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Original Research Article

Soda-Anthraquinone-Catalyzed Delignification of Coconut Husk Waste

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Abstract

This study investigates the role of anthraquinone (AQ) in decomposing coconut husk waste, specifically collected from Banten, to produce pure α-cellulose pulp. The process used sodium hydroxide (NaOH) at 10%, 15%, and 20% concentrations, with 0.1 g of AQ added as a catalyst, and a waste-to-liquid ratio of 1:8 throughout. The goal is to accelerate lignin degradation while protecting cellulose in the material, thereby yielding higher-quality pulp. The Banten coconut husk analysis showed an α-cellulose content of 30.38%. Higher NaOH concentrations reduced pulp yield but increased lignin removal, indicated by lower kappa numbers. AQ addition enhanced lignin removal and preserved cellulose compared to the absence of AQ. The optimal outcome was achieved with 15% NaOH and 0.1 g AQ, balancing lignin removal and cellulose preservation. These findings indicate that anthraquinone can support sustainable pulp production from agricultural waste.

Keywords: Anthraquinone; catalytic pulping; coconut husk; soda delignification; α-cellulose

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1. Introduction

DKI Jakarta, a metropolitan city, lacks sufficient agricultural land to produce coconuts. Yet, its high population density drives strong demand for coconuts. In 2022, Jakarta's population was about 11.25 million, with a density of 17,013 people/km². This population has a high consumption of coconut products, resulting in significant waste of coconut fiber and posing a challenge to local waste management. Most coconuts are sourced from buffer areas, such as Banten, which ranks 17th nationally in

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production. The chemical composition of coconut husks, influenced by ecological factors such as climate, humidity, and soil fertility, affects the content of cellulose and lignin.

Coconut husks are agricultural waste from the outer part of the *Cocos nucifera L.* fruit, which is generally underutilized. This material consists of fibers (coir fiber) and fine powder (coco peat) that are rich in lignocellulose, especially cellulose, hemicellulose, and lignin. Its high cellulose content (27–45%) makes it a potential source of value-added materials, including composites, adsorbents, and aerogels. The high lignin content (40–50%) provides mechanical strength and biological resistance, but it is a barrier to the production of pure cellulose. Therefore, a delignification process is required to remove lignin and increase cellulose purity. Alkali-based methods, such as using NaOH solution, are effective in reducing lignin content and increasing cellulose crystallinity [1].

Delignified cellulose can be used to synthesize aerogels, which are highly porous, lightweight, and environmentally friendly materials. Cellulose aerogels have a large specific surface area (>1000 m^2/g), low density, and are biodegradable. This material has potential as a thermal insulator, pollutant adsorbent, and absorber of fine particles and volatile organic compounds [2-4]. The delignification process is an essential step in breaking down the lignocellulose structure and isolating cellulose from lignin and hemicellulose [5]. For non-wood biomass, such as coconut husks, the soda pulping process is an economical option because it utilizes only NaOH and simple equipment. However, the pure soda process has limitations, including high carbohydrate degradation and the need for large amounts of alkali to achieve the desired degree of delignification.

One efficient and environmentally friendly method to overcome this problem is the soda-anthraquinone (soda–AQ) method. In this process, coconut husks are boiled in a NaOH solution containing anthraquinone (AQ) as a redox catalyst. AQ plays a role in accelerating delignification through a reduction-oxidation cycle between AQ and anthrahydroquinone (AHQ), which stabilizes carbohydrates against base degradation and increases lignin solubility efficiency [6]. The soda–AQ process has been shown to increase pulp yield, reduce the kappa number, and decrease alkali consumption compared to the pure soda process [7-8]. In addition, this method is sulfur-free, does not produce odorous emissions, and generates relatively little organic waste, making it more environmentally friendly than the kraft process [9-10].

Soda–AQ delignified cellulose typically has a pale color and a microfibrillar structure, making it suitable for use as a precursor for aerogels. It can be dissolved in eco-friendly solvents and freeze-dried to produce aerogels with high porosity, which are ideal for air filtration by capturing fine particles and volatile organic compounds.

