

Multi-templated Pb-Zn-Hg Ion Imprinted Polymer for the Selective and Simultaneous Removal of Toxic Metallic Ions from Wastewater

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Abstract

A multi-templated Pb-Zn-Hg ion imprinted polymer was synthesized to demonstrate the selective and simultaneous removal of the named targeted ions. Molecular Imprinting Technology was employed, guided by thermal bulk polymerization method, methacrylic acid as the functional monomer and ethylene glycol dimethylacrylate as crosslinking agent in the presence of the initiator azobisisobutyronitrile; Pb(II), Zn(II) and Hg(II) ions as template ions, and 1,10-phenanthroline as the complexing agent. Rigorous, optimal template removal method was employed. Physical and chemical properties of the sorbent were investigated using Fourier Transform Infrared Spectroscopy, X-ray Diffraction and Atomic Force Microscopy. Operational parameters: time, pH and sorbent dosage for the rebinding batch experiments were optimized and found to be 15 min, 7.5 and 666.7 mg/L respectively. Percentage recoveries of the removed targeted ions from spiked samples were: $92.14 \pm 0.16\%$, $106.09 \pm 0.17\%$ and $99.86 \pm 0.04\%$. The synthesized sorbents showed good selectivity towards the targeted metal ion by removing 90% - 98% of the templated ions as compared to 58% - 62% of the competitive ions.

Keywords: heavy metals, ion imprinting, multi-templating, selectivity, sorbent, wastewater

1. Introduction

The use of treated wastewater is widely employed to compensate for the scarcity of safe and uncontaminated freshwater (Reuse, 2012). Wastewater treatment plants have been set up for cleaning and recycling wastewater for use in irrigation, animal consumption, groundwater recharge, non-potable reuse and domestic activities. However, the existence of toxic heavy metal ions in the wastewater pose a health hazard to animals and the environment (Cormier & Muller, 2000). Agricultural activities, sewage, industrial disposal and even natural disasters have constantly increased the amount of heavy metal ions in the aquatic ecosystems (Javed & Usmani, 2013). Generally, heavy metals are stable under ambient environmental conditions. They are not easily degradable (Chopra, Pathak, & Prasad, 2009), thus, their tendency to accumulate in the environment, and eventually end up in the human food chain. Although the human body needs some of these metal ions in trace quantities, their existence in high concentrations can result in serious human ailments (Rammika, Darko, & Torto, 2011). Henceforth, it is essential that the concentration of heavy metal ions in recycled wastewater be considerably reduced to acceptable levels as set out by international monitoring agencies such as the World Health Organization (WHO) (Javed & Usmani, 2013), Food and Agriculture Organization (FAO) (Elnabris, Muzyed, & El-Ashgar, 2013) and Environment Protection Agency standard (EPA) (Barakat, 2011).

In the past, several methods such as membrane assisted liquid extraction (MALE) (Jönsson, Mathiasson, Chimuka, & Cukrowska, n.d.) liquid-liquid extraction (L. Chen et al., 2009), membrane filtration (Fu & Wang, 2011); ion exchange (Möller, Crescenzi, & Nilsson, 2004), adsorption (Li et al., 2012) have been employed to remove toxic heavy metal ions from aquatic environments. However, these methods have been reported to have some challenges such as high cost (Chee, Wong, & Lee, 1996), require a trained personnel (Ahmad, Mohd, & Universiti, 2015), high energy consumption (Perdew, Burke, & Ernzerhof, 1996), use of large quantities of chemicals (Atassi, Tally, & Ismail, 2008), poor removal rate to meet the pollution control limits (Piletska et al., 2008), low mechanical strength of adsorbents (Özcan, Sahin, & Sahin, 2008), weak hydrothermal stability (Firouzzare & Wang, 2012), poor selectivity (O'Mahony, Molinelli, Nolan, Smyth, & Mizaikoff, 2005) and time consuming (Mijangos et al., 2006).

In recent years, better extraction methods such as membrane extraction (Hashemi & Zanganeh, 2016), use of bio adsorbents (Xu, Zhu, & Chen, 2004), use of solid-phase polymeric extraction sorbents (SPE sorbents) (Yang et al., 2009)

or their combinations have been employed to eliminate the challenges of previous traditional methods (C.-Y. Chen, Chang, & Wang, 2009)(Branger, Meouche, & Margaillan, 2013). These methods exhibit numerous advantages such as high removal factors, high retention capacity, flexibility, robustness, speed and simplicity. However, these extraction methods are challenged as they are non-selective in removing/reducing the unwanted toxic metal ions to acceptable levels, thus other substances which may be needed to remain in the wastewater or pose no threat are co-extracted (Huang, Huang, & Wang, 2011). Therefore, the development of new extraction materials, especially new adsorbents with high specific recognition sites and high affinity for a particular metal ion(s) is of great interest. Ion imprinted polymers (IIPs) are an example of such materials with high recognition sites and affinity for a targeted ion(s). Ion-imprinted polymers are nano-porous polymeric materials which on leaching the imprint ion can selectively rebind, sense or transport the target analyte in the presence of closely related inorganic ions.

In this work, a model, novel multi-templated IIP aimed at selectively removing several ions at the same time will be developed. It is common for IIPs to be developed for the extraction of one metal ion per time but this approach will not be that useful in most cases as waste water usually has contamination from several metal ions hence our proposal of developing a multi-templated IIP to simultaneously remove multiple toxic ions from waste water.

2. Materials and Methods

2.1 Instrumentation

A Varian 220FS Atomic Absorption spectrometer (California, USA) operated with air/acetylene was used for determination of metal ions. A Bruker D8 Advance Power X-ray Diffractometer purchased from Bruker (Bremen, Germany) was used for characterization and identification of polycrystalline phases of washed and unwashed IIPs and NIPs. A Nicolet iS10 FTIR spectrometer purchased from Thermo Scientific (South Africa) was used for characterization of the washed and unwashed IIPs as well as the NIPs. A Dimension edge with ScanAsyst® Atomic Force Microscope (AFM) purchased from Bruker (Bremen, Germany) was used for determining the morphology of the washed and unwashed IIPs.

