Synthesis and application of Tamarind Triazine glutamic acid (TTGA) resin

Hanuman, Parihar Neha, Rathore Sawai Singh and Gupta Vikal*
Department of Chemistry, Jai Narain Vyas University, Jodhpur-342005, Rajasthan, INDIA
*vikal_chem@yahoo.co.in

Abstract
A novel bio-based resin, Tamarind Triazine Glutamic Acid (TTGA), was synthesized through the chemical modification of tamarind seed polysaccharide with triazine and glutamic acid moieties. This study aims to develop a sustainable and eco-friendly resin with potential applications in water treatment, metal ion adsorption and biomedical fields. The resin was characterized using Fourier Transform Infrared (FTIR) spectroscopy. Its ion-exchange capacity, thermal stability and adsorption performance for heavy metals (Fe^{2+}, Zn^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+} and Cr^{3+}) were evaluated. The TTGA resin demonstrated promising properties, underscoring its utility as a biodegradable and functional alternative to synthetic resins. Industrial effluent containing heavy metal ions can be selectively separated using TTGA resin.

The distribution coefficient (Kd) of metal ions at various pH values was investigated using the batch equilibration method. Investigations were conducted into the effects of adsorbent dosage, treatment duration and pH on the removal of heavy metal ions from industrial effluent. The resin can be repeatedly regenerated and is adaptable to continuous processes.

Keywords: Tamarind Kernel, L- Glutamic acid, Chelating ion exchange resin, Industrial effluent and Polysaccharide.

Introduction

Industrial wastewater pollution poses a significant environmental concern globally, threatening ecosystems, human health and water resources. The discharge of untreated or inadequately treated industrial effluents into water bodies introduces a wide range of pollutants including heavy metals, organic compounds and toxic chemicals. These contaminants can persist in the environment, bioaccumulate in organisms and disrupt aquatic ecosystems. Moreover, the contamination of water sources jeopardizes access to safe drinking water and impacts agricultural productivity.

Heavy metals have damaged on both animal and human health as well as terrestrial and aquatic ecosystems. They are also linked to food contamination, environmental pollution and toxicity. Hazardous heavy metals and metalloids including chromium, lead, manganese, nickel, mercury, copper, zinc and iron, above threshold levels, have been identified as priority contaminants and one of the major environmental issues of global concern over the last several decades due to their mobility in terrestrial and natural aquatic ecosystems and their carcinogenic nature. Heavy metals have been extracted from wastewater, contaminated aquatic medium and industrial effluents using a range of methods over the course of the past 40 years.

Nevertheless, there is not a single ideal way to deliver appropriate therapy because every treatment has unique advantages and disadvantages including costs, consistency, efficacy, practicability, viability, operational challenges and environmental impact. These methods include reversible osmosis, ion transfer, precipitation by chemical, membrane screening, absorption, biosorption, coagulation–flocculation, advanced oxidation process and extraction with solvent. Some major adsorption processes are the recovery of precious metals and the remediation of heavy metal ions. These could include derivatives of amines that are carboxyl, hydroxyl, or of other types that can cause metal sorption. Specific metal-selective, less expensive, regenerative, no sludge creation, potential metal recovery, competitive preferences and high efficiency are its advantages over traditional methods.

The goal of this research is to create an economical method of treating contaminated industrial wastewater by synthesising natural polymer-based resins and an agro-residue-based adsorbent. Tamarind Triazine Glutamic Acid (TTGA) resin emerges as a promising solution for industrial wastewater treatment. This novel biopolymer-based material combines the natural abundance and biodegradability of tamarind seed polysaccharide with the versatility of triazine and the functionality of glutamic acid.

