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Utilization of Disposable Paper Cups for Production of Cellulose Acetate Based Film

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ABSTRACT- The aims of research to explore the conversion of disposable paper cups, commonly used in the food and beverage industry, into cellulose acetate film. The increasing environmental concerns regarding plastic waste and the desire for sustainable alternatives have led to the investigation of utilizing cellulose-based materials.

Cellulose, a biopolymer derived from plant-based sources, is the primary component of paper cups. Through a series of chemical processes, cellulose fibers are extracted from the paper cups and subsequently acetylated to form cellulose acetate. Cellulose acetate is a biodegradable and versatile material with various applications in packaging, textiles, and films. The project involves experimental work to extract cellulose fibers from the paper cups, optimizing the acetylation process, and fabricating cellulose acetate films through casting. The cellulose acetate films exhibit favourable properties, including good mechanical strength and thermal stability. These properties make cellulose acetate films a potential alternative to conventional plastic films, offering environmental benefits and promoting sustainability.

The project highlights the importance of utilizing waste materials and transforming them into value-added products. By diverting waste from landfills and reducing dependence on conventional plastics, the project contributes to the promotion of a circular economy and sustainable practices.

KEYWORDS- Cellulose, Cellulose Acetate, Disposable Paper Cups

I. INTRODUCTION

Disposable goods have become increasingly popular and promoted due to economic progress and the ongoing expansion of the world's population [1][2][3][4]. Many families, businesses, and public spaces utilize disposable paper cups (DPCs) because of their many benefits, which include high output, affordability, ease of use, and relative sanitation [5]. In 2018, there were more than 220 billion disposable paper cups used worldwide, with 32 cups used per person [6]. According to reports, China and the UK utilize around 2.5 billion and 10 billion throwaway paper cups yearly, respectively [6][7]. Given that paper cups are known to be composed of roughly 95% high-degree cellulose paper board, their production requires the removal of many trees, which destroys ecosystems [8][9][10]. Large amounts of natural resources are used in the production of paper cups, and enormous amounts of carbon dioxide are released, leading to a major energy waste and a worsening of the greenhouse effect [11][12][13]. As a result, recycling and reusing single-use paper cups is significant and vital for maintaining our ecosystem and maximizing the use of natural resources. Disposable paper cups, as their name implies, are difficult to reuse and are typically thrown away as waste after use because so many people use them only occasionally and for short periods of time [10][14]. 50 billion paper cups are discarded annually in the US, according to research [6][7]. Large amounts of used disposable paper cups (UDPCs) are therefore landfilled or burned in the environment [6][12][15]. However, these two procedures are acknowledged as being environmentally unfriendly because they release harmful gases or because the thin polyethylene (PE) coatings inside are not biodegradable [5][16][17]. Reusing and recycling UDPCs has been attempted on a number of occasions thus far[17][18][19][20]. In order to create cellulose derivative carboxymethylcellulose and cellulose nanomaterials, Chen et al. [19] and Nagarajan et al. [18] removed the PE coatings from used disposable paper cups. To stop leaks, disposable paper cups typically have 5% inner polyethylene (PE) coatings [20]. However, it is challenging to separate the inner PE coatings and the exterior cellulose paper board in an inexpensive and comprehensive manner due to their strong relationship. In order to create new paper-plastic composites (PPCs), Mitchell et al. [21] used polypropylene as a matrix and unpeeled shredded paper cups as an additive. In the meantime, Zhao et al. used Fe2+ as a catalyst to create graphene sheets straight from disposable paper cups [22]. Over the past ten years, biomass resources that are renewable, biodegradable, and environmentally friendly have drawn a lot of attention due to the depletion of fossil fuels and the devastating effects of climate change [23][24][25]. Cellulose, the most prevalent component of biomass, is found all over the world and has been widely converted into a variety of useful materials. These materials include energy storage materials [30][31], fluorescent smart materials [29], packaging and wrapping materials [26][27][28], and more. Low-coat solid wastes, on the other hand, like old disposable paper cups, can be a good source of cellulose.

The present work uses a simple and environmentally friendly technology that allows used disposable paper cups to be fully consumed and valorized in a single procedure. The preparation process is also carried out in mild temperatures and is environmentally friendly [32]. In the meantime, a number of characterizations were conducted to look into the structures and characteristics of the cellulose acetate films. The findings demonstrated the cellulose/polyethylene composite films' strong mechanical, and hydrophobic qualities as well as their biodegradable capabilities, indicating their potential for usage in the packaging and wrapping industries.