2.2 Materials and Reagents

Ultra-pure water, of 18.0 MΩ/cm resistivity, Type I, was prepared by a Millipore-Q purification system from Merck, (Darmstadt, Germany) and was used to prepare all solutions. Reagents used were: analytical grade HCl (32%) purchased from ACE (Johannesburg, South Africa), analytical grade Acetonitrile (99.9%), Lead Nitrate Hexahydrate (99%), Nickel (II) Nitrate Hexahydrate (97.0%), Copper (II) Nitrate Trihydrate ($\geq 98.0\%$), Zinc(II) sulfate heptahydrate (97%) purchased from Sigma-Aldrich (Johannesburg, South Africa), analytical grade Ethanol (99.9%) purchased from Skylabs (Johannesburg, South Africa), analytical grade Methacrylic acid, MAA (99%), α,α' -Azobisisobutyronitrile, AIBN (98%), analytical grade HNO₃ (50%), 1,10-Phenanthroline (99%), analytical grade Ethylene glycol dimethacrylate (98%), ethylenediaminetetraacetic acid, EDTA (98%), Mercuric Nitrate monohydrate (95%) purchased from Sigma-Aldrich (Johannesburg, South Africa), Apparatus/glassware used during the entire experiment were purchased from Pyrex (Frankfurt, Germany). Elemental standard solutions used (1000ppm – Fe, Ni, Cu, Pb, Zn & Hg) and NaOH (97%) pellets were purchased from Rochelle Chemicals (Johannesburg, South Africa). Mortar and pestle were purchased from Pyrex (Frankfurt, Germany). A 0.45 μm pore sized Whatman filter papers (Hardened Ashless Circles 45 mm) that was used for all filtering processes were purchased from Sigma-Adrich (Johannesburg, South Africa), the pH meter was purchased from Crison (Liverpool, England), Thermo Scientific laboratory oven was purchased from Thermo Fisher Scientific Inc. (New York, USA), Benchmark hot plate was purchased from Benchmark Scientific (New Jersey, USA), micropipette from BOECO (Berlin, Germany), a Tyler analytical balance from Mettler Toledo, A.W.S. Tyler™ (Johannesburg, South Africa), and a Laval stainless steel sieve (5 – 20 μm) was purchased from Laval Lab (Minnesota, USA) was used for sieving the IIPs and NIPs.

2.3 Synthesis of Multi-templated Ion Imprinted Polymer and Non-imprinted Polymer

The multi-templated Pb-Zn-Hg IIP powder was synthesized in two steps: i) preparation of the binary complex of lead, zinc and mercury with MAA as the ligand and 1, 10-Phenanthroline as the complexing agent; ii) copolymerizing the complexes with EDGMA as the crosslinking monomer, and a mixture of ethanol/acetonitrile employed as the porogen. The complex of lead (II), zinc (II) and mercury (II) with the ligand was prepared with a mixture of 1 mmol of HgN₂O₆ · H₂O, 1 mmol of Pb(NO₃)₂ · 6H₂O, 1 mmol of ZnSO₄ · 7H₂O, 1.082 g of 1,10-Phenanthroline and 1.0179 mL of MAA dissolved in 35 mL of ethanol/acetonitrile (2:1 v/v) and stirred at 900 rpm for 30 min. 11.313 mL EGDMA and 0.24 g AIBN were added and mixed with the binary complex solution. The mixture was then put in a 100 mL round-bottom flask, sealed after being sonicated for 15 min to degas it. The polymerization was then initiated, and preceded at 60 °C for 24 h under continuous stirring at 600 rpm until the polymeric monolith was formed. The obtained polymer monolith was ground in a mortar and dried in a hot air oven at 60 °C for 3 h. The dry, polymer powder was sieved to get particles smaller than 10 μm . Unreacted materials were removed by employing optimized template removal

procedures. Non-imprinted polymer particles were synthesized in the same way except that the inclusion of Pb (II), Zn (II) and Hg (II) as print ions was skipped.

2.4 Optimal Template Removal

The lead (II), zinc (II) and mercury (II) ions and other unreacted materials were exhaustively removed from the unwashed polymer powder in three steps: i) the unreacted materials were totally removed by refluxing the polymer powder with 40 mL of ultra-pure water for a total of 9 h of 3 h cycles. At the end of every 3 h cycle the solid IIP powder was recovered by centrifugation and dried in a hot air oven for 6 h; ii) The dry polymer powder was refluxed at 60 °C with a solution mixture of a 1:1 volumetric ratio of 1.0 M HCl (32%) and ethylenediaminetetraacetic acid (EDTA) for a total of 20 h of 5 h cycles. At the end of every 4 h cycle the solid IIP powder was recovered by centrifugation and dried in a hot air oven for 6 h, iii) Finally, the dry IIP powder was refluxed at 60 °C with 10.0 M HCl (32%) for a total of 6 h of 2 h cycles (applying same routines as in step iii). Steps II and III were specifically employed to leach out the template ions. At every step and cycle, the metal ions intended to be removed, were determined by AAS in the supernatant washing solutions. The last three supernatant contained no presence of the imprinted ions; thus, marking the completeness of the templates (print ions) removal. The three general steps resulted in a total of 77 h for optimal template removal. Furthermore, XRD was applied on the washed IIP powder to confirm the absence of the template ions.

