Short Communication

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2022.46.007295

Nano Chitosan Coated Cotton Fiber (NCCCF) for the Removal of Heavy Metals from Industrial Effluents

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ARTICLE INFO

Received: August 27, 2022

Published: September 09, 2022

Citation: Marufuzzaman, Firoz Ahmed and Md. Ibrahim H Mondal. Nano Chitosan Coated Cotton Fiber (NCCCF) for the Removal of Heavy Metals from Industrial Effluents. Biomed J Sci & Tech Res 46(1)-2022. BJSTR. MS.ID.007295.

ABSTRACT

Chitosan nanoparticles were prepared by crosslinking chitosan with sodium tripolyphosphate. Chitosan nanoparticles (chitosan NP) were effectively coated on cotton fiber surfaces during adsorption using citric acid as a crosslinking agent. The attachment of nano-chitosan onto cotton fiber was confirmed by Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). Nano chitosan Coated Cotton Fiber (NCCCF) was used in the removal of heavy metals, such as Cr, Cd and Ni from water samples. The effect of parameters, such as temperature, pH, contact time, and the adsorbent dosage was investigated to know the kinetics and thermodynamics of the adsorption. The experimental isotherm data were analyzed using the Langmuir equation for each sample and the enhanced equilibrium adsorption capacity (Qe) of NCCCF has calculated which results were 3.85 mmol/g, 2.31 mmol/g and 2.75 mmol/g for Cr^{6+}, $Cd^{2+}$and Ni^{2+} respectively. Antimicrobial properties were also developed in the cotton fibers after the crosslinking of nano chitosan.

Keywords: Nano Chitosan; Cotton Fiber; Antimicrobial; Heavy Metals

Introduction

Worldwide water request has been continually expanding to satisfy the developing requirements of food creation and the food of the human populace [1]. Water from horticultural, homegrown, and mechanical exercises is delivered into the climate as wastewater [2]. Water contamination is among the rising need worries in the 21st century, for both developing and developed nations [3]. A huge number of water toxins have been contaminating worldwide waters for more than fifty years. These incorporate natural and inorganic miniature toxins, poisonous substantial metals, metalloids, supplements, and manufactured natural synthetics. [2-4]. Innovative work on various materials and methods has uncovered a few promising roads in such a manner. Wastewater impurities, particularly heavy metals, can be taken out from wastewater utilizing various grounded strategies. These incorporate adsorption, nanofiltration, turn-around assimilation, dissolvable extraction, substance precipitation, buoyancy, coagulation and flocculation, layer filtration, ion exchange, and so forth [5]. These methods are flexible and versatile as far as materials and synthetic compounds are utilized [6]. As per many explorations examines looked into here, biomaterials have a high potential for harmless to the ecosystem wastewater treatment procedures like adsorption [7]. A few materials from agrarian origin incorporate hemicelluloses, cellulose (with or without adjustment), gelatin, protein, and lignin [8]. Cotton fiber (CF) as a significant cellulosic segment, can be utilized for the removal of heavy metals. [9]. Some operational problems occur when using agricultural by-products as adsorbents including the low capacity of adsorption in raw form and can be overcome by physically or chemically modifying the adsorbent.

The objectives of the research are to:

i. Prepares Nano Chitosan Coated Cotton Fiber (NCCCF) by crosslinking cotton fiber with Nano chitosan by citric acid.

ii. Minimize the harmful dye and heavy metal contents in textile and tannery effluents for protecting Environment.

iii. Develop a bacterial-resistant fabric filter that can also remove heavy metals and dye compounds from industrial effluents.

Experimental

Materials

Cotton fiber, citric acid monohydrate ($C_6H_8O_7.H_2O$), NaOH, HCl, CH_3COOH, STPP, Tween 80 etc. were purchased and used without further purification.

Methods

Preparation of Chitosan from Shrimp Waste: Shrimp shell was first collected from the Koyra, Khulna and dried and crushed for the efficient extraction of chitin. The process of preparation of chitosan involved 3 steps: Demineralization, Deproteinization and Deacetylation [10].

Chemical Modification ff Cotton Fibers

Cotton fibers were boiled in water and submerged in an aqueous ethanol solution. Then the cotton fibers were treated with NaOH. These fibers were rinsed with deionized water until the rinse water had a constant pH. After washing, the fibers were dried [11].

Preparation of Nano Chitosan

Low-molecular-weight chitosan was dissolved in aqueous acetic acid and stirred. Then STPP solution was added and stirred at ambient temperature and then centrifuged at high speed. The isolated nano chitosan was rinsed with distilled water, freeze-dried, and analyzed [12].

Adsorption of Chitosan NP on Cotton Fiber

Cotton fibers were immersed into chitosan NP suspension with a different mass concentration. Then citric acid was added to the mixture and heated. The cotton fiber was removed from the solution and cured in an oven. The samples were dried under vacuum at room temperature, accurately washed with commercial ionic soap and rinsed with distilled water. The samples were further rinsed with distilled water, dried overnight under vacuum, and weighted prior to analyses [13,14]. Crosslinking reaction of nano chitosan with cotton fiber id shown in (Figure 1).

