Influence of Kappa Number on Enhancing Pulp Brightness through Stage D0 with ClO2 Bleaching Process: Environmental Implications and Considerations

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Abstract

Stage D0 in the pulp bleaching process, utilizing Chlorine Dioxide (ClO2), represents a critical phase aimed at improving pulp brightness while simultaneously addressing environmental concerns. This stage enhancement of pulp brightness can make an environmental impact, as excessive usage can lead to harmful emissions and environmental degradation. The amount of ClO2 used at stage D0 is influenced by the kappa number, the greater the kappa number, the greater the ClO2 use will be to produce brightness that corresponds to standard. The calculation of ClO2 usage at stage D0 is carried out after obtaining data related to ClO2 and the amount of pulp production from DCS (Distribute Control System). Based on the results of calculations and analysis, it can be concluded that the kappa number influences the total use of ClO2 in stage D0. The more ClO2 used in the D0 tower will produce pulp with a higher level of brightness.

Keywords: Bleaching, ClO2, Kappa number, D0 tower.

INTRODUCTION

The pulp industry, vital for the production of paper and packaging materials, stands at the intersection of economic necessity and environmental responsibility. One of the key processes within pulp manufacturing, the bleaching stage, is central to achieving desired paper quality, particularly in terms of brightness and appearance. However, the use of Chlorine Dioxide (ClO2) in the bleaching process raises significant environmental concerns due to its potential adverse impacts on air and water quality. Understanding and addressing these environmental implications are crucial for promoting sustainable practices within the pulp industry.

Chlorine Dioxide (ClO2) is widely utilized as a bleaching agent in pulp processing due to its effectiveness in removing lignin and enhancing pulp brightness. However, the use of ClO2 can lead to the formation of harmful by-products, including chlorinated organic compounds and chlorate ions, which pose risks to human health and the environment. Additionally, ClO2 bleaching processes may contribute to water pollution through the discharge of wastewater containing residual ClO2 and its by-products, impacting aquatic ecosystems and biodiversity.

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Furthermore, the environmental impact of ClO₂ bleaching extends beyond water pollution to air quality concerns. The release of chlorine-based compounds during ClO₂ bleaching operations can result in the emission of hazardous air pollutants, such as chlorine gas and dioxins, which have been linked to respiratory issues and environmental contamination. As such, mitigating the environmental footprint of ClO₂ bleaching processes is imperative for promoting environmental sustainability within the pulp industry.

The bleaching stage is the most important stage in the pulp making process and can determine the quality of the pulp. This stage aims to remove the color of the pulp to increase the brightness level pulp. The color of the dominant pulp is darkbrownish. Lignin contained in largeamounts causes discoloration of the pulp. Therefore, the effectiveness of lignin removal at the bleaching stage is a factor that really determines the brightness results. Bleaching promotes an increase in the brightness of the pulp and is followed by washing and pressing [1]. The measurement of lignin content in pulp is called the kappa number. If the kappa number is high, the color of the resulting pulp tends to be dark and vice versa. Therefore, to remove lignin levels, bleaching is carried out.

Kappa number measurement also plays a role in controlling efficiency and environmental impacts in the pulp industry. By measuring and controlling the Kappa number accurately, pulp mills can optimize the consumption of delignification chemicals such as bleaches and other chemical reagents. This not only reduces production costs, but also helps reduce environmental impact due to more efficient use of chemicals. In addition, environmental regulations often limit the amount of chemical waste that can be discharged into the environment, so measuring the Kappa number helps the pulp industry comply with these standards by optimizing the delignification process and reducing the chemical waste produced. Thus, measuring the Kappa number is not only important in producing quality pulp, but also in maintaining a balance between process efficiency and environmental impact in the pulp industry.

The lignin removal process is carried out using ClO₂. ClO₂ levels and concentrations are variables that play the most important role in the pulp whitening process. Adding ClO₂ that is too low will cause the color of the resulting pulp to tend to be dark. However, if too much ClO₂ is added, even though the color of the pulp will be brighter, it will cause damage to the pulp. Apart from stage D0, the bleaching stage will be continued at the EO stage which uses H₂O₂ as a bleaching liquid and continues to stages D1 and D2 which again use ClO₂ as a bleaching liquid to whiten the pulp and dissolve lignin.

