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Extraction of Cellulose from Organic Waste for Nanocomposites Synthesis with Red Mud and Application

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Abstract

This study focuses on the process of isolating cellulose from organic waste material and using it with red mud to create nanocomposites, with an emphasis on possible uses. After extraction, red mud is used as a reinforcing filler, and cellulose is added to nanocomposites using a simple synthesis technique. Red mud is a byproduct of refining alumina and has special qualities, such as large surface area and mineral content, that make it appropriate for use in nanocomposite applications. Red mud and cellulose work together to provide improved mechanical, thermal, and barrier qualities in the resultant nanocomposites. We also investigate several possible uses for these cellulose-based nanocomposites, from biomedical devices to packaging materials. Using cellulose made from organic waste not only increases the value of an otherwise underused resource but also helps to lower pollution levels in the environment. Additionally, red mud's integration into nanocomposites reduces the environmental effect of its storage while providing a sustainable method of disposal. Overall, this study emphasizes the viability and sustainability of using red mud and cellulose from organic waste to create nanocomposites, as well as the prospective uses of these materials in a variety of disciplines. By supporting further efforts to manage waste and use resources sustainably, this study opens the door for the creation of environmentally friendly materials with useful uses.

Keywords: Red Mud, nanocomposite, cellulose extraction, paper mulberry, wastewater treatment

INTRODUCTION

Numerous hazardous chemicals developed as a result of growing industrial and agricultural activities are the main cause of global water contamination. Textile dyeing is one of the industries that use the most water these days. It also generates a lot of organic compounds and inorganic salts that appear to be carcinogenic and detrimental to both human health and the aquatic ecosystem. Therefore, a range of methods have been used to extract dyes from polluted water, including adsorption, electrochemical, and accelerated oxidation processes such as chemical oxidation and catalytic degradation. It has been noted, although, that the aforementioned methods may be exceedingly costly, generate more harmful sludge, or not be practical for use in large-scale applications [1].

The use of natural fibers in composite materials is gaining significant interest due to their biological degradability, accessibility, and sustainability. The main component of all plant materials, cellulose, falls into this group and has a unique structural arrangement that is characterized by nanofiber assemblies. The cellulose nanofibers, or nanocellulose, that are extracted or individualized from renewable sources have become a notable

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focus because of their high specific surface area, remarkable mechanical capabilities, low coefficient of thermal expansion, and affordability. Naturally derived lignocellulosic materials consist mostly of cellulose, lignin, and hemicelluloses. These components create stiff structures linked by various bonding processes, including covalent and non-covalent connections. These structures resist easy degradation due to their relevant characteristics [2].

Extraction of Cellulose Material from Different Organic Waste

Plant Waste

Cellulose is an organic polymer that occurs in nature in abundance and it is a major part of the cell walls of plants. Cellulose is typically produced from plant sources such as pine trees, cedar, and wood, as well as from other plant wastes. The amount of cellulose in different plants can vary depending on plant species, age, tissue type, and environmental conditions. For example, cotton contains 90% cellulose, whereas hemp contains 70-80% [3].

Fiber that is made up of cellulose can be produced from a variety of agricultural and plant waste. It is one of the most prominent and renewable biopolymers which is produced by plants annually in an amount of over 75 billion tonnes. The waste produced from plants can provide a sustainable alternative to traditional sources of cellulosic materials as wood pulp. The choice of plant waste is based on aspects like availability, regional resources, and the desired characteristics of the cellulose fiber for specific applications.

Fruit and Vegetable Waste

The waste generated from vegetables and fruits can effectively be used for cellulose fiber production by environmentally friendly synthesis. These cellulose fibers can be used as adsorbents and in thin film-making to remove heavy metal ions in water and wastewater treatment processes [4].

The processed fruits and vegetables that are most often used in Europe involve apples, carrots, tomatoes, and cucumbers were the inspiration behind the pomaces' names. The apple is the fruit that is processed the most and generates the most waste. Around 12 million tons of rubbish are produced annually as a result of the 67.9 million tons of this fruit that were grown worldwide in 2013. Over 170 million tons of tomatoes, a commonly eaten vegetable crop, were produced worldwide in 2014. Millions of tomatoes are processed annually to create tomato sauce, ketchup, salsa, paste, juice, and purée, which results in a large amount of waste [5]. Tomato pomace is composed of around 40% pulp, 27% peel, and 33% seed after pressing. Another lignocellulosic material produced in significant quantities in the industry during the juice extraction process is carrot pomace. Carrot pomace is composed of 28% cellulose, 2.1% pectin, 6.7% hemicellulose, and 17.5% lignin on a dry weight basis. Cucumber is made as pickles or as fresh slices for "ready-to-eat" vegetables.

