

REMOVAL OF As(III) FROM INDUSTRIAL WASTEWATER USING BaFe₁₂O₁₉ NANOPARTICLES

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ABSTRACT

The main public health problem is arsenic, As (III) contamination of drinking water. In the current scenario, nanoparticles have emerged as a promising candidate for As(III) decontamination. This study provides a comprehensive solution for the use of nanoparticles (NPs) of barium hexafluoride (BaFe₁₂O₁₉) for the decontamination of As(III). Herein, NPs were synthesised by hydrothermal synthesis at low temperature and characterised by FTIR, XRD, Particle Size Analyser (PSA), FESEM, TEM, and EDX. Among the key observations, PSA, TEM and FESEM revealed a consistent distribution of particle sizes with a 65 nm average diameter. EDX analysis confirmed the presence of the main chemical components Ba, Fe, and O. BaFe₁₂O₁₉ NPs achieved a 55% Ar removal from industrial wastewater and showed five times higher As(III) removal effectiveness than the commercial Fe₃O₄ NPs. These findings demonstrate the potential of BaFe₁₂O₁₉ NPs as a promising As(III)-remediating adsorbent and provide a basis for developing cost-effective nanomaterials for the treatment of industrial wastewater. In addition, this finding provides insights for future research to improve the adsorption efficiency and practical implementation in sustainable water purification systems.

Keywords: As(III) Removal, BaFe₁₂O₁₉ NPP, TEM, FESEM, Waste Water Treatment.

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INTRODUCTION

Heavy metal pollution is one of the main causes of water pollution worldwide, leading to severe water scarcity. The problem is made further worse by irregular urbanisation, population growth and environmental changes, posing a severe threat to global health, economic development, sustainability and social advancement.^{1,2} Among the heavy metal family, As(III) stems from industrial chemical waste, biological pollutants, suspended solids and gases.³ Akin to As(III), other group V elements, namely nitrogen, phosphorus, etc., can pollute water bodies, leading to eutrophication and mass extinctions of aquatic life.^{4,5} However, As(III) is the most virulent among the group V elements owing to its abundance in Earth's crust and potency of being recycled to nature continuously. Lung and skin cancers have been found in humans due to long-term exposure to inorganic As(III) compounds (IARC, 1987).⁶ To be specific from the experimental viewpoint, As(III) is hard to tackle since it exists as an isotopic pair, As(III)

and As(V), and both of them exist in a neutral, non-ionic form at pH 6–8. Hence, a primary challenge of water purification is to decontaminate it from As(III) to make it potable and suitable for other household purposes. In the current period, many articles have been published on the development of water purification methods and the synthesis of suitable nanomaterials for this task. In the case of eradicating heavy metal ions, ferrite-based nanoparticles (NPs) have received significant attention. For example, Fe₂O₃ nanoparticles were used to remove Pb²⁺ ions, while Fe₃O₄ nanoparticles were useful for the simultaneous removal of Pb²⁺ and Cd²⁺ ions due to their high surface area and excellent magnetic confinement properties.^{2,7} Similarly, other ferrite-based materials such as BaFe_{11.5}Co_{0.5}O₁₉ are employed to absorb Cr(VI),⁸ and Fe₂O₃/MXene nanocomposites were showed potential for the adsorption of Cu²⁺ ions.⁹ In addition, hybrid nanostructures such as Fe₃O₄/CeO₂/TiO₂ have been studied for successful Pb²⁺ ion remediation. Table-1 outlines various ferrite-based nanocomposites and their removal efficiency of heavy metals.

