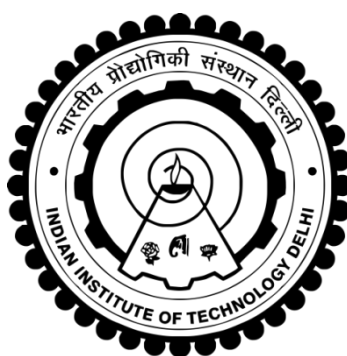


**DESIGN AND SYNTHESIS OF IMINODIACETATE-  
STYRENE BASED CHELATING POLYMERIC MATERIALS  
FOR WATER PURIFICATION**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI  
APRIL 2021**

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by

**RESHU TYAGI**

Department of Materials Science and Engineering

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**APRIL 2021**

*Dedicated to My Family*

## **CERTIFICATE**

This is to certify that the thesis entitled “**DESIGN AND SYNTHESIS OF IMINODIACETATE-STYRENE BASED CHELATING POLYMERIC MATERIALS FOR WATER PURIFICATION**” being submitted by **Ms. Reshu Tyagi** to the Indian Institute of Technology Delhi, New Delhi, for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by her. **Ms. Reshu Tyagi** has worked under my guidance and supervision and has fulfilled the requirements for the submission of her thesis, which to our knowledge has reached the requisite standard.

The results contained in this thesis are original and have not been submitted, in part or full, to any University or Institute for the award of any other degree or diploma.

**Dr. Josemon Jacob**

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## ABSTRACT

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Removal of heavy metal ion using polymeric adsorbents with chelating functionality is one of the most effective and promising technique for wastewater treatment, due to their high efficiency and ease of operation. So, there is an urgent need to develop new polymeric materials with high metal binding capacity for removal of heavy metal ions from aqueous waste. Ethylenediaminetetraacetic acid (EDTA) is a hexadentate chelating ligand capable of forming 1:1 complex with various heavy metal ions, iminodiacetic acid analogues to its half unit, offers high scope if introduced into the polymers. The selectivity of these polymers towards metal ions can be altered by changing the pH of the solution or by introduction of other functionalities in these materials. The present thesis is focused on the design and synthesis of new iminodiacetate-styrene base monomers. Monomers were further homopolymerized and copolymerized with acrylic acid in the absence and presence of crosslinking agent to generate the water-soluble homopolymers and crosslinked water-swelling polymeric gels, respectively. These materials were evaluated for their potential in wastewater treatment applications. All polymeric materials were synthesized by free radical polymerization of these monomers.

In the first Chapter, introduction and literature survey including an overview of chelating polymers and their application in wastewater treatment is presented.

The synthesis of two new styrene-based iminodiacetate functionalized monomers, their polymerization along with metal complexation studies on the synthesized water-soluble homopolymer with various heavy metal ions are reported. New styrene-based monomers, dimethyl 2,2'-((4-vinylphenyl) azanediyl)diacetate, **M1** bearing dimethyl iminodiacetate group, soluble in organic solvents and sodium 2,2'-((4-vinylphenyl)azanediyl)diacetate, **M2** bearing iminodiacetate groups, soluble in aqueous medium were designed and synthesized in good yields and characterized by NMR ( $^1\text{H}$  and  $^{13}\text{C}$ ), Fourier transform infrared (FT-IR) spectroscopy, mass spectroscopy, melting point and elemental analysis. Polymers, soluble in