Waste Generated from Red Mud

Some other easy options involve converting red mud disposal into absorbent material. Arsenic is an organic water pollutant that poses a serious concern to human health in many regions of the world. In recent years, to remove arsenic and other heavy metal ions from wastewater the adsorption method is widely used. Many researchers have investigated the idea of extracting arsenic from water by utilizing red clay that has been dumped. Removing As(III) and As(V) from water effectively may be achieved with red mud. Furthermore, the Red Mud may be used to remove heavy metal ions, dyes, inorganic anions, and phenolic pollutants from water [6].

Red mud has recently been employed as a precursor for the selective leaching process that creates nanocrystalline and high surface area aragonite. Comparing the synthetic red mud aragonite (RMA) to granular ferric hydroxide (GFH), a commercial aragonite-based material, showed that RMA was a highly selective fluoride sorbent. It is currently unknown how well this material will work as a sorbent for other species, such as phosphorus. Therefore, the purpose of the current investigation was to evaluate the performance of RMA with commercial GFH and ascertain if it is suitable for use as a sorbent for phosphorus [7].

Experimental Section

Synthesis of Cellulose Fibre from Paper Mulberry Bark

Materials

The barks of paper mulberry were collected from the forest near Selaqui Dehradun (Uttarakhand), all the required reagents and materials such as bleaching agent (H2O2 15% v/v), leaching agent (NaOH 15% w/v) and Non-ionic surfactant were obtained from Uttaranchal University (Dehradun) chemical laboratory.

Method

- *Preparation of the Paper Mulberry Fibers (Leaching):* Make sure that the bark of paper mulberry is dry if it is not then dry it in sunlight. To remove the other impurities the bark of paper mulberry is submerged in distilled water for one day. Then, the PMB fibers were placed in a solution of NaOH (15%, w/v) at 80-100ºC for 3 hr. After the delignification process, the bark of paper mulberry was rinsed with distilled water and dried in an oven.
- *Bleaching of the Paper Mulberry Fibers:* Fiber bleaching processes involved variable H_2O_2 concentration (10%, v/v) at a temperature range from 80-100ºC with a bleaching time of 2-3 hours. After the subsequent bleaching process, the formed fibers were rinsed with surfactants along with distilled water to remove the residual gum of fiber. The fibers were then dried and used for further characterization process (Figure 1).

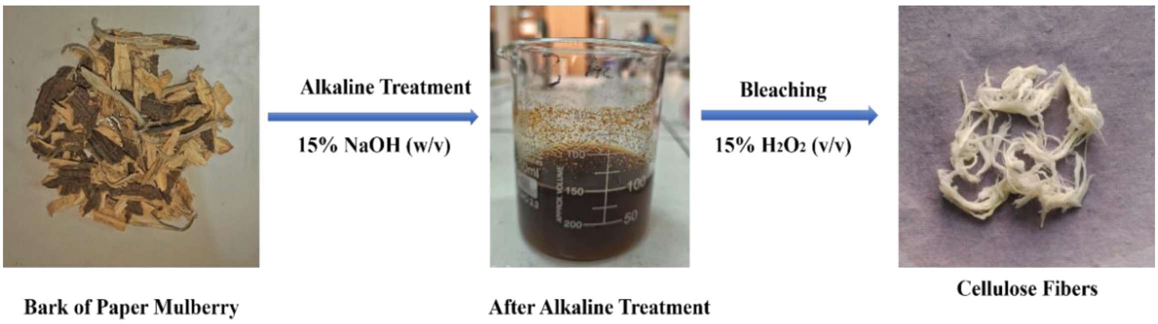

Figure 1. Flow chart of cellulose extraction from mulberry bark.

