56
Surface area (DFT) (m ² /g)	5.07	8.57	4.95
Pore volume (DFT) (cm ³ /g)	0.03	0.04	0.05
Half pore width (DFT) (Å)	22.71	15.85	179.99

A comparison of the data leads to a prediction that mesoporous magnetic nano materials with cavity resemble the 3-dimensional structure shown in Fig. 13.

4. Conclusions

In this study, Fe₃O₄/Perlite was fabricated by co-precipitation method, then Fe₃O₄/Perlite@SiO₂ by sol-gel method, Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were fabricated as the final product. The structures of these materials were clarified by various characterization devices. The characterization indicated that the fabrication and surface coatings of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂

and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials were successful. It was discovered that Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials are crystalline cubic spinels with mechanical and thermal stability and a mesoporous size. Successfully fabricated perlite-supported magnetic nano materials can be used in a variety of applications, including sustainable technologies, environmental safety technologies such as water reclamation and pollution removal, and adsorption technologies.

Declarations

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

Figure 1

Schematic representation of fabrication processes of magnetic nano materials

Figure 2

Magnetization abilities of magnetic nano materials before magnetization (a) and magnetization process (b)

Figure 3

SEM images of Fe₃O₄/Perlite (a), Fe₃O₄/Perlite@SiO₂ (b) and Fe₃O₄/Perlite@SiO₂@Sulfanilamide (c) magnetic nano materials

Figure 4

SEM-EDX analysis of Fe₃O₄/Perlite magnetic nano material

Figure 5

SEM-EDX analysis of Fe₃O₄/Perlite@SiO₂ magnetic nano material

Figure 6

SEM-EDX analysis of Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano material

Figure 7

The FTIR spectra of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials

Figure 8

The XRD patterns of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials

Figure 9

TGA (a) and DTA (b) of Fe₃O₄/Perlite, Fe₃O₄/Perlite@SiO₂ and Fe₃O₄/Perlite@SiO₂@Sulfanilamide magnetic nano materials

Figure 10

N₂ adsorption-desorption isotherms of $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2 @ \text{Sulfanilamide}$ magnetic nano materials

Figure 11

Pore size distributions of 0.5~680 Å calculated by the BJH method of the $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@SiO_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@SiO_2@Sulfanilamide$ magnetic nano materials

Figure 12

Pore size distributions of 0.5~180 Å calculated by the DFT method of the $\text{Fe}_3\text{O}_4/\text{Perlite}$, $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2$ and $\text{Fe}_3\text{O}_4/\text{Perlite}@ \text{SiO}_2@ \text{Sulfanilamide}$ magnetic nano materials

Figure 13

Predicted 3-dimensional structure of magnetic nanomaterial with cavity

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