Table-1: Heavy Metal Removal and Efficacy by Different Iron Oxide Composites

S. No.	Heavy metal /dye removal	Iron Oxide Composites	Method of preparation	Scalability	Environmental Sustainability	Removal Efficiency	Ref.
1	Hg	Fe ₃ O ₄ /MgO composite	Co-precipitation	High and simple, low-cost	Non-toxic materials; effective heavy metal removal	97.17%	10
2	Cu ²⁺	Fe ₂ O ₃ /MXene nanocomposite	Ultrasonic-assisted mixing	Moderate – scalable with control	Good removal efficiency; sustainable material choice	83%	9
3	Pb ²⁺ Cu ²⁺	γ-Fe ₂ O ₃ /CeO ₂ /Cellulose nanofibril films	Solution casting	High–film processing compatible	Renewable cellulose; recyclable nanocomposite	77.9% 69.6%	11
4	Conversion of As(III) to As(V)	Stabilized Fe ₃ O ₄ nanoparticles	Chemical precipitation	High – widely practised	Good remediation with minimal secondary waste	81.1%	12
5	Methylene blue	Fe ₂ O ₃ /Mn ₂ O ₃ nanocomposite	One-step hydrothermal	Moderate – controlled conditions	Efficient dye degradation under neutral pH	80-97%	13
6	Crystal violet Congo red	hetero-phased iron oxide/carbon	Wet chemical synthesis	Moderate – lab-scale	Carbon support improves stability and reusability	35.4% 45.8%	14
7	Pb ²⁺	Fe ₃ O ₄ /Biochar composite	In-situ co-precipitation	High – biochar scalable	Sustainable biochar use; high lead removal	98%	15
8	Pb Cu Cd Ni	HA-modified Fe ₃ O ₄ nanoparticles	Surface functionalization	High – simple surface modification	Enhanced selectivity and eco-friendly	11.11% 7.69% 7.14% 3.33%	16
9	Hg(II) and Pb(II) Cu(II) & Cd(II)	Fe ₃ O ₄ coated with Humic Acid	Layer-by-layer coating	Moderate	High metal removal; low secondary pollution	99% 95%	17
10	Cd	Flower-like α-	Solvothermal	Moderate	Morphology	1.69%	18

	Cr Pb	Fe ₂ O ₃	method		enhances adsorption; minimal toxic by-products	2.22% 2.564%	
11	P-nitroaniline (0.2 mmol/L)	Fe ₃ O ₄ -based nanocomposites	Various (sol- gel, co- precipitation, etc.)	Depends on method used	Summary of methods with green synthesis emphasis	100%	19
12	Acetaminophe n (10 mg/L)	Fe ₃ O ₄		Depends on method used	Non-toxic materials; effective heavy metal removal	75%	20
13	Phenol Aniline (1 mM)	g-C ₃ N ₄ /Fe ₃ O ₄	Chemical co- precipitation method	Depends on method used	Summary of methods with green synthesis emphasis	100%	19
14	Phenol (0.4 mM)	AG/Fe ₃ O ₄	Co- precipitation method	Scalable	Remarkable reusability over up to ten cycles	93.43%	21
15	Rhodamine B (RhB) (10 mg/L)	Fe ₃ O ₄ @CA	Facile hydrothermal method	Suitable for industrial upscaling	Fe ₃ O ₄ is non-toxic, and the composite is reusable, showing excellent stability with only ~3% loss in activity across six cycles	100%	22
16	Pb(II) (10 mg/L)	ZnO-Fe ₃ O ₄	Hydrothermal method	Moderately scalable	Reusable and separable from magnets	39.2%	23
17	Cu(II) (50 mg/L)	ZnO-Fe ₃ O ₄	Hydrothermal method	Moderately scalable	Reusable and separable from magnets	37.66%	23
18	Ni ²⁺	Fe ₃ O ₄ /grapheme oxide/chitosan (FGC)	Co- precipitation method	Moderately scalable	Environmental ly benign if GO and chitosan sourcing are sustainable.	83.08%	24
19	Cd ²⁺	Magnetic iron oxide /GO nanocomposite	Co- precipitation method	low-cost and scalable laboratory techniques	Magnetic recovery enables regeneration and reuse, reducing secondary pollution	52.08%	25
20	Pb ²⁺	BaCo ₂ Fe ₁₆ O ₂₇	citrate-nitrate combustion method	Scalable	Low risk of toxic leaching	99% 28%	26
21	Pb ²⁺	Fe ₃ O ₄ /CeO ₂ / TiO ₂	Co- precipitation	Easy to scale	TiO ₂ and Fe ₃ O ₄ NPs	85%	5

