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The Influence of Chip Size Variation in the Pulping Process from Jabon Wood

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Abstract

Wood is the primary raw material in the pulp and paper industry. Due to its favorable fiber characteristics, Jabon wood (Anthocephalus cadamba Miq.) is a promising fast-growing pulp and paper production species. This study investigates the effect of nine different chip size variations, including their length and thickness (1×3, 3×3, 5×3, 1×5, 3×5, 5×5, 1×7, 3×7, and 5×7), on pulp yield, fiber properties, and chemical performance using the kraft pulping method. Parameters measured include pulp yield, fiber length, fiber diameter, lumen diameter, cell wall thickness, and derived indices such as Runkle ratio, felting power, Muhlsteph ratio, rigidity coefficient, flexibility ratio, and kappa number. Results show that chip size does not significantly affect yield but influences fiber quality and kappa number. Shorter and thinner chips improved chemical penetration, resulting in lower kappa numbers and higher-quality pulp. Fiber classification based on IAWA criteria placed jabon wood in class II, indicating medium to suitable suitability for pulp. The study provides novel insight into optimizing chip geometry for kraft pulping of jabon wood, which has rarely been explored in previous literature. These findings are relevant for enhancing raw material efficiency and pulp quality in industrial applications.

Keywords: Chip size, Fiber Quality, Jabon Wood, Fraft Process, Pulp Yield

INTRODUCTION

Wood is the primary raw material for various uses, especially for pulp and paper making (Dillén et al., 2016; N. Sari & Inayah, 2023), and its demand is increasing along with the industry's growth. The Indonesian Pulp and Paper Association (APKI) stated that national paper consumption increased by 5% from the previous year, reaching 38 kg/capita in 2017, and still has the potential for further growth (R. M. Sari & Nugraha, 2019). The steady supply of raw materials must balance this improvement to support the sustainability of production.

Raw materials for pulp production require a large quantity of wood. Jabon wood (*Anthocephalus cadamba* Miq.) can serve as an alternative raw material for pulp production due to its high yield, short growth cycle, and ability to meet the requirements for pulp production. This species is categorized as fast-growing wood and can be harvested every four years with optimal management (Dirna et al., 2020). A study by Darwis et al. (2024) found that the holocellulose content of jabon wood reached 76.71 – 79.50%, with the α-cellulose content ranging from 39.33 – 42.27%, indicating this wood can be used as pulpwood. Another study by Iswanto et al. (2021) also showed that a holocellulose content greater than 65% is recommended as pulp material and yields high results through chemical processing.

In addition to choosing the right raw materials, it is also essential to consider the method used for pulp processing, as the pulp-making process will determine the final quality of the product. Generally, there are several methods for the pulp-making process, namely mechanical, chemical, and semi-chemical methods (Bahri, 2017; Hastuti et al., 2022). The chemical method is recommended for producing high-quality pulp with high yield; therefore, this study used the kraft process. This method is widely applied in the pulp and paper industry because it can process various raw materials, produce high-quality pulp, and efficiently recycle energy and chemicals (Bajpai, 2016). According to Wistara et al. (2015), high-quality sulfate pulp can be produced from jabon wood as a paper raw material.

Pulp is produced through a cooking process where wood chips are treated with a cooking liquor

obtained from the reaction of green liquor with limestone (CaO), resulting in NaOH, Na_2S, and Na_2CO_3. This reaction is essential for separating lignin content and extractives from the cellulose, which will be utilized to produce pulp (Fadillah, 2019). After considering the selection of raw materials and the appropriate method, improving pulp quality remains a focus of this research. One aspect is analyzing the effect of wood chip dimensions used in the process. Previous studies (Wistara et al., 2015; Lal et al., 2021) have examined the chemicals or general pulping characteristics of wood, while this study specifically investigates the influence of chip dimension variations, which are distinguished by their lengths and thickness, on their pulp yield, fiber derivatives, and kappa number under kraft processing conditions. The detailed dimensional analysis and statistical modeling offer new insights into optimizing chip specifications for enhanced pulping efficiency and fiber quality, which is not comprehensively addressed in the existing literature.

