

Original Article

VALORISATION OF COTTON WASTE FOR SPECIALISED END-USE APPLICATIONS

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ABSTRACT

The fast expansion of the textile industry has led to a growing waste problem, with enormous volumes of cotton-based products being burnt or dumped in landfills, seriously polluting the environment. This study investigates a sustainable solution to this problem by chemically recycling and valorising wood pulp, post-consumer cotton waste, and pre-consumer cotton into high-value nitrocellulose. Alkaline pulping is used to extract cellulose, and the Box-Behnken response surface approach is employed to optimise the parameters of controlled nitration using sulfuric and nitric acids. FTIR examination revealed distinctive nitro group peaks at 1272 cm^{-1} , while CHNS analysis showed Nitrogen levels between 11.01% and 11.49%, confirming the effective conversion. Notably, post-consumer waste produced 11.17% Nitrogen, demonstrating that textile waste can be a sustainable substitute for virgin resources. By converting low-value trash into valuable ingredients for propellants and lacquers, this method advances the ideas of the circular economy.

Keywords: Cellulose Activation, Chemical Recycling, Circular Fashion, Nitro-Cellulose, Wood Lacquer

INTRODUCTION

The textile industry is vast and growing rapidly, but it creates significant pollution problems due to the waste generated from fabrics made from cotton, linen, and hemp. This waste originates from the production of clothes, their use, and subsequent disposal, ultimately filling landfills and releasing harmful gases while wasting water, energy, and chemicals [Chopra et al. \(2023\)](#).

Fast fashion enables brands to keep pace with current trends, but it relies on low-cost materials and rapid production methods, resulting in substantial waste and environmental pollution. Sustainable solutions like chemical, mechanical, and biological recycling, along with the concepts of the circular economy, divert waste, reduce pollution, and promote reuse [Nattha et al. \(2017\)](#).

Strong upcycling and recycling systems, equipped with cutting-edge sorting and technology, recover materials for new fabrics or products, thereby reducing the need for virgin resources [Mishra et al. \(2022\)](#). The recycling of textile waste can be categorised into either closed-loop or open-loop recycling, with the primary difference being the product resulting from the recycling process. Closed-loop cycles reduce the consumption of primary raw materials. Open-loop recycling, on the other hand, utilises material resources from waste, such as recovered fabrics and fibres, to create new and different products, often through processes of downcycling [Giuseppe et al. \(2025\)](#). This research pioneers the sustainable conversion of post-consumer cotton cellulose, extracted via alkaline pulping from fabrics, into Nitrocellulose through controlled nitration with mixtures of nitric and sulfuric acids, substituting hydroxyl groups with nitrate esters to yield a versatile, flammable derivative.

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Nitrocellulose, a pivotal cellulose derivative, emerges from the nitration of cellulose, a linear polysaccharide of β -1,4-linked D-glucose units, wherein hydroxyl groups (OH) at C6, C2, and C3 positions undergo esterification with nitrate groups (ONO_2) via a mixed nitric-sulfuric acid bath, where sulfuric acid acts as a dehydrating catalyst to generate Nitronium ions (NO_2^+) for electrophilic attack. Producing a highly flammable, solvent-soluble polymer whose nitrogen content dictates properties: low-N (10.5-11.5%) forms tough, flexible films soluble in esters/ketones, while high-N variants (>13%) exhibit explosive detonation velocities up to 7,000 m/s. By utilising this approach, the research offers a scalable route to circular economy concepts in materials science while also reducing environmental loads and opening up applications in lacquers, inks, nail polishes, and smokeless propellants. To avoid using virgin resources, the current study examines nitrocellulose synthesis from a variety of cellulosic pre-consumer cotton scraps, post-consumer textile waste, and wood pulp to identify differences in purity, nitration efficiency, and resulting stability [Sampoompuang et al. \(2023\)](#).