**Chemical Components of Wood**

Cellulose is the main part of wood cell walls in the form of a glucose carbohydrate polymer and has the same composition as starch. In 1838, the identification of cellulose as a fundamental component of plant cells was attributed to the findings of the French botanist Anselme Payen. Payen, for the first time, extracted cellulose from wood, leading to the acknowledgment of its significance in plant cellular structure [2]. Some glucose and cellulose molecules have the same composition as starch. Several cellulose molecules form a cellulose chain. Cellulose is a polysaccharide that forms a cellulose chain. Cellulose is also a polysaccharide which indicates that it contains sugar compounds. The chemical formula identifies that it contains sugar compounds. The chemical formula for cellulose is (C₆H₁₀O₅)ₙ where "n" is the number of repetitions of glucose units where "n" is the number of repetitions of glucose units. The other main wood constituents, hemicelluloses and lignin, have been dissolved in the cooking and bleaching stages and consequently the pulp yield is low [3].

Hemicellulose is also formed from sugar as its main component. Unlike cellulose, it is only a polymer of 5 different types of polymers, namely Glucose, Mannose, Galactose, Xylose and Arabinose. Hemicellulose has a degree of polymerization of 300 and below. During pulping, hemicellulose reacts faster than cellulose. Cellulose is quite resistant in the process of reacting more quickly than cellulose.

Lignin is a complex polymer found in plant cell walls, an important component in the pulp and paper industry. In general, the process of making paper pulp involves separating lignin from cellulose and hemicellulose fibers using various chemical and physical methods. This process is known as pulp...
bleaching, which aims to produce cleaner pulp and purer cellulose fiber. Although lignin has a positive contribution to the strength and stability of wood, its presence in finished paper can cause weakness and yellowing in paper products. Therefore, reducing the amount of lignin in pulp has become a major focus in pulp industry research.

**Kappa Number**

The Kappa number is a parameter used to determine the lignin content in the pulp and is used to determine the level of maturity or whitening power of the pulp (SNI 0494-1989A). Kappa number is a measure of the lignin content of the pulp, a higher kappa number indicates a higher lignin content. As the Kappa number and lignin content decreased, depolymerisation and dissolution of the hemicelluloses and cellulose began to occur [4]. Something similar is the permanganate number (or K number). The Kappa number is used to monitor the amount of chemical pulp delignification after pulping and between bleaching stages. Monitoring the Kappa number of bleached pulp and then could be helpful to reduce the extra chemical and energy consumptions in the pulp and paper industry. The amount of bleaching agent needed will be closely related to the lignin content of the pulp, so the kappa number plays an important role in controlling the delignification process as well as several parameters in the bleaching process. The lignin content in unbleached pulp is needed because in the initial stage of the bleaching process it is necessary to remove the remaining lignin content after the cooking process. In the pulp and paper industry the expected kappa value is as low as possible. A low pulp kappa number indicates that the residual lignin content is relatively low, the maturity level of the pulp is high and the degree of delignification is high. The high remaining lignin will provide stiffness to the fiber weave and the sheets formed are rough, resulting in low strength.

**Viscosity**

Viscosity is a measurement that states the viscosity of a fluid or liquid. The viscosity parameter is closely related to flow resistance, so viscosity is needed to determine how fast a liquid will flow. Viscosity in a fluid causes friction between the moving parts of the fluid layer. Viscosity of pulp gives an estimate of the average degree of polymerization of cellulose in the pulp. It indicates cellulose integrity and the relative molecular weight during pulping/bleaching process [5]. The viscosity standard for digester output pulp at Pulp and Paper Industry is 23 mPas. The viscosity of the liquid will cause friction between the moving parts of the liquid layer.

Determination of lignin content and fiber strength is important for wood analysis and pulp characterization. The amount of remaining lignin is usually expressed by the kappa number and the fiber strength is expressed as viscosity. To achieve both, you must pay attention to the concentration of NaOH used. If the use of NaOH is low, the lignin removal process will be less good, resulting in rejects or chips where only part of them will cook and the kappa number and viscosity obtained will be higher. On the other hand, when using high concentrations of NaOH, the cellulose fibers will also be attacked and damaged, resulting in low viscosity produced, as a result, the wood chips are too cooked and the kappa number obtained will be lower.

