Guar Gum Biopolymer: Modification and Application in Separation Technologies

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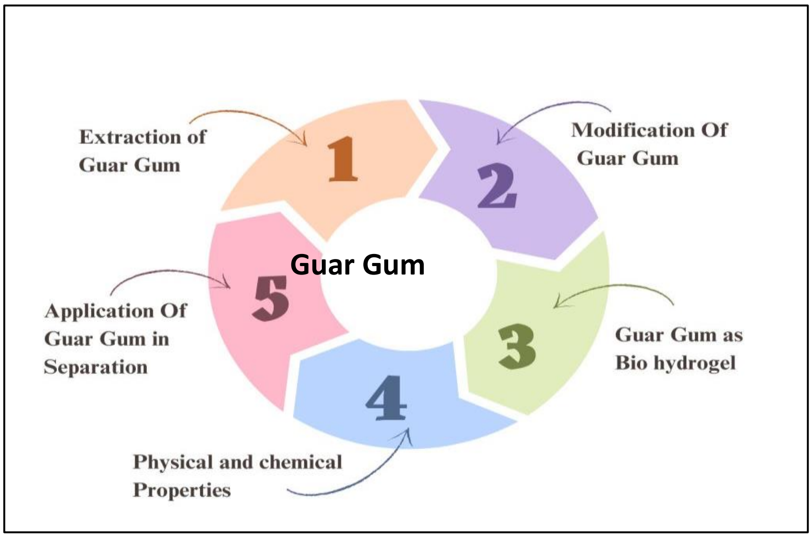
Graphical Abstract



Abstract

Guar gum is a biopolymer derived from the seeds of the Cyamopsis tetragonolobus plant, commonly known as guar, consisting of D-galactose and D-mannose. When added to water, guar gum forms hydrogen bonds facilitated by the presence of rich hydroxyl groups, which leads to a substantial increase in viscosity and thickening of the solution. This imparts significant physical and chemical properties to guar gum enhancing its rheology and fluid properties, which in turn increases viscosity and hydration rate, hence forming a gel-like consistency. In recent decades, extensive research has been conducted on guar gum, focusing on specific chemical-physical modifications such as derivatization, cross-linking, and grafting. Guar gum exhibits remarkable potential with applications extending to various domains including industrial, biomedical, optical, and environment applications. This review gives an insight into the application of bare and modified guar gum in different separation technologies.

Keywords: Guar gum Biopolymer, Galactomannan, Industrial application, Bio hydrogel.

1. Introduction

"In today's world, where we are increasingly conscious of environmental issues and actively seeking sustainable solutions, biopolymers have emerged as crucial players in the quest for eco-friendly alternatives. They offer a promising way to address environmental concerns and meet the growth demand for sustainable materials. Biopolymers are naturally occurring organic substances, found in living organisms like plants and microbes that stand in contrast to petroleum-based polymers. Biopolymers like guar gum, cellulose, chitosan, starch, and xanthan gum are considered ideal materials in scientific applications due to their abundance, biocompatibility, biodegradability, nontoxicity, and efficient adsorption capabilities. These properties enable them to work effectively with living organisms without causing adverse reactions. These distinctive qualities make guar gum extremely valuable for creating advanced and sustainable technologies [1]. Guar gum called guaran is a naturally occurring biopolymer characterized as a galactomannan polysaccharide. It is derived from the endosperm of Cyamopsis tetragonoloba, a plant belonging to the Leguminosae family [2]. Guar gum has a wide range of applications in different fields due to its intrinsic structure and characteristics. By modifying raw guar gum produces derivatives, composites, mixtures, etc. that introduce novel functional groups while preserving the inherent properties of guar gum to a great extent. Guar gum can undergo modifications through methods like carboxymethylation, hydroxypropyl derivatives and chemical derivatization. These methods introduce distinct characteristics to guar gum, enhancing its versatility as a biopolymer. Guar gum hydrogels are complex structures with a dense network of crosslinks and absorb water. They exhibit high hydrophilic characteristics, and a large swelling ratio, and are biocompatible for various applications like drug delivery, biosensors, and agriculture. Exploring the modification techniques helps to understand the adaptability of guar gum and its utilization in separation techniques for example in paper manufacturing it can be added to ink to improve its properties and increase the thickness of the paper [3]. Guar gum powder find applications in wide range of industries like cosmetics formulations, while in textiles; it is used for dyeing and printing. It also have benefits in paper manufacturing and pharmaceutical's. Therefore, guar gum powder have diverse applications. Overall, guar gum's unique combination of adhesive capabilities and ecological capabilities position it as a valuable resource in the pursuit of sustainable innovation. Its contribution extends far beyond its binding properties, offering a promising avenue for the creation of environmentally benign technologies that cater to the needs of various industries while upholding ecological responsibility.