MATERIALS AND METHODS

Cellulose-containing textile waste can arise at various stages of the textile life cycle, including manufacturing (pre-consumer waste) and consumer use (post-consumer waste). Pre-consumer waste was collected from Ichalkaranji, including card noil, comber noil, and waste sliver. The post-consumer cotton fabric was provided by Bombay Recycling Concern (BRC). After the hard portion was manually cut and mechanically sorted, the fabric was shredded in a shredding machine to produce smaller fibres. After that, any necessary cleaning was finished if required. Aditya Birla Group provided wood pulp. Nitric Acid 70%, Sulfuric Acid 98%, Sodium Hydroxide (SD Fine Chemicals Ltd, Mumbai).

Figure 1

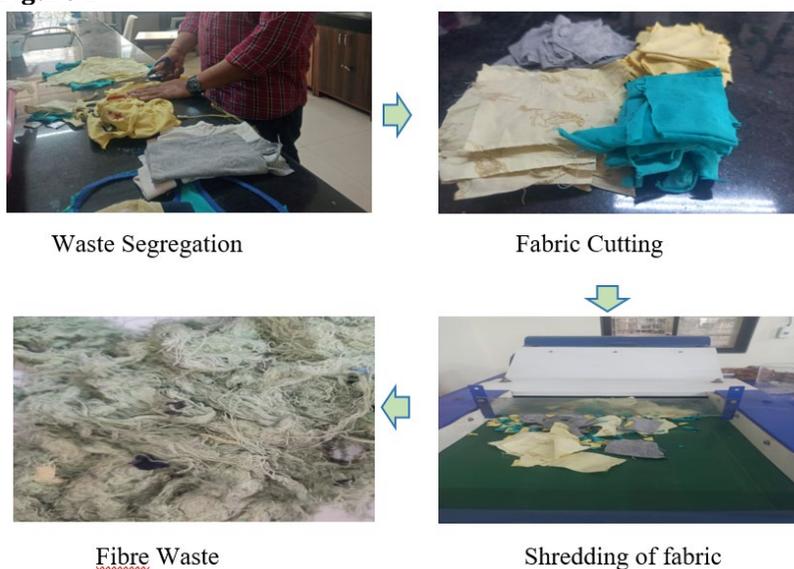


Figure 1 Post Consumer Fabric to Fibre Waste

EXTRACTION OF CELLULOSE

- **Preparation:** waste cotton fibres are sterilised in a 10% solution of sodium hydroxide (NaOH) at a ratio of 1:20 to separate the cellulosic pulp. After that, the mixture is heated for three hours at 80°C. The pulped fibres are filtered out and cleaned with deionised water till the pH reaches neutral [Hasnawati et al. \(2020\)](#).
- **Drying:** waste fibres are preheated to 105°C to remove moisture and improve the efficiency of replacing the hydroxyl group with the nitro group.
- **Nitration:** conversion of cellulose to nitrocellulose.
- **Cooling:** Sulfuric acid and Nitric acid at 20°C for 10 mins.
- **Adding:** 60% Nitric acid into the beaker, and then slowly add 98% Sulfuric acid. Monitoring: temperature using a thermometer. When the temperature drops below 20°C, the prepared cellulose pulp is added.
- **Pressing:** the cellulose to absorb the solution. Then treat it with water to neutralise it. After that, press the material as much as possible and let it dry. When it dries, the colour changes from yellowish to pale white cotton [Khalili et al. \(2025\)](#).

Figure 2



Figure 2 Cellulose Nitration in Ice Bath

PROCESS OPTIMISATION

The changes in four key parameters (concentration, temperature, duration, and material-to-liquor ratio) are used to determine the optimal reaction conditions for the nitration process using waste cotton material. In particular, we intend to change the material-to-liquid ratio, reaction duration, temperature, and concentrations of sulphuric acid (H_2SO_4) and nitric acid (HNO_3). We use a statistical technique called the Box-Behnken method, which enables us to get the same findings with fewer experimental samples. The Box-Behnken technique is a response surface methodology that effectively investigates a variety of experimental factors and their interactions by using a particular design of trials.