The chips' uniformity and pulp productivity are affected by several factors, with chip quality being the most crucial. Smaller-sized chips are suspected to reduce the cooking time, lower cooking chemical consumption, decrease reject content, increase yield, and enhance the mechanical strength of the pulp (Tripathi et al., 2018). Therefore, this study aimed to investigate the most efficient chip dimensions for the pulping process and their impact on the resulting pulp quality.

METHODOLOGY

Materials and Instrumentals

The primary raw material was 7-8-year-old jabon wood (*Anthocephalus cadamba* Miq.), sourced from a community forest in Palembang (figure 1), South Sumatra Province. The chemicals used in this study included sodium hydroxide (NaOH) and sodium sulfide (Na_2S) as the components of the kraft cooking liquor. Additional reagents included hydrochloric acid (HCl) 0.1 N, potassium iodide (KI) 0.1 N, phenolphthalein (PP) indicator, red methyl indicator, acetic acid (CH_3COOH) 10%, thiosulfate ($Na_2S_2O_3$) 0.1 N, starch indicator, sulfuric acid (H_2SO_4) 4 N, potassium permanganate ($KMnO_4$) 0,1 N, 0,1 N, safranin stain, and distilled water.

Methods

Preparation of Chips

Jabon wood was processed into chips with varying dimensions, specifically combinations of length (cm) and width (mm): 1×3, 3×3, 5×3, 1×5, 3×5, 5×5, 1×7, 3×7, and 5×7. Each chip's upper and lower surfaces were cut at a beveled angle to facilitate chemical penetration during the pulping process. Afterward, the chips were air-dried to reduce moisture content before cooking.

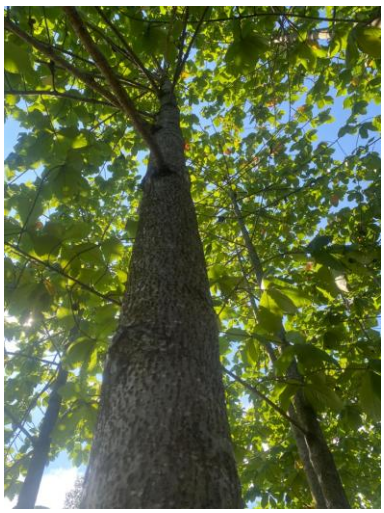

Figure 1. Jabon tree growing in community forest (source: Personal Documentation, 2025)

Preparation of Cooking Liquor

Before the cooking process, both the raw materials and the cooking liquor were prepared. The chip-to-liquor ratio was maintained at 1:6 (w/v), with an active alkali (AA) concentration of 20% and a sulfide level of 25%. The Kraft cooking liquor was composed of sodium hydroxide (NaOH), sodium sulfide (Na_2S), the inherent moisture content of the wood chips, and distilled water. The total volume of the cooking liquor was standardized at 1200 mL.

Required chemicals = AA × oven-dried weight of chip

Na_2S = sulfide × AA × required chemicals

NaOH = (AA-%Na_2S) × required chemicals

Additional solution = (total solution) – (V Na_2S + V NaOH + water content in chips)

Preparation of NaOH Solution

500 g of sodium hydroxide (NaOH) was dissolved and diluted to a volume of 1 L. This requirement calculation is based on the fundamental guide for preparing solutions in the laboratory according to basic concepts of preparing solutions by Flinn Scientific (2011). The solution was filtered through gauze and allowed to stand for 2-3 days. To determine the concentration of the NaOH solution, 5 mL of the stock solution was transferred into a volumetric flask and

diluted to the calibration mark with distilled water. The flask was shaken until the solution reached a homogeneous condition and left to equilibrate for an hour. Subsequently, 25 mL of this diluted solution was taken for titration. First, 2-3 drops of phenolphthalein (PP) indicator were added until the solution turned pink. The solution was titrated with 0.1 N hydrochloric acid (HCl) until it became colorless (volume recorded as mL). Then, 2-3 drops of red methyl indicator were added, turning the solution yellow. Titration was continued with 0.1 N HCl until the solution turned orange (volume recorded as *b* mL). The NaOH concentration (g/L) and volume (mL) were calculated using the following formulas:

$$[NaOH]\left(\frac{g}{L}\right) = \frac{500}{25x5} x\ (2a - b) x\ N_{HCl} x\ BE_{NaOH}$$

$$NaOH\ volume\ (mL) = \frac{mass\ of\ NaOH\ (g)}{concentration}\ 1000$$

Description:

N_{HCl} = HCl normality used in titration

BE_{NaOH} = equivalent weight of NaOH

Concentration (g/L) = the results of the previous calculations.