**Bleaching**

Bleaching is a chemical process carried out to remove residual lignin from the pulping process. Bleaching process of chemical pulp is multistage sequential procedure carried out with two or more chemicals to achieve high pulp brightness [6]. Eucalyptus sp. pulp bleaching usually employs bleaching sequences consisting of four or more alternating bleaching stages to eliminate the residual lignin and chromophores [7]. To remove residual lignin, an oxidation process is carried out followed by a bleaching reaction. The fiber bleaching process must use reactive chemicals to dissolve the lignin content in the fiber to obtain a high degree of brightness. However, the use of chemicals must always be controlled so as not to cause dangerous environmental pollution. Pulp and Paper Industry that using the Elemental Chlorine Free (ECF) processes, which is a bleaching process using chlorine compounds in the form of
ClO₂ and also adding peroxide to increase the degree of whiteness if the degree of whiteness is not achieved. Few of the large sized wood or agro based pulp mills have started elemental chlorine free bleaching process with use of chlorine dioxide (ClO₂) [8].

ClO₂

Chlorine dioxide is one of the most efficient bleaching agents for the elemental chlorine free (ECF) bleaching process. The bleaching mechanism of chlorine dioxide is extremely complex and involves a series of chemical reactions. The reaction of residual lignin in pulp with chlorine dioxide induces structural changes in the residual lignin, which is the main cause of chlorine dioxide bleaching [9]. In comparison to the total chlorine free (TCF) bleaching method, ECF has advantages of high brightness after bleaching, low chemical consumption, and low-cost operation. Chlorine dioxide is an efficient and environmentally friendly oxidant and disinfectant [10].

ClO₂, or chlorine dioxide, is a chemical compound consisting of one chlorine atom and two oxygen atoms. Chlorine dioxide was discovered in 1811 by Sir Humphry Davy and since the mid-20th century, it has been widely used in the paper industry as a bleach and for the treatment of drinking water [11]. One of the main uses of ClO₂ is as a bleaching and disinfectant agent. Due to its strong oxidative properties, ClO₂ is often used to clean drinking water, remove harmful microorganisms, and remove unpleasant odors. Apart from that, ClO₂ is also used in the food processing industry, pulp and paper industry, and in waste water treatment. However, the use of ClO₂ must be done with caution because it is reactive and potentially dangerous if not handled properly.

Chlorine dioxide (ClO₂) is a specific oxidizing agent for lignin removal and provides good quality pulp of high brightness, without carbohydrates degradation [12]. This reduces negative impacts on the environment and follows sustainable trends in the pulp and paper industry. In addition, ClO₂ can also be used in combination with other whitening methods, such as chlorine, to achieve optimal whitening results. However, it is important to remember that the use of ClO₂ must be done carefully, following strict safety guidelines and environmental regulations, to ensure that its use is safe for workers and the environment around the pulp mill.

RESEARCH METHODOLOGY

This research using materials such as cellulose as chemical compound of wood, bleaching such as Chlorine Dioxide or ClO₂, D0 stage and kappa number on pulp samples.

Time and Place of Research

The research was carried out on 15 July–15 August 2023. The research was carried out in the aeration pond section of the Effluent Treatment Plant at the Pulp & Paper Industry, which located in Muara Enim, South Sumatra.

Data Collection

To achieve the aim of the special task, namely analyzing the amount of ClO₂ used for optimal pulp quality based on the parameters kappa number, viscosity and brightness at the D0 stage bleaching plant at Pulp & Paper Industry, there are several things that need to be done as in Figure 1.
Figure 1. Flow diagram for carrying out special tasks

**Calculation**

The required data was obtained from the results of Pulp and Paper Industry's main laboratory analysis Pulp & Paper which is then sent to the Distribute Control System (DCS). Based on observations made at DCS and in the field on the D0 Tower tool, data was collected in August - September 2023 as shown in Figure 1.