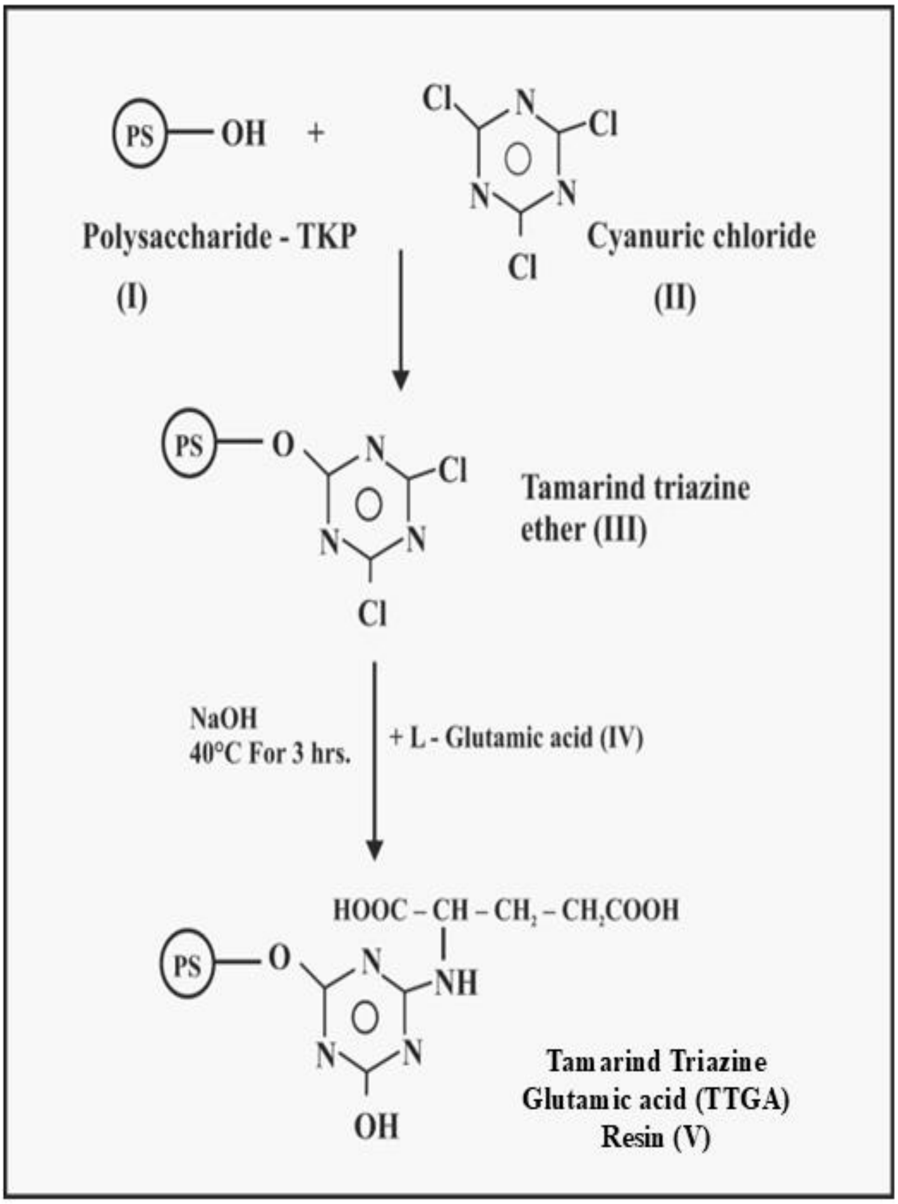
The unique properties of TTGA resin, including its high adsorption capacity, pH sensitivity and biocompatibility, make it an effective adsorbent for various pollutants commonly found in industrial wastewater. TTGA resin offers several advantages over conventional treatment methods. Its biodegradable nature reduces the environmental impact associated with synthetic materials, while its renewable source ensures sustainability. The resin's ability to selectively adsorb contaminants, coupled with its potential for regeneration and reuse, presents a cost-effective and efficient approach to wastewater treatment.

Furthermore, the versatility of TTGA resin allows for its application in diverse industrial sectors, addressing a wide range of wastewater challenges. As industrial activities continue to expand globally, the development and implementation of advanced remediation technologies like TTGA resin become increasingly critical. This introduction sets the stage for exploring the synthesis, characterization and application of TTGA resin in industrial wastewater treatment, highlighting its potential to mitigate environmental pollution and contribute to sustainable water management practices.

