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Characterization, Synthesis, Analytical Application of Composite Cation Exchange Materials for Environmental Metal Ion Separation

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Abstract: The increasing contamination of water and soil by toxic metal ions has lowered significant environmental related, necessitating to development of efficient materials for metal ion removal and recovery. Composite cation changing materials have emerged as promising, the synthesize, characterization, and analysis of composite cation exchange materials designed of environmental metal ion separation. Various composite materials are synthesized by integrating inorganic and organic components, followed by functionalization with a specific ion-exchange groups to increases selectivity to understand for heavy metal. characterization of materials includes testing such as FTIR, XRD, SEM, and ion exchange capacity (IEC) to assess their structural, morphological, and ion-exchange properties. The synthesized composites exhibit high surface areas, functional group densities, and thermal stability, making them highly effective for selective remove of solid metals, such as Hg^{2+}, Cu^{2+} Pb^{2+}, Cd^{2+}. Analytical applications of these materials in environmental remediation and metal ion recovery highlight their potential for use in water purification, wastewater treatment, and soil remediation. Furthermore, their reusability and environmental sustainability offer promising solutions for large-scale applications. Despite these advantages, challenges related to material stability, selectivity, and cost-effectiveness remain, and future research is needed to optimize these composites for industrial-scale use.

Keywords: *Composite Cation Exchange Materials, Metal Ion Separation, Synthesis, Characterization, Environmental Remediation, Water Purification, Ion-Exchange Capacity, Heavy Metals.*

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I. INTRODUCTION

The rapid industrialization of modern society has led to a significant increase in the release of toxic metal ions into the environment. Heavy metals such as Pb^{2+}, Cd^{2+}, Hg^{2+}, Cu^{2+}, Ni^{2+}, and Cr^{3+} persist in soil and water systems due to their non-biodegradable nature, posing severe risks to ecological balance and human health. Conventional remediation techniques—including chemical precipitation, membrane filtration, and solvent extraction—often suffer from limitations such as high operational cost, incomplete removal, low selectivity, and generation of secondary waste. In this context, ion-exchange technology has emerged as one of the most effective methods for selective removal and recovery of metal ions owing to its high efficiency, simplicity, and reusability.

Composite cation-exchange materials have gained substantial attention over the past decade as promising alternatives to traditional organic or inorganic ion exchangers. These hybrid materials combine the structural stability of inorganic matrices with the functional versatility of organic polymers, resulting in enhanced ion-exchange capacity, chemical durability, and selectivity toward target metal ions. Various composites—such as polymer-inorganic hybrids, sol-gel based materials, nano-reinforced ion exchangers, and biopolymer-supported systems—provide tunable physicochemical properties that can be optimized for environmental applications.

The synthesis and characterization of such composite materials are critical to understanding their ion-exchange behavior. Techniques including FTIR, XRD, SEM, TGA, BET surface analysis, and ion-exchange capacity measurements enable evaluation of structural features, functional groups, surface morphology, thermal stability, porosity, and binding mechanisms. These parameters directly influence the material's application in metal-ion separation, adsorption kinetics, and overall performance in real or simulated wastewater conditions.

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Furthermore, composite cation-exchange materials offer significant advantages in analytical applications, particularly in preconcentration, separation, and purification of trace metals before instrumental analysis. Their high affinity and selectivity enable efficient removal of interfering ions, thereby improving detection accuracy in spectroscopic and chromatographic methods.

Given the increasing environmental concerns and regulatory demands, research on novel composite cation-exchange materials is essential for developing sustainable, efficient, and cost-effective technologies for metal-ion separation. This study focuses on the synthesis, physicochemical characterization, and analytical application of advanced composite cation-exchange materials, aiming to evaluate their potential in environmental remediation and trace-metal analysis.