Unlike most previous studies that utilized other lignocellulosic biomass such as Aleppo pine wood, palm kernel fiber, okra stems, and coconut fronds [8,11-13]. This study focuses explicitly on coconut fiber, characterized by high lignin content and a denser, more resistant cell wall structure. The application of the soda–anthraquinone (SAQ) method to this biomass provides a relevant approach for quantitatively evaluating delignification process performance by measuring the kappa number, which indicates residual lignin and α-cellulose content and thereby reflects cellulose purity. This approach enables a deeper understanding of coconut fiber's response to the SAQ-based delignification process, given its distinct characteristics relative to other non-wood biomass.

However, quantitative studies that systematically link the delignification efficiency of the SAQ method to the production of high-grade cellulose suitable as a precursor for aerogel from coconut fiber remain very limited. Therefore, this study aims to evaluate the effectiveness of the soda–anthraquinone delignification method on coconut fibers using kappa number and α-cellulose content analyses, and to assess the suitability of the resulting cellulose as a precursor for cellulose aerogels derived from coconut husk waste.

2. Materials and Method

2.1. Materials

Dried coconut husks were obtained from local agricultural waste in the village of East Cikujang (Pandeglang, Banten), Indonesia. The plant was identified at the UPT Laboratorium Herbal Materia Medica, Batu, Malang, Indonesia, and a voucher specimen (No. 074/692/102.20-A/2022) was deposited in its herbarium. The chemicals used in this study were of pro-analytical purity and were used without further purification. Sodium hydroxide (NaOH, ⩾97%), glacial acetic acid (CH_3COOH), anthraquinone (AQ, 97%), potassium permanganate ($KMnO_4$, 99%), ethanol (C_2H_5OH), benzene (C_6H_6), sodium thiosulfate ($Na_2S_2O_3$), sulfuric acid (H_2SO_4, 98%), sodium chlorite ($NaClO_2$), starch, and potassium iodide (KI, 99%) were obtained from Merck (Germany).

2.2. Coconut Husk Preparation

A 5 kg sample of coconut husk was dried and ground in a Wiley mill to a particle size of 40–60 mesh. The powder was then used to analyze the

contents of lignin, holocellulose, alpha-cellulose, and hemicellulose.

2.3. Lignin Content Test

A total of 2 g of coconut husk powder was extracted using the Soxhlet apparatus with a solvent mixture of alcohol and benzene (1:2, v/v) for 4–6 hours. Following extraction, the remaining solvent was removed by drying the sample at 105 ± 2 °C until a constant weight was achieved. After drying, the sample was hydrolyzed with 72% H_2SO_4 (1.5 mL per 0.15 g of sample) at room temperature for 2 hours. After hydrolysis, the mixture was diluted to 3% acid and reheated at 100 °C for 4 hours. Subsequently, the residue was filtered, washed with hot water until acid-free, and then dried to constant weight. The mass of the dry residue was determined as insoluble lignin. The lignin content is calculated according to the ratio of the dry residue mass to the initial dry sample mass using the equation:

$$\%\text{lignin} = W_l/W_i \times 100\% \quad (1)$$

where W_l is the mass of lignin residue (g), and W_i is the mass of the dry sample (g).

2.4. Holocellulose Content Test

Two grams of dry powder were processed with distilled water (150 mL), glacial acetic acid (0.3 mL), and $NaClO_2$ (1 g) at 70–80 °C for 60 minutes, with periodic stirring. This step is repeated with fresh reagents until the residue turns white. The mixture is then filtered, thoroughly washed with water to remove residual acid, washed with ethanol (50 mL), dried at 105 ± 3 °C, cooled in a desiccator, and weighed. The holocellulose content is calculated according to the ratio of the dry residue mass to the initial dry sample mass using the equation:

$$\%\text{lignin} = W_h/W_i \times 100\% \quad (2)$$

where W_h is the mass of holocellulose residue (g), and W_i is the mass of the dry sample (g).

