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REVIEW ARTICLE

Arsenic Removal Using Ion Imprinted Polymer: Synthesis and Characterization

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ABSTRACT - Efforts to mitigate arsenic contamination have spurred the development of various remediation technologies, among which ion-imprinted polymers (IIPs) have emerged as a promising solution. IIPs are a class of functional polymer materials tailored to selectively recognize and adsorb specific ions from solution based on their molecular imprinting technique. IIP can be develop using different kinds of monomer. There were 8 potential monomers that can be used such as vinyl pyridine, allylthiourea, methyl methacrylate, methacrylic acid, acrylic acid, allylamine, 1-vinylimiadzole and styrene. In this mini review, different types of monomers used was studied based on their functional group which affect in selectivity of arsenic. The parameters study to determine the effectiveness of IIPs in removing arsenic also was discussed

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1.0 INTRODUCTION

The water plays an important role in human daily consumption such as food, drink, and hygiene use. The uses of the clean water ensure the sustainability of human health from disease. Furthermore, the rise in water consumption induces heavy metal especially arsenic contamination through normal procedure and anthropogenic behaviour of the groundwater and surface water (e.g., industrial, agricultural, mining, and traffic activities). Long-term exposure to arsenic-contaminated water can cause damage to the skin, kidneys, lungs, and bladder [1]. Along with its complicated water composition, removing arsenic is quite challenging. The oxidation state of arsenic is either "III" or "V," and it produces oxyanions. At neutral pH, the oxyanions in water are pentavalent arsenate ($H_2AsO_4^-$ or $HAsO_4^{2-}$) or three valent arsenite (H_3AsO_3) [2]. Ion imprinted polymer has excellent recognition ability. IIP is characterized by high affinity, high selectivity to target ions, low preparation cost, easy to use, reusable, easy to store and long service life. IIP is usually prepared using a reaction mixture composed of functional monomers, cross linkers, initiators, and templates. Complex formation between the monomer and the template happens during the polymerization step [3]. The complex is then encased in a cross-linking agent, which forms a three-dimensional polymer network, and the template ions are caught. The prototype ions are then leached out, leaving locations that are complementary to the template in terms of structure, scale, and contact [4]. IIP shows a promising material as an additive to the carbon which has been used conventionally at tertiary water treatment.

Arsenic pollution in water, particularly groundwater, has been identified as a serious issue with potentially disastrous consequences. For many years, toxicological and health risks have been recorded. Because it is now well recognised that arsenic in low quantities in drinking water has serious health consequences, arsenic removal methods are becoming increasingly relevant [5]. However, the aim study the implication of monomer in absorption of arsenic. By compare the ability of monomer to bind or recognize the template sorption of molecular imprinted polymer. This report covered the kinetics, characterization, and application monomer of arsenic-ion imprinted polymers (As-IIPs) made from bulk polymerization of arsenic as a template for the removal of arsenic from wastewater samples [6]. The role of the monomer structure effect on the polymer's selectivity is discussed, as well as different factors that influence the IIPs' removal or adsorption efficiencies. The objectives of this review work are 1) to describe the information on the significant of IIP in removing arsenic from water; 2) to provide different types of crosslinker, initiator, and monomer used during IIP synthesis; and 3) to provide information on common parameters used to study the IIP performance.

2.0 CONVENTIONAL REMOVAL METHODS BEING IMPLEMENTED AT WASTEWATER TREATMENT PLANT

For inorganic pollutants many heavy metals will not be subject to microbial or chemical oxidation for inorganic contaminants in the atmosphere, meaning that the overall accumulation and ecotoxicology will last for a long time. At wastewater treatment plant (WWTP), conventional treatment methods include chemical precipitation, coagulation/co-precipitation, membrane filtration, ion exchange, and carbon adsorption [7]. From Figure 1 stated coagulation and flocculation, adsorption, ion exchange and filtration membrane are also processes. Arsenic removal also includes alternative approaches such as ozone degradation, biomedicine and electrochemical therapy [5]. Above all these methods,

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arsenic was still present at the effluent discharge. Another approach needs to be implemented to overcome this problem such as IIP.