organic medium were synthesized by free radical polymerization of **M1** in bulk (**P1-P9**) and solution (**P11-P14**) using BPO and AIBN initiators, respectively. Water-soluble homopolymer **P10**, bearing sodium salt of IDA as the chelating group was obtained upon base hydrolysis of **P9** with an overall yield of 77%. Free radical polymerization of **M2** in aqueous medium using APS initiator generated the water-soluble chelating homopolymer **P15**, bearing sodium salt of IDA as the chelating group in 50% yield. The solubility of water-soluble polymer was obtained as 5 mg mL<sup>-1</sup> at room temperature. The water-soluble polymer **P10** was investigated for its ability to bind various heavy metal ions by UV-vis spectroscopy and was found to efficiently sequester Cu<sup>2+</sup>, Cd<sup>2+</sup>, Zn<sup>2+</sup>, Pb<sup>2+</sup>, Ni<sup>2+</sup>, Co<sup>2+</sup>, Cr<sup>3+</sup>, Fe<sup>2+</sup> and Fe<sup>3+</sup>. The effect of pH on Cu<sup>2+</sup> binding with **P10** was studied and it showed that every two IDA bearing monomeric repeat units bind with one Cu<sup>2+</sup> ion at pH 7 suggesting that complexes analogous to EDTA are formed. Thermogravimetric analysis (TGA) showed that the synthesized water-soluble polymer possesses high thermal stability up to 400 °C. The potential for recovery and reuse of the polymer has been demonstrated with Cu<sup>2+</sup> ion. The reported results suggest that this water-soluble chelating homopolymer is an excellent material with very high potential for application in wastewater treatment.

Furthermore, two new approaches for the design and synthesis of highly porous polystyrene based resin (**IDASR**) bearing iminodiacetate functional groups in every repeat unit are reported. The first method reports a two-step process consisting of free radical polymerization of monomer **M1** with N,N'-methylenebisacrylamide as crosslinker in organic medium, followed by base hydrolysis. The second method is a one-step process involving the free radical polymerization of **M2** (water-soluble) with N,N'-methylenebisacrylamide as crosslinker in aqueous medium. The physiochemical properties of the resins were characterized by FT-IR, TGA, scanning electron microscope (SEM) and equilibrium swelling value (ESV). Metal uptake capacity of water-swellaible gel **IDASR15** towards low concentrations of various

toxic heavy metal ions such as  $\text{Cu}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Co}^{3+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  were investigated from their aqueous solution by batch method and found to be 0.943–2.802  $\text{mmol g}^{-1}$ . The maximum capacity was 2.802  $\text{mmol g}^{-1}$  obtained for  $\text{Cu}^{2+}$  ion at pH 5. The potential for regeneration and reuse has been demonstrated with  $\text{Cu}^{2+}$  ion by batch and column methods. The reported results suggest that **IDASR15** is a highly efficient and porous complexing agent for commonly found toxic metal ions in aqueous streams with a high ESV of 68.55 g of water/g of **IDASR15**. It could also be reused with ~97% and ~99.5% of adsorption efficiency as determined by batch and column methods, respectively which is very promising and holds significant potential for wastewater treatment applications.

To enhance the adsorption capacity, three new porous crosslinked iminodiacetate functionalized copolymers of monomer **M1** with acrylic acid were designed. The copolymers were synthesized in two steps: in the first step, free radical copolymerization of monomer **M1** with acrylic acid (25/50/75 wt %) and N,N'-methylenebisacrylamide as crosslinker using AIBN initiator was used to generate the resin **IDAESAR**, bearing dimethyl iminodiacetate functional groups in 80–90% yield. In the second step, the methyl ester groups of **IDAESAR** were hydrolyzed in presence of NaOH to synthesize the hydrophilic gel **IDASAR**, bearing sodium salt of iminodiacetate functional groups in 80–85% yield. The resins were characterized by SEM, FT-IR, ESV and TGA. **IDASAR** showed highly porous structure with good ESV of 16–19 g of water/g of copolymer. Thermogravimetric analysis showed **IDASAR** to have good thermal stability up to 350 °C. Adsorption capacity of gels, **IDASAR25**, **IDASAR50** and **IDASAR75**, towards various toxic heavy metal ions such as  $\text{Mn}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Co}^{3+}$  and  $\text{Cr}^{3+}$  were determined from their aqueous solution by batch method and found to be 0.041–9.9635  $\text{mmol g}^{-1}$ . The maximum capacity was obtained for **IDASAR25** with  $\text{Zn}^{2+}$  ion at pH 5 and found to be 9.9635  $\text{mmol g}^{-1}$ . **IDASAR** copolymers showed the highest adsorption capacities of 9.9635, 9.3476, 7.1109, 6.1505 and 5.6225  $\text{mmol}$