2.5. α-Celluloce Content Test

A total of 2 grams of holocellulose residue was placed in a container and maintained in an ice bath to keep the temperature constant during the alkaline treatment. To the sample, 25 mL of a 17.5% NaOH solution at 20 ± 2 °C was added gradually: first, 10 mL was added while stirring for 2 minutes, and then the solution was stirred for an additional 3 minutes. Next, another 5 mL was added and stirred for 5 minutes. This step is repeated until the entire volume of 17.5% NaOH solution (25 mL) has been added. The suspension is then held at 20 °C for 30 minutes, bringing the total contact time to 45 minutes. Next, 33 mL of distilled water at 20 °C is added to the mixture, which is then stirred and allowed to stand for 1 hour. The precipitate is filtered using a funnel or a weighed beaker. The residue is washed successively with 100 mL of 8.3% NaOH solution at 20 °C, then with cold distilled water (20 °C) until all the residue has been completely transferred to the funnel. Washing with distilled water is repeated twice more to ensure the residue is clean. Subsequently, the residue is soaked in 15 mL of 10% acetic acid (CH_3COOH) for 3 minutes, then washed again with cold distilled water (20 °C) until the solution is neutral. The sample is dried at 105 °C to a constant weight, then weighed. The final weight of the residue is expressed as the α-cellulose content in the sample. The α-cellulose content is calculated based on the ratio of the dry residue mass to the initial dry sample mass using the equation:

$$\%\alpha\text{-selulosa} = W\alpha/W_i \times 100\ \% \quad (3)$$

where W_α is the mass of α-cellulose residue (g), and W_i is the mass of the dry sample (g). The analysis was performed in triplicate, and the results were reported as the mean ± standard deviation. High α-cellulose content indicates good cellulose purity and suitability for dissolving pulp applications.

2.6. Determination of Hemicellulose Content

Hemicellulose content is calculated as the difference between holocellulose and α-cellulose content, based on the weight of the dried sample.

2.7. Delignification Process using the Soda–Anthraquinone (SAQ) Method

A total of 100 grams of dry coconut husk was placed in a stainless steel reactor, and then 800 mL of distilled water was added to maintain a solid-to-liquid ratio of 1:8 (w/v). The reactor was sealed and heated to 170 °C for 60 minutes under autogenous pressure. After the process was complete, the reactor was cooled to room temperature. The mixture was then filtered, and the solid residue was washed repeatedly with distilled water until the pH was neutral (~7). The prehydrolyzed fibers were dried at room temperature before use in the delignification stage.

The delignification process was carried out using the soda-anthraquinone (SAQ) method, with NaOH concentrations of 10%, 15%, and 20% (w/w) relative to the fiber dry weight. As a redox catalyst, 0.1 g of anthraquinone (AQ) was added to each cooking solution. The cooking solution was prepared by dissolving NaOH in distilled water to a final volume of 800 mL, maintaining a liquid-to-solid ratio of 8:1 (v/w). The prehydrolyzed fiber was then placed in a stainless steel reactor, and

the prepared SAQ solution was added. The reactor was sealed and heated to 165 °C for 90 minutes under autogenous pressure. After the cooking process was complete, the reactor was cooled to room temperature. The cooking mixture was then filtered to separate the pulp from the black liquor (the remaining dissolved lignin solution). The pulp obtained was washed repeatedly with hot distilled water until it reached a neutral pH (~7), then dried with air and stored in a closed container for further analysis.

2.8. Determination of Kappa Value

To assess the effectiveness of the delignification process, the efficiency index (EI) is calculated as the ratio between the α-cellulose content (%) and the corresponding Kappa number. This index provides a comparative measure of lignin-removal efficiency relative to the yield of purified cellulose. The Kappa value is determined to assess the residual lignin content in delignified pulp. Dried pulp (500 mg) was dissolved in distilled water (100 mL) and stirred for 5 minutes, followed by the addition of 4 N H_2SO_4 (50 mL, 200 mmol) and 0.1 N $KMnO_4$ (50 mL, 5 mmol). The total volume is adjusted to 500 mL with distilled water, and the mixture is stirred at room temperature for 10 minutes. The reaction is stopped with 10% KI (10 mL), and the released iodine is titrated with 0.2 N $Na_2S_2O_3$ using a 1% starch solution as an indicator. A blank sample is prepared under the same conditions, excluding the pulp. The Kappa number was calculated as follows using Equations (4) and (5) [14]:

$$K = (P \times f)/w \quad (4)$$

$$P = ((b\text{-}a)p \times N)/0.1 \quad (5)$$

Where K is kappa number; f is the factor for correction to a 50% permanganate consumption, dependent on the value of p; w is the weight of pulp (g); p is the amountof 0.1 N permanganate consumed by the test specimen (mL); b is the amount of the thiosulfate consumed in the blank determination (without adding pulp) (mL); a is the amount of the thiosulfate consumed by the pulp (mL); and N is the normality of the thiosulfate solution.