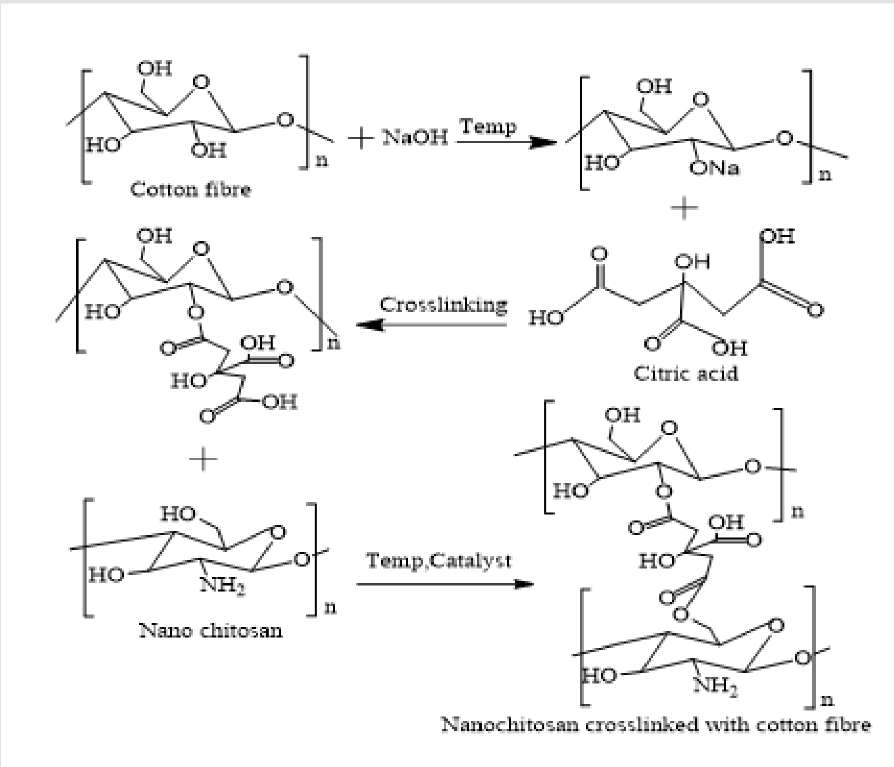

Figure 1: Crosslinking reaction of nano chitosan with cotton fiber [13].

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Characterizations

The FTIR spectra of nano chitosan cross-linked cotton fiber (NCCCF) shows the presence of the C=O ester stretching peak at 1723 cm_{-1} (Figure 2). This indicates the attachment of the chitosan onto cellulose occurred through an ester bond formation. The peak at 1653 cm_{-1} due to C=O stretching of the secondary amide of chitosan was also observed in the FTIR spectra of the treated fibers [15]. The SEM micrographs of samples with and without Nano chitosan treatment are shown in Figure 3. It can be observed that the chitosan-treated samples (Figure 3b) displayed morphological changes compared to those non-treated ones (Figure 3a). As well, the fibers coated with Nano chitosan showed a veil-forming like onto the cellulose fibers [16].