Extraction of Nanocellulose from Pomelo Peels

- *Materials:* The pomelo peels were collected from the fruit stalls in the Dehradun local market (Uttarakhand). All the required reagents and materials such as magnetic stirrer, NaOH, H_2SO_4, etc for the synthesis of nanocrystalline cellulose from pomelo peels were obtained from Uttaranchal University (Dehradun) chemical laboratory.
- *Method:* To synthesize cellulose from pomelo peels subsequent delignification and bleaching process was used. Firstly, the pomelo peels were dried in sunlight and ground to get fine powder. A The resulting pomelo peel powder is treated with 8% (w/w) NaOH solution containing at 90°C for 3 hours. subsequently, the mixture was washed and rinsed with distilled water until a neutral pH was obtained. The delignified mixture was subjected to the bleaching process in which the resulting mixture was treated with a mixture of 68% nitric acid-80% acetic acid in the ratio of 1:10 at 90°C for 30 min for the removal of resilient lignin and hemicellulose present in the mixture. In the end, the synthesized cellulose was freeze-dried for 1 day and then it was kept for further characterization (Figure 2).

Nanoparticle Synthesis from Waste Red Mud

- *Materials:* The red mud waste used in the synthesis process was collected from Dehradun. To remove the moisture of red mud it was dried in an oven at 80°C for 2 h. Subsequently, the dried red mud is ground using mortar and pestle to convert it into powder form. The reagent required for the acid treatment of red mud and further processes was obtained from the central laboratory (Uttaranchal University)

- *Method:* To synthesize red mud nanoparticles from red mud waste, the acid treatment followed by a calcination process was used. For this, the red mud waste is first pretreated with 2M of HCl solution with distilled water with continuous stirring along with refluxing for 2-3 hours. Subsequently, after two hours the red md nanoparticles were washed with distilled water until the pH became neutral. The resulting mixture is filtered and dried in the oven, and at the end, the formed red mud mixture is calcinated for 2 hours at 450ºC and the resulting red mud nanoparticle is kept for further characterization.

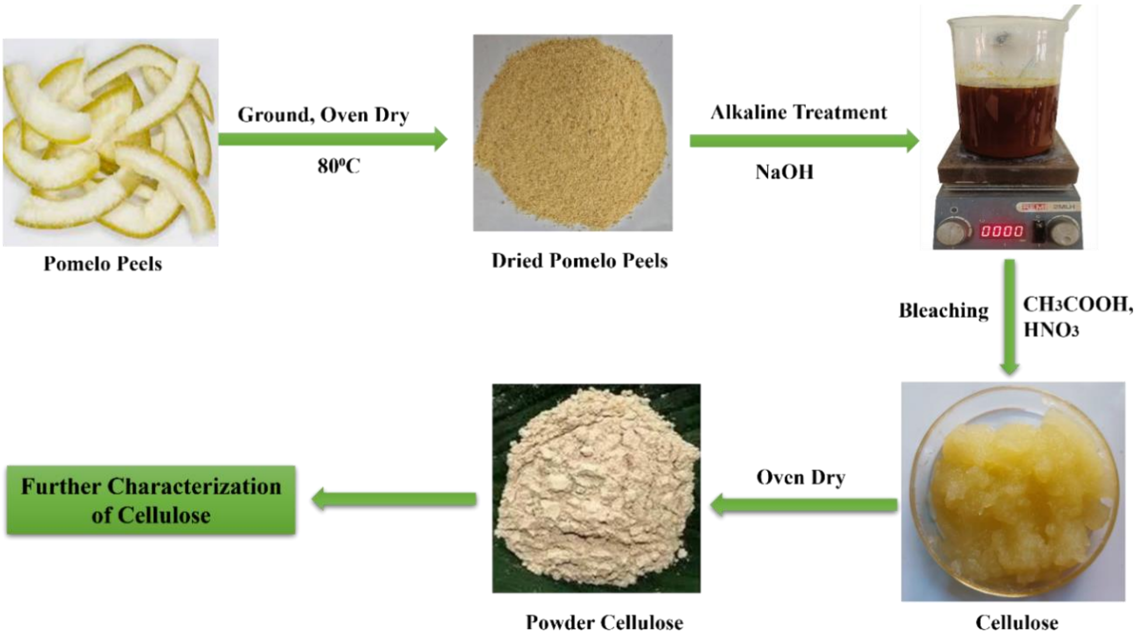

Figure 2. Flow chart of synthesis of nanocellulose from pomelo peels.

Synthesis of adsorbent material from Red Mud

The Red Mud was first oven-dried at 105ºC for 2hr. Acid leaching of red mud was performed using phosphoric and hydrochloric acids, with concentrations of 1 and 5 M, respectively. The ratio of red mud to acid for all experiments was 0.005, the length of digestion was 24 hours and the temperature during the reactions was 25ºC with phosphoric acid and 70ºC using hydrochloric acid. For all experiments, the red mud residue was separated from the acidic supernatant by centrifugation at 3000 rpm for 5 minutes. The pH of the separated acidic extract was adjusted to a value between 3.0 to 3.5, after which the reaction was allowed to age in a closed vessel at 70ºC for three days. The resulting precipitate was extracted using a centrifugation machine dried at 60ºC for 6 hours and then kept for further characterization (Figure 3).