3. Results and Discussion

3.1. Chemical Composition of Coconut Husk

The first stage of this research involved collecting raw coconut fiber materials in the Cikujang Timur area of Tanjungan, Cikeusik, Banten. The selection of sampling locations was based on the availability of raw coconut materials in areas surrounding DKI Jakarta that lack coconut production. Banten province is a leading supplier, with coconut production reaching 48,275 tons/year, a planting area of 92,711 ha, and the highest output in Pandeglang Regency (47.45%).

Approximately 35% of the coconut's weight consists of coconut fiber (coconut husk), which has not been optimally utilized. Given that its main components are cellulose, hemicellulose, and lignin, coconut fiber has the potential to serve as a raw material for air filters. Starting with the selection of Banten and its surrounding areas as the source, this study uses coconut fiber from these areas as a raw material for producing filter media. The determination of coconut species was carried out at the Materia Medica Herbal Laboratory, Batu, using samples from Cikujang (Banten). The study's results showed that the samples originated from the following coconut species: Kingdom: Plantae; Division: Magnoliophyta; Subdivision: Angiospermae; Class: Liliopsida (Monocots); Family: Arecaceae (Palm Family)/Palmae; Genus: Cocos; Species: *Cocos nucifera L.*

3.2. Extractable Free Water Content

A sample of coconut husk was extracted three times with a 1:2 (v/v) alcohol-benzene mixture to remove non-cellulosic extractive components. The extraction residue was then dried in an oven until a constant weight was achieved to determine the extractable free-water content. Table 1 shows that coconut fiber from Banten has a reasonably high extractive moisture content, at 10.60%. This is because relatively young coconut fiber contains readily soluble extractive components that increase its moisture content. Extractive content directly affects the fiber's physical and mechanical properties, corrosion resistance, and natural durability [15]. Variations in the chemical composition of coconut fiber result from differences in extractive content. In addition to age, environmental factors such as altitude influence extractive content; specifically, higher altitudes are associated with lower extractive content. Since Banten's elevation ranges from 5 to 100 meters above sea level, its lowland location promotes relatively high extractive content.

Table 1. Chemical content of coconut husk from Banten.

Component	Extractive water (%)	Lignin (%)	Holocellulose (%)	α-cellulose (%)
Coconut husk	10.60	42.93	57.99	30.38

3.3. Lignin Content

Lignin is an amorphous aromatic compound found in the middle lamella and cell walls. It acts as an intercellular adhesive, providing mechanical strength to plant tissues. Determining lignin content quantifies the proportion of lignocellulosic components and assesses the effectiveness of chemical treatments for lignin removal. The test follows the Klason lignin method, in which lignin is defined as the fraction that remains insoluble in 72% sulfuric acid. Based on Table 1, coconut husk samples from Banten have a lignin content of 42.93%. Acting as a framework for cellulose, lignin enhances the density and mechanical strength of coconut husks. These results support Putra *et al.* [16] assertion that lignin is the second-largest component in coconut husks, after cellulose. In addition to supporting prior findings on lignin content, our values are consistent with those reported in several earlier studies. For example, researchers studying coconut husks reported 42% in India [17], 59.40% in Jamaica [18], and 37% in Brazil [19]. Ecological factors, such as climate, altitude, humidity, and soil fertility, vary lignin content across regions by influencing the formation and distribution of chemical components in coconut husks.

3.4. Holocellulose Content

Besides lignin, holocellulose is the main macromolecular component in biomass. Holocellulose consists of cellulose and hemicellulose. It is a polysaccharide fraction obtained by removing lignin from raw materials, a process known as delignification. Table 1 shows that coconut shells from Banten have a high holocellulose content of 57.99%. This value is inversely proportional to the lignin content, indicating the relationship between lignin and holocellulose in biomass. A high holocellulose content suggests a higher proportion of cellulose and hemicellulose, which can increase the chemical reactivity and adsorption capacity of the shells. Fruit maturity, geography, and the local environment influence these differences.