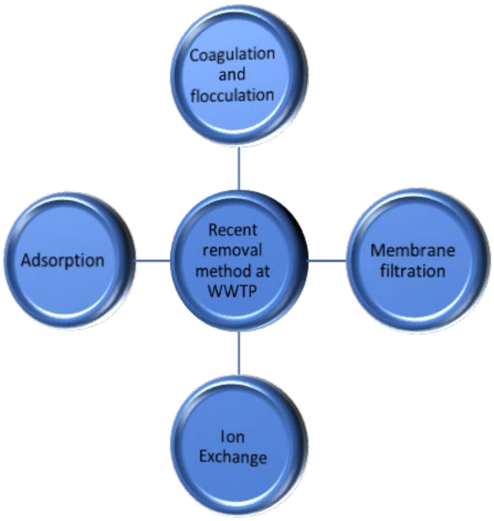


Figure 1. Various techniques used for the removal of arsenic from water

3.0 ION-IMPRINTED POLYMER (IIP)

IIPs are a class of extremely specific materials that can distinguish ions even though opposing ions from the same matrices are present. IIPs resemble molecularly imprinted polymers (MIPs), which are made up of enzymes and antibodies that act together. MIPs and IIPs vary in terms of the form of recognition material they use, which may be molecules or ions [4]. Because of their low cost and stability in various environments, molecular imprinted materials (MIP) are more selective than popular solid [8]. A lot of IIPs for toxic metals, such as nickel, cadmium, arsenic, cobalt, lead, mercury and selenium, have been studied [4]. ion-imprinted polymers exhibit excellent stability and reusability, making them cost-effective and environmentally sustainable alternatives for arsenic remediation compared to conventional sorbents. Their potential for regeneration through simple elution procedures enhances their attractiveness for large-scale applications in water treatment facilities and industrial settings. Despite these promising attributes, the development of ion-imprinted polymers for arsenic removal remains an active area of research, with ongoing efforts focused on enhancing their adsorption capacity, selectivity, and stability. Additionally, the scalability and practical feasibility of integrating IIP-based technologies into existing water treatment infrastructures warrant further investigation. In Figure 2, the fundamental of preparation of IIP was described.

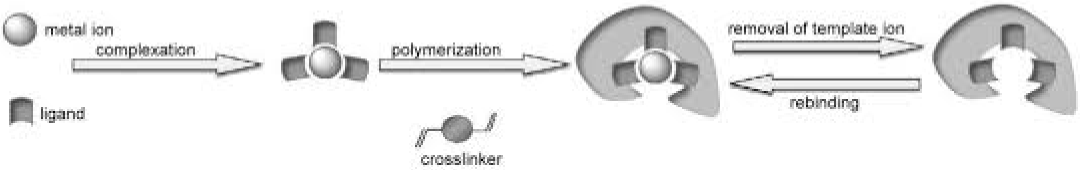


Figure 2. General steps in the ionic imprinting technique [4]

The general procedure for IIPs synthesis consists in three steps:

a) Ion (template) complexation to a polymerized ligand by mixing with monomer, initiator, and crosslinker
b) Polymerization of this complex for about 24 hours at certain temperature controlled
c) Removal of the template after polymerization via soxhlet extraction or sonicate-assisted extraction

The template, functional monomers, cross-linkers, and initiators are all important parts of the polymerization process. When the polymerization process starts, the template molecule and the functional monomer form a bond together. During this process, the monomer–template complex is made into a three-dimensional polymer matrix around the template [9]. Among them, the commonly used preparation methods include bulk polymerization, emulsion polymerization, suspension method and precipitation polymerization. Organic IIPs are generally synthesised using free-radical polymerization, except for a few instances of IIPs generated via poly-condensation. Bulk polymerization produces monolithic IIPs, whereas heterogeneous (suspension or emulsion) or homogeneous (precipitation) polymerization produces well-defined IIP particles.

4.0 PARAMETER STUDY

4.1 Pre-Polymerization study

The pre-polymerization stage represents a critical aspect of IIP synthesis, involving the formation of a complex between the target ion (template), functional monomers, cross-linkers, and initiators. This phase is characterized by the delicate balance between the stoichiometry of the components, the choice of solvent, temperature, and reaction kinetics, all of which influence the imprinting process and the final polymer properties. Pre-polymerization investigations are a collection of tests carried out prior to polymerization to confirm that the template-monomer adduct is stable and to investigate the influence of various physicochemical factors. In most cases, a significant difference can be noticed between both spectra that can give useful information about information of any bonds besides to their strength and stability [10]. Commercial and synthetic monomer in remove arsenic in water has been use such as vinyl pyridine, allylthiourea, methyl methacrylate, methacrylic acid, acrylic acid, allylamine, 1-vinylimidazole and styrene. The interaction between monomer and template contribute in reaction mechanisms information.