$\text{g}^{-1}$  for  $\text{Zn}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Cu}^{2+}$  and  $\text{Ni}^{2+}$ , respectively. Regeneration studies of **IDASAR** were performed with HCl/NaOH by batch method and demonstrated with  $\text{Cu}^{2+}$  ion as an example. The reported results suggest that synthesized water-swelling gels are highly efficient adsorbents for commonly found toxic metal ions in aqueous streams and could also be reused with small loss in adsorption capacity.

## सार

कैलेटिंग कार्यक्षमता के साथ पॉलिमरिक एडसोर्बेंट्स का उपयोग करके भारी धातु आयन को हटाना दूषित जल के उपचार के लिए सबसे प्रभावी और आशाजनक तकनीक में से एक है, जो उनकी उच्च दक्षता और संचालन में आसानी के कारण है। तो, जलीय कचरे से भारी धातु आयनों को हटाने के लिए उच्च धातु बाध्यकारी क्षमता के साथ नए पॉलिमर पदार्थ विकसित करने की तत्काल आवश्यकता है। ईथीलीनडाइअमिनोटेट्राएसिटिकएसिड (इ डी टी ए) एक हेक्साडेंटेट कैलेटिंग लिगैंड है जो विभिन्न भारी धातु आयनों के साथ १: १ कॉम्प्लेक्स बनाने में सक्षम है, इमिनोडाइएसिटिकएसिड (आई डी ए) इसकी आधी इकाई के समान हैं, यदि पॉलिमर में पेश किया जाता है तो उच्च गुंजाइश प्रदान करता है। धातु आयनों के प्रति इन पॉलिमर की चयनात्मकता को विलयन के पीएच को बदलकर या इन पदार्थों में अन्य कार्यात्मकताओं को सम्मिलित करके बदला जा सकता है। वर्तमान थीसिस नए इमिनोडाइएसिटेट-स्टाइरीन आधारित मोनोमर्स के डिजाइन और संश्लेषण पर केंद्रित है। पानी में घुलनशील होमोपोलिमर और क्रॉसलिंग किए गए पानी के प्रफुल्लित पॉलीमरिक जैल उत्पन्न करने के लिए इन मोनोमर्स को क्रॉसलिंग एजेंट की अनुपस्थिति और उपस्थिति में क्रमशः होमोपॉलीमेराइज़्ड और ऐक्रेलिक एसिड के साथ कोपॉलीमेराइज़्ड किया गया। इन पदार्थों का मूल्यांकन अपशिष्ट जल उपचार अनुप्रयोगों में उनकी क्षमता के लिए किया गया था। इन मोनोमर्स के मुक्त कण बहुलकीकरण द्वारा सभी बहुलक पदार्थ को संश्लेषित किया गया था।

पहले अध्याय में, कैलेटिंग बहुलक के अवलोकन और अपशिष्ट जल उपचार में उनकी उपयोगिता सहित परिचय और साहित्य सर्वेक्षण प्रस्तुत किया गया है।

दो नए स्टायरीन-आधारित इमिनोडाइएसिटेट कार्यात्मक मोनोमर्स के संश्लेषण, विभिन्न भारी धातु आयनों के साथ संश्लेषित पानी में घुलनशील होमोपोलिमर पर धातु के जटिल अध्ययन के साथ उनके पोलिमेराइजेशन की सूचना दी जाती है। नए स्टायरीन-आधारित मोनोमर्स, डाइमिथाइल २,२ '-