Preparation of Na_2S Solution

250 g of sodium sulfide (Na_2S) was dissolved in distilled water and diluted to a final volume of 500 mL. This solution was filtered through gauze and allowed to stand for approximately 7 days to stabilize. To determine the concentration of Na_2S solution, 5 mL of Na_2S was pipetted into a volumetric flask and diluted to the calibration mark with distilled water. The solution was shaken until homogeneous and left to equilibrate for approximately an hour. For the titration, 25 mL of the prepared Na_2S solution was mixed with 20 mL of 10% acetic acid (CH_3COOH) and 20 mL of 0.1 N sodium thiosulfate ($Na_2S_2O_3$) in an Erlenmeyer flask. A few drops of starch indicator were added, turning the solution blue. The mixture was titrated with 0.1 N sodium thiosulfate until the solution became milky white. The titration volume was recorded in mL. A blank solution was also titrated under identical conditions, and the volume was recorded as *b* mL. The concentration (g/L) and volume (mL) of Na_2S were calculated using the following formulas:

$$[Na_2S]\left(\frac{g}{L}\right) = \frac{250}{25x5} x\ (b - a) x\ N_{Tiosulfat} x\ BE_{Na_2S}$$

$$Na_2S\ volume(mL) = \frac{mass\ of\ Na_2S\ (g)}{density\ of\ Na_2S} x\ 1000$$

Description:

$N_{Thiosulfate}$ = normality of thiosulfate used in titration

BE_{Na2S} = equivalent weight of Na_2S

Cooking Process

The jabon wood chips were subjected to kraft pulping in a laboratory-scale digester. The cooking was carried out for 3.5 hours at a maximum temperature of 165 °C to ensure adequate delignification and fiber separation.

Determination of Pulp Yield

Pulp yield was determined based on the ratio between the resulting pulp's oven-dried weight and the wood chips' initial oven-dried weight. The total weight of the produced pulp was recorded as A (g). A representative sample of the pulp, denoted as B (g), was oven-dried at 103±2 ºC until a constant weight, C (g), was achieved. The pulp yield (%) was calculated using the following equation:

$$Pulp\ yield = \frac{{}^{C}/_{B}\ x\ A}{oven - dried\ chip}\ x\ 100$$

Fiber Measurement

Fiber dimensions are critical parameters for assessing pulp quality. To measure fiber characteristics, a representative pulp sample was soaked in distilled water within a film bottle for 24 hours to hydrate the fibers fully. Subsequently, 2-3 drops of safranin stain were added, and the sample was left to stand for 3-4 hours to ensure proper staining. The fibers were then washed with distilled water and sequentially rinsed in alcohol solutions of increasing concentration to remove excess stains and prepare the sample for microscope observation. The stained fibers were gently dispersed, sliced, and mounted on microscope slides using tweezers or a fine brush. Measurements were performed on 50 randomly selected fibers under a light microscope. The parameters recorded included fiber length, fiber diameter, and cell wall thickness across samples subjected to various cooking conditions. The calculation of derived fiber parameters is according to the following formulas:

- Runkle ratio = (2 ×wall thickness)/lumen diameter
- Weaving power = fiber length/lumen diameter

- Muhlsteph ratio = (fiber diameter^2 – lumen diameter^2)/fiber diameter^2
- Coefficient of rigidity = cell wall thickness/fiber diameter
- Flexibility ratio = lumen diameter/fiber diameter