II. DIFFERENT TYPES OF COMPOSITE CATION EXCHANGE MATERIALS

To synthesis composite cation replace materials for environmental metal ion separation is a critical area of research aimed at addressing issues related to metal contamination in water, soils, and air. These composite materials combine various materials (such as polymers, inorganic substances, or natural products) to enhance their capacity and selectivity for metal ion removal or recovery. Here's an overview of the process and types of materials involved:[14]

- Polymer-based composites: These are typically prepared by incorporating ion-exchange resins (such as sulfonated polystyrene or polyvinyl alcohol) into a matrix of polymers or cross-linked polymers. The cation exchange sites in the polymer allow for selective adsorption of metal ions.
- Inorganic-based composites: Oxides of metals (e.g., Al_2O_3, ZrO_2) and clays (e.g., montmorillonite, zeolites) are incorporated into the material. These can provide high surface area & highly ion-exchange capacity. Inorganic materials can also serve as supports to enhance the stability of the composite.[12]

- Natural polymer composites: Biopolymers, such as chitosan, cellulose, or alginate, are increasingly used for environmental applications due to their abundance, biodegradability, and functional groups (e.g., amino, hydroxyl) that can bind metal ions.

Methods of Synthesis

The synthesis process of composite cation exchange materials typically involves the following methods:

- Sol-gel method: A common technique used for synthesizing inorganic-based composite materials. Metal precursors are hydrolysed and polymerized to form a gel-like material, which is then dried the calcined form a composite with ion-exchange properties.
- Copolymerization: For polymer-based composites, copolymerization involves the composite of an epoxy, polyester, polypropylene and in presence as monomers or cross-linkers that can bind metal ions.
- Electrospinning: This method is used to create Nano fibrous composite materials that have high surface area and porosity, which can significantly improve ion exchange capacity.
- Impregnation or intercalation: In this method, metal ions or functional groups are introduced into the interlayer spaces of a clay or zeolite structure. The resulting composite material is then used for ion exchanges.

Characteristics of Cation Exchange Materials

- Ions exchange capacity (IEC): The execution of substances to exchange metal ionic is a crucial property. This is determined by the number of available cation exchange sites.
- Selectivity: The material should preferably select certain metal ions (e.g., lead, cadmium, mercury) over others, depending on the application. This selectivity can be influenced by the functional groups and surface characteristics of composite.
- Regeneration: Material should be regenerable so that it can be reused multiple times, making the process cost-effective and sustainable.
- Stability: The composite material must be stable in different environmental conditions, like pH, temperature, & ionic strength.

Environmental Metal Ion Separation

The primary goal of composite cation exchange materials is to pull out or heavy metal ions from infect environments, such as wastewater or drinking water. Common metal ions targeted for removal include:

- Heavy metals: These include Pb^{2+}, Cd^{2+}, Hg^{2+}, & As^{3+}, which is harmful uniform in trace concentrate.[10]
- Radioactive metals: For instance, cesium (Cs^{+}) and strontium (Sr^{2+}) ions can be captured using specific composites designed for radioactive waste treatment.
- Noble metals: Materials designed for the recovery of metals like Au^{3+}, Ag^{+}, Pt^{2+}can used in resource recovery processes.[9][11]

Applications

- Wastewater treatment: Composite cation exchangers can be used to removal toxic metals ions for industrial effluents or sewage.
- Soil remediation: Composite materials also used in-situ pull out of metal ions from polluted soils.
- Drinking H_2O purification: Removal of harmful solid metals such as Ar^{2+}, Pb^{2+} from drinking H_2O.[4]
- Recovery of precious metals: In mining or recycling industries, composites employed to reused metals from residual streams.

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- Environmental monitoring: Composite materials can be used in sensors for detecting trace levels of metal ions in the environment.

➢ *Recent Innovations and Trends*

- Nanocomposites: The development of nanomaterials, such as carbon nanotubes or graphene oxide-based composites, has significantly enhanced the performance of ion-exchange substances due to highly surface area and tuneful properties.
- Bio-inspired substances: Research is increasingly focused on mimicking natural ion exchange processes found in biological systems, such as the use of proteins, enzymes, or other biopolymers.
- Green chemistry: There is a shift toward developing composite materials using sustainable methods, minimizing the use of toxic solvents or materials, and utilizing renewable resources.