2. Guar gum:

Guar gum also known as Guran, a naturally occurring biological polymer classified as a galactomannan polysaccharide. Extracted from the guar beans, derived from the endosperm of Cyamopsis tetragonoloba, a member of the Leguminosae family. Based on the literature survey, the guar gum industry in the United States experienced significantly growth during the 1940s and 1950s. Before World War 1, primarily imported for green manure, but its industrial use began in 1943. In India and Pakistan are the primary cultivators of guar, accounting for 90% of global production. In India, the Rajasthan state alone contributes 84.5% of the total guar seed output.

During the fiscal year, 2013-201, India produced approximately 650 tonnes, with over 50% of the exports directed towards the USA. Notably, the introduction of substances like boron and calcium can initiate a cross-linking process, leading to the formulation of a gel structure with guar gum [4]. This gel has about eight times the water-thickening capacity of other agents, reducing costs. It can also meet requirements with smaller quantities. Scientists use these methods to study guar gum's molecular composition, enhancing its characterization and expanding its application in different industries [5].

3. Properties of Guar gum:

Guar gum is available in different particle sizes, from coarse to fine powder. Its exhibits stability within a pH range between 5.5 and 7.0. The viscosity of guar gum influenced by factors like concentration and temperature, imparts unique characteristics to solutions. Visually, guar gum appears as a white to yellowish-white powder and easily dissolves in hot and cold water, forming thick solutions. These properties may contribute to its wide range of applications across various industries. Moreover, when it comes to studying how materials flow and change shape that is the rheology is all about! In aqueous solutions, guar gum exhibits thinning behaviour, which means viscosity decrease with higher shear rates. The factors like the amount of guar gum and its size affect its behaviour. In 1% aqueous solution exhibits a high viscosity of 10,000 Cp and behaves as a macromolecular biopolymer [6]. The hydration of guar gm takes about 2 hours to reach its maximum thickness [7].

4. Extraction of Guar gum:-

The process of obtaining guar gum from guar seeds involves several stages of mechanical processing to isolate the endosperm, which is rich in galactomannan. Initially, the endosperm extracted from the husk (outer covering) and embryo (germinating part) of the guar seed. This extraction process involves multiple steps shown in fig:1 like grinding and sieving, paired with additional physical treatments designed to break and separate the different components of the seeds [8].

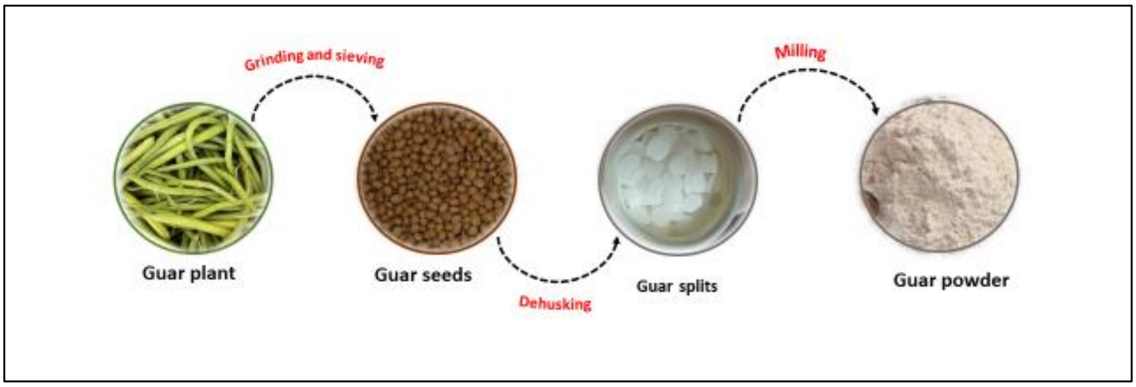


Fig:1 Extraction of Guar gum

Once successfully separating the endosperm from the guar seed, referred to as "guar splits". These guar splits, containing the galactomannan, and then further processed by grinding them into a fine powder, which is the marketable form of guar gum [9]. Guar gum a polysaccharide is composed of repeating units of galactose and mannose sugars.