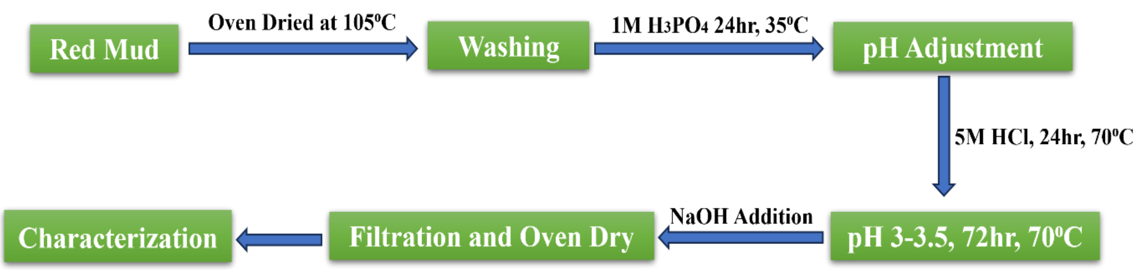

Figure 3. Flow chart of synthesis of adsorbent material from Red Mud.

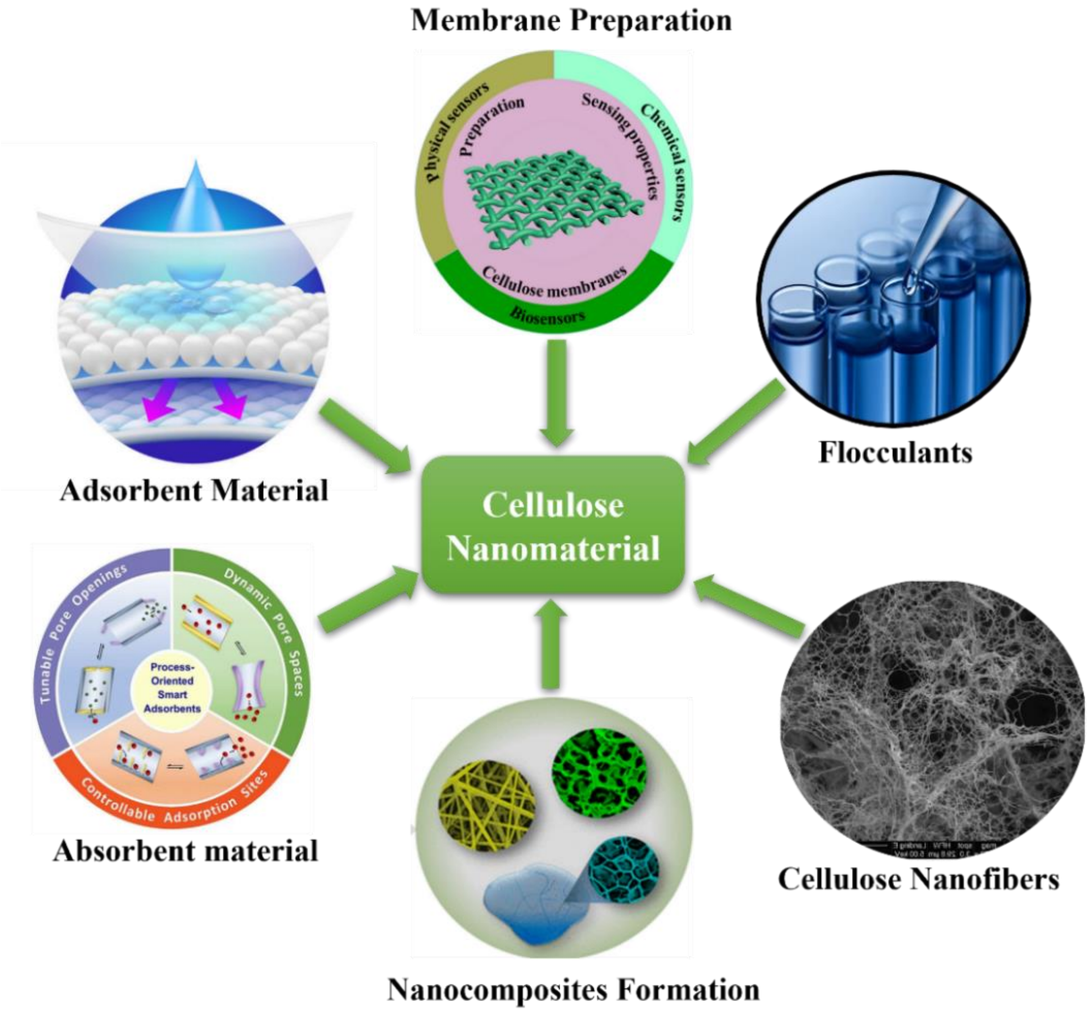

Figure 4. Application of cellulose nanomaterial in various fields.

Application of Cellulose-based Material for Waste-Water Treatment

Because cellulose and cellulose-based polymers can help remove impurities and increase treatment process efficiency, they are used in wastewater treatment. Here are a few methods for treating wastewater using cellulose:

- *Heavy Metal Ion removal:* The adsorption of heavy metals from wastewater can be achieved using cellulose fibers and derivatives, which possess a large surface area and can be changed to increase their adsorption capacity. Lead, cadmium, and copper can be efficiently captured by cellulose-based adsorbents [8].
- *Organic pollutant:* Cellulose materials can also adsorb organic pollutants, including dyes and various organic compounds, helping to reduce the organic load in wastewater.
- *Flocculation and coagulation:* Cellulose-based flocculants are used as coagulant aids to enhance the settling and filtration of suspended particles in wastewater. They stimulate the association of tiny particles into bigger flocs, which enables their removal through centrifugation or filtering procedures [9].
- *Biofilms support:* Microorganisms can stick to and grow on cellulose fibers. In water treatment, biofilms grown on cellulose substrates may serve an important role in the breakdown of organic material and the removal of contaminants [10].
- *Membrane filtration:* Cellulose-based materials can be used as support structures in membrane filtration processes. Cellulose membranes, including those made from regenerated cellulose or

cellulose acetate, are employed for their high permeability and selectivity in separating contaminants from water [11].

- *Ion exchange resin:* Cellulose derivatives can be modified to act as ion exchange Resins, selectively removing ions from wastewater. This is particularly useful for removing specific pollutants, such as heavy metal ions [12]. Utilizing cellulose-based ion exchange resins has several benefits, such as biocompatibility, renewability (cellulose comes from renewable resources), and possible cost savings over synthetic substitutes. Furthermore, cellulose-based polymers could be more environmentally sustainable than ion exchange resins derived from petroleum [13].