II. MATERIALS AND METHODS

A. Materials

Paper cup was purchased from local market of Lucknow, Uttar Pradesh. Distilled water a form of purified water, obtained by simple distillation free from impurities was of laboratory grade. Sodium acetate, NaOH, H2SO4 was procured from LOBA Chemie Pvt. Ltd. (Mumbai, India). Glycerol was generously given by Central Drug House Pvt. Ltd. (Mumbai, India).

B. Methodology

- **Removal of LDPE Film from Paper Cups**

We took disposable paper cups and washed them with water then with distilled water. After washing, we cut the cup into smaller pieces and boiled it at 120°C for 15~20 min after that we filter it and peel its inner LDPE layer manually by hands. Illustrated in figure 1.

- **Pre-treatment**

About 5 g of paper cups was cut into small pieces. The cut paper was then boiled for 1 hour. Then, the paper was mechanically ground into slurry using a blender and filtered and rinsed several times with distilled water in order to partially disperse the fibrous materials prior to the next treatment. Then, the slurry was boiled again for about 1 hour to remove any excess dirt. The boiled paper was then filtered and rinsed with distilled water and dried in an oven at about 80°C for 2 hours.

- **Alkali Treatment**

The alkali treatment was carried out using a sodium hydroxide solution (NaOH). The slurry from the prior pre-treatment was treated with NaOH to remove the fillers and hemicellulose. The treatment was performed under reflux at 100°C for 90 minutes with a paper-to-NaOH solution ratio of 1:20 (w/v) and concentrations of 8 wt.% and 16 wt.% NaOH solution. The mixture was then filtered via filter paper and rinsed with distilled water to achieve a neutral pH. The samples were oven-dried for 2 hours at 50°C.

- **Acetylation of Cellulose**

First, cellulose obtained by adding to acetic acid to (using 1.0g of cellulose and 35 mL of acetic acid) and the resulting mixture was stirred for 30 min at room temperature. Then, a catalytic amount of 0.02 g/mL H_2SO, in acetic acid was added to the system, which was stirred again for 25 min. After that, 64 mL of sodium acetate was added to the system and agitated for another 30 minutes. Following that, the mixture was allowed to stand at room temperature for 24 hours. Then, a total of ca. 300 ml. water was continuously added to the filtrate to stop the reaction and until the precipitation of all cellulose acetate, which was filtered and washed with distilled water to remove the excess of acetic acid. Finally, the product was neutralized with 10% Na_2CO3, until pH 7. Then, we washed the cellulose acetate and dried at 90 °C for 4 h.