In Fig:2, a schematic diagram illustrates the chemical structure of guar gum, where galactose units are linearly attached to the mannose backbone. This arrangement forms a structure known as a galactomannan [10].

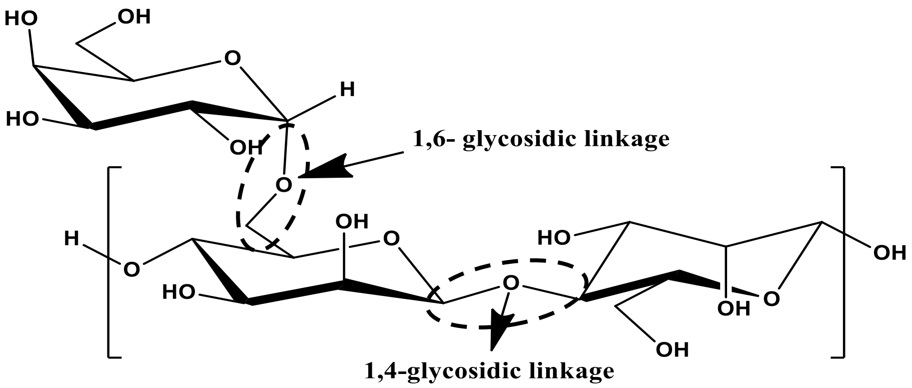


Fig: 2 Chemical structure of Guar Gum

Typically the galactose units are linked to the mannose backbone through β-1,4-glysosidic Bonds The galactose-to-mannose ratio in guar gum can vary depending on the source and processing methods. However, in the typical galactomannan structure of guar gum, the galactose parts remain attached at regular intervals on the mannose backbone, creating a polymer with distinct characteristics like solubility, viscosity, and functionality that make it

valuable in various industrial applications [11]. This distribution of galactose and mannose unit visually represented in Fig.3 elucidation the arrangement and relative abundance of these sugar units within the guar gum structure.

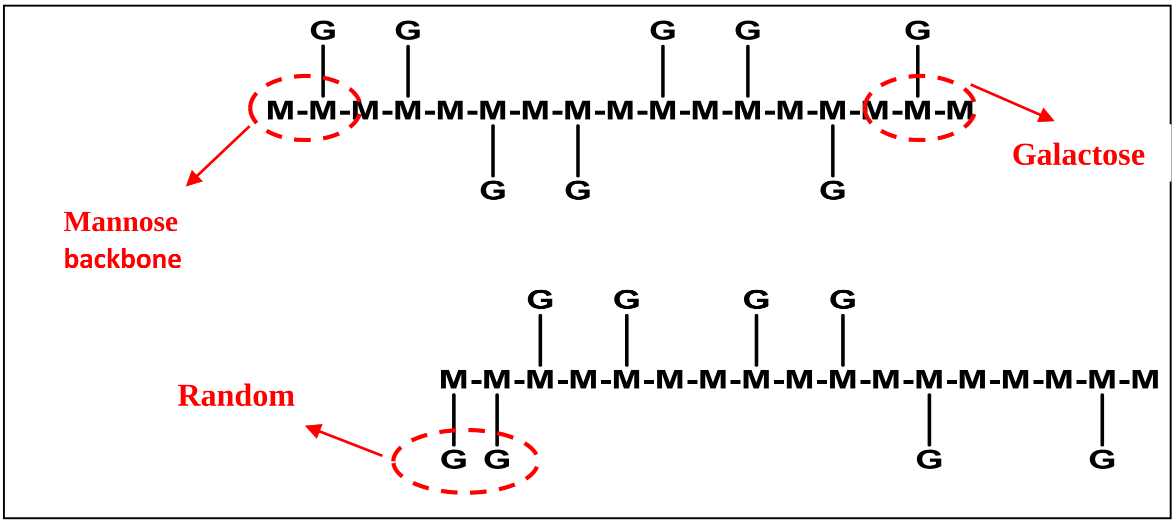


Fig: 3 Regular and Irregular intervals of Galactose and mannose

Chemical modification on Guar gum:

Gums have a wide range of applications on different fields due to their intrinsic structure and characteristics. However natural gum itself has certain limitations and may not meet all the specific requirements of applications [12]. Modifying these raw gums produces hybrid derivatives that only retain the inherent advantages of gums to the highest extent [13].