This statistical technique enables us to significantly reduce the number of trials required while still producing trustworthy data that help inform the choice of appropriate reaction conditions for the nitration of waste cotton material. It minimises resource usage, streamlines the experimental procedure, and lowers the total amount of time and effort required for the study [Mohammed et al. \(2021\)](#).

Table 1

Table 1 Box-Behnken Method Response Surface Methodology					
Run	Factor 1 Concentration of HNO_3 %	Factor 2 Time Seconds	Factor 3 M.L.R	Factor 4 Temperature $^{\circ}C$	Response 1 Nitrogen content %
1	30	120	15	18	09.06
2	40	180	15	28	10.47
3	40	120	15	23	11.01
4	40	120	20	18	11.01
5	40	60	10	18	11.55
6	30	60	15	23	09.07
7	50	120	10	23	10.78
8	40	120	15	23	09.54
9	30	180	15	23	09.21
10	50	120	15	18	09.56
11	40	120	15	23	10.54
12	40	120	10	18	10.09
13	40	120	15	23	09.67
14	30	120	10	23	9.34
15	40	180	15	18	10.08
16	40	60	15	28	09.67
17	30	120	15	28	09.06

18	30	120	20	23	09.14
19	40	120	15	23	10.54
20	40	180	20	23	10.32
21	50	60	15	23	10.01
22	40	120	20	28	10.45
23	50	120	20	23	10.45
24	40	60	20	23	10.11
25	40	60	15	18	11.12
26	40	120	10	28	10.34
27	50	180	15	23	11.01
28	40	180	10	23	11.11
29	50	120	15	28	09.89

HANDLING AND STORAGE OF NITROCELLULOSE

It is a highly flammable material that ignites easily when exposed to low heat. Nitrocellulose must be handled and stored with care. It is stored in galvanised drums, steel drums, or cardboard boxes. The storage area must also be maintained dry, cool, and free of heat sources and flammable objects. An antistatic polypropylene bag is used to store nitrocellulose.

RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy (FTIR).

Nitrocellulose is characterised by FTIR spectroscopy, which confirms the degree of nitration and structural alterations by detecting distinctive absorption bands for nitro groups. In order to assess the effectiveness and conversion of cellulose to nitrocellulose component, the presence of chemical functional groups in cotton waste and nitrocellulose material generated from cotton lint, post-consumer cotton, and wood pulp was assessed.

The reaction was performed on cotton lint, and the FTIR spectra of both the cotton lint and the resulting nitrocellulose demonstrate similar results. Here are the FTIR graphs depicting the spectra of cotton lint before the reaction and nitrocellulose derived from cotton lint. The results are depicted in the Figure below:

Figure 3

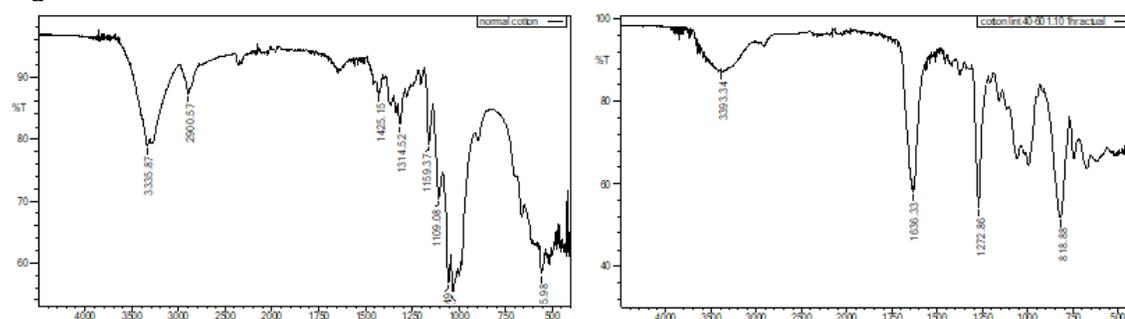


Figure 3 (a) Before Nitration, (b) After Nitration

Achieved the best outcome at the fifth reaction run after optimising the process conditions by applying Box-Behnken method response surface methodology