2.5 Characterization of the Imprinted Polymer and Non-imprinted Polymer

2.5.1 X-Ray Diffractometer Analysis

A powder D8 Advance Powder X-Ray Diffractometer (XRD) analysis was employed to investigate the physical properties as it relates to the crystallinity of the washed and unwashed IIP particles and also to investigate the optimal template removal procedures applied during template removal. The XRD was operated with Cu K α emission ($\lambda = 1.54105\text{\AA}$, 40 kV, 40 mA per sec) and with high efficiency linear detector of Lynx Eye type. The scanning mode used was coupled 2θ on the scanning range $10^\circ - 120^\circ$ values. The crystallite size of the sample was calculated by Deby-Scherrer method.

2.5.2 Atomic Force Microscopic Analysis

In order to determine the size and the morphology of the washed, unwashed IIP and the NIP, scans of each were taken in tapping mode using a Dimension edge with ScanAsyst® Atomic Force Microscope (AFM) with a piezo scanner that was set to scan the films at 1–1.5 lines/s. Commercially available tapping mode tips (TAP300- 10, Silicon AFM probes) with a resonant frequency in the range of 260–410 kHz were used as cantilevers. All AFM micrographs were filtered and analyzed using the Gwyddion Software (Ver. 2.19).

2.6 Optimization Studies

2.6.1 Optimization of Time

30 mg of the IIP particles was weighed and put into each of 7 conical flasks; 25 ml of the 5 mg/l standard mixture solution was added to each flask. The mixture was shaken for 2 h but after some interval minutes, the mixture was filtered using Whatman 45 mm \varnothing filter paper and the filtrate was analyzed with AAS.

2.6.2 Optimization of pH

To optimize for pH, 25 ml of the 5 mg/l standard mixture solution was put into 7 different 100 ml conical flasks and pH was adjusted to of 2, 4, 6.5, 7.5, 8, 9, 10 using 0.1 M HCl and 0.1 M NaOH. 30 mg of IIP particles was added into each flask (Zhu et al. 2009). The mixture was shaken for 15 min then filtered with Whatman 45 mm \varnothing filter paper and put in a 50ml volumetric flask, then later analyzed with AAS.

2.6.3 Optimization of Sorbent Dosage

5 mg, 10 mg, 20 mg, 30 mg, 40 mg and 50 mg of the IIPs sorbent was weighed and put into different conical flasks. Then 25 ml of the 5 mg/l standard mixture solution at pH 7.5 was added into each flask (Zolgharnein et al. 2011). The mixture was shaken for optimum time (15 min), filtered with Whatman 45 mm \varnothing filter paper and analyzed with AAS.

2.7 Binding Studies

In order to investigate the imprinting effect of the IIP sorbents, 20 mg of the imprinted sorbent was added to a 25 ml of the 5 mg/l standard mixture solution at optimal conditions and shaken for optimal time filtered with Whatman 45 mm \varnothing filter paper and analyzed with AAS.

Selectivity of both the IIPs and NIPs were investigated by competitive adsorption of Fe(II), Ni(II), Cu(II), Pb(II), Zn(II) and Hg(II) from their mixture. 20 mg of the IIP sorbent was added to a 25 ml of the 5 mg/l standard mixture solution containing all of the ions (in a 100 ml conical flask) and another one with the non-imprinted sorbent (in another 100 ml

conical flask) at optimal conditions and shaken for optimal time filtered with Whatman 45 mm Ø filter paper and analysed with AAS.

2.8 Sampling and Storage

Water sample was obtained from Gaborone waste water treatment plant, Gaborone, Botswana. At the treatment plant five sampling sites were identified (Inlet point, primary settling, secondary settling point, aeration point and effluent point). Random sampling technique was employed to obtain the sample from the sampling sites. Grab sampling technique was employed to obtain the water samples from individual sampling sites. Each sample was put in labelled brown glass bottle and acidified to $\text{pH} < 2$ in order to prevent further microbial activity which could eventually affect the composition of metal in the sample. Also acidifying the samples ensured that undissolved metals that remained after sampling did not undergo further reaction such as precipitating or oxidizing. The water sample was placed in the cold room at $4\text{ }^{\circ}\text{C}$; this was to help immobilize any microbial activity or degradation of the sample. Samples were stored until analysis.

2.9 Determination of Metallic Ions in the Wastewater Sample

50 ml of waste water from inlet, primary, secondary, aeration and effluent points were pulled in five 250 ml conical flasks. 1 ml of 55 % HNO_3 and 0.5 ml of 37 % HCl was added to each flask. The mixture was heated until the initial volume reduced to approximately 0.5 ml. The mixture was then filtered into a 50 ml volumetric flask and deionized water added to the mark. The sample was then analyzed with AAS to determine the concentration of three metals (Pb, Zn, & Hg). Table 1 reflects the concentrations of Pb, Zn and Hg ions after analysis.

Table 1. Concentration of Pb, Zn, and Hg in the wastewater sample

Concentrations (mg/l)			
Waste Water			
Conc.	Pb	Zn	Hg
	3.3610 ± 0.0202	4.2511 ± 0.0103	4.0855 ± 0.0049

2.10 Methods of Validation

2.10.1 Linearity

The linearity of the analytical method was evaluated by analysing standards solutions spiked at different concentrations ranging from 0.1 mg/l to 10.0 mg/l using AAS and the linearity of the calibration curves are shown in Table 2.

Table 2. Calibrations values

Metals	Regression Eqn.	R²
<i>Pb</i>	$0.0241x + 0.0013$	0.9996
<i>Zn</i>	$y=0.1045 + 0.0511$	0.9579
<i>Hg</i>	$y= 0.1053x + 0.0059$	0.9995

2.10.2 Detection Limits

The limit of detection (LODs) and Limit of quantification (LOQs) were both investigated. The LODs were calculated as three times standard deviation of ten replicates of blank water samples spiked with low concentration of analytes (2ppm). While LOQs were calculates as ten times of standard deviation.