3.5. α-cellulose Content

α-Cellulose is a fiber fraction that is insoluble in 17.5% sodium hydroxide solution and has a high molecular weight. This component plays an essential role in determining the fiber's mechanical strength and structural stability. Based on Table 1, coconut husk samples from Banten exhibit high alpha-cellulose content. This high value is attributable to the lower lignin content observed in the Banten sample; as lignin decreases, delignification becomes more efficient, thereby increasing the cellulose fraction. The chemical composition of coconut fiber comprises cellulose, hemicellulose, lignin, extractives, and ash, and changes in one component can affect the levels of others during purification.

This study found α-cellulose values similar to those reported in various regions. For example, India had 27.2% [20], Jamaica had 32.65% [18], Brazil had 32.5% [19], and Thailand had 32.69% [21]. Ecological factors, such as climate, altitude, humidity, and soil fertility, can lead to variation in chemical composition across regions. These factors influence the formation of lignocellulose components in coconut plants.

3.6. Dissolving Pulp from Delignification

The dissolving pulp manufacturing process has two main stages: prehydrolysis and cooking (delignification) [22]. Prehydrolysis aims to weaken the hemicellulose-lignin bonds in coconut fibers. This helps the delignification process in the next stage. It also partially hydrolyzes hemicellulose, reduces extractives, and results in pulp with higher cellulose purity. After prehydrolysis, the treated fibers move to the cooking stage to remove lignin more intensively. This stage uses an anthraquinone soda solution (soda–AQ) with a fixed material-to-chemical ratio of 1:8. The chemicals include NaOH at 10%, 15%, or 20%, and anthraquinone (AQ) at 1% as a catalyst. NaOH breaks lignin-carbohydrate bonds. AQ acts as a redox catalyst. It accelerates delignification without reducing cellulose yield. Several studies reported that low concentrations of AQ (0.05–0.1%) in the soda process can increase the delignification rate, yield, and pulp strength [23,24]. This is consistent with results from the sulfate process. Using AQ in the soda method results in more complete lignin bond breaking. Delignification results obtained using the anthraquinone soda method are presented in Table 2. The results of the delignification process using the soda–AQ method for dissolving pulp

Table 2. Dissolving pulp yield.

Parameter	Wet Weight (g)	Initial Weight (g)	Final weight (g)	Water content (%)	Dried Weight (g)	Yield (%)
B 10%	543.3	10.3	2	19.42	105.51	35.17
B 15%	585.2	10.8	2	18.52	108.38	36.13
B 20%	578.8	10.5	1.6	15.24	88.20	29.40

indicate that increasing NaOH concentration decreases pulp yield (Table 2). This is due to greater lignin degradation and dissolution into the cooking solution at higher base concentrations.

3.7. Kappa Number

The Kappa number test measures the amount of lignin remaining in pulp after cooking. A high Kappa number indicates greater lignin content, making the pulp harder to bleach and requiring more chemicals in the process. The testing principle involves several key steps: (1) Dry pulp samples are mixed with potassium permanganate ($KMnO_4$) solution in sulfuric acid (H_2SO_4) and allowed to react for about 10 minutes; (2) Potassium permanganate oxidizes phenolic groups and aromatic structures in lignin; (3) The sample amount is set so that about 50% of $KmnO_4$'s oxidizing capacity remains after reaction; (4) The remaining $KMnO_4$ is quantified by iodometric titration: potassium iodide (KI) is added, reducing $KMnO_4$ to Mn^{2+} and releasing iodine (I_2); (5) The released iodine is titrated with sodium thiosulfate ($Na_2S_2O_3$) using a starch indicator; (6) The difference between the initial and residual $KMnO_4$ is used to calculate how much oxidizer reacted with lignin, which is then converted to the Kappa number [25]. This number is crucial for assessing the effectiveness of delignification and determining the final pulp quality. The primary mechanism is depicted in Equations (6-9).

Lignin residue + other oxidizable compounds + MnO_4^- + $4H^+$ → Oxidized lignin + other oxidized compounds + excess MnO_4^- + MnO_2 + $2H_2O$ (6)

$$2MnO_4^- + 10I^- + 16H^+ \rightarrow 2Mn^{2+} + 5I_2 + 8H_2O \quad (7)$$

$$MnO_2 + 4H^+ + 2I^- \rightarrow Mn^{2+} + 2H_2O + I_2 \quad (8)$$

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^- \quad (9)$$

Based on theoretical calculations and experimental observations, a 60% (mass/mass) consumption of permanganate ions is the endpoint at which the ions have been reduced to excess MnO_2. Upon addition of potassium iodide solution, the reaction is stopped, and the liberated iodine is titrated with sodium thiosulfate. The values obtained are corrected by 50% consumption of the total oxidation capacity of permanganate. The kappa values are presented in Table 3. As shown in Table 3, increasing alkali base concentration reduces the Kappa number. This demonstrates that higher base levels promote greater lignin removal during delignification. These findings correspond with those of Jincy et al. [20], who reported a kappa range of 40-70 for Indian coconut fiber at 160-170 °C. A lower Kappa number signifies more effective delignification, as it reflects lower residual lignin in the pulp.