Determination of Kappa Number

A sample weighing either 1 g or equivalent, estimated to consume approximately 50% of the added permanganate, was placed into a 200 mL Erlenmeyer flask. The sample was mixed with 50 mL of distilled water using a magnetic stirrer to ensure uniform dispersion. Subsequently, 10 mL of 4 N sulfuric acid (H_2SO_4) and 10 mL of 0.1 N potassium permanganate ($KMnO_4$) were added to the mixture, which was then allowed to stand undisturbed for 10 minutes. After the reaction, 2 mL of potassium iodide (KI) and 3-5 mL of starch indicator solution were added to the mixture. The liberated iodine was titrated with 0.5 N sodium thiosulfate ($Na_2S_2O_3$) until the solution became colorless (transparent). The Kappa number and permanganate consumption were calculated using the following formulas:

$$Kappa\ number = \frac{pxf}{w}\ [\ 1 + 0{,}013(25\ °C - t)]$$

$$Permanganate(p) = \frac{(b-a)xN_{Thiosulfate}}{0.1}\ x\ 100\%$$

Description:

f = correction factor
w = oven-dried weight of pulp
a = the number of thiosulfate in the sample penetration
b = the amount of thiosulfate in the blank penetration
N = normality of thiosulfate

Determination of The Alkali Consumption

A volume of 25 mL of black liquor was placed into a 250 mL volumetric flask. Subsequently, 25 mL of 10% barium chloride ($BaCl_2$) solution was added, and the mixture was diluted to the calibration mark with distilled water. The flask was gently shaken to ensure thorough mixing, and the solution was allowed to stand undisturbed for 24 hours to enable complete precipitation of insoluble components. After settling, 25 mL of the clear supernatant was pipetted into a 300 mL Erlenmeyer flask. A few drops of methyl red indicator were added, and the solution was titrated with 0.1 N hydrochloric acid (HCl) until the color changed from yellow to orange, indicating the endpoint. The amount of alkali consumed during the pulping process was calculated using the following equation:

$$Alkali\ consumption = \frac{S_1 - S_2}{oven} - W\ x\ 100\%$$

Description:
S_1 = alkali weight used in the cooking process
S_2 = residual alkali weight
B = oven-dried weight of the cooked chips

Data Analysis

The data obtained in this study were analyzed using a multiple linear regression model, which enables the simultaneous evaluation of chip length and thickness effects on pulp yield and quality parameters. This statistical approach allows for the identification of significant relationships and the quantification of the individual contributions of each variable to the response. The general form of the regression equation used is as follows:

$Y = a + b_1X_1 + b_2X_2$
Description:
Y = yield (%)
X_1 = chip length (cm)
X_2 = chip thickness (mm)
a = intercept
b_1, b_2 = regression coefficients for length and thickness

RESULT AND DISCUSSION

Pulp Yield

Pulp yield is the ratio of the amount (quantity) of pulp produced from the chip cooking process. The commercial pulp yield typically ranges from 40-55% (Supraptiah et al., 2014). The yield is necessary for determining the pulping process's effectiveness, where a higher yield indicates a more efficient pulping process. The result of pulp yield measurement with length (cm) and thickness (mm) of 1×3, 3×3, and 5×3 is shown in Table 1.

Table 1. Pulp yield with variations in chip length and size at a thickness of 3 mm

	Chip dimensions length (cm) x thickness (mm)		
	1×3	3×3	5×3
Yield (%)	46.65	40.24	37.11

The data above shows that the yield produced decreases as the chip dimensions increase in length. This may be due to the improved surface-to-volume ratio in shorter chips, which makes the cooking process more effective in extracting fibers. Shorter chip lengths

can also reduce the cooking time required, thereby improving the overall efficiency of the pulping process. It can also reduce chemical consumption during chip cooking (Tripathi et al., 2018). These results were further supported by a study from Poschner et al. (2024), which stated that substantial chip sizes result in shorter fibers and lower tensile strength.

Table 2. Pulp yield with variations in chip length and size at a thickness of 5 mm

	Chip dimensions length (cm) x thickness (mm)		
	1×5	3×5	5×5
Yield (%)	53.51	53.05	49.96

The results of the pulp yield measurements were then carried out with chip lengths (cm) and thickness (mm) of 1×5, 3×5, and 5×5, as shown in Table 2. The result showed that the yield decreases as the chip length increases. Longer chips can lead to clumping in the digester, which slows the cooking process and results in a higher remaining alkali consumption (Apriani & Akbar, 2021).

Furthermore, it measured pulp yield with lengths (cm) and thickness (mm) of 1×7, 3×7, and 5×7; listed in Table 3. Based on the data obtained, there is no noticeable reduction in the pulp yield during the pulping process, with the most significant drop occurring at the chip dimension with a length (cm) and thickness (mm) ratio of 3×7. It is suspected that the difficulty in distributing the cooking solution throughout the wood chips is causing an uneven cooking process.