			method		showed no observable toxicity		
22	As(III) and As(V)	Fe_3O_4	Co-precipitation method	Amenable to upscaling	Green process; recyclable with minimal change	>90%	27
23	Ni^{2+}	Fe_3O_4 impregnated on tea waste (Ratio tea waste: Fe_3O_4 ; 5:5)	Chemical co-precipitation	Highly scalable	Environmentally benign with low ecological footprint.	>95%	28
24	Ni^{2+}	Fe_3O_4 modified by oak shell	Co precipitation followed by batch adsorption	large-scale	Environmentally benign with low ecological footprint.	93.88%	29
25	Cd^{2+}	Nanocomposite of ZnO and Fe_2O_3	Mechanical milling	Large scalable	Environmentally benign with less toxicity and minimal waste	100%	30
26	Ni^{2+}	Nanocomposite of ZnO and Fe_2O_3	Mechanical milling	Large scalable	Environmentally benign with less toxicity and minimal waste	99%	30
27	Cr^{2+}	Nanocomposite of ZnO and Fe_2O_3	Mechanical milling	Large scalable	Environmentally benign with less toxicity and minimal waste	24%	30
28	Cr(VI)	M-type $\text{BaFe}_{12}\text{O}_{19}$	Citrate auto-combustion synthesis	Industrial scale production	Eco-friendly, with sustainable manufacturing and low environmental impact.	10%	8
29	Cr(VI)	$\text{BaFe}_{11.5}\text{Co}_{0.5}\text{O}_{19}$	Citrate auto-combustion synthesis	Industrial scale production	Eco-friendly, with sustainable manufacturing and low environmental impact.	35%	8

Among ferrites, $\text{BaFe}_{12}\text{O}_{19}$ NPs, traditionally used as permanent magnets due to their excellent structural and magnetic properties, including high Curie temperature, high crystalline magnetisation, high coercivity, high magnetisation, and resistance to chemical and corrosion, are promising candidates for the removal of As(III) from industrial wastewater.^{31,32} The hexagonal structure of $\text{BaFe}_{12}\text{O}_{19}$ NPs exhibits tunable magnetic properties by positioning metallic ions relative to oxygen ions and leads to superparamagnetic character, which aids in filtering out the heavy metal from wastewater. To date, several methods have been developed to prepare $\text{BaFe}_{12}\text{O}_{19}$ NPs, such as co-precipitation³³, glass crystallization³⁴, hydrothermal synthesis³⁵, sol-gel techniques³⁶, organometallic methods³⁷, microemulsion³⁸, spray deposition³⁹, and organic ligand-assisted supercritical water methods⁴⁰, to name a few. However, these methods often

present several limitations, such as high pH sensitivity, controlled drying environments, the need for highly complex equipment, use of expensive raw materials and the challenges in by-products disposal. For the sake of chemical synthesis, most of these methods produce an amorphous crystal structure that requires high-temperature calcination to procure the desired crystal structure and magnetic properties. To date, the synthesis of cost-effective, monodisperse $\text{BaFe}_{12}\text{O}_{19}$ NPs with nanoscale dimensions (less than 100 nm) remains a challenge, as the synthesis methods generate hard agglomerated particles with high diameters and irregular morphologies. Since synthesis methods substantially influence the structural and magnetic properties of $\text{BaFe}_{12}\text{O}_{19}$ NPs, it is imperative to employ a method that ensures the uniformity of the crystal and minimises the agglomeration. In this study, this issue was alleviated by the proposed synthesis method for $\text{BaFe}_{12}\text{O}_{19}$ NPs with regular morphology as reported by Komarneni *et al.* in 1998.⁴¹ This technique aligns with the green chemistry principles operating at low temperature and enables atomic-scale mixing of precursors. Simultaneously, it maintains uniformity across the dispersed NPs with tunable size and morphology. We report the hydrothermal method for the synthesis of $\text{BaFe}_{12}\text{O}_{19}$ NPs, offering a cost-effective, simple, economical, and rapid approach. The concentration of precursors was optimised, and the synthesis was carried out at low temperature to enhance the production of uniformly dispersed NPs with controlled size and morphology. The NPs were further characterised to capture their crystalline properties, morphological analysis, particle size distribution, and magnetic properties. Following this exercise, the potential application of $\text{BaFe}_{12}\text{O}_{19}$ NPs in environmental remediation was investigated with a specific emphasis on their efficacy in removing As(III) from industrial wastewater. This research highlights the multifunctional capabilities of these NPs encompassing their potential to be implemented as magnetic material and environmental cleaning.