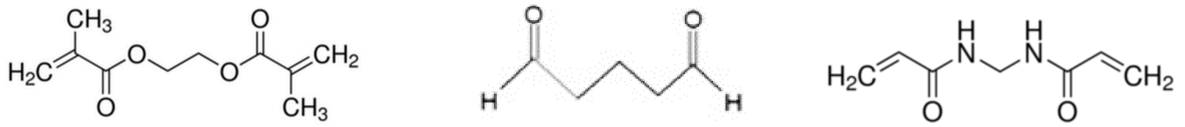
In recent years, significant advancements have been made in the pre-polymerization study of IIPs, driven by the need for more efficient and sustainable ion recognition materials. Novel approaches, such as molecular modeling, combinatorial synthesis, and template engineering, have expanded the toolkit available for designing and optimizing IIPs with enhanced performance characteristics. Moreover, the integration of advanced characterization techniques, including spectroscopic methods, surface analysis, and computational modeling, has enabled a deeper understanding of the molecular interactions and structural features governing the imprinting process. This knowledge has paved the way for the rational design of IIPs with improved recognition properties and stability under diverse environmental conditions. Despite these advancements, several challenges remain in the pre-polymerization study of IIPs, including the need for standardization of protocols, reproducibility of results, and scalability of synthesis methods for industrial applications. Additionally, the exploration of alternative template removal strategies and sustainable monomer choices represents an ongoing area of research aimed at enhancing the environmental compatibility and cost-effectiveness of IIP synthesis.

4.2 Cross linker effects in IIP synthesis

A cross-linker is utilized during the MIP polymerization process to attach functional monomers around template molecules, resulting in a very stiff cross-linked polymer even after the templates are removed. The cross-linker serves three key purposes during the imprinting process:

a) controlling the morphology of the polymer network, whether macro porous or microgel powder or gel-type,
b) stabilizing the imprinted binding site, and
c) imparting mechanical stability to the polymer network.

There are many cross-linkers that are well-suited for molecular imprinting, some of which may instantly bind with the template molecule and therefore operate as functional monomers [11]. From Figure 3**,** the common crosslinker EGDMA present the majority of works in this review. Quite alternative crosslinker are GLA and BiS.

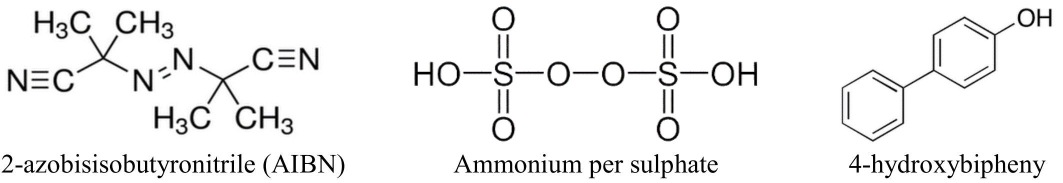


Ethylene Glycol Dimethacrylate (EGDMA) Glutaraldehyde (GLA) N, N-methylene bis acrylamide (BiS)

Figure 3. Common cross-linkers used in MIP synthesis

4.3 Initiator in MIP synthesis

The initiator oversees initiating free radical polymerization in monomers to happen. The selection of initiator is based on the stability of the template ion and its electrostatic interactions with the monomers, primarily for complex formation. The formation of radicals in the system is directly proportional to the initiator concentration, which increases the particle size of the IIPs [12]. The use of free radical polymerization is common. For MIPs/IIPs synthesis, Azo N, N'- bis isobutyronitrile (AIBN) is a popular and frequently utilized polymerization initiator [13]. Some of the initiators used are shown in Figure 4 that are used in polymerization process.