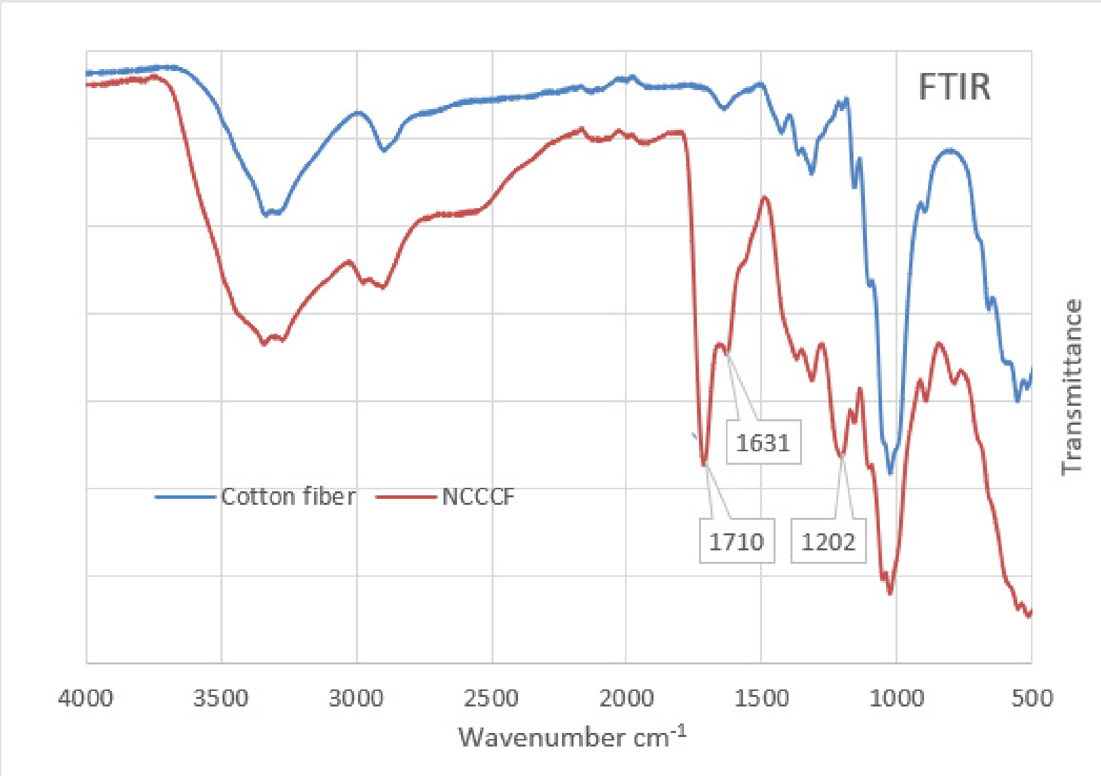

Figure 2: FTIR graph of cotton fiber and nano chitosan cross linked cotton fiber.

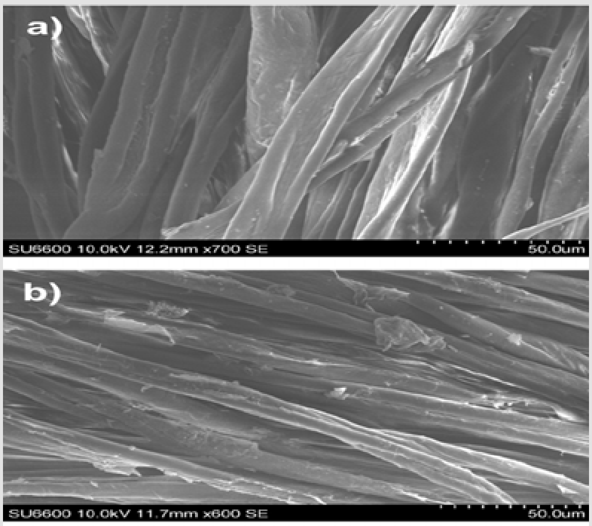

Figure 3: SEM photograph of
(a) cotton fiber and
(b) Nano chitosan cross-linked cotton fiber.

Equilibrium Adsorption Capacity

The equilibrium adsorption capacity of cotton fiber and NCCCF for Cr^{6+}, Ni^{2+} and Cd^{2+} and $Cr^{6+} > Ni^{2+} > Cd^{2+}$. Langmuir adsorption isotherm describes quantitatively monolayer adsorbate on the outer surface of the adsorbent (Table 1). It was seen that it needs different time to reach adsorption equilibrium for different metal ions. The adsorption equilibriums were established within 12 h for each experiment. The equilibrium adsorption capacity Qe (mmol/g) was calculated using the Langmuir adsorption equation.

Table 1: Saturated Adsorption capacity at (pH= 6.3–6.5; T= 25).

Adsorbent	Cr6+	Cd2+	Ni2+
Cotton fibre (mmol/g)	0.49	0.14	0.15
NCCCF (mmol/g)	3.85	2.31	2.75

Table 2: Antibacterial activity of NCCCF.

Sample	Antibacterial activity (%)	
	E. coli	S. aureus
Cotton	---	---
NCCCF	99.8-99.8	88-98

Antimicrobial Properties

The antibacterial activity of the NCCCF was evaluated by assessing the reduction in bacterial growth on the treated cotton fibers. As most bacteria have a net negative surface charge, the protonated amine group of nano chitosan are able to kill them. In order to evaluate the antibacterial activity of the treated samples, the quantitative antibacterial test according to the AATCC 100 standard was used. The reduction percentage of the untreated cotton and NCCCF against *S. aureus* and *E. coli* microorganisms are presented in (Table 2) [17].

Antibacterial activity of the NCCCF against gram-negative microorganisms (*E. coli*) is more than gram-positive microorganisms (*S. aureus*). Gram-positive bacteria have a thicker and more rigid peptidoglycan cell wall. Therefore, the antibacterial activity of NCCCF as an antibacterial biopolymer against gram-positive bacteria are less than gram-negative bacteria [18].

Conclusion

The equilibrium adsorption capacity of cotton fiber was enhanced by the green adsorption of nano chitosan on the surface of cotton fiber. The behavior of the NCCCF as an adsorbent to remove heavy metals from its aqueous solution was investigated and found that the saturated adsorption capacity of NCCCF is likely Cr6+>Ni2+>Cd2+. The adsorption capacity of NCCCF is higher towards chromium ions due to the ester bonds between the nano chitosan and cotton fiber instead of amide bonds as the amine group of chitosan becomes protonated and more strong bonds are formed with chromium ions. These protonated amine groups of nano chitosan also develop antimicrobial properties of the cotton fibers.

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ISSN: 2574-1241

DOI: 10.26717/BJSTR.2022.46.007295

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