The processes include methyl etherification sulfation, hydroxyalkylation, and carboxymethylation. In the case of methyl etherification, guar gum undergoes a chemical modification that introduces methoxyl groups to the polysaccharide chains [14]. Methyl etherification is a specific derivatization technique where guar gum partially modified under heterogeneous reaction conditions, resulting in the creation of products like methyl ether guar gum with different degrees of substitution. The incorporation of methoxyl groups into the polysaccharide chains plays an important role in modifying the properties of guar gum [15].

5.1. Derivatization of Guar gum:

The chemical and structural modifications of guar gum performed my adding different functional groups known as derivatization. This transformation enhances specific properties like solubility and viscosity. Many industrial processes include methods like carboxymethylation, Hydroxypropylation and acylation to modify guar gum [16]. These modified guar gums have strong thickening properties and in various applications. Some other derivatives of guar gum such as hydroxypropyl guar gum, methyl methacrylate guar gum and methylated guar gum, sulphated guar gum, etc. are conducted to prepare, analyze and evaluate for their utility across different fields [17].

5.1.1. Guar gum can modify by mixing it with methyl methacrylate through graft-copolymerization modification this process is illustrated in fig; 4. Sharma and Kumar conducted an experiment using ceric ammonium nitrate-nitric acid as an initiator in water. They measured the percentage of guar gum that reacted with methyl acrylate (%G) and how effectively it happened (%G). This modifications breakthrough has the potential as a thickening agent in culinary products improving stability and the overall quality [18].

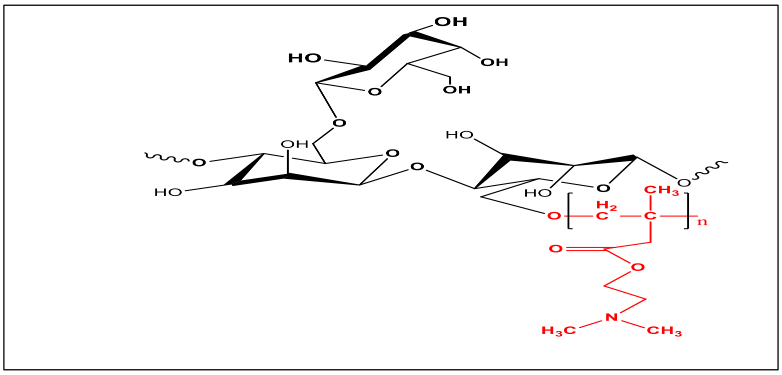


Fig 4: Graft Copolymerization

5.1.2. There are three processes used to obtain hydroxypropyl guar derivatives with carboxymethylation modulated by polyalkoxyalkylene amines: amidation utilizing a sequence of polyalkoxyalkylene amines, esterification with dimethyl sulphate and carboxymethylation using sodium chloroacetate [19].

5.1.3. In 2008, Mazhar Pasha developed a derivative of hydroxypropyl guar known as sodium carboxymethyl hydroxypropyl guar (NaCMHPG). This modification achieved through a reaction involving guar, propylene oxide, and monochlorosodium acetate. When used in a water-based medium, this derivative demonstrates significant potential in pharmaceuticals applications. Specifically, it serves as a viscosity-imparting agent for controlled-release tablets and as a thickening agent for water-based gels [20].

5.1.4. Acetylated guar gum has obtained by interacting guar gum with acetic acids, pyridine and vinyl acetate. This derivative has an impact of acetylation on the functional groups of guar gum: n 2015 scientist conducted this study by exploring the potential application of acetylated guar gum (AGG) as a sustainable renewable additive in various industrial applications [21].

5.1.5. Guar gum undergoes methylation with methyl groups added to its structure through a reaction with a methylating agent, such as dimethyl sulphate and methyl iodide. The addition of methyl groups improves its stability and solubility. This modified form of guar gum is used for binding and disintegration properties for tablet formulation [22].

