# Design and Development of a Nanomembrane for Filtering Arsenic from Drinking Water

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## I. INTRODUCTION

In rural areas the contamination of drinking water with heavy metals such as Arsenic, Cadmium, Lead and Mercury due to agricultural fertilizers and chemicals poses a significant health risk. Arsenic, in particular, is known to cause severe kidney problems and has a high impact on cancer incidence. According to the previous literature adsorption, ion exchanges, electrokinetic processes, electrocoagulation, chemical precipitation, phytoremediation, nano phytoremediation, membrane technology and phytobial remediation are the methods that have been used in removing arsenic from water. To address this critical issue this project focuses on developing advanced nanomembrane technology specifically designed to filter out arsenic from drinking water. Nanomembrane technology is highly effective and suitable for use in as other existing methods are time consuming, cost-prohibitive and sludge forming while these nanomembranes(NM) depicts higher specific area, nanoporous structure, easy tuneable surface functionalities and affordable. This technology will enhance the filtration process by removing arsenic ion from the drinking water.

## II. LITERATURE REVIEW

Arsenic contamination in drinking water is a severe global issue affecting the health of millions. It occurs in both organic and inorganic forms with arsenite ($As^{3+}$) and arsenate ($As^{5+}$) being the predominant species found in groundwater among most common oxidation states; −3, 0, +3, and +5 [1][2][3]. Arsenic enters water through the dissolution of arsenic-containing minerals like arsenopyrite, mining, industrial discharges and the use of arsenical pesticides and fertilizers [3][4][5]. Regions such as Bangladesh, India, Vietnam and parts of China face severe arsenic contamination with groundwater concentrations often exceeding the WHO guideline of 0.01 mg/L and reaching up to 73.6 mg/L in certain areas [2][3][4]. In Sri Lanka, arsenic has been implicated in chronic kidney disease of unknown etiology (CKDu), particularly in the North Central and Eastern provinces where heavy metal contamination in drinking and irrigation water is considered a contributing factor [7]. Among arsenic species $As^{3+}$ and $As^{5+}$ are the most toxic in ground and surface water with $As^{3+}$ being approximately 60 times more toxic due to its greater solubility and mobility whereas $As^{5+}$ is stable in oxidizing and alkaline environments [1][2][3]. And also, The removal of arsenite ($As^{3+}$) from water is more challenging than arsenate ($As^{5+}$) due to its chemical nature and environmental behaviour. Unlike $As^{5+}$, which is easily rejected through electrostatic interactions (Donnan effect), $As^{3+}$ lacks a strong charge making it harder to filter. These differences in charge, stability and binding affinity result in a lower rejection rate for $As^{3+}$ requiring specialized strategies for its removal [7].Chronic exposure leads to arsenicosis, characterized by skin lesions, black foot disease and vascular disorders while both acute and prolonged intake are linked to cancers (skin, bladder, liver), reproductive issues and pregnancy complications [1][5]. Arsenic remediation methods include adsorption, ion exchange, electrocoagulation and membrane filtration [4][5]. While conventional approaches are cost-effective, they are often inefficient, time-consuming and generate hazardous waste [3][4]. But nanomembrane technology offers a high removal efficiency with low energy demand, large surface area, nanoporous structure and tuneable surface functionalities [5]. Electrospinning is a promising technique for producing nanomembranes with high surface area and excellent porosity [6]. Electro spun membranes offer high stiffness, strong filtration performance and low operational costs, making them ideal for arsenic removal in resource-limited settings [1][6]. Various polymers and nanomaterials have been explored for electro spun membranes targeting arsenic ion removal including sodium alginate(SA), chitosan, polyvinyl alcohol(PVA) , polyacrylonitrile(PAN), graphene oxide(GO), ferrous oxyhydroxide(FeOOH) and montmorillonite(MMT) [2][7]. While SA and chitosan are biodegradable and non-toxic they suffer from low electrospinning compatibility and aqueous stability [7]. PVA offers hydrophilicity but is water-soluble, whereas GO provide strength and stability but face dispersion challenges [7]. PAN stands out for its mechanical, thermal and chemical stability, FeOOH exhibits strong arsenic affinity via hydroxyl and Fe–O groups and MMT enhances ion exchange, especially when iron-modified [2]. Based on these merits PAN, FeOOH and MMT were selected for membrane fabrication in this study.

## III. MATERIALS AND METHODS

### A. Materials

In this study polyacrylonitrile (PAN) powder (Average Mw: 150000) was purchased from Sigma-Aldrich Inc. St. The bentonite (80% montmorillonite) was obtained from the University of Moratuwa.