Table 3. Pulp yield with variations in chip length and size at a thickness of 7 mm

	Chip dimensions length (cm) x thickness (mm)		
	1×7	3×7	5×7
Yield (%)	68.05	31.48	44.35

Overall, chips that meet the standard specifications have 16 mm in length, 25 mm in width, 25 mm in thickness, and 3 mm in thickness (Istikowati et al., 2020). These standard dimensions contribute to the pulp quality, including pulp doneness rate and yield. The thicker the chips used, the lower the yield and the higher the kappa number resulted, and vice versa. The size of the chips can cause rejects due to residuals left at the end of the pulping process, resulting from an inefficient pulping process (Poschner et al., 2024). However, this study found that as the chip thickness increased, the yield also increased. Several factors, such as the diffusion of chemicals, cooking solution penetration, and reaction homogeneity, may influence this. When chips have the right thickness, the cooking solution in the Kraft process can penetrate well, leading to efficient delignification without excessive cellulose fiber degradation. On the other hand, thinner chips are more prone to fiber degradation due to excessive chemical reactions, resulting in more carbohydrates being broken down into solution rather than remaining as pulp. Smaller chip sizes result in higher pulp doneness and lower kappa numbers, but the yield is lower, though the quality is better (Poschner et al., 2024).

The pulp yield obtained from this study ranges from 31.48 to 68.05%. This number is quite similar to the pulp yield in commercial-scale pulping processes. An ANOVA analysis was also done to determine if the variation in chip dimensions significantly impacts the yield, as shown by the ANOVA analysis result in Table 4.

Table 4. ANOVA analysis result of the chip size variations on the pulp yield produced

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	,367	1	,367	,043	.841[a]
Residual	59,633	7	8,519		
Total	60,000	8			

a. Predictors: (constant), yield
b. Dependent Variable: Groups

Based on Table 4, the dimension of the chip does not significantly affect the yield produced. The differences in chip sizes within the range used in this study did not result in any substantial changes in the yield.

Fiber Dimensions

Fiber dimensions are a fundamental parameter in selecting wood raw materials for pulp and paper production. The wood fiber dimensions (fiber length, fiber diameter, lumen diameter, and fiber wall thickness) observed in this study are shown in Tables 5 and 6.

Table 5. The length and diameter of the jabon wood fiber

Chip dimensions (length (cm); thickness (mm))	Fiber length	Fiber diameter
1×3	1254.5	28.5
3×3	1308.0	39.0

5×3	1360.0	30.0
1×5	1120.5	32.0
3×5	1023.0	22.0
5×5	1123.0	38.0
1×7	1341.5	25.2
3×7	1224.0	41.0
5×7	1210.3	25.4
Average	1218.3	31.2

The fiber length of jabon wood used has an average of 1218.3 microns and is classified as the medium fiber category, according to the International Association of Wood Anatomists (IAWA). The long wood fiber results in pulp with high strength, as longer fibers provide a larger surface area and tighter bonds between fibers. The average fiber diameter of the jabon wood used is 31.2 microns. Larger fiber diameter can affect the absorption of chemicals in the cooking process, as fibers with a greater diameter may have thicker cell walls, which can influence the delignification process. Additionally, thicker fibers can contribute to the durability and physical properties of the resulting paper. Further results of lumen diameter and fiber wall thickness can be found in Table 6.

Table 6. Lumen diameter and fiber wall thickness of jabon wood

Chip dimensions (length (cm); thickness (mm))	Lumen diameter	Fiber wall thickness
1×3	20.7	3.9
3×3	32.0	4.0
5×3	20.0	10.0
1×5	15.3	8.4
3×5	14.0	8.0
5×5	30.0	4.0
1×7	16.3	8.9
3×7	34.0	8.0
5×7	15.7	4.2
Average	22.0	6.6

Based on Table 6, the lumen diameter observed is 22 microns, and the average cell wall thickness is 6.6 microns. Wood fibers with thin cell walls are more likely to flatten. Meanwhile, fibers with thicker cell walls can produce pulp sheets with higher tear strength. To obtain higher-quality pulp, fibers with thicker cell walls should be blended with those with thinner cell walls to produce pulp with greater bonding and tear strength (Kardiansyah & Sugesty, 2016).