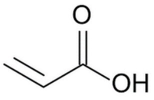
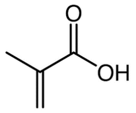
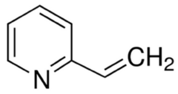
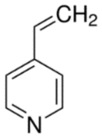
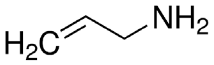
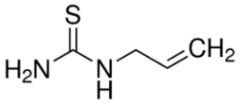
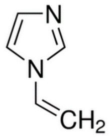
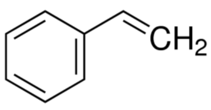
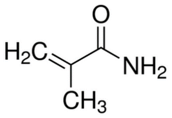
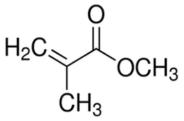
2,2-azobisisobutyronitrile (AIBN) Ammonium per sulphate 4-hydroxybipheny

Figure 4. Common initiators used in MIP synthesis

4.4 Monomer in Synthesis of Molecularly Imprinted Polymer Using Arsenic as A Template

Molecularly Imprinted Polymers (MIPs) can interact non-covalently (electrostatic interactions, hydrophobic interactions, hydrogen bonds), or make covalent bonds between the template and the monomers. So, from the Table 1 can represent eight monomer or ligand that found that can used commonly which is Vinyl Pyridine [14], Allylthiourea, Methyl Methacrylate, Methacrylic acid, Acrylic Acid, Allylamine, 1-Vinylimiadzole and Styrene. This monomer commonly used in IIP process that in remove arsenic in water. Each monomer characterizes by their type which acidic, base, and neutral.

Table 1. Types functional monomers used in non-covalent MIPs in synthesis of arsenic

Character	Chemical structure	Compound name
Acidic		Acrylic acid (AA)
		Methacrylic acid (MAA)
Base		2-Vinylpyridine(2-VP)
		4-Vinylpyridine(4-VP)
		Allylamine (ALA)
		Allylthiourea (AT)
		1-vinylimidazole (1-VI)
Neutral		Styrene (ST)
		Methacrylamide (MAAM)
		Methylmethacrylate (MMA)

4.5 Adsorption Isotherm

Langmuir (1) and Freundlich (2) isotherm models were implemented to explain the adsorption of the analyte with the surface of the adsorbent. This model allows for the comparison of the maximum adsorption capacity, $Q_e$max. Various adsorption isotherm models, such as Langmuir and Freundlich, were used to assess the nature of metal ion adsorption toward gel particles. The Langmuir model implies monolayer adsorption with a homogeneous surface and equal affinity for adsorbate molecules at active sites. To assess the data, the linear version of the Langmuir adsorption isotherm from Eq. 1 given.

$$Q_e = \frac{K_L Q_m C_e}{1 + K_L C_e} \text{a} \tag{1}$$

$$Q_e = K_F C_e^{\frac{1}{n}} \tag{2}$$

To account for adsorbent surface roughness and the multi-layered adsorption process, another model known as the Freundlich adsorption isotherm model was used. This model depicts the adsorption of metal ions on a heterogeneous surface. Eq. 2 is the linear version of the Freundlich isotherm model [15]. Q_e and C_e are the adsorption quantity and concentration of template at equilibrium state, respectively. Q_m (mg/g) is the maximum amount of adsorption. K_L (L/mg) and K_F (mg/g) are the Langmuir and Freundlich adsorption isotherm constants. Langmuir and Freundlich model linear fitting to the experimental data, respectively. The Langmuir mostly model fitting correlation coefficients (R^2) for linearity close to 1.

4.6 Kinetic Study and Models

From the adsorption capacity study, kinetic study was identified based on Lagergren pseudo Lagergren 1st order (Eq. 3) and pseudo 2nd order (Eq. 4) linearized models. To understand well the mechanism of adsorption, the Lagergren pseudo 1st order and pseudo 2nd order linearized models has been introduced many years ago. The formulae as follows:

$$\log\left(Q_e - Q_t\right) = \log Q_e - \frac{k_1 t}{2.303} \tag{3}$$

$$\frac{t}{Q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{Q_e} t \tag{4}$$

- $K_{1,\text{ ads}}$ Lagergren rate constant for first order biosorption (min^{-1})
- K_2 second order rate constant (g μg^{-1} min^{-1})
- Q_t amount of adsorbate adsorbed at time t
- q_e amount of adsorbate adsorbed at equilibrium

The validity of each model can be checked by comparing the R_2 values, and the adsorption of phosphate can be well fitted by the pseudo-second order mode. The pseudo first-order and pseudo second-order equations are shown in supporting information [16].