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### B. Ferrous oxyhydroxide (FeOOH) Preparation

FeOOH was synthesized using urea and ferric chloride in a 2:1 molar ratio. The mixture was stirred at 100 rpm and heated to 95 °C until it completely dissolve and promote the intended chemical transformation. After the reaction, the mixture was cooled overnight, then washed with distilled water to remove residual chloride ions. The resulting product was dried at 105 °C and ground into powder. The dried FeOOH was stored in a desiccator to minimize moisture uptake and agglomeration ensuring a well-dispersed form suitable for subsequent applications.

### C. Nanomembrane Fabrication

To prepare the spinning solution at first, 10% of PAN solution was prepared by dissolving PAN in DMF, followed by the addition of 0.7% of FeOOH and 0.275% of MMT. The mixture was stirred at 300 rpm for 4 hours at room temperature to ensure complete dissolution of PAN, FeOOH and MMT in DMF and obtain a sufficient viscous solution. The resulting solution was then ultrasonicated at 45°C for 30 minutes to ensure homogenization by breaking down aggregates and improving dispersion. After that, PAN/FeOOH/MMT solution was spun using an 18G syringe needle with a 20 mm inner diameter. The electrospinning was carried out under the following conditions: 15 kV applied voltage, 0.07 mL/min flow rate, and a 15 cm tip-to-collector distance. The collector was an aluminium-foiled plate.

### D. Characterization

The characterization of nanomembranes was conducted using various analytical techniques to evaluate their structural, chemical and surface properties. Scanning Electron Microscopy (SEM) was employed to examine the surface morphology and fibre diameter distribution of the membranes. Fiber diameters were estimated using ImageJ software with at least 100 measurements taken per membrane sample.

### E. Adsorption Experiment

The adsorption behaviour of PAN/FeOOH/MMT based nanomembrane was investigated by using adsorption of $As^{3+}$ and $As^{5+}$ using ICP-MS. The 1 mg/L arsenate solution (~ groundwater concentration) was prepared by dissolving sodium arsenate (Na3AsO4) in 1L of deionized water.

### F. Effect of Contact Time

Then, the 0.1 g weight of the nanomembrane was immersed in the solution for a defined period and according to the time such as 2 hours and 4 hours two different samples were prepared. After that, the final concentration of $As^{5+}$ in the solution was then measured using ICP-MS. Then the adsorption capacity and removal efficiency were calculated accordingly using the below (1) and (2). Here $I_0$ denotes the initial concentration, $I_1$ the final concentration, m the weight of the nanomembrane and the V solution volume.

$$Removal\ Efficiency\ \% = \frac{I_0 - I_1}{I_0}\ X\ 100 \qquad (1)$$

$$Adsorption\ Capacity = \frac{I_0 - I_1}{m}\ X\ V \qquad (2)$$

## IV. Results and Discussion

### A. Charaterization of FeOOH

SEM analysis (Fig. 1) confirmed the successful formation of FeOOH nanoparticles exhibiting a rough, porous architecture indicative of high specific surface area and abundant active binding sites favourable for adsorption applications. The particles appeared flaky, irregular and plate-like which can be seems like types of iron oxyhydroxide such as goethite or lepidocrocite. Using ImageJ software average particle size was found to be 300.66 nm, validating their nanoscale nature. This morphology supports both physical and chemical adsorption, aligning with the membrane's high arsenic removal performance.

### B. Characterization of Nanomembrane

The surface morphology of the synthesized PAN/MMT/FeOOH nanomembrane was investigated using Scanning Electron Microscopy (SEM). The SEM image (Fig. 2) reveals a randomly oriented fibrous structure which is a characteristic of electro spun PAN nanofibers. The particles embedded on to the fibre surface carried out the fact that incorporation of montmorillonite (MMT) to the fibres. The observed rougher fibre surfaces in comparison to pure PAN nanofibers further confirm the presence of FeOOH (Fig. 2). These features indicate uniform dispersion of inorganic components with no significant aggregation which supports effective integration of MMT and FeOOH into the polymer matrix.

Using ImageJ software, fibre diameter measurements were taken from 100 individual data points, yielding a mean diameter of 714.3 nm. This confirms that the fibres are within the nanoscale range indicating formation of nanofibers. The distribution of fibre diameters is shown in Fig. 3.

### C. Adsorption of $As^{5+}$

The adsorption capacity of the synthesized PAN/MMT/FeOOH nanomembrane was evaluated through batch experiments using a known concentration of arsenate ($As^{5+}$) solution with the initial concentration of 1 mg/L (1000 ppb). As shown in Table 1, arsenate removal efficiency increased with longer contact time, starting at 44.15% (0.441 mg/g) after 2 h, rising to 56.90% (0.569 mg/g) at 4 h.