Material and Methods

0.1 mole of tamarind kernel was taken in a round bottom flask holding dioxane (100 ml) and agitated at a temperature of roughly 5°C with help of external cooling. 7.2 gm cyanuric chloride was further added to this solution. The pH was raised from 7 to 8 by using sodium bicarbonate. This entire mixture was swirled for about two hours. 0.1 mol L-glutamic acid was added to the aforesaid product and the pH was raised from 9 to 10 by adding a concentrated NaOH solution. The mixture was heated at 35 to 40^0C and aggressively swirled for near about 3 hrs using a magnetic stirrer. The newly synthesized Tamarind triazine glutamic acid (TTGA) was filtered, washed in distilled water and dried at 100°C. Scheme 1 depicts the preparation.

Treatment of Effluents: Effluent samples from the Jodhpur region's common outflow of the metallurgical and mineral industries contained heavy metals, paper pulp, mud and turbidity. The features of the effluent samples are displayed in table 1. The column approach was employed to remove heavy metal ions from laboratory synthesised TTGA resin. Using above procedure, the diameter of the resin bed was less than tenth of the height of the column. An exchange resin was supplied within a narrow size range, resulting in a densely packed column. After a few minutes of storage in an open beaker with water, the resin was divided into portions and decanted to remove any remaining small particles before being added to the water-filled column. In the laboratory-scale column experiments, the TTGA resin demonstrated a high capacity for metal ion adsorption.



Scheme 1: Synthesis of TTGA Resin

The narrow size distribution of the resin particles contributed to a densely packed column, enhancing contact between the resin and the metal ions. The ion exchange process was monitored by observing the displacement of sodium ions with metal ions, which was confirmed by the formation of coloured bands during elution. The elution pattern, where the weaker complexes were released first, aligns with findings from similar studies on fixed-bed column systems. Sodium was present as a polymer-bound chelating agent when the metal ion solution was introduced into the column. It later created a chelate and expelled sodium ions.

After the solution was eluted by a perchloric acid solution, a coloured band was created when it went through the resin column. First to be released was the band that formed the weaker complex when two or more cations were present. The amount of metal ions in the eluate was then measured and collected in a flask for analysis. Table 2 shows the concentration of different metal ions following TTGA resin treatment.

Characterization of TTGA resin: The availability of distinct functional groups on the surface of TTGA resin can be determined with the help of FTIR spectra. A peak at 3436.6 cm^{-1} (Fig. 1) represents N-H stretching, indicating the presence of amine groups crucial for metal ion coordination. C-H stretching (asymmetric and symmetric) is indicated by the peaks at 2922.2 cm^{-1} and 2847.7 cm^{-1} respectively, confirming the organic backbone structure of the resin. The peak at 1736.9 cm^{-1} shows the presence of a carbonyl (-C=O) functional group, which is commonly involved in chelation mechanisms. Additional peaks at 1558 cm^{-1}, 1401.5 cm^{-1}, 1360.5 cm^{-1} and 1013.8 cm^{-1} can be attributed to secondary amine N-H bending, C-CH bending, phenolic O-H bending and C-O stretching respectively. These peaks collectively confirm the successful incorporation of tamarind, triazine and glutamic acid moieties into the resin structure. The presence of these diverse functional groups significantly contributes to the resin's strong metal-binding capacity and its efficiency as an ion-exchanging material.

Table 1
Features of effluent samples contaminated with heavy and toxic metal ions

Characteristics	**Effluent Sample (1)**	**Effluent Sample (2)**
Colour	Brown	Colorless
pH	7.8	6.8
Total hardness (ppm)	669	969
Fe^{2+}	44	28
Cu^{2+}	2.2	1.82
Zn^{2+}	4.14	1.14
Pb^{2+}	0.89	0.69
Cd^{2+}	0.45	0.15
Mg^{2+}	88	72
Ca^{2+}	153	133

Table 2
Removal of heavy metal ions from the samples effluents from various metal processing industries.

