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Chitosan Microspheres for Oil Spill Treatment

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Abstract | **Original Research Article**

Oil spills pose significant environmental challenges, leading to ecological degradation and threats to marine life. Traditional methods for oil spill remediation often fall short in terms of efficiency and environmental compatibility. This study explores the application of chitosan microspheres as a novel approach to addressing oil spills. Chitosan, a biopolymer derived from chitin, exhibits unique properties such as biodegradability, non-toxicity, and a high affinity for hydrocarbons, making it an excellent candidate for oil sorption. The study also discusses the potential for reusability of the microspheres and their implications for sustainable oil spill management strategies. Overall, this review highlights the promise of chitosan microspheres as a feasible, eco-friendly solution for mitigating the impacts of oil spills, paving the way for further advancements and applications in environmental remediation.

Keywords: Chitosan, Oil, Biodegradation, Microspheres, Treatment.

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INTRODUCTION

Petroleum is extracted along with a significant volume of water. While the majority of this oil-field wastewater is not emulsified, a sizeable amount is, necessitating both chemical and physical treatment techniques. Only when the oil and suspended particles have been removed and reduced to appropriate levels is this oilfield waste water allowed to be discharged or even re-injected [1].

The limited amount of water that may be utilized directly without risk and the high expense of purification systems make the purification of waste water from diverse industrial operations a major worldwide issue [2]. More stringent laws and regulations have led to a recent surge in interest in appropriate methods for treating wastewater and other effluents.

Numerous methods for treating tainted wastewater and other effluents are documented in the literature [3]. Currently, various technologies and procedures are employed for this [4,1]. Adsorption is unique among these treatment modalities in that it is affordable, effective, and efficient [5]. Adsorbents can come from biological, organic, or mineral sources [6]. Organic pollutants have been extensively removed from natural waters and industrial wastewaters using polymeric adsorbents [7].

Because of their high concentration of hydroxyl and amino functional groups and low cost, derivatives of chitin and chitosan have garnered a lot of interest as efficient bio-sorbents with the potential to remove a wide range of pollutants from water [8]. Because of its qualities, which include nontoxicity, abundance in nature, biocompatibility, and biodegradability, it has been used extensively [9].

Because of its bioactivity, adhesion, biodegradability, and biocompatibility, chitosan is one of the most researched biopolymers. Second only to cellulose in the world in terms of biopolymer abundance, chitosan has piqued the interest of researchers who are working to create novel and sustainable materials based on it. However, its affordability also contributes to its suitability as a material [1]. Among the many industries and applications for

chitosan are those in food, textile, medicine, pharmacy, and agriculture [2–6].
However, recent advances in biomedicine, biotechnology, wastewater treatment, catalysis, packaging, and bio-imaging are crucial for ushering in a new sustainable era in which chitosan can offer affordability, versatility, and recyclability. Because of its biodegradability, bioactivity, and method of extraction, chitosan's nature and qualities make it suitable for use in sustainable projects. However, there are also certain applications where chitosan can be very useful in terms of cost, yield, and efficiency. In this field, chitosan is most likely most useful when it comes to treating wastewater, absorbing pollutants, or using it as a chelation agent, an antiviral agent, or a replacement material in the paper industry [7]. A few of these new developments use chitosan to prepare composites or functionalized materials, like soot and chitosan aerogels. There are several studies utilizing chitosan in the re-motion of oil in addition to its widespread use in water treatment, particularly in the removal of metals, dyes, and phenols.

Production of Chitosan

Chemical (figure 1) and biological (figure 2) techniques can be used to extract chitin and chitosan from the exoskeleton [9,10]. Compared to the chemical method, the biological method of producing chitin has a higher viscosity, is more cost-effective and environmentally friendly (depending on the microorganism used), and has excellent decalcification efficacy (up to 86%). The remaining proteins in the shrimp shell are likewise reduced by the natural method. Additionally, research has shown that biological processes yield chitosan of a higher quality than that of the chemical method [11].