The optimal Kappa value is generally below 100. Research conducted by Ulfa & Isnaini [26] Shows that increasing the concentration of NaOH from 10% to 20% gradually decreases the Kappa number, from 159–162 at 10% NaOH, to 149–152 at 15% NaOH, and 148–151 at 20% NaOH. In comparison, the addition of anthraquinone in this study further reduced the Kappa number, indicating a more effective delignification process than increasing the NaOH concentration alone.

3.8. α-Cellulose Content of Dissolving Pulp

The main components of pulp are cellulose, hemicellulose, lignin, moisture, extractives, and ash. As shown in Table 3, increasing NaOH concentration results in a proportional increase in α-cellulose content. For example, at a 10% NaOH concentration, the Banten sample showed 61.10% α-cellulose. This value increased to 72.48% at 15% NaOH and to 80.56% at 20% NaOH. In contrast, Ulfa & Isnaini [26], observed α-cellulose contents of 48–49% (NaOH 10%), 48% (NaOH 15%), and 46.78% (NaOH 20%). These comparisons indicate that the addition of anthraquinone (AQ) can significantly raise α-cellulose content. This result also agrees with Lukmandaru [27], who found that AQ serves as a redox catalyst in the soda delignification process, accelerating lignin degradation and preventing carbohydrate breakdown.

Based on the data in Tables 2 and 3, increasing NaOH concentration from 10% to 20% is associated with an inverse relationship between delignification efficiency and dissolving pulp yield. At 10% NaOH, the pulp yield is relatively high (35.17%), but it is still accompanied by a very high kappa number (185.2), indicating significant residual lignin and suboptimal α-cellulose (61.18%). Increasing the NaOH concentration to

Table 3. Pulp chemical composition.

Component	Dissolving pulp		
	NaOH 10%	NaOH 15%	NaOH 20%
Kappa number	185.2	67.55	40.27
Holocellulose	71.68	88.87	93.29
α-cellulose	61.18	72.48	80.56

15% drastically reduced the kappa number to 67.55, indicating more effective delignification, while increasing α-cellulose to 72.48% yielded the highest value (36.13%). This condition shows that at 15% NaOH, lignin was efficiently removed without causing excessive carbohydrate degradation. Conversely, at 20% NaOH, although the kappa number continued to decrease to 40.27 and α-cellulose increased to 80.56%, the pulp yield actually dropped sharply to 29.40%. This decrease in yield indicates that excess alkali not only dissolves lignin but also causes extensive hemicellulose dissolution and partial cellulose degradation via alkaline peeling and alkali hydrolysis. Thus, the 15% NaOH condition represents the optimal compromise between lignin removal, increased α-cellulose purity, and minimized pulp mass loss, confirming the role of anthraquinone in expanding the window of efficient delignification of coconut fiber biomass.

3.9. Delignification Mechanism with Anthraquinone Catalyst

Mechanistically, anthraquinone operates through a redox cycle between its oxidized form (AQ, a synthetic aromatic compound) and its reduced form (anthrahydroquinone, AHQ). The mechanism by which AQ facilitates the breakdown of lignin, a complex plant polymer, via this redox cycle is shown in Figure 1. The Figure 1 shows the mechanism of the soda–anthraquinone (SAQ) reaction through a redox cycle between anthraquinone (AQ) and anthrahydroquinone (AHQ), which plays a vital role in the delignification process. Under alkaline conditions, the reducing end group of carbohydrates acts as an electron donor that reduces AQ to AHQ, accompanied by the oxidation of the aldehyde group in carbohydrates to a carboxylate group. This stage contributes to carbohydrate stabilization and inhibits cellulose degradation during alkaline cooking. The AHQ then functions as a lignin-reducing agent by transferring hydrogen to the lignin structure, particularly at the *β*–O–4 bond, thereby depolymerizing lignin into smaller phenolic fragments that are readily soluble in alkaline solutions [28]. After hydrogen transfer, AHQ is reoxidized to AQ, enabling a repeated catalytic cycle. This mechanism explains how the addition of anthraquinone can increase lignin removal efficiency while maintaining cellulose purity, as evidenced by a decrease in kappa value and an increase in α-cellulose content in SAQ-delignified pulp.