	Metal ions	**Metal ion concentration in untreated effluent Sample**	**Concentration of metal ion after treatment with lime at 8.0 pH**	**Metal ion concentration after treatment with TTGA resin**
Effluent Sample (1) pH 7.8	Fe^{2+}	44	2.0	Nil
	Cu^{2+}	2.2	2.2	Nil
	Zn^{2+}	4.14	1.0	0.01
	Pb^{2+}	0.89	0.10	Nil
	Cd^{2+}	0.45	0.32	Nil
	Mg^{2+}	88	88	88
	Ca^{2+}	153	82	0.01
Effluent Sample (2) pH 6.8	Fe^{2+}	28	68	0.01
	Cu^{2+}	1.82	0.44	0.01
	Zn^{2+}	1.14	0.02	Nil
	Pb^{2+}	0.69	0.05	Nil
	Cd^{2+}	0.15	0.02	Nil
	Mg^{2+}	72	72	72
	Ca^{2+}	133	133	133

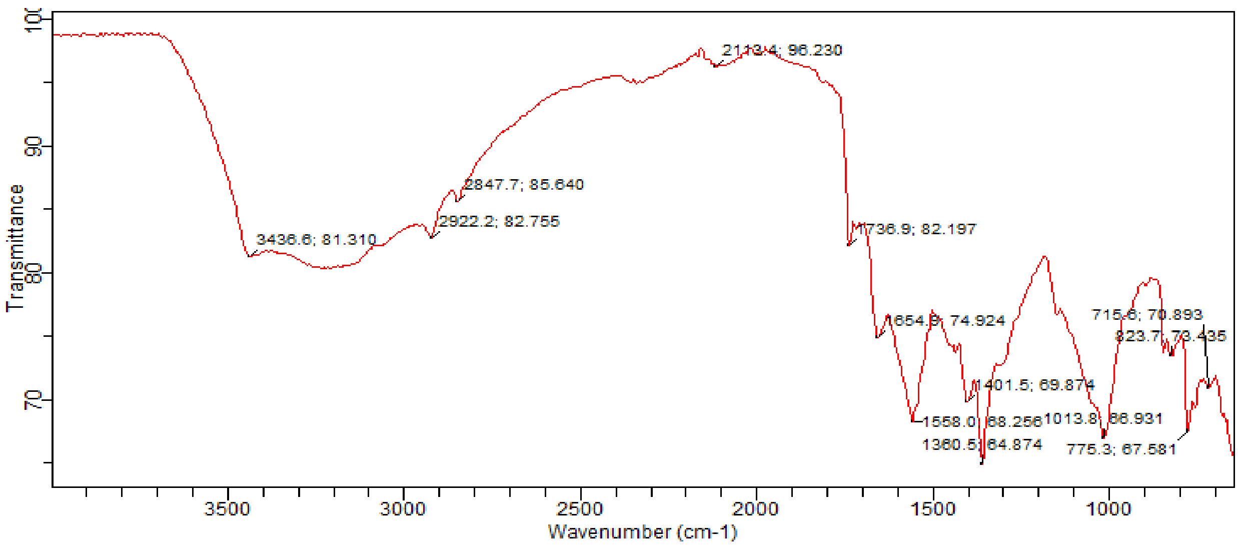


Fig. 1: FTIR Spectra of TTGA - Resin

Table 3
Peaks of FT-IR spectra

Assignment	**Frequency (cm^{-1})**
C-H Stretching	2922.8
-C=O Stretching	1571
CH_2 Stretching	1408
O-H bending	875
N-H Stretching	3270
C-N vibration (aliphatic)	1112

Results and Discussion

The primary cause of metal contamination is industrial effluents. Various industrial processes, including those in the mineral and metals industries, produce industrial effluents. Depending on the metal in question, heavy and toxic metal ions can be released into the natural stream up to their tolerance limit. By using wastewater treatment technology, concentrations of heavy and hazardous metal ions can be reduced to a level that is safe. Based on these discoveries, it is possible to lower the concentration of heavy metal ions in effluents to safer levels by using TKP's secondary amine derivative. The study indicates that ion exchange, adsorption and membrane separation are the most often studied techniques for the remediation of wastewater contaminated with heavy metals.