((४-विनाइफेनिल) अज़नेडीइल) डायसेटेट, **M1** डिमिथाइल इमिनोडायसेटेट समूह, कार्बनिक सॉल्वेंट्स में घुलनशील और सोडियम २,२' - ((४- विनाइफेनिल) अज़नेडायल) डायसेटेट **M2** इमिनोडाइएसिटेट समूह होने से, जलीय माध्यम में घुलनशील डिजाइन किए गए थे और अच्छी पैदावार में संश्लेषित और NMR ( $^1\text{H}$  और  $^{13}\text{C}$ ), फूरियर इन्फ्रारेड स्पेक्ट्रोस्कोपी (एफ टी आई आर) स्पेक्ट्रोस्कोपी, मास स्पेक्ट्रोस्कोपी, गलनांक और तात्विक विश्लेषण द्वारा रूपांतरित किए गए थे। पॉलिमर, कार्बनिक माध्यम में घुलनशील क्रमशः बीपीओ और एआईबीएन आरंभकर्ताओं का उपयोग करके बल्क (**P1-P9**) और विलयन (**P11-P14**) में **M1** के मुक्त कण पोलीमराइजेशन द्वारा संश्लेषित किए गए थे। पानी में घुलनशील होमोपोलिमर **P10**, आई डी ए के सोडियम नमक के कैलेटिंग समूह के रूप में ७७% की कुल उपज के साथ **P9** के बेस हाइड्रोलिसिस पर प्राप्त किया गया था। ए पी एस आरंभकर्ता का उपयोग करके जलीय माध्यम में **M2** के मुक्त कण पोलीमराइजेशन ने पानी में घुलनशील कैलेटिंग होमोपोलिमर **P15**, आई डी ए के सोडियम नमक के कैलेटिंग समूह के रूप में ५०% उपज में उत्पन्न किया। पानी में घुलनशील बहुलक की घुलनशीलता कमरे के तापमान पर ५ मिलीग्राम प्रति मिलीलीटर के रूप में प्राप्त की गई थी। पानी में घुलनशील बहुलक **P10** को यूवी-विज़ स्पेक्ट्रोस्कोपी द्वारा विभिन्न भारी धातु आयनों को बांधने की क्षमता के लिए जांच की गई थी और  $\text{Cu}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Fe}^{2+}$  और  $\text{Fe}^{3+}$  को कुशलतापूर्वक पाया गया था। **P10** के साथ  $\text{Cu}^{2+}$  बाइंडिंग पर पीएच के प्रभाव का अध्ययन किया गया और यह पता चला है कि हर दो आई डी ए मोनोमेरिक रिपीट इकाइयां पीएच ७ में एक  $\text{Cu}^{2+}$  आयन के साथ बांधती हैं जो सुझाव देती हैं कि इ डी टी ए के अनुरूप कॉम्प्लेक्स बनते हैं। थर्मोग्रैविमेट्रिक विश्लेषण से पता चला कि संश्लेषित पानी में घुलनशील बहुलक में ४०० ° C तक उच्च तापीय स्थिरता होती है।  $\text{Cu}^{2+}$  आयन के साथ बहुलक की पुनर्प्राप्ति और पुनः उपयोग की क्षमता का प्रदर्शन किया गया है। रिपोर्ट किए गए परिणाम बताते हैं कि यह पानी में घुलनशील कैलेटिंग होमोपोलिमर अपशिष्ट जल उपचार में अनुप्रयोग के लिए बहुत अधिक क्षमता के साथ एक उत्कृष्ट पदार्थ है।