EXPERIMENTAL

Material

Iron oxide (Fe_2O_3), Barium chloride (BaCl_2), Teflon-lined Morey autoclave, distilled water, Formic acid, Hot air oven, Sodium hydroxide (NaOH).

Synthesis of $\text{BaFe}_{12}\text{O}_{19}$ NPs

Iron oxide Fe_2O_3 (99% purity) and barium chloride BaCl_2 (99% purity) were combined in a 6:1 molar ratio for the synthesis of $\text{BaFe}_{12}\text{O}_{19}$ NPs. The solutions of metal salts were dissolved in suitable solvents: BaCl_2 in water (10 mL) and Fe_2O_3 in formic acid (HCOOH , 10 mL), respectively. The solutions were mixed thoroughly at room temperature (RT) to obtain a homogeneous and relatively viscous solution, which was then transferred into a Teflon liner filled to 80% of its volume. The liner was sealed in the autoclave vessel and then was placed in the PID temperature-controlled hot air oven (Fig.-1).

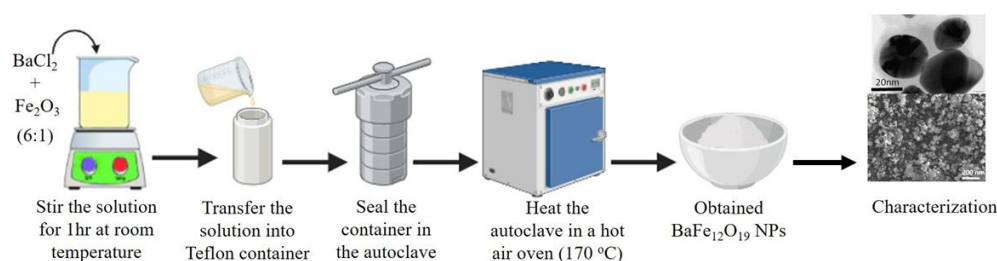
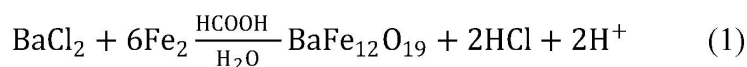


Fig.-1: Flow Diagram for $\text{BaFe}_{12}\text{O}_{19}$ NPs Synthesis by Hydrothermal Method



The synthesis of $\text{BaFe}_{12}\text{O}_{19}$ NPs was performed at different temperatures (125, 150, 175, and 200 °C) and different time durations (5, 10, 15 and 20 h). It was found that 175 °C and 5 hours were suitable reaction conditions for the synthesis of $\text{BaFe}_{12}\text{O}_{19}$ NPs with a diameter of 65 nm. The obtained materials were

neutralised using diluted NaOH solution (pH adjusted to 7) and washed with water and dried in an oven at 80 °C for further characterisation.

As(III) Adsorption and Desorption Study

Batch adsorption studies were performed to evaluate the uptake of As (III) by the synthesised $\text{BaFe}_{12}\text{O}_{19}$ NPs. Stock solutions of As(III) were prepared using sodium arsenate at five initial concentrations: 0.1, 0.5, 1, 5, and 10 mg/L. All solutions were formulated in a background electrolyte comprising 0.01 M NaCl, 0.01 M tris(hydroxymethyl)aminomethane, and 0.01 M NaN_3 , and the pH was maintained at 8.0 throughout the experiments. A fixed adsorbent dose of 10 mg of $\text{BaFe}_{12}\text{O}_{19}$ NPs was introduced into 1 L of each test solution and subjected to continuous stirring for 24 h at RT to ensure attainment of adsorption equilibrium. Upon completion, the adsorbent was recovered from the suspension by magnetic separation, and the clarified supernatant was analyzed for residual As(III) concentration by inductively coupled plasma atomic emission spectroscopy (ICP-AES) and inductively coupled plasma–mass spectrometry (ICP-MS). The experimentally obtained equilibrium data were subsequently fitted to the Langmuir and Freundlich isotherm models to elucidate the adsorption behaviour and surface interaction mechanisms. Desorption experiments were performed in batch conditions using a sodium hydroxide solution maintained at pH 13. After each adsorption cycle, the recovered $\text{BaFe}_{12}\text{O}_{19}$ NPs were dispersed in 10 mL of the alkaline solution and agitated for 24 h at RT to facilitate As(III) desorption. The NPs were then separated using an external magnetic field, and the collected supernatant was neutralised with dilute nitric acid before quantifying the released As(III). The proposed mechanism for As(III) removal by the synthesised $\text{BaFe}_{12}\text{O}_{19}$ NPs is illustrated in Fig.-2.