The ideal treatment strategy is influenced by the wastewater structure, investment and operational costs and environmental implications in the event of elevated metal concentration. Utilizing affordable biosorbents for adsorption, heavy metal effluent can be treated effectively and efficiently. The content of heavy metal ions in industrial effluents has been successfully reduced by TTGA resin to a level significantly lower than that of the beginning stage. Polymeric reagents are particularly useful secondary treatment reagents.

TTGA resin's renewability is by far its greatest benefit. By slightly changing the pH, this can be restored. The treatment of effluents with synthesized resin cannot remove metal ions such as calcium and magnesium, as table 2 illustrates. The cause was the partial dissociation of magnesium and calcium divalent ions seen in these effluent samples. Data from IR strongly support the synthesized resin's suggested structure. The FTIR spectra of the recently synthesized tamarind resin (TTGA), are displayed in fig. 1. The FT-IR spectra have several peaks that can be used to analyze TTGA resin, as shown in table 3. These resins have dual applications as ion binders and flocculants. Polysaccharides, or TKP, are utilized in the preparation of resin. TKP is essentially a flocculent and is employed in large-scale commercial applications. Since reagents are supplied directly to the effluent, the amount of water that can be treated in a single batch is unlimited.

On the other hand, if the resin bed's size and flow rate are variables, the circumstances might alter. The synthesis of TTGA resin involves the functionalization of tamarind kernel powder (TKP) with triazine and glutamic acid, resulting in a resin with enhanced chelating properties. The FTIR analysis confirms the presence of functional groups such as amines and carboxyls, which are pivotal for metal ion binding. These functional groups enable the resin to effectively adsorb heavy metals from aqueous solutions. In column adsorption studies, TTGA resin demonstrated efficient removal of various heavy metals, including lead (Pb^{2+}), copper (Cu^{2+}) and cadmium (Cd^{2+}), under optimal conditions.

The resin's performance was influenced by factors such as pH, flow rate and resin bed height. Notably, the resin exhibited selective adsorption with a preference for certain metal ions over others. This selectivity is attributed to the resin's unique structure and functional groups. The regeneration of TTGA resin was achieved by adjusting the pH, allowing the desorption of adsorbed metal ions and restoring the resin's adsorption capacity. This reusability is a significant advantage, making TTGA resin a cost-effective and sustainable option for large-scale wastewater treatment applications.

In conclusion, TTGA resin synthesized from tamarind kernel powder offers a promising solution for the removal of heavy metals from industrial effluents. Its high adsorption capacity, selectivity and reusability make it an attractive alternative to conventional treatment methods. Future studies should focus on optimizing the synthesis process, exploring the resin's performance in real-world effluents and assessing its long-term stability and environmental impact.

Conclusion

The study's findings demonstrate the successful and rapid uptake of metal ions by the newly synthesized TTGA chelating resin, highlighting its effectiveness in environmental remediation. Notably, the resin’s performance is consistent across varying pH levels, indicating its stability and adaptability in diverse aqueous environments. FTIR analysis confirms the presence of functional groups derived from tamarind, which actively participates in chelation, ion exchange and cross-linking with heavy metals mechanisms crucial for efficient metal adsorption.

The synthesis of TTGA resin using TKP, triazine and glutamic acid offers a sustainable and economically viable approach to water purification. Tamarind kernel powder, a widely available and low-cost natural resource, plays a central role in enhancing the resin’s chelating properties while maintaining its environmental compatibility. TTGA resin is not only hydrophilic and biodegradable, but it can also be safely disposed of without ecological harm, offering a significant advantage over conventional synthetic ion exchangers.

The TTGA resin presents itself as a promising, eco-friendly and efficient alternative for heavy metal remediation. Its synthesis aligns with green chemistry principles and its performance indicates strong potential for industrial-scale applications in wastewater treatment and environmental protection. Continued exploration and optimization of this bio-based resin could lead to broader adoption in sustainable water treatment technologies.

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