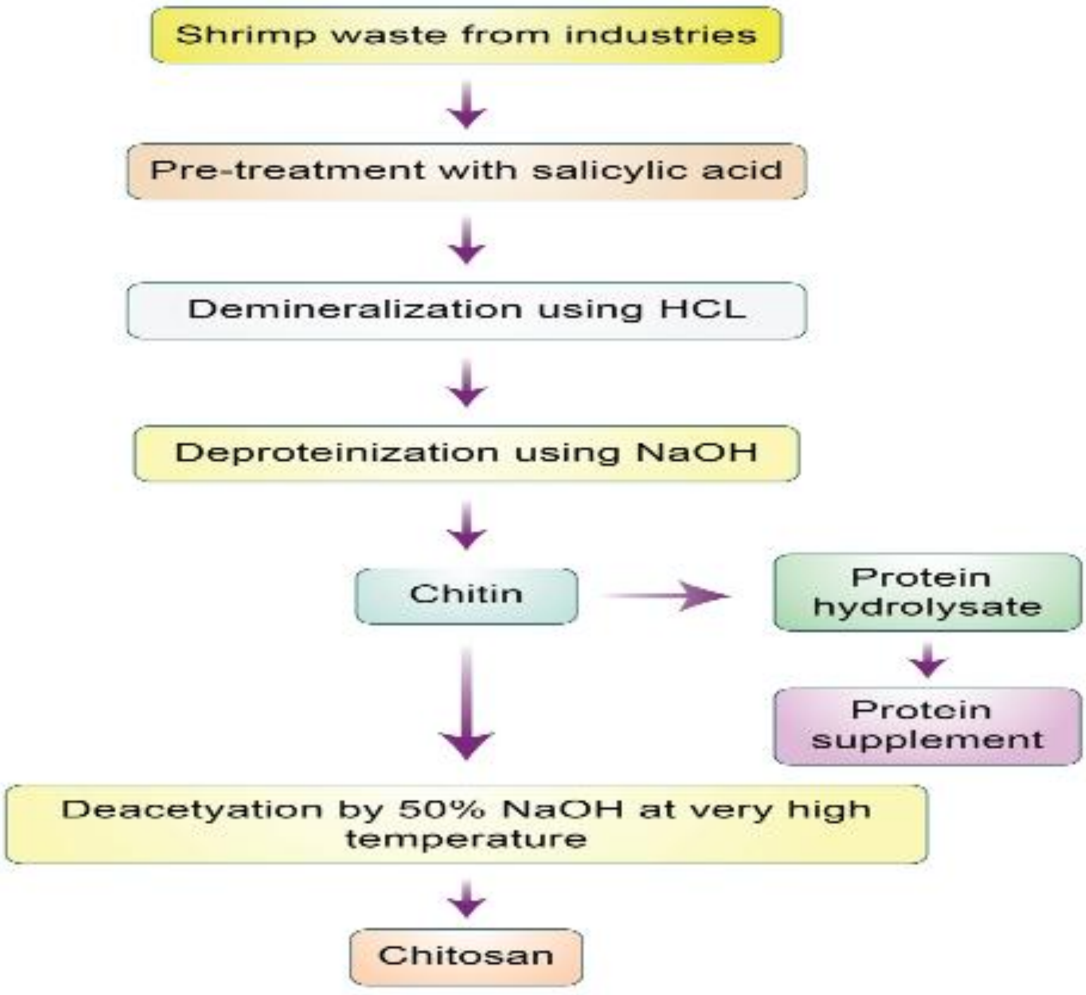

Figure 1: Chitin and chitosan production flowchart using a chemical approach. The fundamental processes of demineralization, deproteinization, and chitosan production in the chemical method of producing chitin and chitosan are carried out by various chemicals, such as HCL, NaOH, etc. [9,10].