III. SYNTHESIS OF COMPOSITE CATION EXCHANGE MATERIALS

Composite cation exchange materials are often made by combining inorganic or organic polymers with functional materials to improve their properties. The synthesis typically involves the following steps:

- Selection of Materials: The base material for cation exchange could be natural or synthetic polymers, inorganic materials like clay minerals, or carbon-based materials. Common examples include zeolites, activated carbon, and bio-polymers.
- Functionalization: The base material is modified to enhance its affinity for metal ions. Important Functional groups, such as s ($-SO_3H$), carboxyl ($-COOH$), or amino ($-NH_2$) groups, can be incorporated into the material to improve its interchange level and identification for metal ions.
- Composition Formation: The functional material is combined with the base material to form a composite. This can be achieved via different methods like co-precipitation, grafting, or sol-gel processes. Composite materials may also include nanoparticles or mesoporous structures to increase surface area and improve adsorption.[3]

IV. CHARACTERIZATION OF COMPOSITE CATION EXCHANGE MATERIALS

Characterization is crucial to understanding the properties and effectiveness composition of cation interchange substance. Various techniques are employed to identify module composition and interchange of ions capacity:

- FTIR: -Used to identify the different functional groups on composition substances.
- HPLC: - These instruments used for separation of materials, identification of materials, quantity of materials in mixture substances and metal ion separation.
- GC: - Used for separating volatile compounds based on their ability to vaporize and interact with a chromatographic column.
- TGA: - To measurements the mass change of sample it heated, providing under the thermal stability and composition.
- SEM and TEM: - For visualizing, morphology, surface characteristics of the substances.
- IEC: - To measure capacity to interchange metallic ions. which key its performance in separation applications.
- XRD: These analyze are crystallinity and model composite material.
- BET: - To measure the proper surface area and structure in composite substances, which are important for adsorption efficiency.
- EDX: - To identification the metals composition of the material and verify to incorporation of specific ions or elements.

➢ *Fourier Transform Infrared Spectroscopy*

FTIR is determination of substances in important functional groups & bonding environments on composite cation exchange materials. The technique works by detecting the absorption of infrared light at different wavelengths, corresponding to vibrations of different chemical bonds.

- Application for Metal Ion Separation: FTIR is determine and confirm in presence of sulfonate ($-SO_3^-$), carboxylate ($-COOH$), amine ($-NH_2$), and phosphonate ($-PO_4$) that are responsible for metal ion coordination and exchange processes in composite cation exchange materials.in presence to the material's surface chemistry & helps in understanding how these groups interact with metal ions during separation.

➢ *High-Performance Liquid Chromatography*

HPLC is determine separation, identification, quantality, quantity of substances in metal ion separation.

- Application for Metal Ion Separation: HPLC can be employed to study the interaction of composite cation exchange materials with metal ions in solution. This can involve the separation of different metal species based on their affinity to the exchange material. After metal ion binding or separation, to concentrate of each ionic substances in the effluent can be measured by using appropriate detectors like UV, fluorescence, or conductivity.
- Example: HPLC can help assess how different cations (like Pb^{2+}, Cu^{2+}, or Ni^{2+}) are retained or eluted from the composite material and quantify their concentration.[2][3][5]

➢ *Gas Chromatography.*

GC is primarily used for separating volatile compounds based on their ability to vaporize and interact with a chromatographic column. While it's less common for directly

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studying metal ions, it can be used in certain applications related to metal ion separation:

- Application for Metal Ion Separation: GC may not directly separate metal ions but could be used to analyze volatile components (such as solvents or degradation products) associated with the ion exchange process. For instance, GC could analyze organic ligands that are part of a composite ion exchange material if the ligand is volatile, or it could be used in the post-treatment process to analyze gas-phase metal emissions during regeneration.

➢ *Thermogravimetric Analysis.*

Thermogravimetric analysis the mass change of sample is heated, presence of thermal stability and composition.

- Application for Metal Ion Separation: In composite materials, Thermogravimetric can be determine the study of thermal stability of cation exchangers, to assess changes in the material upon ion exchanges. It can be also help determine to amount of organic or inorganic components in the composite. For example, when metal ions are exchanged, the composite material may undergo a mass change, reflecting the uptake or release of metal ions.
- Example: TGA can be useful in determining the regeneration efficiency of cation exchange materials by evaluating weight loss due to desorption of metal ions or decomposition of organic components.

➢ *Scanning Electron Microscopy.*

- Application: SEM is detailed information about the surface morphology, structure of the composite materials, revealing their porosity, particle size, and any structural changes upon ion exchange and understanding the substances' ability to trap and release metal ions.