Method detection limits (MDL) was determined by analysing three replicates of real water samples spiked with low concentration of analytes and was calculated using US EPA Method 40 formula:

$$MDL = t(n-1, 1-\alpha=0.99) \times SD \quad (1)$$

Where:

$T(n-1, 1-\alpha=0.99)$ is the student's t value appropriate for 99% confidence level

($t = 3.14$ at 99%, 6 degree of freedom.)

n is the number of replicates measured

SD is the standard deviation.

The limit of detection and quantification of the selected metals using FAAS is shown on Table 3.

Table 3. Limit of detection and quantification of selected ions

Metal	IDL (mg/l)	IQL (mg/l)	MDL (mg/l)
Pb	0.9368 ± 0.14	0.11079 ± 0.14	0.031 ± 0.01
Zn	0.0331 ± 0.007	0.0823 ± 0.007	0.015 ± 0.005
Hg	0.0544 ± 0.005	0.0864 ± 0.005	0.015 ± 0.005

2.10.3 Recovery Studies

In order to do method validation, the water samples were spiked with a solution of 2ppm concentration of the selected metals (Hg, Zn and Pb). The analyses were done in triplicate using FAAS. Table 4 shows the percentage recoveries for the selected metallic ions. Using the below equation, percentage recoveries were obtained for each of the metallic ions.

$$\%Recovery = \frac{\text{Concentration of ions in spiked sample} - \text{concentration of ions in unspiked sample}}{\text{concentration of ions in added to the spiked sample}} \times 100\% \quad (3)$$

Table 4. Percentage recoveries of metallic ions

	Spiked	Unspiked	Difference	Recoveries
Hg	2.007	0.0145	1.9925	99.625
Pb	2.115714286	0.265	1.850714286	92.535714
Zn	2.0348	0.11575	1.91905	95.9525

3. Results and Discussions

3.1 Synthesis and Characterization of Multi-templated Ion Imprinted Polymer

A monolithic whitish lump was formed, after which it was removed from the round bottom flask, ground and placed in a hot air oven for 3 h. After drying the polymers were washed in several steps as previously indicated, along with optimal template and unreacted materials were removed.

3.1.1 XRD Analysis

The XRD patterns of the washed (after optimal removal of lead, zinc and mercury ions) IIPs powder reflects the total and optimal removal of the templated ions, unlike the unwashed which indicated the presence of elemental lead, zinc and mercury as shown in Fig 1.

The crystalline phase of the washed IIPs, as evident by the XRD, has absorption properties due to its mesoporosity and selective active sites, which are necessary in sorption activities. A mesoporous structure promotes percolation by increasing the permeability; as such, a significant amount of reactant can be diffused well into the particle interior to reach the active sites.

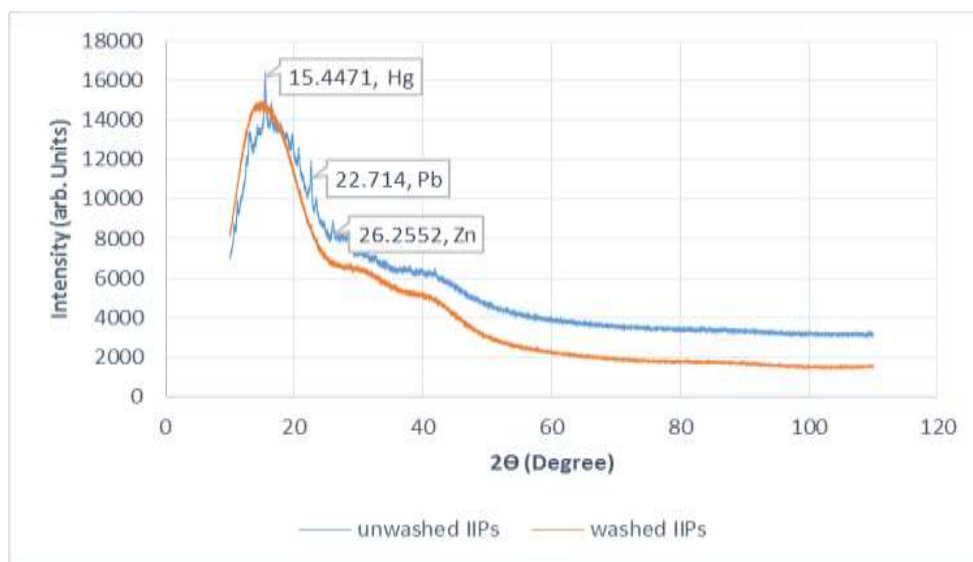


Figure 1. XRD spectra for the washed and unwashed IIP

3.1.2 Atomic Force Microscopic Analysis

The AFM image obtained revealed the sponginess of the sorbent, which reflects its absorptive nature and the surface roughness and its mesoporosity is also revealed. The AFM analysis also provided the physical properties of the sorbents as shown in Table 5.