Figure 4

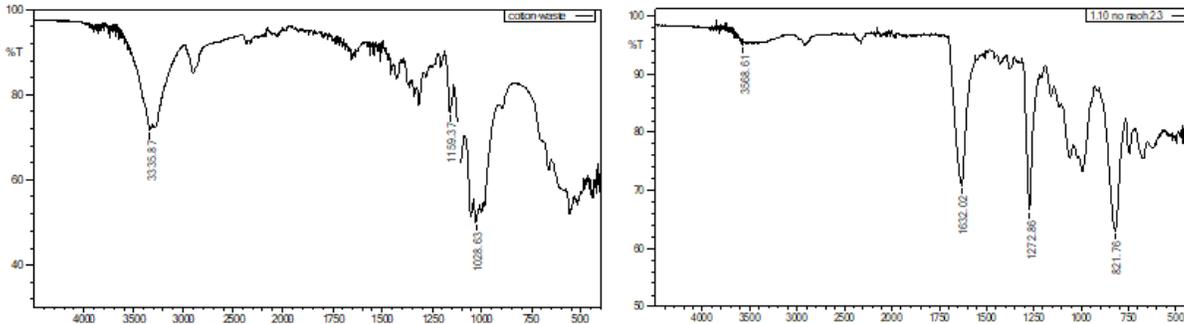


Figure 4 (a) Before Nitration, (b) After Nitration

The FTIR spectrum of waste cotton prior to nitration shows the presence of hydroxyl (OH) groups, Figure 4. The stretching vibrations of OH groups are probably seen as a broad absorption band in the 3200–3600 cm⁻¹ region. Cellulose, a significant component of cotton, is one of the many organic molecules that frequently include OH groups. The modified waste cotton's FTIR spectrum, shown in Figure 4, exhibits a new peak at 1272 cm⁻¹ following the nitration procedure. The presence of the nitro group (NO₂) is shown by this peak, which is related to the n-o symmetric stretch vibration. The existence of this peak indicates that nitro groups were added to the waste cotton during the nitration process.

In the preheating of cotton fibres at 105°C, extra water will be removed, and the efficiency of replacing the hydroxyl group by the nitro group may increase.