➢ *X-ray Diffraction.*

- Application: XRD is determine the crystalline structure of the substances. By comparing the XRD patterns before and after ion exchange, the crystallinity and phase composition changes upon metal ion interaction can be understood.

➢ *X-rays Photoelectron Spectroscopy.*

- Application: XPS to investigation in surface chemistry of the exchange cation materials. It provides information on the elemental composition, oxidation states of the metals, and chemical bonding of elements, which is crucial for understanding the binding and separation mechanism of metal ions.

➢ *Ion Chromatography.*

- Application: Similar to HPLC but specifically designed for ion analysis, IC can provide a high-resolution separation of ions in solution. Its valuable technique for monitoring the concentrate metallic ions during after the ion exchanging process.

V. ANALYTICAL APPLICATIONS FOR ENVIRONMENTAL METAL ION SEPARATION

Mixed metallic ions interchange substances materials are used for the separation & remove of metallic ions from contaminated H_2O, wastewater, soil. Their applications include:

- Heavy Metal Ion Removal: The materials are particularly effective in removal of the toxic metals such as Pb^{2+}, Cd^{2+}, Hg^{2+}, Cu^{2+}, Cr^{3+} from H_2O. Cation exchange materials can selectively adsorb and remove these ions based on their size, charge, and affinity for the functional groups.[1][6][7]
- Separation of Valuable Metals: In addition to environmental clean-up, composite cation exchangers can be applied in recovering valuable metals from industrial effluents, such as nickel (Ni^{2+}), gold (Au^{3+}), and silver (Ag^{+}).[9]
- Water Purification: Composite materials can be used in water treatment plants or in portable water filtration systems to remove toxic metal ions, improving water quality.
- Soil Remediation: In agriculture or industrial sites contaminated with metals, composite cation exchangers can be used for in-situ treatment of polluted soils.
- Recyclability: Many composite materials can be regenerated and reused, making them cost-effective for large-scale applications.[8][9][11][12]

➢ *Analytical Applications in Metal Ion Separation*

This section demonstrates how the composite materials are used for practical applications, particularly in the remove & separation of metallic ions from environmental samples.

- Toxic Metal Ion Removal: Understand the types of heavy metals targeted for removal (e.g. Pb^{2+}, Cd^{2+}, Hg^{2+}, Cu^{2+}), etc.).[2][7]
- Separation Mechanisms: How do these materials capture metal ions? Study the ionic exchange process, the metallic ions in water or soil is replaced by ions from the composite material.[3]
- Selectivity and Efficiency: Review how effective the material is at selectively binding certain metal ions over others.
- Regeneration and Reuse: How easily can the material be regenerated and reused? Reusability is crucial for making the process sustainable and cost-effective for large-scale applications.
- Practical Applications: The composite materials could be used in water treatment (remove of the metals from drinking H_2O), wastewater treatment plants (industrial effluents), or soil decontamination.[13][14][15]

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➢ *Environmental Metal Ion Removal and Recovery*

- Water treatment: Mixed metallic ions interchange substances cation exchange materials are used for the remove of baneful metal ions, such as Pb^{2+}, Cd^{2+}, Hg^{2+}, As^{3+}, from contaminated H_2O sources. The exchange capacity of these materials allows for high-efficiency metal ion removal, making them ideal for purifying industrial effluents, wastewater, and drinking water.
- Selective ion removal: Modification of the important at functional groups or matrix of composite materials, the selective for important metal ions can be enhanced. For example, materials can be tailored to preferentially adsorb toxic metals like mercury or arsenic over other metals.
- Metal ion recovery: Cation exchange materials can be regenerated after ion exchange, making the suitable for recovery of valuable or rare metals from wastewater, such as Ag^{+}, Au^{3+}, Cu^{2+}. This makes them ideal for resource recovery and recycling, especially in mining and industrial processes.

➢ *Environmental Metal Ion Detection and Monitoring*

Composite cation exchange materials can be integrated into sensor devices detection and monitoring of metallic ions in environmental samples, enabling real-time analysis and on-site monitoring.