Fiber Derivative Values

Fiber length and the derivative values of fiber dimensions determine the fiber requirement for pulp and paper production. The derivative values of fiber dimensions, including Runkle number, weaving strength, Muhlsteph ratio, coefficient of rigidity, flexibility ratio, and the fiber class values of the wood, are outlined in Tables 7, 8, and 9.

Species of wood that are suitable for pulp production have characteristics such as thin cell walls and large lumen diameter, resulting in a low Runkle number (<0,25) or equal to 0.25 (Tembe et al., 2021). Meanwhile, the Runkel ratio obtained in this study is 0.67. It indicates that the cell walls are neither too thick nor too thin, and the lumen diameter is still large enough to form strong fiber bonds. The fibers have medium flexibility, which allows for the formation of pulp sheets with fairly good mechanical strength. Fiber wood with a Runkle ratio of 0.67 can still be used for pulp production, but its quality is not as high as wood with a Runkle ratio of ≤ 0.25.

Table 7. Runkle number and weaving strength of jabon wood fiber

Chip dimensions (length (cm); thickness (mm))	Runkel ratio	Felting power
1×3	0.38	44.06
3×3	0.24	34.71
5×3	0.25	48.56
1×5	1.43	36.64
3×5	0.69	49.33
5×5	0.35	30.01
1×7	1.17	19.38
3×7	0.49	39.24
5×7	1.01	43.75
Average	0.67	38.41
Score	**50**	**50**

Felting power indicates high tear resistance and causes the fiber network to become longer, with the tear forces being distributed over a larger area (Syafii & Siregar, 2006). The felting power obtained in this study is 38.41. It suggests that the wood fibers in this study fall into the medium to low category, meaning the tear strength of the resulting pulp is likely quite good. Further measurements of the Muhlsteph ratio and coefficient of rigidity can be seen in Table 8.

Table 8. The comparison of the Muhlsteph ratio and the coefficient of rigidity of jabon wood fiber

Chip dimensions (length (cm); thickness (mm))	Muhlsteph ratio	Coefficient of rigidity
1×3	44.05	0.14
3×3	33.54	0.09
5×3	45.33	0.54
1×5	75.60	0.27
3×5	62.90	0.18
5×5	40.70	0.12
1×7	34.90	0.35
3×7	29.85	0.19
5×7	56.68	0.22
Average	47.06	0.23
Score	**50**	**25**

The fibers of jabon wood have a Muhlsteph ratio of 47.06%. A smaller value indicates that the pulp sheets have higher density, while a larger value suggests lower pulp density. Optimal pulp density is crucial in the paper industry as it affects the strength and quality of the final product. The pulp quality directly impacts the paper production process, including ink absorption and the durability of the final product. Another fiber derivative value is the coefficient of rigidity. According to Syafii & Siregar (2006), this ratio negatively correlates with the tensile strength of paper, so for pulp production, it is ideal to have a lower rigidity coefficient. The jabon wood tested showed a value of 0.23, which places it in Class III in the IAWA fiber classification. The result of the flexibility ratio measured can be seen in Table 9.

Table 9. The flexibility ratio of jabon wood fiber

Chip dimensions (length (cm); thickness (mm))	Flexibility ratio
1×3	0.73
3×3	0.82
5×3	0.46
1×5	0.47
3×5	0.63
5×5	0.76
1×7	0.35
3×7	0.81
5×7	0.56
Average	0.62
Score	**75**

Another significant fiber derivative value is the flexibility ratio, which has a parabolic relationship with tensile strength. Fibers with a high flexibility ratio have thin cell walls and are easy to shape. This ability to change shape allows for more flexible contact between the fiber surfaces, leading to better fiber bonding and stronger pulp sheets (Syafii & Siregar, 2006). The jabon wood fibers produced in this study have a flexibility ratio of 0.62, which indicates that they are relatively good. Overall, the evaluation of the fibers based on IAWA scoring, as shown in Tables 7, 8, and 9, gives jabon wood a total score of 325, classifying it as a class II fiber, which is considered suitable for pulp and paper production.