4.7 Comparison of Monomer Analysis by Kinetic and Adsorption Study

From the Table 2 the synthesized adsorption kinetics of arsenic (V) by [2] stated the plotted as removal (%) versus time for composites (Alu-cryo and MIP- cryo), free particles (Alu-NPs and MIPs) and functionalised cryogel material (SH-cryo). The lower concentration range (Ce <10 mg/l) did not have as strong impacts, which might be attributed to the reduced binding capacity compared to, for example, Alu-cryo. The adsorption of arsenic by NIPs is like that of MIP, and the little difference may be attributed to the higher surface area of the NIP polymer. While for adsorption capacities (%) show that MIP-Cryo and Alu-Cryo in arsenic (V) in wastewater and synthetic water showed that the imprinted selective adsorbent, MIP-cryo, showed less decrease in adsorption compared to Alu-cryo. The results were not surprising since Alu-NP is due to the Alu-NPs have a positive surface charge, which in turn explains an existing concurrence for adsorption sites in the Alu-cryo composite. The high phosphate adsorption by Alu-cryo is probably due to its molecular similarity with the hydroxy anion for arsenic (V). As-IIP according Mafu et al., Langmuir and Freundlich plots generated, it can be concluded that As-IIPs prefer monolayer adsorption whereby after the exhaustion of all the adsorption sites in the homogeneous surface, no further adsorption is experienced as outlined by the principles of Langmuir isotherm. This is shown by the correlation value of 0.9698 against that of 0.9632 for Freundlich isothermal studies [17].

Adsorption of As(III) in aqueous solution by Abu Samah et al. stated percentage removal of arsenite increased with increasing of arsenite concentration until saturation point was reached at 10 mg/L .Then, percentage removal of As (III) at different pH (1–11) with initial arsenic concentration 10 mg/L show that pH 7, As(III)-IIP works as a good sorbent at high percentage of removal (90%). Hence, As (III)-IIP works at the best at neutral pH of aqueous solution. The thiols group is the main functional groups to form the Arsenite complex. As (III)-IIP also used the thiols group as main functional groups to form thioarsenic complex with arsenite [18]. Rahangdale et al. stated in Acrylamide grafted chitosan based as adsorbent show Langmuir isotherm is fit successfully. The observed decrease in the values of K_L(Langmuir equilibrium constant) and Q_L (maximum of Cd adsorbed) with elevation in the temperature indicates the exothermic nature of adsorption process. So, the maximum of Cd adsorbed stated 167 mg/g at 303 Kelvin in Langmuir Model isotherm parameter with (R^2) regression at 0.988. The adsorption process followed the pseudo-second-order kinetics. CdIIP could be reused effectively for 5 cycles. 84.3% of Cd could be recovered using CdIIP from the complex matrix of Ni-Cd battery waste [19]. Joydeb et al. stated that the adsorption isotherm using AA monomer between Freundlich, and Langmuir isotherm parameters obtained from linear and non-linear fittings for oxyanions adsorption on phosphate@ Microsphere Structure from the data given Langmuir ion-exchange mechanism is the main force for removal of the metal ions. Q_{max} for is Langmuir parameter 319.4 mg/g and Freundlich parameter k [(mg/g) $(L/mg)^{1/n}$] is 28.1. So, the fitted isotherm in Arsenic removal is Langmuir with better Regression Coefficient (R^2) 0.992 than Freundlich is 0.927. The results showed that the adsorption capacity of phosphate@MS decreased in the following order with respect to the competitive anion present in the solution: $CO_3{}^{2-}$ > $HPO_4{}^{2-}$ > $SO_4{}^{2-}$.

Sulfate caused the greatest decrease in arsenate/chromate adsorption amongst the anions, the carbonate ions had only a little effect. The arsenate showed a removal capacity of 261 mg/g for arsenate anions. It is also interesting to note that though the polyamine interaction with multivalent anion is non-specific, the MSs prepared using phosphate show selectivity towards binding / removal of arsenate [20]. For a certain period, As-IIP or NIP was suspended in a portion of standard solution with steady shaking. Tsoi et al. using among 23 competing elements, 1-vinylimidazole-based As-IIP demonstrated higher analyte identification for As ion, with a 25-fold increase in practical dynamic and static adsorption capacity range (0.048–4.925μmol g^{-1}). For static adsorption capacity, using Langmuir model e adsorption capacities of As-IIP and NIP were found to be 4.926 and 0.191 μmolg^{-1}. Ion-binding cavities created by imprinting fundamentally activated the polymer surface for broad ion absorption, but NIP interactions remained unspecific due to a lack of ion-recognition capabilities. As-IIP sorbent has a remarkable adsorption capability of up to 6 mgL^{-1}, demonstrating the material's robustness in SPE applications [21].