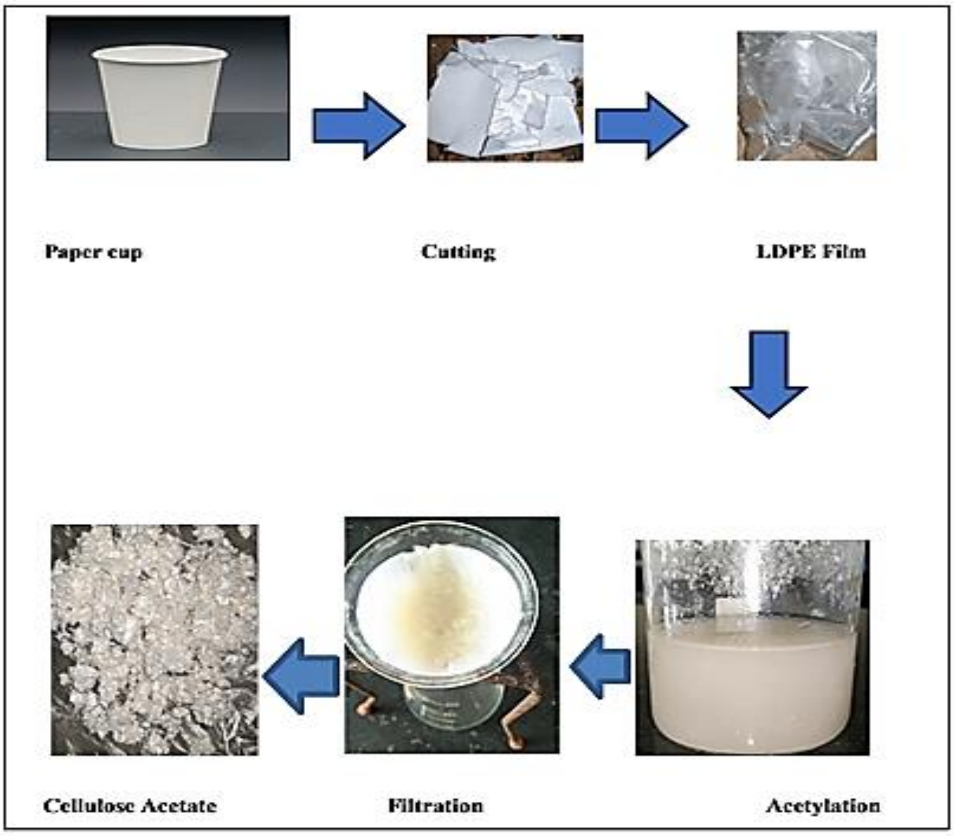

Figure 1: Extraction of Cellulose acetate from waste aper cup

- **Film Preparation**

First, 3g of cellulose acetate obtained from previous step was taken and a slurry solution was made and mixed until cellulose acetate stops dissolving and A highly concentrated solution is obtained, and the solution is put onto a petri dish. Small amount of glycerol was used for easy removal. Then, it was dried for 1~1.5 hours at room temperature. Finally, the film was gently removed from the petri dish [35]. And tests were performed. As shown in figure 2.

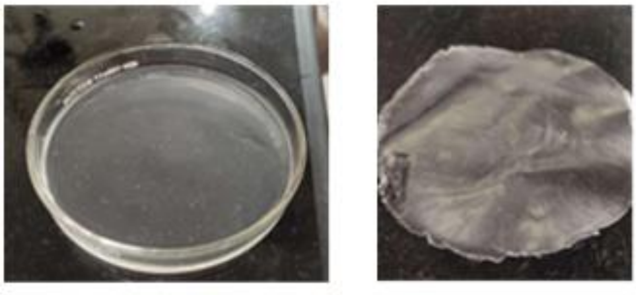

Figure 2: Cellulose Acetate Film

III. CHARACTERIZATION

A. Fourier Transform Infrared Spectroscopy (FTIR)

FT-IR spectra were recorded at room temperature using a Thermo-Scientific Nicolet 6700. FT-IR Spectrometer (Thermo Nicolet Limited, USA) on a diamond disc in the range of 4000-400cm^{-1}.

B. Water Absorption Test

Water absorption were measured as per ASTM D570. The given formula below used to calculate water absorption (%).

IV. RESULTS AND DISCUSSION

A. FTIR Analysis

In cellulose acetate, the hydroxyl groups of cellulose are esterified, resulting in a decrease in the intensity of the hydroxyl peak observed in cellulose in figure 3. In the FTIR spectrum of cellulose acetate, the hydroxyl peak typically appears as a broad and weak absorption band between 3200 and 3600 cm^{-1}. C=O stretching vibration **of the ester groups (carbonyl groups):** One of the characteristic peaks of cellulose acetate is the strong and sharp absorption band around 1740 cm^{-1}, which corresponds to the C=O stretching vibration of the ester groups. This peak indicates the presence of the acetyl groups introduced during the acetylation process. C-O stretching vibration **of the ester groups:** The C-O stretching vibration of the ester groups in cellulose acetate appears as a medium intensity peak in the region of 1230-1250 cm^{-1} [33].