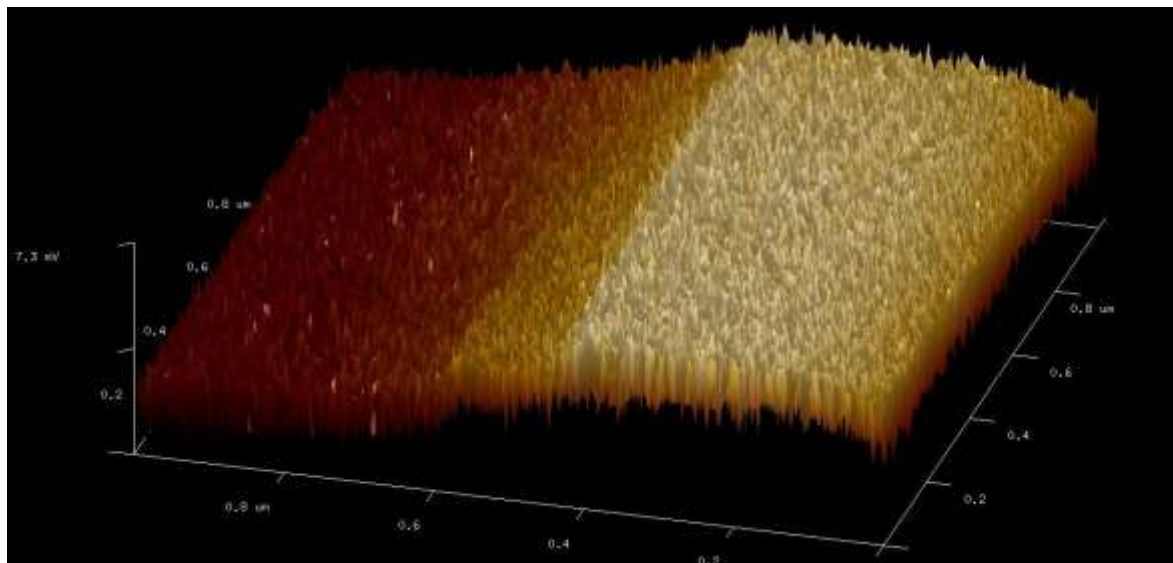


Figure 2. 3D AFM image of the Washed IIP

Table 5. IIPs Physical properties based on AFM analysis

Parameters	Minimum	Maximum	Mean/Average
Total Count	1844.000	1844.000	1844.000
Density of peaks at the surface of an IIP particle.	1844.000 (/μm ³)	1844.000 (/μm ³)	1844.000 (/μm ³)
Height	3.903 (mV)	15.704 (mV/μm)	5.192 (mV/μm)
Surface Area	15.259 (μm ³)	14892.578 (μm ³)	43.832 (μm ³)
Diameter an IIP particle	4.408 (μm)	137.702 (μm)	5.723 (μm)

3.2 Optimization Studies

The removal efficiency was determined by computing the percentage removal using the formular in equation (1) below

$$\% \text{ Removal} = \frac{C_i - C_f}{C_i} \times 100 \tag{2}$$

where

C_i – is the initial concentration before sorbent is added

C_f – is the concentration after removal of metal ion

3.2.1 Optimal Time

When using the IIPs the optimal removal efficiency was reached within about 15 minutes. Further increase in contact time did not show significant change. The optimum time was considered to be 15 minutes and therefore the subsequent experiments using the sorbents were performed at the optimum contact time of 15 minutes as shown in Fig. 3.

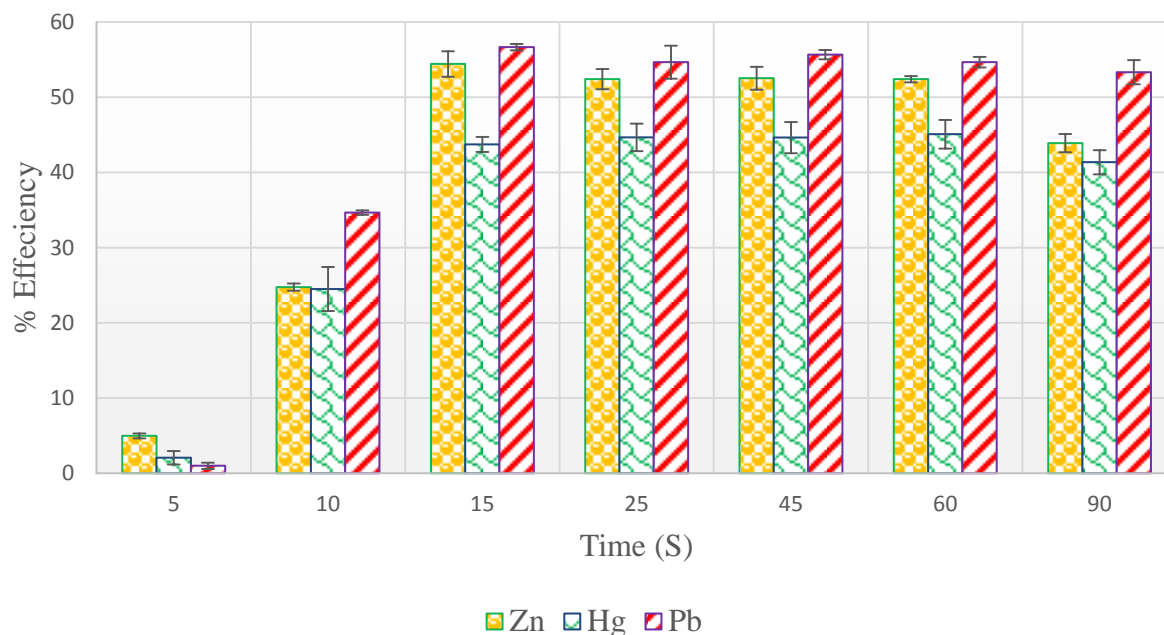


Figure 3. Percentage removal of Zn (II), Pb (II) and Hg (II) ions at optimal time

3.2.2 Optimal pH

Using the 20 mg of the sorbent, the pH was adjusted from 2 to 9.5, percentage removal increased up to pH 7.5 after which there was gradual decrease in percent removal. At low pH, the cations compete with the hydrogen ions in the solution for the binding sites and hence lower adsorption. Meanwhile, at higher pH, the surface of the adsorbent has a higher negative charge which results in higher attraction of metallic cations (Say et al. 2003). In other words, at $\text{pH} > 7.5$, precipitation of metal hydroxide is most likely to occur and also the formation of complexes. Therefore, the optimum pH was taken to be 7.5 for all metals since there was highest percentage removal before the precipitation process started. pH 7.5 was also used for all the other experiments carried out using the IIPs. Fig. 4 shows removal efficiency when the IIPs were used.