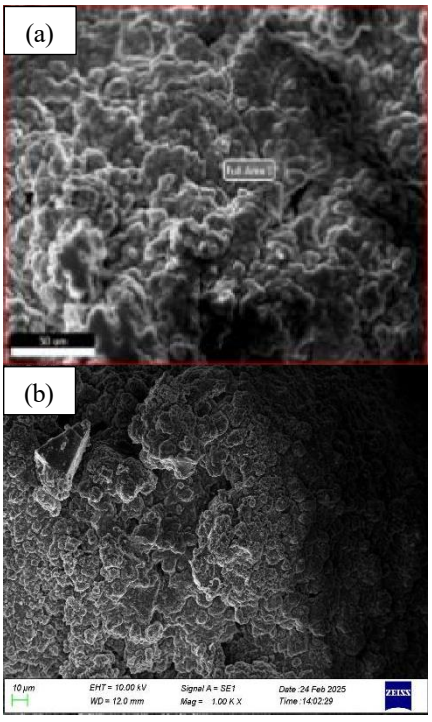


Fig. 2. SEM images of synthesized FeOOH: (a) FeOOH surface structure (b) High resolution 15KX SEM image and

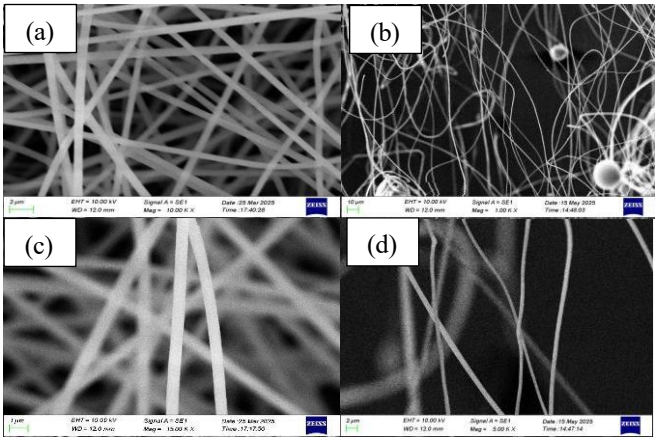


Fig. 2. SEM images of developed nanomembranes: (a)10% PAN nanomembrane at 10KX magnification (b)PAN/FeOOH/MMT nanomembrane at 1KX magnification (c)PAN fibers at 15 KX magnification (d)PAN/FeOOH/MMT nanomembrane at 5KX magnification

TABLE I. ARSENATE ION ADSORPTION PEREFORMANCE OF THE NANOMEMBRANE OVER DIFFERENT CONTACT TIME

| No. | Contact time (hours) | Final Concentration (ppb) | Removal % | Adsorption Capacity (mg/g) |
|---|---|---|---|---|
| 1 | 2 | 558.514 | 44.14 | 0.441 |
| 2 | 4 | 431.041 | 56.89 | 0.569 |

### *D. Adsorption Kinetics*

The adsorption of arsenate ions onto the fabricated membrane was evaluated using the pseudo-first-order kinetic model expressed as (3):

$$\ln(q_e - q_t) = -K_t.t + \ln(q_e) \quad (3)$$

where $q_e$ and $q_t$ are the adsorption capacities at equilibrium and at time t, respectively and $K_t$ is the rate constant. The model exhibited excellent linearity ($R^2 = 0.9984$) indicating that the adsorption process is well-described by first-order kinetics. The calculated $q_e$ was 0.52 mg/g with a rate constant $K_1$ of 0.5611 $h^{-1}$.

## V. CONCLUSION

This research successfully synthesized β-FeOOH using urea and $FeCl_3$ and characterization via FTIR confirmed the presence of functional groups β-FeOOH while SEM analysis revealed nanostructured morphology with an average particle size of 300.66 nm. Adsorption studies demonstrated effective removal of $As^{5+}$ ions with uptake increasing over time and reaching notable efficiencies within hours of contact. Kinetic modeling showed that the adsorption process fits well to pseudo-first-order model. The FeOOH/MMT/PAN membrane demonstrated a notable arsenic removal capacity of 0.569 $mg \cdot g^{-1}$ under realistic conditions, highlighting its potential for practical water treatment. This project is ongoing, and future work will focus on optimizing the membrane by adjusting the ratios of FeOOH, MMT, and PAN. The goal is to enhance its efficiency in removing both the more common arsenate ($As^{5+}$) and the more challenging arsenite ($As^{3+}$) ions. While the present study highlights the potential of the developed membrane for arsenic removal further investigations under actual filtration conditions are needed to evaluate flux, permeability and rejection efficiency. Such studies would provide stronger validation of its real-world applicability.

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