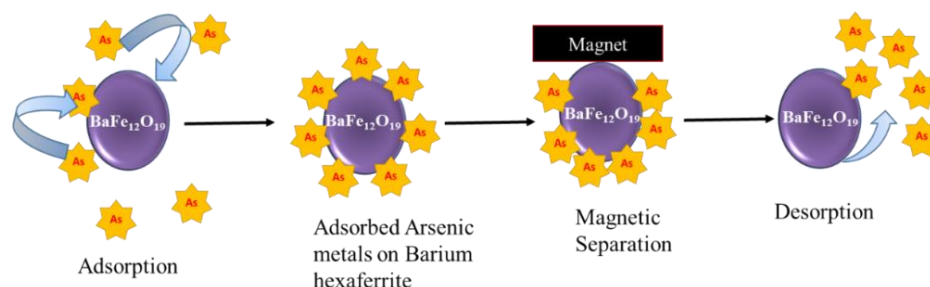


Fig.-2: Adsorption and Desorption Mechanism of Magnetic $\text{BaFe}_{12}\text{O}_{19}$ NPs in the Removal of As(III)

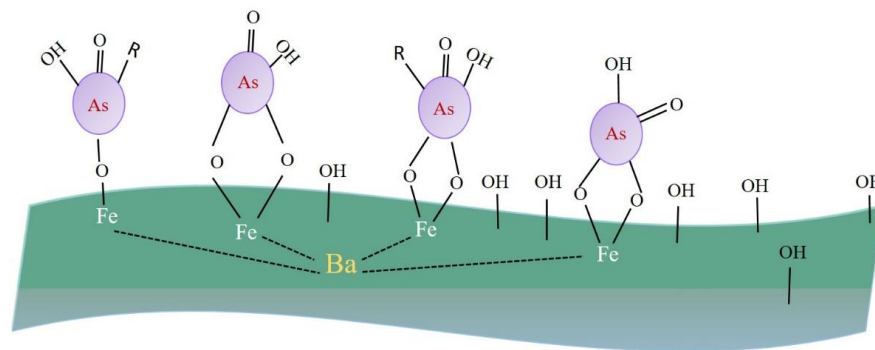


Fig.-3: Complex Formation Between $\text{BaFe}_{12}\text{O}_{19}$ NPs and As(III) Species

The As(III) adsorption mechanism onto the surface of $\text{BaFe}_{12}\text{O}_{19}$ involves a combination of hydrogen bonding interactions and surface complexation. Generally, the $\text{BaFe}_{12}\text{O}_{19}$ surface acquires hydroxyl groups on exposure to water; depending on the pH of the solution, it undergoes protonation or deprotonation. The hydroxyl groups present on $\text{BaFe}_{12}\text{O}_{19}$ act as active sites for As(III) binding (Fig.-3). As(III), commonly present as H_3AsO_4 in aqueous environments, approaches the surface, they undergo ligand exchange reactions with these hydroxyl ions, resulting in the formation of inner-sphere surface complexes. For example, H_3AsO_4 , upon partial dissociation, releases an H^+ ion, which combines with and results in the formation of H_2O , thereby creating space for anion binding.⁴² The embedded Ba^{2+} ions will

not directly interact with As(III) but play a significant role by stabilising the structural integrity and surface charge of ferrite, potentially enhancing the adsorption environment. The fundamental adsorption reaction of As(III) is shown below:



Characterization

The morphology of the synthesised nanoparticles was examined using a ZEISS Evo/IS 15 scanning electron microscope (SEM, Tokyo, Japan). Elemental composition and surface micrographs were obtained using an energy-dispersive X-ray spectroscopy (EDS) system (LINK ISIS EDS 300) operated at an accelerating voltage of 200 kV, with images recorded at 5 kV. The crystalline phase and structural properties of the nanoparticles were investigated by X-ray diffraction (XRD) using a Rigaku desktop powder diffractometer equipped with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$). In addition, the magnetic behaviour of the synthesised material was evaluated at room temperature using a Lake Shore vibrating sample magnetometer (VSM).