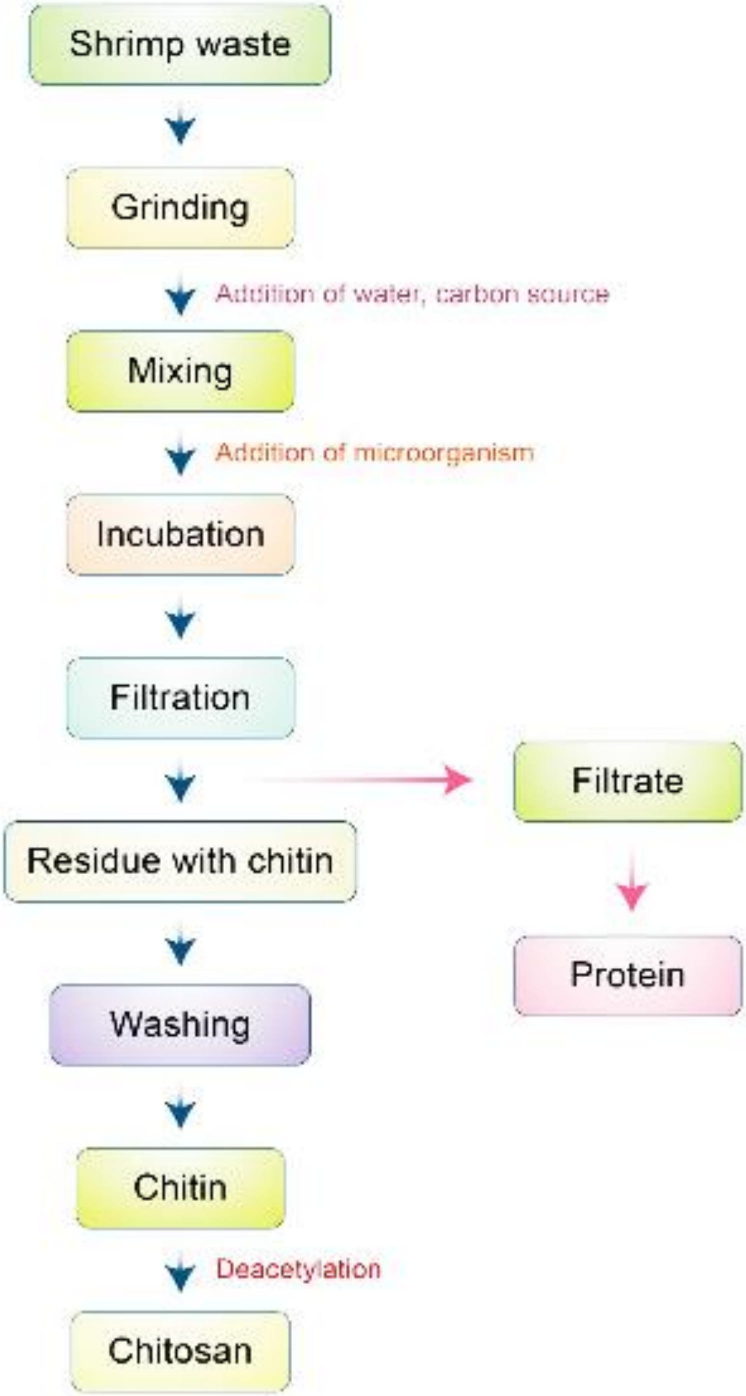

Figure 2: Chitin and chitosan production flowchart using an enzymatic approach. Enzymes such as trypsin, alcalase, pepsin, and others carry out the fundamental processes of demineralization, deproteinization, and chitosan production in the chemical process of producing chitin and chitosan [9,10].

Deacetylation of Chitin to Produce Chitosan

One of the most common biomaterials after cellulose is chitin, which can be converted to chitosan by deacetylating it. This polysaccharide is present in fungi, insects, and crustaceans (Table 1) [12]. Chitin, made up of N-acetyl glucosamine, is a linear long-chain homopolymer that can take on three polymorphic forms: chitin-α, chitin-β, and chitin-γ [13].

Table 1: Some major sources of chitin and percentages [12]

Source	Percentage
Krill	20 – 30%
Fungi	10 – 25%
Shrimps	30 – 40%
Crabs	15 – 30%
Oysters	3 – 6%
Clams	3 – 6%
Squids	20 – 40%
Insects	5 – 25%

Commercial chitosan (Figure 3) is made from partially deacetylated chitin and contains D-glucosamine and N-acetyl glucosamine. Acetamido groups are changed into amino groups by this reaction. Depending on its molecular weight, this biopolymer comes in three different forms: oligochitosans, high molecular weight, and low molecular weight [14].

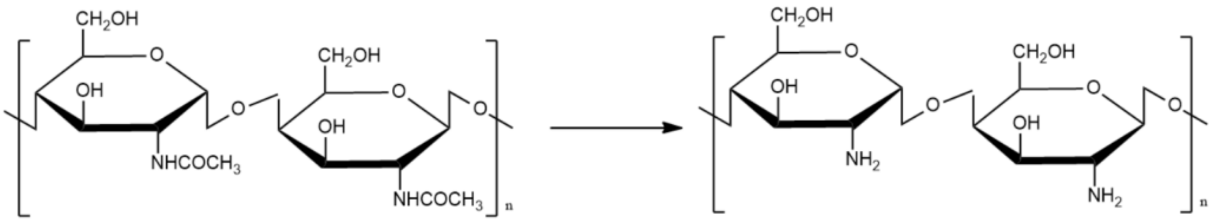

Figure 3: Deacetylation of chitin to produce chitosan [14]