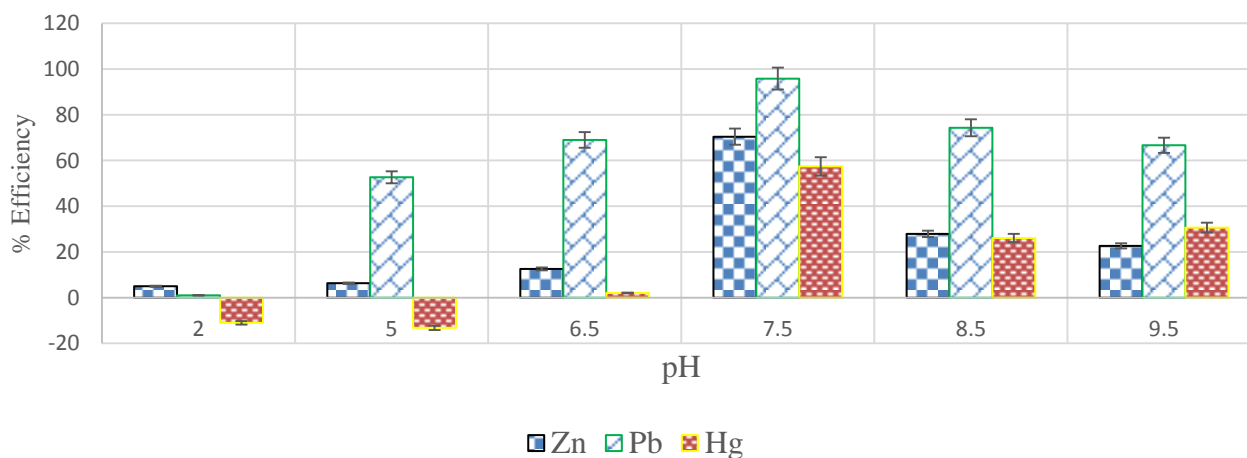


Figure 4. Percentage removal of metallic ions at optimal pH

3.2.3 Optimal Sorbent Dosage

As the sorbent dose was increased from 5 to 50 mg, the percentage removal increased. This is expected because as the sorbent amount increases, the ratio of sorbent particle to metal ion increases, hence these particles absorb more ions. As shown in Fig. 5, at 20 mg, the highest percentage removal of the metallic ions was reached, after which further increase in the sorbent dosage did not yield any significant increase. This marked the optimum sorbent dosage of the polymeric sorbent (20 mg) needed to bind maximally. Therefore, the optimal sorbent dose was recorded as 20 mg.

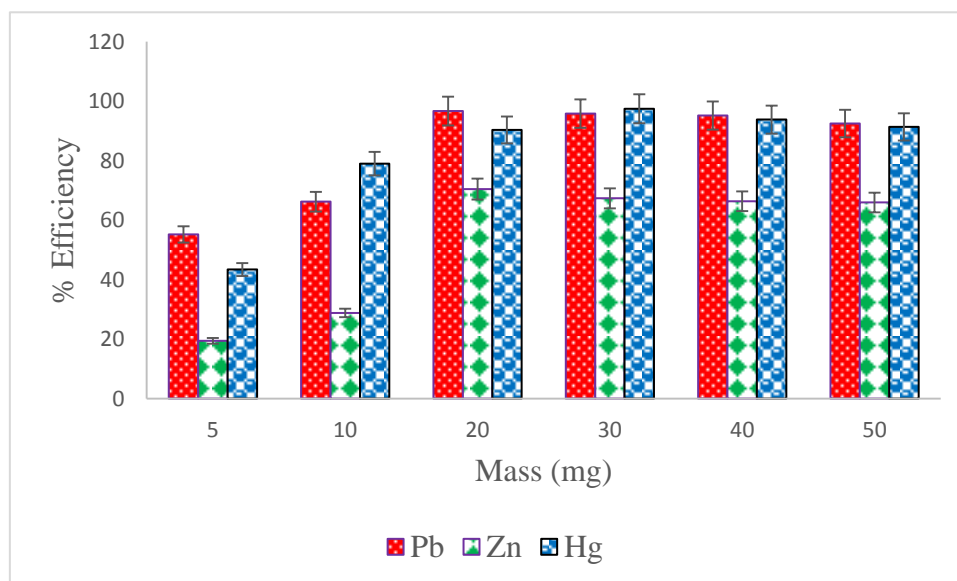


Figure 5. Percentage removal of Zn (II), Pb (II), and Hg (II) ions at optimal sorbent dose

3.3 Binding Studies

Fe (II), Cu (II) and Ni (II) were chosen as the competitor ions for selectivity studies, due to the same charge, nearly identical size (ionic radius e.g. Zn (II) – 74 pm, Ni (II) – 72 pm, Cu (II) – 69 pm). The percent removal of Zn (II), Pb (II) and Hg (II) was higher than that of Fe (II), Cu (II) and Ni (II). Also observed was the low selectivity of the NIP for the metallic ions. Fig. 6 shows the high level of selectivity of the IIPs towards the target ions (Zn (II), Pb (II) and Hg (II)). Fig. 7 shows a comparison studies between the selectivity of the IIPs and NIPs towards competitive ions.

The reason for the selectivity of the IIPs is due to the fact that the cavities imprinted by the templated ions are not suited to Fe (II), Cu (II) and Ni (II) in size, shape and spatial arrangement of action sites.

Fig. 8 shows the imprinting effect of the IIPs as it was compared to the adsorption capacity of NIPs. Under optimal conditions (pH 7.5, 15 min and 20 mg), both the IIPs and the NIP were used to remove 5 mg/l standard solution of Pb, Zn & Hg ions. Employing batch experiment, the IIPs displayed an excellent recognition selectivity and binding affinity towards Pb, Zn & Hg as compare to the NIPs. Hence proving a robust imprinting effect (Luo et al. 2011).