Kappa Number

The kappa number is the amount of 0.1 N potassium permanganate (in millimeters) consumed per gram of dry pulp under standard conditions (SNI 0494:2008). The kappa number is a parameter to determine the pulp's lignin content and assess the pulp's doneness or bleaching potential. This parameter is a comparative tool to measure lignin content across different treatments. During testing, pulp with a reasonable degree of doneness will yield a low kappa number. The higher the kappa number, the greater the lignin content in the pulp, which requires more chemicals for the bleaching process (Komari et al., 2024). The kappan number shows the doneness of the pulp. A low kappa number means the pulp is more

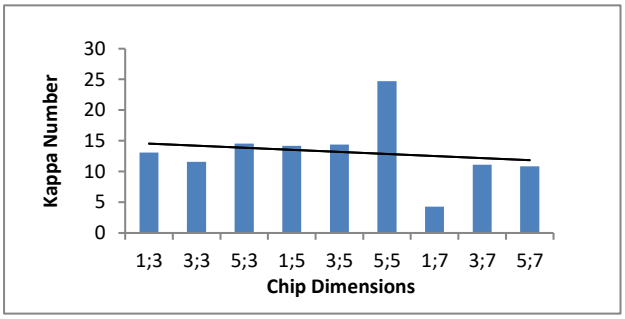

Figure 2. The relationship between the kappa number and chip dimensions

cooked, and its lignin components are effectively broken down, making bleaching easier. The following graph (Figure 2) shows the relationship between the kappa number and chip dimensions.

Based on this parameter, the kappa numbers for jabon wood ranged from 4.29 to 24.73. These results are relatively low, influenced by variations in active alkali, the chemical composition of the wood, and tree age. The consumption of active alkali varies for each chip's thickness and length. The highest alkali consumption was found in chips with a length of 5 cm and a thickness of 3 mm, at 1.537%. The lowest alkali consumption was observed in chips with a length of 3 cm and a thickness of 3 mm, at 0.2%. An increase in active alkali at constant sulfidity can lower the kappa number.

The kappa number can be used to estimate kraft pulp yield, as both parameters have a strong correlation. A higher kappa number typically indicates a higher pulp yield. However, the results of this study showed the opposite. The highest yield, 68.05%, was obtained from chips with a kappa number of 4.29, while the lowest yield, 31.48%, was from chips with a kappa number of 11.21. This discrepancy is likely due to the increase in the concentration of the cooking solution, which accelerates delignification and increases cellulose solubility. Excessively high active alkali concentration can damage cellulose and hemicellulose, while too low a concentration can lead to incomplete cooking.

The degree of cellulose and hemicellulose degradation can be determined by measuring the viscosity using an Ostwald viscometer. High viscosity results in a low decomposition rate and a high pulp yield, while low viscosity indicates a high decomposition rate, leading to a low yield and poor pulp quality. Sjostrom (1995) stated that the addition of 60-70% alkali is aimed at neutralizing the hydroxyl acids produced during the degradation of polysaccharide bases, 20-30% is used to neutralize lignin degradation products, and 10% neutralizes uronic and acetic acids. Furthermore, Rebia et al. (2025) found that bending strength increased in their research on hemp fibers pretreated with alkali.

Casey (1980) stated that alkali is used to dissolve carbohydrates, react with various organic acids in wood, and interact with wood resins, some of which are evaporated by the fibers. Alkaline must be present in every cooking process. This chemical shortage will result in dark-colored pulp, making bleaching difficult. The pulp and paper industry strives to achieve the lowest possible kappa number. A low kappa number indicates a relatively low residual lignin content, a high pulp doneness, and a high degree of delignification. High residual lignin adds stiffness to the fiber network, and the resulting sheet becomes rough, reducing its strength (Bowyer et al., 2007).

CONCLUSION

The results indicate that the wood chip size factor did not affect the pulp yield obtained. However, based on the fiber length, fiber dimensions, and fiber derivative values, including the runkle number, felting power, Muhlstep ratio, coefficient of rigidity, flexibility ratio, and kappa number, it can be concluded that the jabon wood fibers have good quality and high potential as a raw material for pulp and paper production. With these values, the fibers are classified as class II (medium) according to the IAWA classification.

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