Waste Water Treatment

The chemical pollution of water by a variety of hazardous substances, including dyes, heavy metals, aromatic compounds, and more. This is a significant environmental issue that could have detrimental effects on people's health. These days, it's common knowledge that inexpensive chitin and chitosan are beneficial for treating wastewater. Researchers have investigated how the characteristics of chitosan affect the adsorption of organic compounds, dyes, and heavy metals and discovered a new method for eliminating ananionic dyes: the use of chitosan-based material [16]. Aquaculture waste water has been treated using chitosan as a bactericide, coagulant, and adsorbent. Samples of chitosan with low molecular weight and high Deacetylation degree (DD) are more effective at coagulating and flocculating organic suspensions at pH values near neutrality and low ionic strength [15,16].

Oil Spill Treatment

There are currently three main types of oil spills on sea surfaces that can be cleaned up and recovered using different methods and techniques (Figure 4). Three methods are available: chemical, biological, and mechanical [17]. These techniques can be chosen singly or in combination, depending on the actual conditions of sea surfaces covered in oil spills. The chemical method entails burning in place, using dispersants to disperse, and using solidifiers to solidify the mixture [17]. Oil spills can be quickly and effectively cleaned up by in situ burning; however, the hazardous emissions that is released during the burning process such as carbon dioxide, aromatic hydrocarbons, nitrogen oxides, etc. cause significant secondary pollution to the atmosphere.

By adopting surfactants or solidifiers and interacting or reacting with oil, dispersive and solidification methods remove oil contamination while utilizing hazardous and non-sustainable chemical materials. The biological method uses particular microorganisms (such as bacteria, algae, fungi, etc.) to naturally biodegrade the oil into simple and non-toxic molecules [18]. Because of the introduction of exotic species, the marine environment may become secondarily contaminated. In comparison to chemical and biological methods, the mechanical method of recovering oil spills involves the use of specialized equipment like booms, skimmers, and sorbents. This approach poses the least environmental harm [19, 20]. The most appealing approach out of all of them is to use oil sorbents to clean up oil spills in water because they are recyclable, inexpensive, and allow for the complete collection and recovery of oil from water surfaces. As a result, the use of sorbents in oil spill cleanup has drawn more attention, particularly in regards to the creation of effective and environmentally friendly oil sorbents.

Based on the characteristics of the materials, oil sorbents can generally be divided into three main groups: inorganic, synthetic, and natural materials. Each group has advantages and disadvantages of its own. Natural or processed minerals or inorganic materials, such as zeolites, silica, activated carbon, etc., are examples of inorganic sorbents [19,21,22]. These sorbents, which are classified as universal sorbents because of their fine grain, porous nature, and high density, also offer the benefits of a large surface area, chemical inertness, no flammability, and ease of availability. Nevertheless, their low oil sorption capacity, low separating efficiency, and difficulty of recovery restrict their further use in oil/water separation. Polymers created artificially, such as polypropylene, polyethylene, polystyrene, and polyurethane, are examples of synthetic sorbents. Despite their inherent hydrophobic qualities, high sorption capacity, and good reusability, their non-biodegradability raises concerns about their potential effects on the environment and ecology. Natural sorbents have the benefits of being plentiful, affordable, biodegradable, and environmentally friendly. Examples of these include straw, cotton, and fruit peels. Even with low selectivity, low hydrophobicity, and low capacity, researchers continue to make great efforts to develop effective natural sorbents and advance their industrialization.