5.2.Other modifications of Guar gum:-

Other modifications of guar gum is tabulated below in table 1

S.No.	Guar gum modification type	Initiated by	Application	Reference
1.	Methyl methacrylate onto guar gym	Ceric ammonium nitrate-nitric acid	Controlled drug delivery system	[18]
2.	Sodium carboxymethyl grafted with polyacrylamide	Propylene oxide and monochloroacetic acid	In the field of enhanced oil recovery (EOR)	[20]
3.	Carboxymethyl guar gum grafted with polyacrylamide	Potassium Persulphate solution	Treatment of wastewater	[23]
4.	The acryloyl chloride esterification onto guar gum	Acryloyl chloride and methacryloyl chlorides	The realm of water treatment	[24]
5.	Methylation of guar gum	Methyl iodide or dimethyl sulphate	The binding and disintegration properties, for tablet formulation.	[22]
6.	Hydroxypropyl group on to guar gum	Docosylglycidylether in isopropyl alcohol presence of catalyst	Production of biodegradable films an in oil & gas for hydraulic fracturing fluids	[25]
7.	By etherification, guar gum is linked with polystyrene	(PMDETA).ascorbic acid and styrene	Petroleum industry and materials engineering	[26]
8.	Grafting guar gum onto the carbon nanotubes surfaces	Catalytic synthesis of ethylene and propylene using F/Al2O3 catalyst	To eliminate dye from water	[27]
9.	Acrylamide onto guar gum	Potassium bromate and thiourea dioxide as redox system	Removal of metal ions from waste water	[28]
10.	Polyaniline on guar gum	Ammonium Peroxodisulfate, N-methyl-2-prrolidone and ammonium	Environmentally friendly semiconductors and fabrication of various electronic devices	[29]
11.	Carboxymethyl guar gum on silver nanoparticles	Silver nitrate and a mixture of all aqueous solutions	Ammonium sensor used for clinical and medical diagnosis	[30]

12.	Oxidized guar gum to guar gum Nano-zinc oxide	Zinc acetate and sodium hydroxide	Production of antibacterial composites of ZnO	[31]
13.	2-Hydroxy-3-butoxy propyl guar gum (HBPG)	Sodium hydroxide as a catalyst and 2-propanol	For enhancing stability and rheological properties	[32]
14.	Copolymerization of ethyl acrylate onto guar gum	Potassium Persulphate	Removal of metal ions	[18]
15.	Acetylated guar gum	Acetic acids, pyridine and vinyl acetate	Sustainable renewable additive	[21]

Table 1: Other modifications of guar gum

6. Advantages of Guar gum as a bio-hydrogel:

Guar gum exhibits several advantages when employed as a bio-hydrogel gel, making it a valuable material in biomedical and technological applications. One notable advantage is its water solubility, allowing for easy dispersion and formulation into hydrogels. This characteristic enables Guar gum to create hydrogel systems with desirable properties for drug delivery and tissue engineering applications. Additionally guar gum has high viscosity in solution. Even at low concentrations, contributes to the formulation of stable and rebuts hydrogels. The ability to control viscosity is crucial for tailoring the hydro gel's mechanical properties to meet specific application requirements. Moreover, guar gum's biocompatibility ensures minimal adverse reactions when interacting with biological systems, making it suitable for medical and pharmaceutical purposes. Its natural origin and non-toxic nature further enhance its appeal for use in bio-hydrogels. Guar gum's capacity to absorb and retain water, along with its gel-forming abilities, make it advantageous for creating drug release. Overall, the advantages of guar gum as a bio-hydrogel position it as a versatile and promising material in the realm of advanced biomedical technologies. Guar gum hydrogels fine use in wound healing and tissue engineering. The hydrogels capacity to hold water and furnish a moist environment supports the healing process, while its compatibility with biological systems makes it suitable for tissue engineering applications [2].

7. Applications of Guar gum.

Guar gum powder used in various industries for different purposes. In paper, manufacturing enhancing the strength of the paper. In pharmaceuticals, it could be part of the ingredients I medicines. In printing, guar gum powder used in the ink to improve its properties [33]. Cosmetics could contain Guar gum powder for its texture or thickening abilities. Therefore, guar gum powder is quite versatile and finds applications in paper, pharmaceuticals, printing, cosmetics, and textiles for different beneficial reasons [3].

Some of the applications in Separation technologies are

Industrial applications: -

7.1 Oil and Gas Industry:

In the oil and gas industry, guar gum plays a crucial role, particularly in the process of hydraulic fracturing, commonly known as fracking.

Guar gum utilized as a key component in the formulation of drilling fluids used in this extraction technique. Its exceptional viscosity-modifying properties make it an ideal additive to maintain the viscosity of drilling fluids. This is essential for preventing the settling of solid particles and ensuring the efficient transportation of prop pants into fractures during the fracturing process [34]. Guar gum's ability to withstand high temperatures and pressures in deep reservoirs make it particularly valuable in the challenging conditions of oil and gas extraction. As a result, guar gum significantly contributes to the success and efficiency of hydraulic fracturing operations in the Oil and Gas industry.