इसके अलावा, प्रत्येक दोहराने वाली इकाई में इमिनोडाइएसिटेट कार्यात्मक समूहों के साथ अत्यधिक छिद्रपूर्ण पोलीस्टाइरीन-आधारित रेजिन (**IDASR**) के डिजाइन और संश्लेषण के लिए दो नए दृष्टिकोण बताए गए हैं। पहली विधि दो-चरणीय प्रक्रिया की रिपोर्ट करती है जिसमें मोनोमर **M1** का एन, एन'-मेथिलीनबिसएक्रीलमाइड क्रॉसलिंग के साथ कार्बनिक माध्यम में मुक्त कण बहुलककरण होता है, उसके बाद बेस हाइड्रोलिसिस होता है। दूसरी विधि एक एकल-चरण प्रक्रिया है जिसमें एम २ (पानी में घुलनशील) के साथ एन, एन'-मेथिलीनबिसएक्रीलमाइड क्रॉसलिंग के जलीय माध्यम में मुक्त कण बहुलकीकरण शामिल है। रेजिन के भौतिक-रासायनिक गुणों की विशेषता का एफ टी आई आर, टी जी ए, स्कैनिंग इलेक्ट्रॉन माइक्रोस्कोप (एस ई एम) और संतुलन सूजन मूल्य (ई एस वी) द्वारा विश्लेषण किया गया। जल प्रफुल्लित जेल **IDASR15** की धातु बंधन क्षमता की जांच विभिन्न जहरीले धातु आयनों जैसे  $\text{Cu}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Co}^{3+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  और  $\text{Al}^{3+}$  के साथ उनके कम सांद्रता के जलीय घोल से बैच विधि द्वारा की गई और ०.९४३-२.८०२ मिलिमोल प्रति ग्राम प्राप्त हुई। पीएच ५ पर  $\text{Cu}^{2+}$  आयन के लिए अधिकतम क्षमता २.८०२ मिलिमोल प्रति ग्राम प्राप्त की गई। बैच और कॉलम विधियों द्वारा  $\text{Cu}^{2+}$  आयन के साथ पुनर्प्राप्ति और पुनः उपयोग की क्षमता का प्रदर्शन किया गया है। रिपोर्ट किए गए परिणाम बताते हैं कि ६८.५५ ग्राम पानी प्रति ग्राम **IDASR15** के उच्च संतुलन सूजन मूल्य (ई एस वी) के साथ **IDASR15** जलीय धाराओं में आमतौर पर पाए जाने वाले जहरीले धातु आयनों के लिए एक अत्यधिक कुशल और छिद्रपूर्ण कॉम्प्लेक्सिंग एजेंट है। यह भी क्रमशः ९७ और ~ ९९.५% सोखना दक्षता के साथ पुनः उपयोग किया जा सकता है, जैसा कि बैच और स्तंभ विधियों द्वारा निर्धारित किया गया है, जो बहुत ही आशाजनक है और अपशिष्ट जल उपचार अनुप्रयोगों के लिए महत्वपूर्ण क्षमता रखता है।

सोखना क्षमता को बढ़ाने के लिए, ऐक्रेलिक एसिड के साथ मोनोमर **M1** के तीन नए छिद्रपूर्ण क्रॉसलिंगेड इमिनोडाइएसिटेट फंक्शनल कोपोलिमर तैयार किए गए थे। कोपोलिमर्स को दो चरणों में संश्लेषित किया गया था, पहले चरण में, मोनोमर **M1** और ऐक्रेलिक एसिड (२५/५०/७५ wt%) की