Figure 5

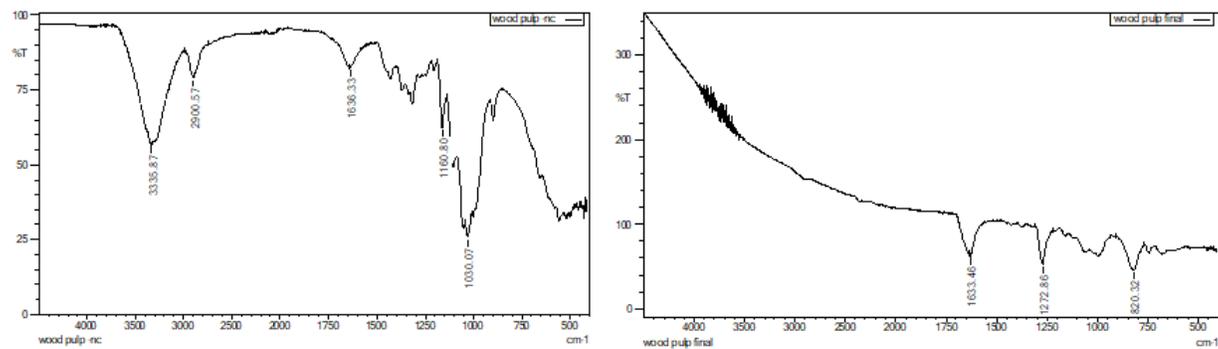


Figure 5 Wood Pulp (a) Before Nitration, (b) After Nitration

Figure 6

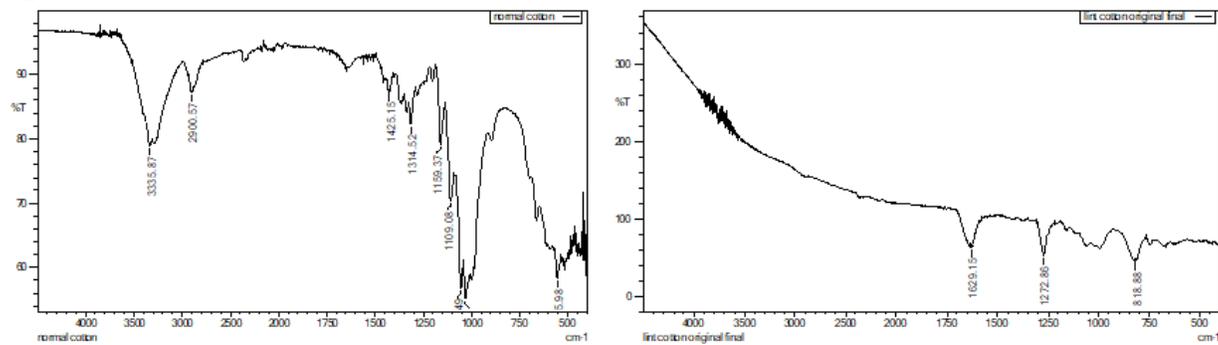
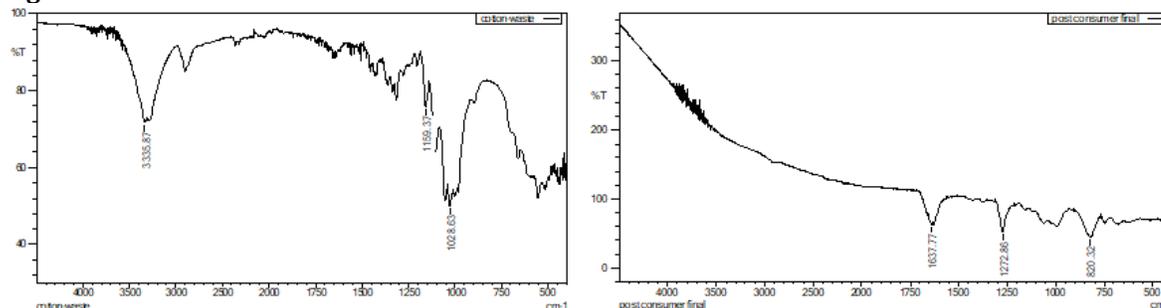


Figure 6 Pre-Consumer Cotton Waste (a) Before Nitration, (b) After Nitration

Figure 7

Figure 7 Post-Consumer Cotton Waste (a) Before Nitration, (b) After Nitration

Nitrocellulose derived from commercial wood pulp, post-consumer cotton waste, and pre-consumer cotton waste all consistently displayed a strong peak at around 1272 cm^{-1} in FTIR analysis, which is suggestive of symmetric NO_2 stretching vibrations. This indicates that nitro (NO_2) functionalities were able to effectively substitute for hydroxyl (OH) groups in every sample. The optimum pre-nitration drying temperature for cellulose sources was 105°C , as it eliminates any residual water that evaporates without breaking the polymer chain. This reduces hydrolysis side reactions and increases the availability of nitronium ions for dependable esterification. These results demonstrate the feasibility of utilising textile wastes as sustainable alternatives to conventional wood pulp in the synthesis of nitrocellulose, with comparable nitration efficiency.

CARBON, HYDROGEN, NITROGEN AND SULPHUR (CHNS) ELEMENTAL ANALYSIS

CHNS elemental analysis, a combustion-based method that accurately determines the proportion of Nitrogen (N) together with Carbon (C), Hydrogen (H), and Sulphur (S) by high-temperature oxidation and thermal conductivity detection, was used to evaluate the nitrogen content in nitrocellulose samples. Accurate nitro group substitution levels were determined using this approach, which is crucial for evaluating the material's viability as a propellant precursor. High-energy applications are indicated by nitrogen concentrations of more than 12%.