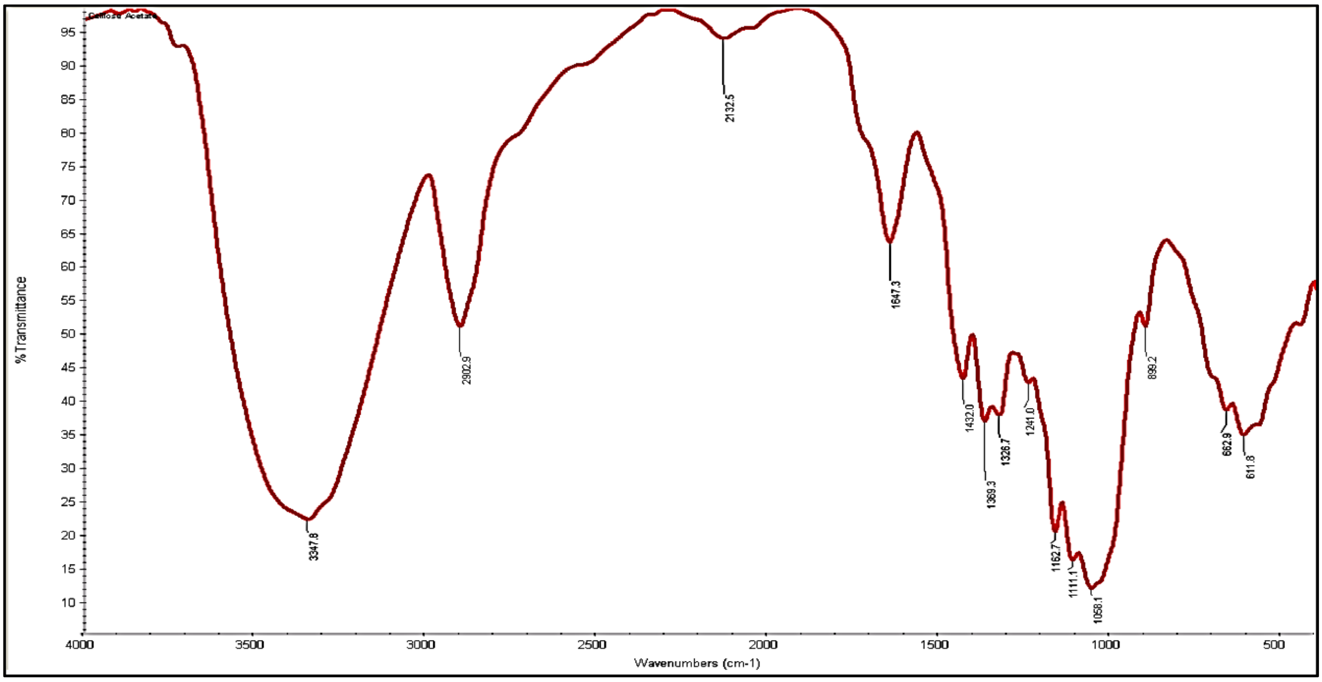

Figure 3: FTIR Cellulose Acetate

B. Water Absorption Test

There are a few reasons why weight loss occurs during water absorption tests (see table 1):

Table 1: Water absorption tests result

Specimen No.	Initial Weight	Final Weight	% Absorption
S_1	0.2732	0.2109	22.80
S_2	0.1853	0.1351	27.09

C. Porosity

Cellulose acetate film is generally a porous material, meaning it has small openings or gaps between its polymer chains. When immersed in water, these pores can allow water molecules to penetrate and be absorbed by the film. The absorbed water molecules occupy space within the film, displacing the original mass of the cellulose acetate and resulting in weight loss.

D. Hydrophilicity

Cellulose acetate has some inherent hydrophilic properties, meaning it has an affinity for water. The hydroxyl groups present in the cellulose structure can attract and interact with water molecules. As a result, when cellulose acetate film is exposed to water, it can absorb water molecules into its structure, leading to weight loss.

E. Solubility

While cellulose acetate is not highly soluble in water, it can undergo some degree of dissolution or swelling when exposed to water. This dissolution or swelling can contribute to weight loss during water absorption tests [34].

V. CONCLUSION

In conclusion, this project thesis has explored the conversion of disposable paper cups to cellulose acetate films as a sustainable solution. The increasing consumption and waste generation of paper cups have led to significant environmental concerns, highlighting the urgent need for alternative materials. Cellulose acetate has emerged as a promising sustainable material due to its renewable and biodegradable nature. By converting paper cups into cellulose acetate films, we can reduce waste and minimize the burden on landfills. Additionally, cellulose acetate offers various advantages such as its versatility, compatibility with existing manufacturing processes, and potential for wide-ranging applications. The conversion process involves key steps including collection and sorting of paper cups, pulping to break them down into cellulose fibers, acetylation to modify the fibers, and film formation. These steps require careful consideration of parameters, such as the pulping technique, aacetylating agents, and film formation methods. While the conversion of disposable paper cups to cellulose acetate films offers significant advantages, there are challenges that need to be addressed. Cost, scalability, and consumer acceptance are some of the key challenges that require further research and development efforts. Collaboration between industry and academia is crucial to drive innovation in this field. Looking ahead, there is a promising future for the conversion of disposable paper cups to cellulose acetate films. Ongoing research and development can lead to advancements in production techniques, cost reduction, and increased market acceptance. It is essential for stakeholders to embrace sustainable practices and contribute to the adoption of cellulose acetate films as a viable alternative. In conclusion, the conversion of disposable paper cups to cellulose acetate films represents a significant step towards achieving a more sustainable and environmentally-friendly future. By reducing waste and utilizing renewable materials, we can contribute to a circular economy and mitigate the environmental impact caused by disposable paper cups.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest

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