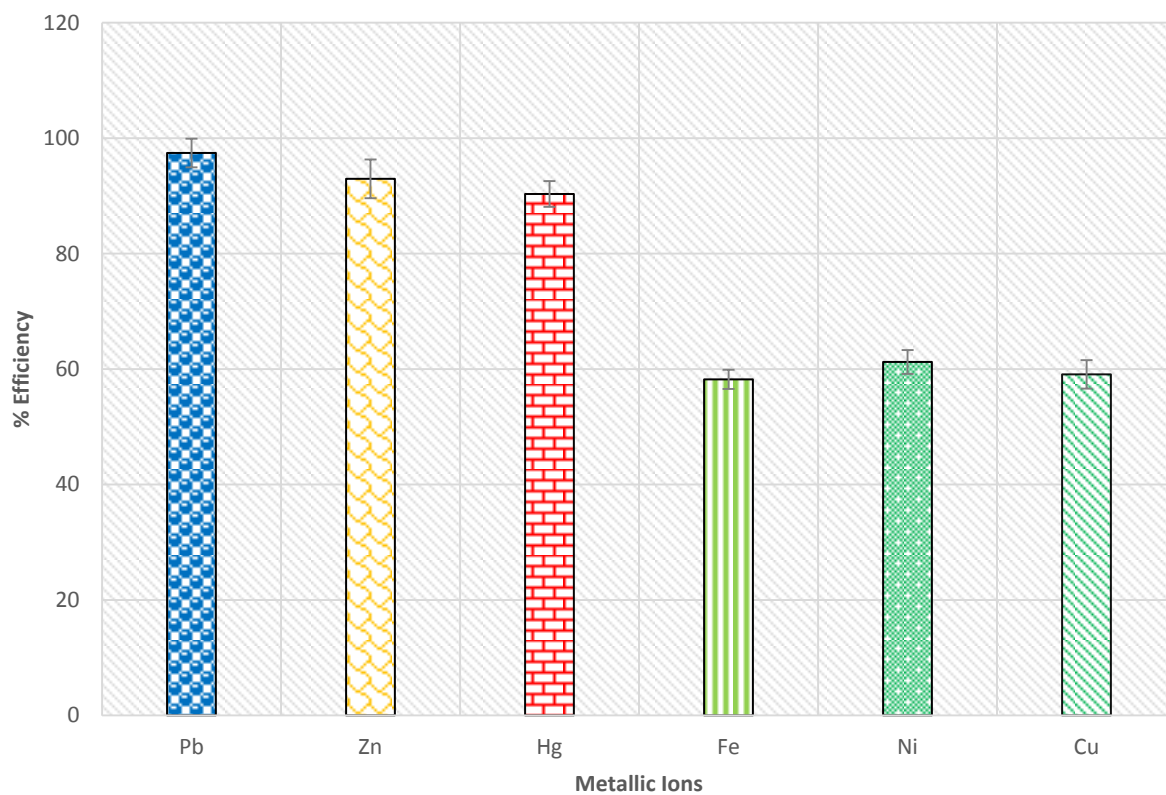


Figure 6. Selectivity of the IIP towards target ions

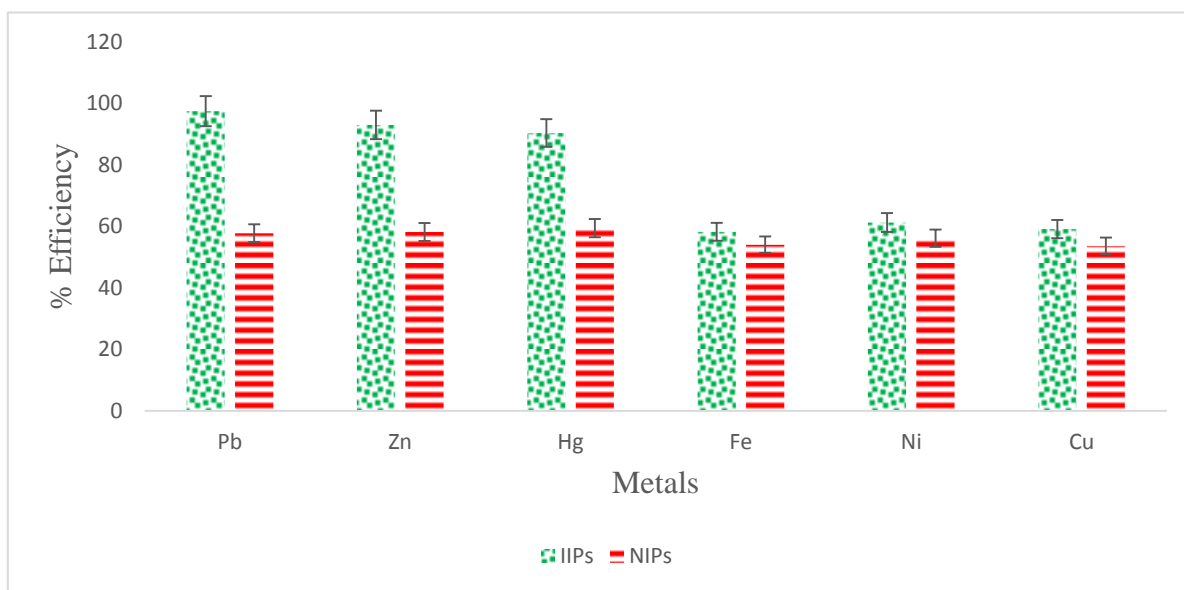


Figure 7. Comparison between the selective of the IIPs and that of the NIPs

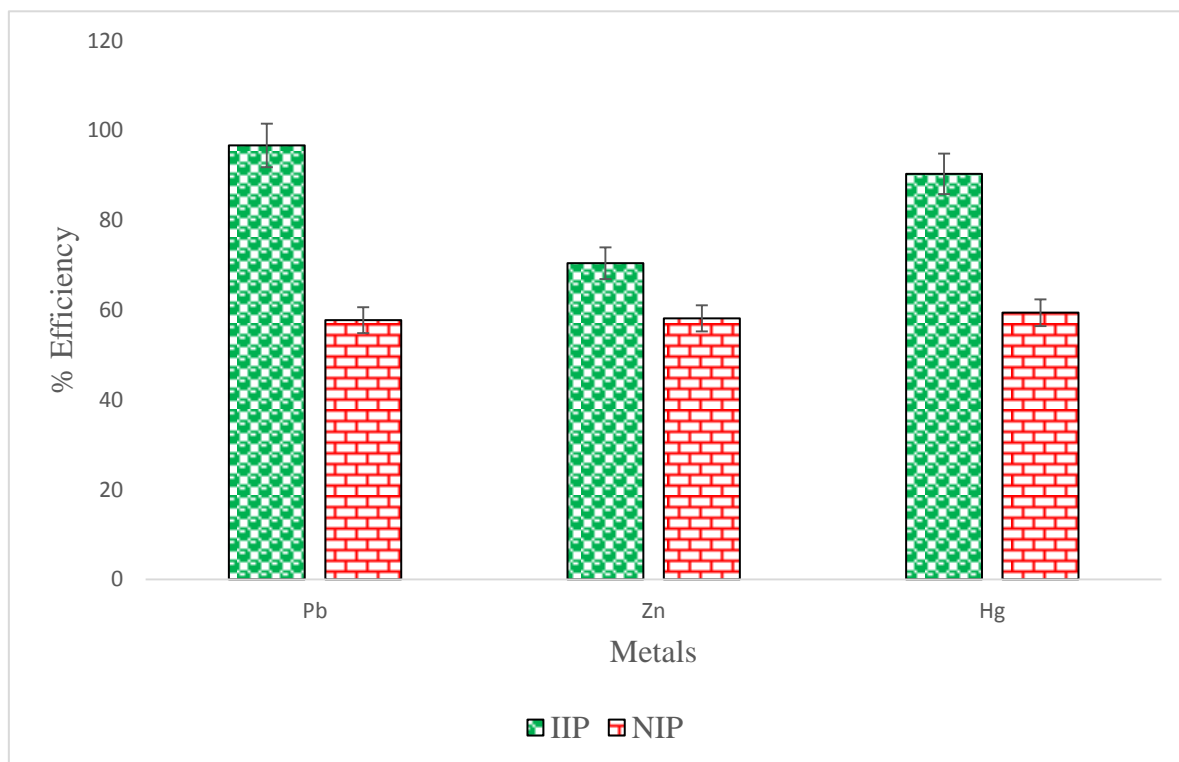


Figure 8. Percentage efficiency of the IIP and NIP

3.4 Application of Method

The efficiency, selectivity, robustness and hence relevance of the multi-templated IIPs in selective separation of metallic ions from aqueous solution was tested by selectively removing target metallic ions from the waste water sample.

The optimized parameters were applied to the water samples. The percentage removal is as shown in Fig. 9 Hg recorded a low percentage removal (90.32%) as compare to Zn (92.95%) and Pb (97.44%) with highest percentage removal, therefore Pb > Zn > Hg in terms of percentage removal.