RESULTS AND DISCUSSION

The synthesised BaFe₁₂O₁₉ NPs were characterised by their structural, morphological, magnetic, and adsorption properties. The results obtained are discussed below in relation to their efficiency in As(III) removal from industrial wastewater. Figure-4 shows the phase recognition of the X-ray diffractograms of the synthesised BaFe₁₂O₁₉ NPs under hydrothermal conditions of 170 °C and 15 hours. Sharp peaks in the powder XRD pattern reveal the tiny crystallite size and a high degree of crystallinity of the samples. The obtained peaks all correspond to the BaFe₁₂O₁₉ structure, and there are no impurity peaks present. The spectrogram peaks shown in Fig.-6 confirm the hexagonal structure of the sample and are identical to the reference pattern (JCPDS-391433). The (h, k, l) diffraction peaks 006, 100, 107, 205, 209, 300, and 220 are very sharp at respective 2 theta values to confirm the crystalline phases of BaFe₁₂O₁₉ NPs. A sharp peak at 107 indicates the presence of the BaFe₁₂O₁₉ NPs, and it has a much greater intensity than other peaks in the spectrogram due to the small width of the crystals compared with their thickness.

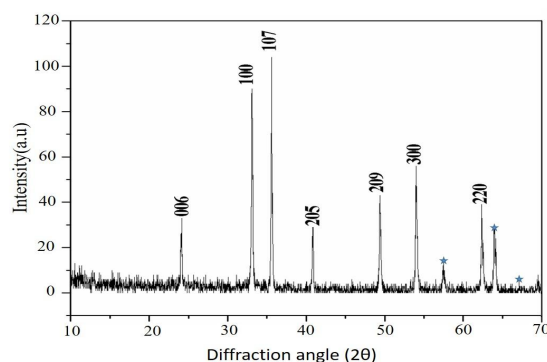


Fig.-4: X-ray Diffraction Pattern Showing BaFe₁₂O₁₉ Magnetic NPs

The SEM images of the synthesised BaFe₁₂O₁₉ NPs under hydrothermal conditions are shown in Fig.-5. This micrograph image shows the NPs formation in the range of nanometers (< 20 nm) with spherical structures. These SEM images were captured for the material under hydrothermal conditions of 170°C at the time duration of 15 hours at pH 7 (neutral condition), during which the formation of BaFe₁₂O₁₉ was investigated with desirable morphology. The majority of the NPs have a uniform size and morphology throughout the whole material. Figure-5 shows nanoparticle formation with slight agglomeration. The particles appear to be spherical to hexagonal in shape and are moderately dispersed.

The elemental composition of the tailored materials was examined using an EDAX spectrogram to map the distribution of Fe, Ba and O (Fig.-5(e)). The EDAX spectra reflect strong peaks of Ba, Fe, and O. Quantitative analysis indicated that the atomic percentage of oxygen (49.81) and the weight percentage of Fe were high (50.36) in the BaFe₁₂O₁₉ NPs. Carbon also appeared in the EDAX spectra and showed carbon at a very low weight percentage (14.64). Dynamic light scattering (DLS) was employed to determine the hydrodynamic particle size of magnetic nanoparticles (MNPs) and to determine the zeta-

potentials. In this technique, suspended nanoparticles scatter incident light and variations in the detected intensity are analysed to estimate the particle size.⁴³

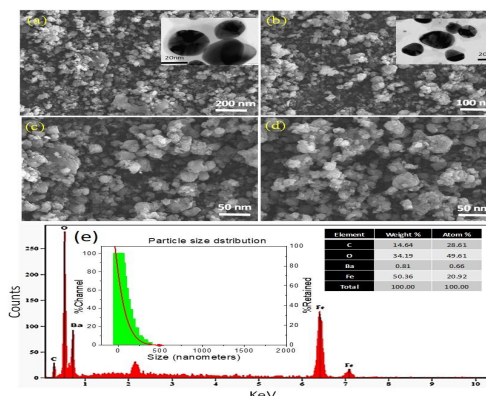


Fig.-5: (a-d) FESEM and TEM images (inset of a and b) at different nanometer Scales and (e) EDX Profile of BaFe₁₂O₁₉ NPs (inset shows the Particle size distribution)