Table 2
Table 2 CHNS Analysis Results

Sample	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)
Wood pulp	28.20	4.43	11.01	Not detected
Pre-consumer cotton lint	28.25	4.33	11.49	Not detected
Post-consumer cotton	28.25	4.45	11.17	Not detected

All samples had a closely clustered carbon content of 28.20–28.25%, which indicates sustained cellulose backbone integrity after nitrations. Cotton lint has a lower hydrogen content (4.33–4.45%), indicating a somewhat stronger nitrate substitution at the C6 hydroxyls. The most obvious difference is in Nitrogen.

Wood pulp lags (11.01%), suggesting a 4% relative spread that corresponds to the degree of substitution, while cotton lint leads at 11.49% and post-consumer cotton is in the middle (11.17%). To prevent explosive instability or lacquer discoloration, the consistent absence of sulfur (< detection limit) verifies clean pulping/nitration.

The characteristics of post-consumer cotton and cotton lint are nearly identical, indicating that waste textiles can function as well as virgin lint without relying on new supplies. The nitrogen content of wood pulp is lower (11.01%), perhaps as a result of shorter chain lengths or lingering lignin residues.

THERMOGRAVIMETRIC ANALYSIS (TGA)

By monitoring mass loss as temperature rises, thermogravimetric analysis (TGA) assesses nitrocellulose's thermal stability and breakdown behaviour. Nitrate content affects nitrocellulose breakdown, as higher nitrogen levels result in lower decomposition temperatures.

Figure 8

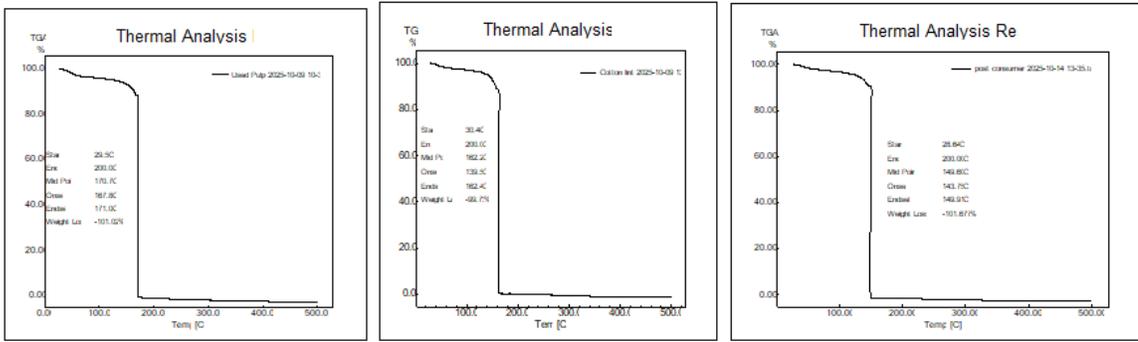


Figure 8 Nitrocellulose (Wood Pulp, Pre-Consumer and Post-Consumer Cotton)

Table 3

Table 3 TGA Analysis of All Samples

Material	Onset (°C)	Mid (°C)	End (°C)	Range (°C)	Weight loss (%)
Wood pulp	167.84	170.78	171.04	3.20	101.023
Pre-consumer Cotton	139.56	162.2	162.41	22.85	99.73
Post-consumer cotton	143.75	149.60	149.91	6.16	101.67

TGA data show that wood pulp, pre-consumer (cotton lint) and post-consumer cotton, have different thermal breakdown profiles, emphasising variations in content, purity, and previous processing that affect thermal stability.

Cotton lint achieves greater mid (162.20°C) and end points (162.41°C) than post-consumer cotton (143.75–149.9°C), but it has the lowest onset temperature (139.56°C), suggesting early hemicellulose or moisture-related breakdown. The shorter decomposition range of post-consumer cotton suggests that mechanical wear or contaminants speed its breakdown. Because of its refined cellulose content, which reduces low-temperature volatiles, wood pulp exhibits exceptional stability with an onset at 167.84°C and a narrow range (3.2°C span to 171.04°C). All samples approach total mass loss (approximately 100%).