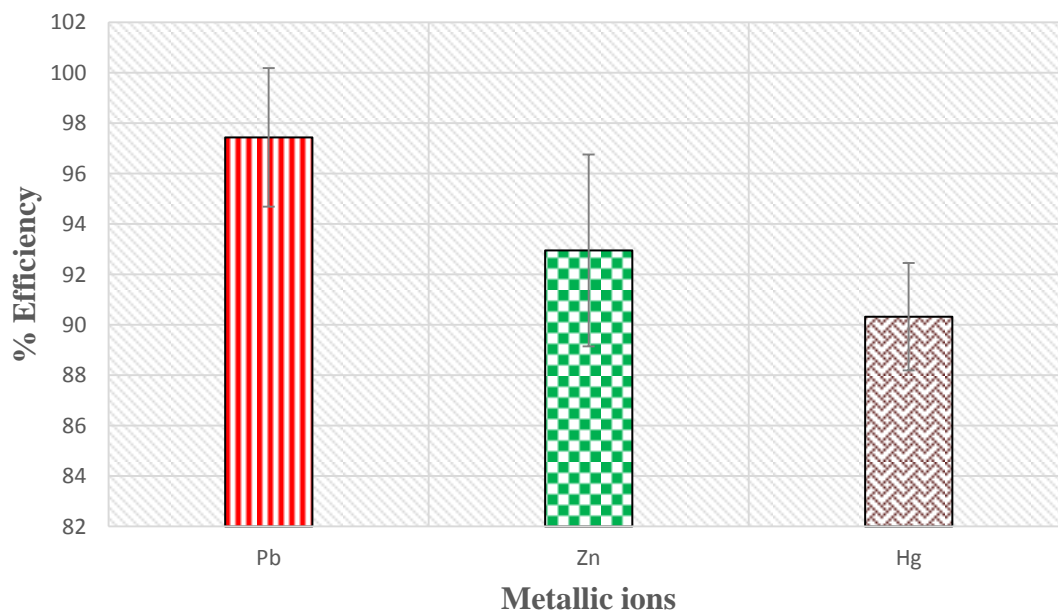


Figure 9. Efficiency of the IIP towards target ions

4. Conclusion

Multi-templated ion imprinted polymers with metallic ion recognition for Hg, Zn, and Pb ions have been prepared in this study. This polymer has been synthesized using a non-covalent bulk polymerization approach and while it has demonstrated group selectivity towards three metallic ions (Hg, Zn, and Pb); it also demonstrated the ability to differentiate between closely related structural analogues.

The multi-templated IIPs were investigated for use in metallic ion extraction applications as sorbents and it was shown to specifically recognise and retained the target.

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