मुक्त कण कॉपोलिलाइजेशन एआईबीएन आरंभकर्ता और एन, एन'-मेथिलीनबिसएक्रीलमाइड क्रॉसलिंगर का उपयोग **IDAESAR** रेजिन उत्पन्न करने के लिए किया गया था, जिसमें 80-90% उपज में डाइमेथाइल इमिनोडायसेटेट कार्यात्मक समूह होते हैं। दूसरे चरण में, **IDAESAR** के मिथाइल एस्टर समूहों को हाइड्रोफिलिक जेल **IDASAR** को संश्लेषित करने के लिए सोडियम हाइड्रोकसाइड की उपस्थिति में हाइड्रोलाइज्ड किया गया, जिसमें ८०-८५% उपज में इमिनोडायसेटेट कार्यात्मक समूहों का सोडियम नमक होता है। रेजिन का एस ई एम, एफ टी आई आर, ई एस वी और टी जी ए द्वारा विश्लेषण किया गया। **IDASAR** ने 16-19 ग्राम पानी / कोपोलिमर के अच्छे ई एस वी के साथ अत्यधिक छिद्रपूर्ण संरचना दिखाई। थर्मोग्रैविमेट्रिक विश्लेषण ने **IDASAR** को ३५० ° C तक अच्छी तापीय स्थिरता के रूप में दिखाया।  $Mn^{2+}$ ,  $Zn^{2+}$ ,  $Ni^{2+}$ ,  $Cu^{2+}$ ,  $Pb^{2+}$ ,  $Fe^{2+}$ ,  $Cd^{2+}$ ,  $Co^{2+}$ ,  $Mg^{2+}$ ,  $Ca^{2+}$   $Fe^{3+}$   $Co^{3+}$  और  $Cr^{3+}$  जैसे विभिन्न विषैले भारी धातु आयनों के साथ जेल, **IDASAR25**, **IDASAR50** और **IDASAR75** की सोखने की क्षमता बैच विधि द्वारा उनके जलीय घोल से निर्धारित की गई और ०.०४१-९.९६३५ मिलिमोल प्रति ग्राम प्राप्त हुई। **IDASAR२५** के लिए अधिकतम क्षमता ९.९६३५ मिलिमोल प्रति ग्राम पीएच ५ पर  $Zn^{2+}$  आयन के साथ प्राप्त की गई। **IDASAR** कॉपोलिमर ने  $Zn^{2+}$ ,  $Cd^{2+}$ ,  $Pb^{2+}$ ,  $Cu^{2+}$  और  $Ni^{2+}$  के लिए क्रमशः ९.९६३५, ९.३४७६, ७.११०९, ६.१५०५ और ५.६२२५ मिलिमोल प्रति ग्राम की उच्चतम सोखना क्षमता दिखाई। **IDASAR** के पुनर्प्राप्ति अध्ययन को एच सी एल / सोडियम हाइड्रोकसाइड के साथ बैच विधि द्वारा किया गया था और उदाहरण के लिए  $Cu^{2+}$  आयन के साथ प्रदर्शित किया गया था। रिपोर्ट किए गए परिणाम बताते हैं कि जलीय धाराओं में आमतौर पर पाए जाने वाले जहरीले धातु आयनों के लिए संश्लेषित जल-प्रफुल्लित जेल अत्यधिक कुशल एडसोर्बेंट हैं और सोखने की क्षमता में छोटे नुकसान के साथ भी इसका पुनः उपयोग किया जा सकता है।

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## **LIST OF ABBREVIATIONS AND SYMBOLS**

%	Percent
$\delta$	Chemical shift
s	Singlet
d	Doublet
dd	Double doublet
t	Triplet
m	Multiplet
br	Broad signal
<i>vs</i>	Versus
cm	Centimeter
mm	millimeter
kDa	kilodalton
kg	Kilogram
g	Gram
mg	Milligram
mol	Mole
mmol	Millimole
M	Molar
L	Litre
mL	Millilitre
$\mu$ L	Microlitre
ppm	Part per million
ppb	part per billion
$^{\circ}$ C	Degree centigrade

h	Hour
Min.	Minute
$\nu$	Frequency
Hz	Hertz
MHz	Megahertz
$\lambda_{\max}$	Absorption maximum
$T_g$	Glass transition temperature
$T_5$	Decomposition temperature at 5% weight loss
$T_d$	Decomposition temperature
e.g.	For example
i.e.	That is
$\mathcal{D}$	Dispersity
$M_w$	Weight average molecular weight
$M_n$	Number average molecular weight
$A_{\text{eff}}$	Adsorption efficiency
Q	Adsorption capacity
$N_2$	Nitrogen
Ar	Argon
pH	Potential of hydrogen or power of hydrogen
AIBN	2,2'-Azobis(isobutyronitrile)
BPO	Benzoyl peroxide
DCM	Dichloromethane
DMF	Dimethylformamide
DMSO	Dimethylsulfoxide
DME	Dimethylether