The distribution of particle size can be measured by the information retrieved from the constant random motion due to the kinetic energy associated with MNPs.⁴⁴ The particle sizes of dispersed BaFe₁₂O₁₉ varied from 60 nm to 90 nm with the average size of 70 nm (Fig. 5e). The zeta-potentials of the prepared nanoparticles were measured for BaFe₁₂O₁₉ MNPs, and -20 mV was considered the threshold value for electrostatic stabilization.⁴⁵ The FTIR spectrum of the synthesised BaFe₁₂O₁₉ nanoparticles was recorded in the range of 400–4000 cm⁻¹ (Fig.-6). The characteristic absorption bands observed at approximately 450 and 580 cm⁻¹ confirm the formation of the hexagonal ferrite structure and correspond to Fe–O vibrations at tetrahedral and octahedral sites. A broad band between 2500 and 3300 cm⁻¹ is attributed to O–H stretching vibrations, indicating the presence of surface hydroxyl groups. The absorption bands in the range of 2850–3000 cm⁻¹ correspond to C–H stretching vibrations, while the peak near 1600 cm⁻¹ is assigned to C=O and/or C=C stretching vibrations. In addition, the band around 1150 cm⁻¹ is associated with lattice vibrations characteristic of the BaFe₁₂O₁₉ structure.

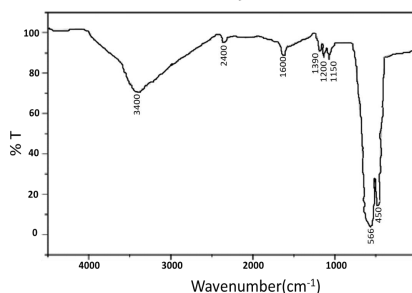
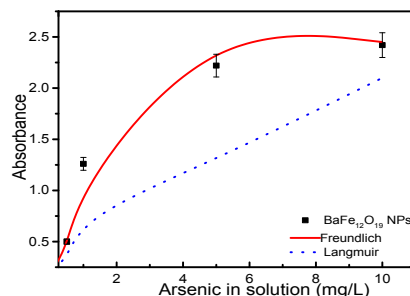


Fig.-6: FTIR Spectrum of BaFe₁₂O₁₉ Magnetic NPs

As(III) is the most dangerous toxic substance to be considered by the WHO while describing drinking water specifications. The As(III) contamination in drinking water leads to carcinogenic effects in human beings. Currently, it is estimated that over 100 million people across the countries like India, Bangladesh, Vietnam, Nepal, China and several others are exposed to drinking water contaminated with As(III) at the concentrations up to 100 times higher than the WHO guideline value of 0.01 mg/L. Patel *et al.*⁴⁶ reported that BaFe₁₂O₁₉ NPs are capable of removing 0.1 to 10 mg/L concentrations of As(III) in the prepared standard solutions. In the present study, we have used synthesised BaFe₁₂O₁₉ NPs for demonstrate the efficiency of As(III) removal in water samples containing As(III) in the range of 0.1 to 10 mg/L. The As(III) adsorption by the BaFe₁₂O₁₉ NPs is monitored by using ICP-AES and ICP-MS methods. The Langmuir and Freundlich isotherm models were used to analyse As(III) adsorption data. Below Fig.-7 shows the As(III) adsorption by the BaFe₁₂O₁₉ NPs with respect to different concentrations. The As(III) removal process occurred rapidly in the initial stage and slowed down after reaching certain saturation levels in the solutions. It was found that 55 % of the As(III) was desorbed from synthesised BaFe₁₂O₁₉ NPs. The adsorbed As(III) was removed by using a high magnetic field separation method.