4. Conclusions

This study evaluated the effectiveness of the soda–anthraquinone (SAQ) delignification process for coconut husk fibers by assessing kappa number and α-cellulose content as indicators of lignin removal and cellulose purity. The results demonstrate that increasing NaOH concentration from 10% to 20% consistently reduced the kappa number, indicating enhanced delignification efficiency, while simultaneously increasing the α-cellulose content of the resulting pulp. The addition of anthraquinone (0.1 g) improved lignin removal without excessive cellulose degradation, as evidenced by higher α-cellulose values than those reported for soda pulping in the literature. Among the tested conditions, the use of 15%

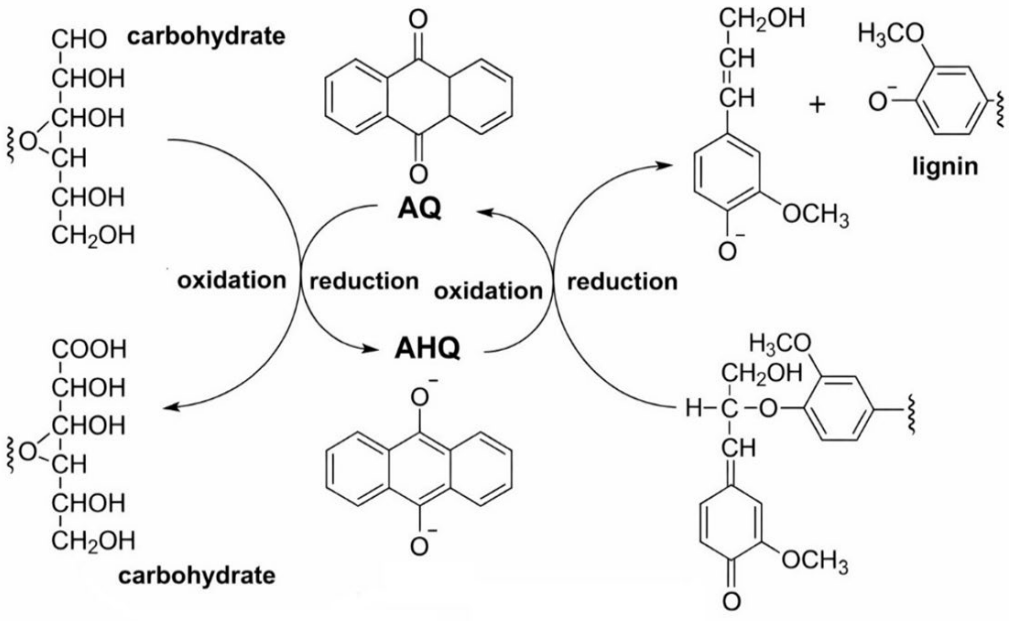

Figure 1. The mechanism of the soda-anthraquinone (SAQ) reaction in the lignin delignification process.

NaOH in the presence of anthraquinone provided the most balanced outcome, achieving substantial lignin removal with a high α-cellulose content while maintaining a reasonable pulp yield. These findings confirm that the SAQ method is effective for producing high-purity cellulose from coconut husk waste and that delignification performance can be systematically optimized by controlling alkali concentration. The obtained cellulose characteristics indicate its suitability as a precursor material for further processing, such as dissolving pulp or cellulose-based aerogel applications.

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CRedit Author Statement

Author Contributions: E.F. Ahmad: conceptualization, investigation, methodology, data curation, formal analysis, writing an original draft; P. Lestari: Supervision, research design, conceptualization; K. Oginawati: Supervision; Y. Yulizar: Supervision; J. Sianturi: Supervision; M.M. Munir: Supervision; A. Adawiah: review. proofreading & editing. All authors have read and agreed to the published version of the manuscript.

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