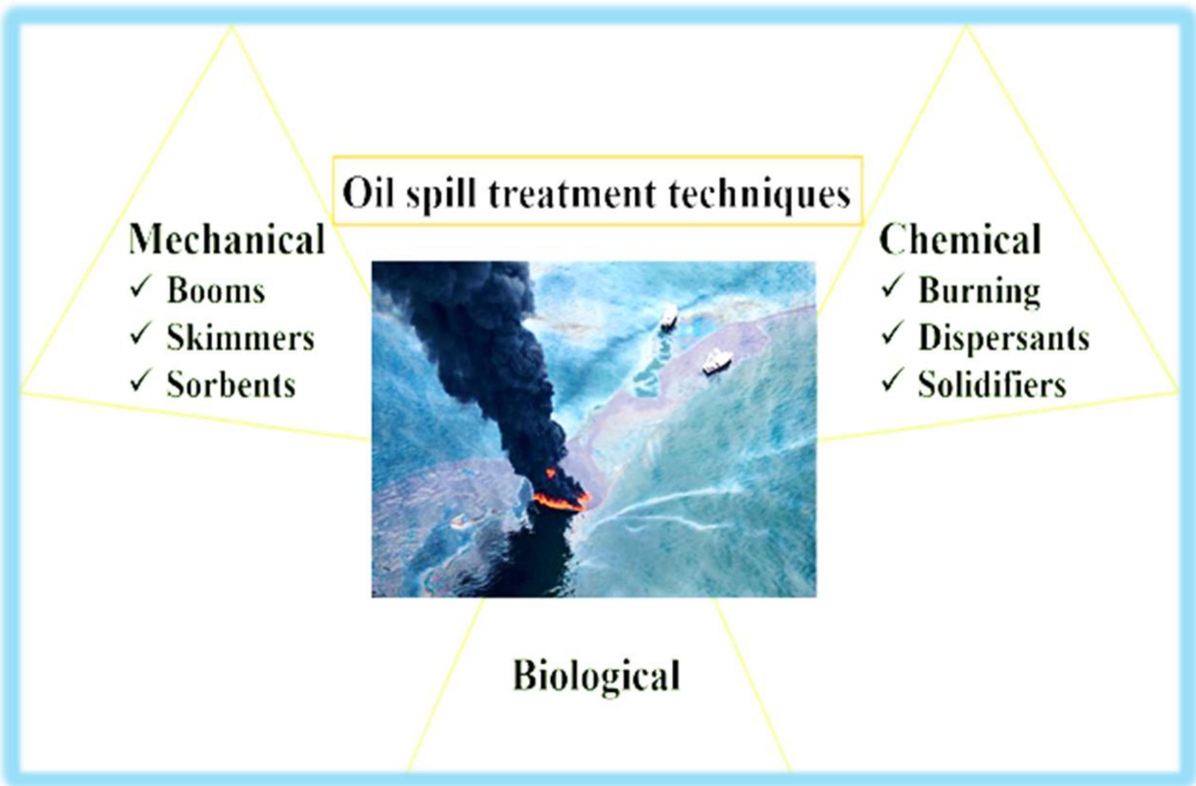

Figure 4: Three types of main techniques used for treating oil spills [17].

Chitosan in Treatment of Oil Spill

Because it can maintain the integrity of the oil mass, chitosan is used to clean up oil spills. Its qualities are also demonstrated for anionic waste, in which the metal ions in the acid solutions can be eliminated by chitosan. A study comparing the use of chitosan with other natural adsorbents (bentonite and activated carbon) in a jar test for oil removal found that it was more effective in removing a residual oil mill effluent from palm oil [18,22]. In a different study, the adsorption capacity of chitosan flakes used as an adsorbent to remove pollutants from biodiesel wastewater was found to be approximately 67% lower than the initial oil and grease level [23]. In another study, the authors used chitosan powder and flake to compare the adsorption of residue oil from palm oil mill effluent; they found that the powder had better results because of its larger surface area [24].

Grem *et al*. (2013) study [25] demonstrates the effectiveness of chitosan microspheres in eliminating oil. The outcomes demonstrate that the chitosan microspheres, which were employed as natural polymeric resins, work effectively to remove heavy oil from produced water. At the start of the test, the adsorption efficiency was more than 90%, meaning that more than 180 ppm of this oil was removed from oily water for both flows that were used [21]. Having the lowest flow resulted in a much higher volume of treated water during the test, demonstrating how much the flow reduction affected efficiency. It is materially present high capacity for this application, given that the incoming water had an oil concentration of about 200 parts per million and the output was below the 29 parts per million limits established by Brazilian environmental legislation. In addition, the microspheres demonstrated strong resistance, holding their spherical shape under pressure in the elution column [25].

CONCLUSION

Chitosan microspheres demonstrate a significant ability to absorb various types of oils due to their porous structure and the presence of amino and hydroxyl groups, which interact effectively with hydrophobic molecules. As a natural polymer, chitosan is biodegradable, which reduces the environmental impact post-remediation, unlike many synthetic absorbents that can contribute to pollution.

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