Fig.-7: As(III) Adsorption by BaFe₁₂O₁₉ NPs

Adsorption isotherms were evaluated to describe the equilibrium relationship between As(III) adsorption and solution concentration. The Langmuir isotherm was applied for monolayer adsorption (Fig.-8) on a homogeneous surface with identical adsorption sites, where no interaction or lateral migration occurs between adsorbed molecules. Langmuir isotherm is mathematically expressed as,

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (3)$$

The Freundlich isotherm describes adsorption on heterogeneous surfaces and accounts for multilayer adsorption, reflecting the adsorptive capacity (loading factor) of the adsorbent. The equation is expressed as,

$$q_e = K_F C_e^{1/n} \quad (4)$$

Where q_e (mg g⁻¹) and C_e (mg L⁻¹) denote the equilibrium adsorption capacity and As(III) concentration, respectively; K_L and q_m are the Langmuir constants, whereas K_F and $1/n$ are the Freundlich constants related to adsorption capacity and surface heterogeneity.

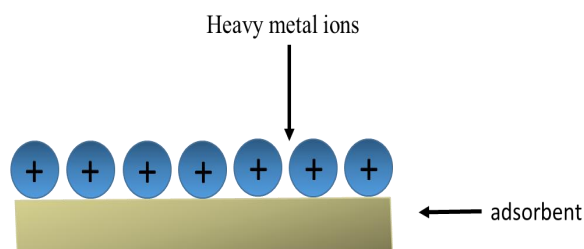
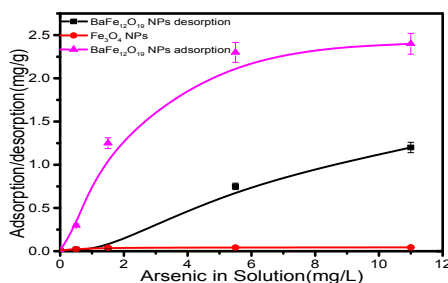


Fig.-8: Proposed Monolayer Adsorption Mechanism of Langmuir Isotherm

Hence, the concentration of adsorbed As(III) from the water samples was also calculated by using a desorption study. BaFe₁₂O₁₉ nanoparticles removed 0.055–5.5 mg L⁻¹ of As(III) from solutions containing 0.1–10 mg L⁻¹, demonstrating their effectiveness for As(III) remediation. For comparison, the As(III) adsorption capacities of commercial Fe₃O₄ and synthesised BaFe₁₂O₁₉ nanoparticles were 0.03 and 0.7 mg g⁻¹ respectively. The enhanced adsorption performance of BaFe₁₂O₁₉ nanoparticles is illustrated in Fig.-9. The results demonstrate that hexaferrite of nano-dimensional size gave better As(III) removal efficiency than commercial Fe₃O₄ NPs.⁴⁶

Fig.-9: As(III) Removal Capacity of Commercial Fe₃O₄ and BaFe₁₂O₁₉ NPs

The desorption studies at pH 13 show that 55% of the adsorbed As(III) was recovered by applying a strong magnetic field. In this way, the synthesised BaFe₁₂O₁₉ NPs can be used for the removal of As(III) in polluted water or wastewater.

CONCLUSION

The facile hydrothermal method for the synthesis of BaFe₁₂O₁₉ NPs has emerged as a cost-effective novel method. The hydrothermal preparation of an aqueous suspension of Ba and Fe hydroxides in the presence of a solvent at 170°C ends up in the formation of uniform, ultrafine nanoparticles, approximately 70 nm. The XRD spectra of BaFe₁₂O₁₉ confirm the crystallinity of nanoparticles, and SEM analysis shows the morphological structure has a spherical shape. The elemental composition shows the percentage of the weight of elements present in the synthesised magnetic nanomaterial, in which oxygen content was high. The presence of hexaferrite was confirmed by FTIR analysis, and the average particle size distribution in the solvent of BaFe₁₂O₁₉ was found to be 70 nm. The magnetisation measurements were performed for BaFe₁₂O₁₉ NPs and exhibited approximately 12 Am²/kg. These investigations and the results obtained provided new insight into the application of hydrothermal processing parameters for the preparation of uniformly distributed ultrafine particles and the synthesis of magnetic BaFe₁₂O₁₉ nanoparticles. The findings show that synthesised BaFe₁₂O₁₉ NPs can serve as both an efficient and competent material to Fe₃O₄ for As(III) removal in wastewater. Therefore, this study underscores the potential of this material in large industrial applications with respect to water and wastewater treatment systems, especially in targeting heavy metal and toxic metal removal processes.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-6: Clean Water and Sanitation*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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