7.2 Pharmaceutical Industry:

In the pharmaceutical industry, guar gum plays a pivotal role in various applications owing to its unique properties. One significant use of guar gum is as a binder and disintegrant in tablet formulations [35]. When included in the production of tablets, guar gum helps the active pharmaceutical ingredients together, contributing to the structural integrity of the tablet.

- Guar gum utilized in the preparation of the suspensions and syrups, providing stability to these liquid pharmaceutical formulations. Its thickening and stabilizing properties contribute to the uniform distribution of pharmaceutical ingredients in liquid medications.
- The pharmaceuticals industry enhances the formulations and effectiveness of various dosage forms, ensuring proper drug delivery, stability and patient acceptance. Its biocompatibility and safety make it a preferred choice in pharmaceutical formulations [36].

7.3 Textile Industry:

Guar gum plays a crucial role in the textile industry by enhancing sizing, dying, printing and finishing processes. Its unique properties contribute to the overall quality, appearance and texture of textiles, making it a valuable component in various stages of textile manufacturing.

- One significant use of Guar gum is in the sizing process, where its acts as a sizing agent. Sizing is crucial in textile manufacturing as it involves applying a substance to the yarn or fabric to improve its strength, smoothness, and resistance to abrasion during subsequent processing [6].
- Guar gum's ability to control viscosity and form stable gels harnessed in the dyeing and printing processes. It is used as a thickening and binding agent in the preparation of dye solutions and printing pastes. The controlled viscosity ensures the even dispersion of dyes and pigments, leading to uniform and vibrant coloration of fabrics [3].
- Guar gum utilized in the production of handcrafted textiles, where it acts as a binder for various decorative elements such as sequins or beads. This application helps secure embellishments onto fabrics during the manufacturing process [37].

7.4 Environmental Applications:-

In the field of wastewater treatment, Guar gum emerges as a versatile and valuable component [38]. Guar gum employed as a flocculent, a substance that promotes the aggregation and settling of suspended particles in water. Its unique ability to form a gel-like structure becomes instrumental in the process of flocculation. During wastewater treatment, various impurities and solid particles need to separate from the water to achieve a cleaner and safer effluent. Guar gum aids in this separation by facilitating the binding together of fine particles, forming larger flocs that settle more easily [39]. This process enhances the efficiency of sedimentation and filtration stages in wastewater treatment plants, ultimately leading to the separation of solids from water.

Guar gum's effectiveness as a flocculants makes it an essential component in the pursuit of cleaner water and more efficient wastewater treatment processes [40]. Its biodegradable and environmentally friendly nature further contributes to its suitability in sustainable wastewater treatment practices.

8. Future scope:-

The future perspective of Guar gum holds promise and influenced by a confluence of factors across various industries. With an increasing, global on sustainability, the eco-friendly and biodegradable nature of Guar gum positions it favourably in the context of evolving environmental consciousness. The ongoing demand for green alternatives in industries such as food, textiles, and pharmaceuticals could propel the continued exploration and adoption of Guar gum. In the oil and has sector, the future of Guar gum closely tied to the trajectory of the energy industry and advancements in extraction technologies. As innovations in research and technology unfold, there is the potential for discovering new applications and refining extraction methods, leading to expanded markets and increased demand for Guar gum products. In the food industry, the trend towards health and wellness could contribute to sustained demand for natural thickeners and stabilizers, with guar gum serving as an attractive alternative to synthetic additives. Moreover, ongoing research and advancements in the textile and pharmaceutical sectors may uncover new application for Guar gum market will influenced by economic factors, global trade policies, and geopolitical considerations. Fluctuations in prices, supply chain disruptions, or changes in demand from major consumer markets may affect the industry's trajectory.

Conclusion:

Guar gum biopolymer stands as a promising biomaterial with the capacity to revolutionize separation technologies, offering solutions that not only meet the demands of various industries but also align with the growing emphasis on sustainability and environmental responsibility. As we advance into the future, the continued exploration and development of guar gum biopolymer hold the potential to contribute significantly to a more sustainable and efficient industrial landscape. As research in this field continues to evolve, further investigation to optimize the modification processes and to uncover new application for guar gum biopolymer in separation technologies. Additionally, exploring its compatibility with emerging technologies such as nanotechnology and membrane processes could open avenues for innovation and efficiency.

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