According to Negrea et al., adsorption capacity polymer with phosphonium pendant groups impregnated with crown ether for because of the homogeneous distribution of active sites on the surface, the Langmuir isotherm suited the experimental data better than the Freundlich isotherm. Langmuir assumes that the adsorbent's surface is homogeneous, and that the sorption energy is identical for each sorption site Using the separation factor, the main properties of the Langmuir isotherm parameters may be analyzed to estimate the affinity between the sorbate and sorbent. It can be said that the arsenic ions are adsorbed uniformly onto the surface of the investigated adsorbent. The value of separation parameter R_L provides 0.9271 for Freundlich isotherms and 0.9975 Langmuir isotherm. The adsorption kinetics was better described by pseudo-second-order kinetic model compared to pseudo-first-order model [22].

From Table 3, it can be observed that degree of fit R^2 for the pseudo-second-order model ($R^2 > 0.99$) is greater than that of the pseudo-first-order model ($R^2 \approx 0.90$). They might be caused by the overlapping of active sites with arsenic species, as well as a decrease in effective surface area, which results in the aggregation of exchange particles. Adsorption capacity increases with temperature, indicating that adsorption is endothermic. The adsorption procedure being described by Maohua et al., adsorption of As(V) and As(III) onto MIIP was studied separately. As(V) adsorption capacity enhanced with increasing As(V) concentration, however As(III) removal was unfavourable and stayed below 0.5mg/g at all starting concentrations examined. This is owing, in part, to the imprinting effect mentioned above, and in part to the fact that between pH 4-6, As(III) was predominantly present in the form of neutral H_3AsO.

Then, data was analysed using two widely known isotherms, Langmuir and Freundlich. The Langmuir isotherm model is shown to be more accurate than the Freundlich model in describing the adsorption performance of As(V) ions on MIIP. Furthermore, the difference in maximum adsorption capacity between the experiment (7.13mg/g) and the estimate (7.53mg/g) was minor [24]. For the methyl methacrylate monomer in Polymerization PMMA-gft-Alg/Fe_3O_4 nanocomposite exhibits excellent capacity for the adsorption of Pb(II) and Cu(II) from aqueous solution also stated by [25], that the maximum sorption capacity for Pb(II) and Cu(II) was found to be 15.72 and 12.39 mg g^{-1}, respectively, after single desorption. The model for adsorption isotherm tested using Langmuir, Freundlich, Sips and Temkin models, and the data were best followed by Freundlich model. It occurs Freundlich model showed a higher determination coefficient 0.998 for Pb(II) and 0.995 for Cu(II) than the Langmuir, Sips and Temkin models.

Furthermore, kinetic parameters obtained by the sorption of heavy metal ion. That the correlation coefficients R^2 for the pseudo- second-order kinetic model are 0.9999 for both Pb(II) and Cu(II) ions, respectively, that is higher than the correlation coefficient obtained for other model.it because adsorbent behaviour may involve in valence forces through sharing of electrons between transition metal cations and the PMMA-gft-Alg/Fe_3O [25]. Precipitation polymerization, 4-VP, 2-HEMA as ligand and functional monomer, EGDMA as a crosslinker, and AIBN as an initiator in the methanol solvent were used to make As-IP. According [26], the sorption of IIPs is fast and follows the Langmuir isotherm mode R2 value of Langmuir isotherm was 0.992 sorption capability of As-IP was 106.3 mg/g. Pseudo-second-order kinetic model. R^2 in pseudo-second order is 0.999, while the R^2 value in pseudo-first order is 0.952. At pH 6.0, the highest sorption capacity was reported to be 106.3 mg/g (starting concentration of metal ion 5 mg/L). Due to the presence of specialised As^{3+} binding sites in a polymer matrix, the relative selective coefficient of all As^{3+}/coexisting ions is greater than one [26].