Table 1. Calculating total production based on total pulp flow and pulp consistency
### Table 2. Calculation results of ClO₂ use at D0 Stage Bleaching Plant

<table>
<thead>
<tr>
<th>Flow rate (m³/h)</th>
<th>konsentrasi ClO₂ (g/l)</th>
<th>ClO₂ Charge (Kg/h)</th>
<th>kg/adt</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.27</td>
<td>9.00</td>
<td>740.42</td>
<td>10.95</td>
</tr>
<tr>
<td>86.45</td>
<td>8.90</td>
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<td>12.02</td>
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<td>73.11</td>
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<td>650.72</td>
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</tr>
<tr>
<td>83.77</td>
<td>9.00</td>
<td>753.89</td>
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</tr>
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<td>89.47</td>
<td>9.00</td>
<td>805.22</td>
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<td>96.55</td>
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<table>
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<tr>
<th>Flow inlet press 2nd post</th>
<th>Consist</th>
<th>Pulp production</th>
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</thead>
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<tr>
<td>1 m³/h</td>
<td>2 m³/h</td>
<td>3 m³/h</td>
</tr>
<tr>
<td>493.0</td>
<td>491.2</td>
<td>984.2</td>
</tr>
<tr>
<td>445.0</td>
<td>476.4</td>
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<td>477.8</td>
<td>485.5</td>
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</tr>
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<td>465.8</td>
<td>470.7</td>
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</tr>
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<td>426.1</td>
<td>474.4</td>
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<tr>
<td>427.5</td>
<td>472.4</td>
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<td>475.8</td>
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</tr>
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<td>479.2</td>
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</tr>
<tr>
<td>452.8</td>
<td>447.7</td>
<td>900.5</td>
</tr>
</tbody>
</table>
**Calculation of Total Production (Adt/h)**

- Calculation of Total Production (Adt/h)
  \[
  \text{Total Flow} \left(\frac{\text{m}^3}{\text{h}}\right) \times \text{Konsentrasi Inlet and press} \rightarrow \text{Adt/h} \]
  ......................................................... (1)

- Calculation of ClO\textsubscript{2} charge (Kg/h)
  \[
  \text{Flow ClO}_2 (\text{m}^3/\text{h}) \times \text{Konsentrasi ClO}_2 (\text{g/l}) \]
  ......................................................... (2)

- Calculation of ClO\textsubscript{2} Charge (Kg/Adt)
  \[
  \frac{\text{ClO}_2 \text{ charge (Kg/h)}}{\text{Production (ADT/h)}} \]
  ......................................................... (3)

**RESULTS AND DISCUSSION**

**Comparison of kappa number and ClO\textsubscript{2} charge per hour**

![Graph showing the relationship between kappa number and ClO\textsubscript{2} charge per hour](image)

**Figure 1.** Relationship between kappa number and ClO\textsubscript{2} charge per hour

The graph above shows that the higher the kappa number value, the greater the amount of ClO\textsubscript{2} needed to bind lignin in the pulp and vice versa, if the kappa number value is low, then not too much ClO\textsubscript{2} is needed. However, in some cases there was a decrease in the use of ClO\textsubscript{2}, this was due to differences in the amount of pulp production at that time. A decrease in the amount of pulp production and flow rate will also affect the use of ClO\textsubscript{2} which will also decrease.

Based on theory, the higher the kappa number value, the higher the lignin content in the pulp. The higher the lignin content means the higher the ClO\textsubscript{2} needed to degrade the lignin content in the pulp so that the brightness of the pulp will increase. However, it can be seen in the graph above that the kappa number 9.45 value uses ClO\textsubscript{2} of 650.72 Kg/h and is smaller when compared to pulp with kappa number 9.44 which uses ClO\textsubscript{2} of 769.40 Kg/h. The decrease in ClO\textsubscript{2} use is due to the fact that determining the use of ClO\textsubscript{2} has several factors that must be considered besides the kappa number. One factor that greatly influences the use of ClO\textsubscript{2} is the amount of pulp produced in the process, where the more pulp produced, the more ClO\textsubscript{2} that must be used in the bleaching process.

**Relationship between Kappa number and Usage per Adt**

![Graph showing the relationship between kappa number and ClO\textsubscript{2} charge per ADT](image)

**Figure 2.** Relationship between kappa number and ClO\textsubscript{2} charge per ADT
The graph above shows that the kappa number value is linear with the ClO$_2$ requirement. In the graph it can be seen that pulp with a low kappa number requires less ClO$_2$ than pulp with a higher kappa number. Pulp with kappa number 9.23 requires 10.95 Kg/ADT of ClO$_2$. The need for ClO$_2$ is much less than the need for ClO$_2$ for kappa number 10.67 which requires 14.83 Kg/ADT of ClO$_2$. The reason for using a higher ClO$_2$ requirement for pulp with a larger kappa number is because it is in accordance with the function of ClO$_2$, namely to reduce the amount of lignin content in the pulp.