WEIGHT OF CELLULOSE AFTER NITRATION

The change in the weight of cotton waste after the nitration process provides a measure to estimate the extent of chemical add-on.

Figure 9

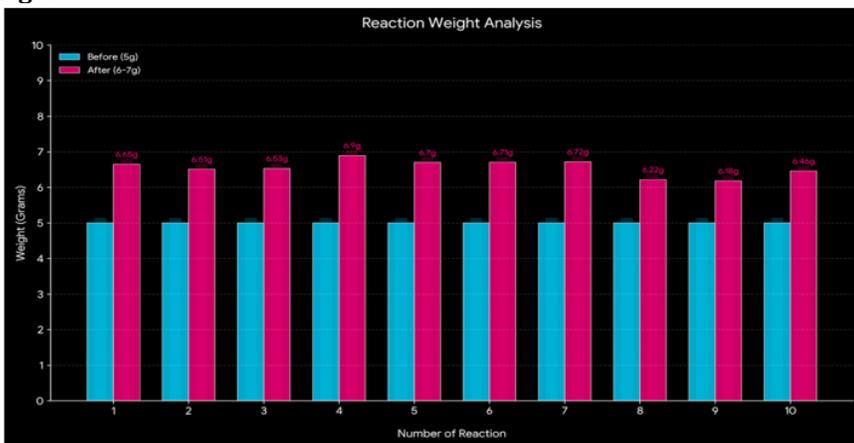


Figure 9 Weight Comparison Graph of Cotton Before and After Nitration

As seen in Figure 9, the weight of the raw materials, such as wood pulp and post-consumer cotton waste, including cotton lint fibres, increases following the nitration process. The incorporation of heavier nitro groups into the cellulose structure is responsible for this weight shift, which increases the overall molecular weight.

This is explained by the reaction's substitution of NO₂ groups for OH groups, which raises the molecular weight. The total atomic mass of the atoms that make up a molecule determines its molecular weight. When it comes to cotton, the nitro group (NO₂) added during the nitration process has a higher molecular weight than the OH groups in the cellulose structure. The OH group has a lower molecular weight (17.01 g/mol) than NO₂ (46.01 g/mol). Consequently, the total molecular weight of the substance rises as the heavier NO₂ groups in the cellulose structure replace the lighter OH groups.

CONCLUSION

Through optimised chemical recycling, this study successfully demonstrates the valorisation of pre- and post-consumer cotton waste, as well as commercial wood pulp, into high-quality nitrocellulose. Consistent nitration efficiency is demonstrated by FTIR peaks at 1272 cm⁻¹ (symmetric NO₂ stretch), nitrogen contents of 11.01-11.49% via CHNS analysis, and comparable thermal stabilities by TGA. Pre-nitration drying at 105°C emerges as a crucial parameter for optimising hydroxyl substitution while maintaining cellulose integrity.

A comparative analysis between nitrocellulose produced by Post-consumer, Pre-consumer cotton waste and wood pulp reveals pre-consumer cotton lint yielding the highest nitrogen content (11.49%) indicative of superior nitrate substitution, wood pulp exhibiting optimal thermal onset stability (167.84°C) due to refined purity, and post-consumer cotton waste performing intermediately (11.17% N, 143.75°C onset) despite processing impurities yet all samples display equivalent FTIR signatures and 10-15% weight gain post-nitration, affirming waste materials as viable sustainable alternatives to virgin pulp. These discoveries advance the circular economy concepts in materials science by diverting cellulosic waste from landfills towards the resource-efficient manufacture of adaptable nitro-esters for lacquers, propellants, and coatings. Future research may investigate nitrocellulose nanocomposites for high-performance applications, scale Box-Behnken optimised techniques for pilot production, and incorporate life-cycle evaluations to quantify environmental benefits, thereby connecting laboratory innovation with industrial sustainability.

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