Table 2. Comparative evaluation of adsorbents for arsenic removal by adsorption isotherm

Adsorbent	Template	Ligand, Monomer	Cross linker	Initiator	Model of adsorption capacity	Kinetic Model	Analysis Method	Capacity (mg/g)	SPE technique	Reference
SH-cryo Alu-cryo Alu-NPs MIPs-cryo	As^{5+} arsenate	2-VP AAM ALA 5.17:1.0:2.45(ratio)	EGDMA	4-hydroxybipheny	Langmuir	-	SEM TGA	20.28± 0.8 (Alu-Cryo)	Batch	[2]
As (III)-IIP)	As^{3+} arsenite	AT	EGDMA	AIBN	Langmuir	-	FTIR ICP-MS NMR FESEM	0.0679	Batch	[18]
Acrylamide grafted chitosan based	Cd	AAM	GLA	Ammonium persulphate	Langmuir	Pseudo Second-Order	FTIR SEM ICP-OES UV-Vis	152±3	Batch	[19]
As-IIP	As^{3+}	MAA 4-VP	EGDMA	AIBN	Langmuir and Freundlich	-	SEM FT-IR	0.175	Batch	[23]

Table 3. (cont.)

As-IIP	As^{5+} arsenate	AA	EGDMA	AIBN	Langmuir		FTIR SEM TGA	0.482	Batch	[17]
Oxyanion-Binding in Bio-Inspired Nanoparticle-Assembled Hybrid Microsphere	As^{5+} arsenate	A poly (allylamine hydrochloride)	EGDMA	AIBN	Langmuir isotherms	-	SEM TG-DTA XRD	319.4 mg/g	Column	[20]
arsenic-ion imprinted polymer (As-IIP)	As^{5+} arsenate	1-VI	EGDMA	AIBN	Langmuir isotherms	Lagergren first-order	FTIR SEM	0.048–4.925μmol g^{-1}	Batch	[21]
Phosphonium pendant groups impregnated with crown ether	As^{5+} arsenate	ST	-	-	Langmuir isotherms	pseudo-second order	FTIR SEM XRD	0.0326 μg/g	Batch	[22]
Magnetic As(V)-imprinted Polymers	As^{5+} arsenate	ALA	N, N'-methylene bisacrylamide	K2S2O	Langmuir model	-	FTIR SEM	7.53mg/g	Batch	[24]
poly (methyl methacrylate)-grafted alginate/Fe_3O_4 nanocomposite	Pb(II) Cu(II)	MMA	N, N'-methylene bisacrylamide	KPS	Freundlich model	pseudo-second order	FT-IR, XRD, SEM, TEM, TGA.	15.72 and 12.39 mg g^{-1}	Batch	[25]
As-IP Polymer	As^{3+} arsenite	4-VP 2-HEMA	EGDMA	AIBN	Langmuir model	Lagergren first-order	FT-IR, XRD, SEM,	106.3 mg/g	Batch	[26]

Table 4. The findings of models at different temperature; 298K, 308K and 318K [22]

Temperature	298K	308K	318K
Model/parameters			
$q_{e,exp}$, μg/g	23.5	24.5	25
Pseudo-first order model			
$q_{e,exp}$, μg/g	12.4	12.5	15.8
k_1, 1/h	0.4062	0.4571	0.5928
R^2	0.8343	0.8513	0.8967
Pseudo-second order model			
$q_{e,exp}$, μg/g	27.5	27.7	27.9
k_1, 1/h	0.0265	0.0340	0.0418
R^2	0.9907	0.9912	0.9961

5.0 CONCLUSION

With the increasing stringency of regulations on arsenic contamination, there is a growing need to treat huge volumes of wastewater that contain low concentrations of heavy metal contaminants. This research aims to provide accurate data and a dependable initiator, crosslinker and monomer for use in IIP technology, hence enhancing the efficiency of polymerization for arsenic removal. The adsorption capacity and kinetic study can be determined using several models, such as the Langmuir Model and Freundlich Model, in adsorption isotherm analysis. The adsorbent's adsorption capacity is directly related to the quantity of active sites present on its surface. Additionally, chemisorption might operate as the rate-limiting phase that governs the entire adsorption process. Therefore, the results can be used to refer to another study to identify the appropriate monomer, crosslinker, and initiator for the polymerization of As-IIP. In addition, comparing the monomer in IIP can be used to remove As and determine the removal effectiveness. The filtrates were subsequently utilised for determining the concentration of As. As a conclusion, the As-IIP exhibits a higher removal efficiency for As(III) due to the presence of a greater number of monomers, resulting in a highly effective and cost-efficient product.

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7.0 CONFLICT OF INTEREST

The authors declare no conflicts of interest.

8.0 AUTHORS CONTRIBUTION

N. A. Samah (Conceptualization; Methodology; Formal analysis; Investigation; Visualisation; Supervision)
I. Kamal (Writing - original draft; Formal analysis; Investigation)
S. M. Kabeb (Writing - review & editing)
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