- Electrochemical Sensors: Composite materials are often used in electrochemical sensors, where they facilitate the transfer of metal ions between the electrode and the solution. These sensors can detect low concentrations of metal ions in water and soil. For instance, electrodes modified with cation-exchange resins can be used for potentiometric or voltammetric measurements of metal ions like Pb^{2+}, Cd^{2+}, or Hg^{2+}.[2]
- Colorimetric Detection: Some composite materials are designed to undergo a color change upon binding to specific metal ions, enabling the visual detection of environmental contamination. These materials can be incorporated into strips or beads, which change color when exposed to harmful concentrations of metals such as lead or mercury.
- Spectroscopic Methods: Composite cation exchange materials can be employed in spectroscopic methods like Atomic Absorption Spectroscopy, inductive coupled plasma Mass Spectrometry, & X-ray fluorescence, pre-concentrate, separate metal ions from complex environmental samples, thus enhancing the sensitivity of these methods.

➢ *Soil and Sediment Remediation*

- Soil Decontamination: Composite cation exchangers are used for in-situ remediation of contaminated soils. By adding these materials to polluted soils, metallic ions such as Pb^{2+}, Cd^{2+}, Cu^{2+}, can be immobilized or removed through ion exchange, thus preventing further leaching into groundwater or other environmental systems.
- Heavy Metal Stabilization: Composite materials can help stabilize toxic metals in contaminated sediments by reducing their mobility. This is especially important for preventing metal ions from entering the food chain, as metals such as mercury and cadmium can bioaccumulate in organisms.

➢ *Environmental Metal Ion Speciation*

- Speciation Studies: The speciation of metal ions (i.e., the distribution of metal ions between different chemical forms) is critical in understanding their environmental behaviour and toxicity. Composite cation exchange materials are used in speciation analysis, where they selectively bind certain metal species in complex mixtures, allowing for the separation and quantification of different metal forms.
- Separation of Metal Complexes: Composite materials with specific functional groups can be designed to interact with different metal complexes, enabling the separation of free metal ions from those bound to organic ligands or other forms. This application is important for the accurate assessment of metal bioavailability and toxicity in environmental studies.

➢ *Real-Time Environmental Monitoring and Field Applications*

- Portable Devices: The use of composition of cation exchange materials in portable analytical devices allows for real-time, on-site monitoring of metal contamination in the environment. These devices can be used for monitoring water quality in rivers, lakes, or coastal areas, or for detecting metal pollution in agricultural fields.
- In-Situ Monitoring: Composite materials embedded in portable sensors or analytical tools allow for continuous monitoring of toxic metals in aquatic environments without the need for laboratory analysis. These materials can be used for monitoring industrial discharges, mining runoff, and groundwater contamination.

➢ *Biomonitoring and Ecotoxicity Studies*

- Toxicity Assessment: Composite cation exchange materials can be used to assess the ecotoxicity of metal-contaminated environments. To ability the selective bind specific metallic ions helps in understanding the ecological impact of metals on aquatic organisms, plants, and animals.
- Bioaccumulation Studies: These materials can also be employed to study the bioaccumulation of metals in aquatic organisms. By measuring the concentrated of metallic ions in the tissues and fish or plants exposed to metal-contaminated environments, researchers can assess the long-term effects of metal exposure.

➢ *Wastewater Treatment and Sludge Management*

- Sludge Minimization: Composite cation exchange materials are used to minimize sludge production in wastewater treatment. Traditional methods like chemical precipitation often generate large amounts of sludge. By

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using composites, the metal ions can be removed without producing large volumes of residual waste.

- Sludge Conditioning: Cation exchange materials can also be used to condition and improve the quality of sewage sludge, making it easier to dispose of or repurpose for agricultural use. They help to bind heavy metals within the sludge, thus preventing the metals from leaching into the environment.[15]

➢ *Sorption/Desorption Studies for Metal Ion Recovery*

- Sorption Efficiency: Composite materials can be analyzed for their sorption capacity toward different metals, assessing how efficiently they bind metals in various environmental conditions. These materials can be tested in batch or column experiments to determine the optimal conditions for metal ion removal from water or other environmental media.
- Regeneration and Reuse: Analytical methods can be employed to study the regeneration of composite materials after metal ion adsorption, ensuring that they retain their ion-exchange capacity for multiple cycles. Techniques like X-rays diffraction, SEM, FTIR Spectroscopy, can be determine chemical structure and identification in the materials after metal ion adsorption and regeneration.