- *Biodegradation and bioremediation:* Cellulose materials can serve as carriers for microbial cultures in biological treatment systems. Microorganisms attached to cellulose surfaces can metabolize organic pollutants and contribute to the overall degradation of contaminants. Cellulose-based materials may be incorporated into constructed wetlands for wastewater treatment. Wetland plants and cellulose-rich substrates encourage the growth of microorganisms that enhance the removal of pollutants through biological processes [14].
- *Cellulose-based composite material:* Composite materials that combine cellulose with other substances (such as nanoparticles or polymers) can exhibit improved adsorption properties. These composites are designed to enhance the efficiency of removing specific contaminants from wastewater (Figure 4) [15].

CONCLUSION

The effective utilization and extraction of cellulose fibers from these various sources are shown by the production of several types of cellulose fibers from different waste, such as plants, organic waste, and fruit and vegetable waste, for wastewater treatment procedures. Researchers were able to extract cellulose fibers with unique characteristics from a variety of waste items, such as food trash, fruit peels, and agricultural leftovers, by using a variety of experimental approaches and methods. These cellulose fibers were good candidates for wastewater treatment applications because they showed desired properties such as high purity, surface area, high contact angle, porosity, and mechanical strength.

The best option for long-term and economical alternatives is the use of waste resources to produce cellulose fibers for wastewater treatment. The findings presented in this book chapter demonstrate the viability and adaptability of employing fruit, organic, and plant wastes as possible sources of cellulose fibers. These cellulose fibers made from trash have several benefits, such as reduced waste, improved resource efficiency, and favorable environmental effects. Furthermore, by offering environmentally benign substitutes for traditional treatment techniques, the development of cellulose-based materials for wastewater treatment advances the fields of sustainable engineering and green chemistry. Overall, the results highlight the possibility of using waste materials to create cellulose fibers for wastewater treatment, opening the door for more study and possible real-world use.

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