DMIDA	Dimethyl iminodiacetate
DSC	Differential scanning calorimetry
DIPEA	N,N'-Diisopropylethylamine
EDTA	Ethylenediaminetetraacetic acid
ESV	Equilibrium swelling value
FT-IR	Fourier transform infrared spectroscopy
GMA	Glycidyl methacrylate
GPC	Gel permeation chromatography
HRMS	High resolution mass spectra
ICPMS	Inductively coupled plasma mass spectrometry
IDA	Iminodiacetate
<b>IDASR</b>	Iminodiacetate styrene resin
<b>IDAESR</b>	Iminodiacetate methylester styrene resin
<b>IDASAR</b>	Iminodiacetate styrene-co-acrylic acid resin
<b>IDAESAR</b>	Iminodiaceate methylester styrene-co-acrylic resin
NMR	Nuclear magnetic resonance
<b>M1</b>	Dimethyl 2,2'-((4-vinylphenyl) azanediyl)diacetate
<b>M2</b>	Sodium 2,2'-((4-vinylphenyl)azanediyl)diacetate
MBA	N,N'-methylenebisacrylamide
MeCN	Acetonitrile
PPH <sub>3</sub>	Triphenylphosphine
SEM	Scanning electron microscope
TGA	Thermogravimetric analysis
THF	Tetrahydrofuran
TMS	Tetramethylsilane

TLC	Thin layer chromatography
UV–Vis	Ultraviolet–visible
VBIDA	N-(4-Vinylbenzyl)iminodiacetic acid
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
Na <sub>2</sub> SO <sub>4</sub>	Sodium Sulphate
Na <sub>2</sub> CO <sub>3</sub>	Sodium Carbonate
K <sub>2</sub> CO <sub>3</sub>	Potassium carbonate
HCl	Hydrochloric acid
H <sub>2</sub> SO <sub>4</sub>	Sulphuric acid
HNO <sub>3</sub>	Nitric Acid
EtOH	Ethanol
CH <sub>3</sub> OH	Methanol
CHCl <sub>3</sub>	Chloroform
HCHO	Formaldehyde
H <sub>2</sub> O	Water
Pd(PPh <sub>3</sub> ) <sub>4</sub>	Tetrakis(triphenylphosphine)palladium(0)
(CH <sub>2</sub> OH) <sub>2</sub>	Ethylene glycol
(CH <sub>3</sub> ) <sub>2</sub> O	Diethyl ether
KBr	Potassium bromide
Cu(NO <sub>3</sub> ) <sub>2</sub> ·3H <sub>2</sub> O	Copper(II) nitrate trihydrate
Ni(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	Nickel(II) nitrate hexahydrate
Cd(NO <sub>3</sub> ) <sub>2</sub> ·4H <sub>2</sub> O	Cadmium(II) nitrate tetrahydrate
Pb(NO <sub>3</sub> ) <sub>2</sub>	Lead(II) nitrate
Zn(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	Zinc(II) nitrate hexahydrate

$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Iron(II) sulfate heptahydrate
$\text{MnSO}_4 \cdot \text{H}_2\text{O}$	Manganese(II) sulfate monohydrate
$\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	Cobalt(II) nitrate hexahydrate
$[\text{Co}(\text{NH}_3)_6]\text{Cl}_3$	Hexaamminecobalt(III) chloride
$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	Iron(III) nitrate nonahydrate
$\text{FeCl}_3$	Iron(III) Chloride
$\text{CaCl}_2$	Calcium(II) Chloride
$\text{Mg}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}$	Magnesium(II) Nitrate Hexahydrate
$\text{KCr}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$	Chromium(III) potassium sulfate dodecahydrate
$\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	Aluminum(III) nitrate nonahydrate