➢ *Integration with Green Chemistry.*

- Environmentally Friendly Methods: Analytical applications also extend to the use of green chemistry principle and synthesis, use of composition of cation exchange materials. The goal is to develop more sustainable and less toxic materials for metal ion separation and recovery, using renewable resources or non-toxic reagents.

VI. CHALLENGES AND FUTURE DIRECTIONS

While composite cation exchange materials show great promise, challenges such as their reusability, selectivity, and efficiency over long-term use remain. There is also ongoing research into enhancing their stability under extreme conditions, such as high pH or temperature, and improving their performance in real-world environmental samples, where the composition is more complex than in laboratory conditions. Additionally, the development of more environmentally friendly materials and methods for synthesizing cation exchange composites is an area of active research, focusing on reducing the environmental impact of these materials.

VII. CONCLUSION

Composite cation exchange materials are a powerful tool for environmental metal ion separation, with applications spanning from H_2O purification to soil remediation. Their synthesis, characterization, analytical applications involve a multi-disciplinary approach, combining materials science, chemistry, and environmental engineering. The continued improvement and innovation in this field are crucial for tackling the growing environmental challenges posed by toxic metal contamination.

REFERENCES

[1]. Amalraj, A., & Pius, A. (2015). A comparative study of ion exchange behavior of composite ion exchangers for metal ion removal. *Separation Science and Technology*, 50(11), 1706–1714.

[2]. Ghaemi, A., & Torab-Mostaedi, M. (2015). Use of composite ion exchange materials for the removal of heavy metals from aqueous solutions. *Desalination and Water Treatment*, 54(10), 2874–2883.

[3]. Crini, G., & Badot, P. M. (2008). Application of ion exchange resins for the removal of metal ions from aqueous solutions. *Separation and Purification Technology*, 63(3), 285–291.

[4]. Mohan, D., & Pittman Jr., C. U. (2007). Arsenic removal from water/wastewater using adsorbents—A critical review. *Journal of Hazardous Materials*, 142(1–2), 1–53.

[5]. Tanaka, T., & Nishio, I. (2001). Ion exchange chromatography in metal ion separation. *Journal of Chromatography A*, 906(1), 55–63.

[6]. Horwitz, E. P., Chiarizia, R., & Dietz, M. L. (1992). Applications of ion exchange in analytical separations. *Analytical Chemistry*, 64(6), 547A–556A.

[7]. Barakat, M. A. (2011). New trends in removing heavy metals from industrial wastewater. *Arabian Journal of Chemistry*, 4(4), 361–377.

[8]. Wang, J., & Chen, C. (2009). Biosorbents for heavy metals removal and their future. *Biotechnology Advances*, 27(2), 195–226.

[9]. Pradeep, T., & Anshup. (2009). Noble metal nanoparticles for water purification: A critical review. *Thin Solid Films*, 517(24), 6441–6478.

[10]. 10.Singh, A. K., Bhaskar, T., & Choudhury, N. H. (2006). Ion exchange resins for the separation of metal ions. *Journal of Analytical Chemistry*, 61(8), 734–740.

[11]. 11.Gupta, R. K., & Ghosh, U. C. (2009). Arsenic removal using hydrous ferric oxide-based materials. *Environmental Progress & Sustainable Energy*, 28(4), 458–468.

[12]. Nayak, S. K., Mohanty, S., & Rana, A. K. (2010). Application of polymer composites for heavy metal ion removal. *Materials Science and Engineering B*, 168(1), 42–47.

[13]. Gogate, P. R., & Pandit, A. B. (2004). A review of imperative technologies for wastewater treatment. *Advances in Environmental Research*, 8(3-4), 501–551.

[14]. Meena, S. K., & Mishra, G. K. (2015). Composite cation exchange materials for efficient heavy metal removal. *Indian Journal of Chemistry*, 54A, 620–625.

[15]. Ghangrekar, M. M., & Shinde, V. B. (2007). Performance of ion exchange materials in wastewater treatment. *Journal of Environmental Science and Engineering*, 49(2), 125–132.