**Relationship between Kappa number and Brightness**

![Graph showing the relationship between Kappa number and Brightness](image)

**Figure 3.** Relationship between Kappa number and Brightness

The relationship between kappa number and brightness is that an increase in kappa number will usually cause a decrease in brightness, because more lignin remains in the pulp. Conversely, if the kappa number value is reduced through an effective bleaching process, the brightness will increase because the dark color caused by lignin has been removed. The delignification to a lower kappa number is one of the factors to get high pulp brightness [12].

The theory regarding the relationship between kappa number and brightness of the pulp above is in accordance with the graph shown. In the graph it can be seen that the highest brightness value produced at stage D0 is 73.21 % ISO because the pulp sample data has a low kappa number value at D0 tower inlet, namely 9.45. The lowest brightness of the pulp is 66.85 % ISO because the pulp sample in this data has a kappa number value which is quite high at the D0 tower stage, namely 10.31.

The values of brightness and kappa number in the D0 tower influence the amount of ClO$_2$ used charge. The large need for the use of ClO$_2$ will improve the quality of the pulp in terms of brightness. Pulp brightness increased and viscosity decreased with increasing ClO$_2$ charge in bleaching stage [13]. Pulp sample data number 1 shows that pulp with an inlet Kappa number D0 9.23 only requires a ClO$_2$ charge of 10.95 kg/adt to produce pulp with a brightness of 71.4 % ISO. The amount of ClO$_2$ required is much less compared to the kappa 10.63 sample which requires 14.83 kg/adt of ClO$_2$ to produce pulp with a brightness of 70.4 % ISO.

**Relationship between Kappa number and pulp viscosity**

![Graph showing the relationship between Kappa number and pulp viscosity](image)

**Figure 4.** Relationship between Kappa number and Pulp Viscosity
One of the side effects of the bleaching process that needs to be considered is the degradation of cellulose, because this will cause a decrease in fiber strength which results in a decrease in the tensile strength of the paper as the final result [14]. The lignin content in the pulp is what binds the fibers in the pulp such as cellulose and hemicellulose, as a result the strength of the pulp fibers will decrease. On the other hand, a lower viscosity often indicates that the fibers in the pulp separate and move around each other more easily. This can increase the potential of the fibers to withstand pressure, tension and bending in the resulting pulp.

It can be seen in the graph that the pulp has a low kappa number, namely 9.23. The viscosity of this pulp is also relatively low, namely 13.3 mPa.s. The low viscosity of this pulp indicates that the fibers in the pulp such as cellulose and hemicellulose are more easily separated or are not bound to large amounts of lignin because the kappa number is low. The highest viscosity is 16.8 mPa.s. The reason for the high viscosity is because the kappa number in the pulp is 10.03. A high kappa number means that there is still a lot of lignin content that binds the fibers in the pulp. The minimum standard for the viscosity of the D0 bleaching stage is 11.0 mPa.s which in the next bleaching stage is expected to continue to decrease in line with the process so that at the end it is able to produce pulp with the expected physical properties.

**CONCLUSION AND SUGGESTION**

**Conclusion**

In conclusion, the utilization of Chlorine Dioxide (ClO$_2$) in the bleaching process at the D0 stage is intricately tied to the lignin content present in the pulp. As observed, higher lignin content necessitates a corresponding increase in ClO$_2$ usage to achieve desired brightness levels. This underscores the importance of considering pulp composition when determining ClO$_2$ application rates to minimize environmental impact.

Several factors influence the quantity of ClO$_2$ utilized in the D0 stage bleaching plant, including the kappa number, production volume, and ClO$_2$ flow rate. A higher kappa number signifies greater lignin content, resulting in heightened ClO$_2$ requirements. Moreover, increased production volume directly correlates with higher ClO$_2$ flow rates, necessitating careful monitoring and control to optimize ClO$_2$ utilization while ensuring optimal bleaching outcomes.

It is essential to maintain a delicate balance between ClO$_2$ usage and bleaching production to achieve optimal brightness levels while minimizing environmental repercussions. Calculating ClO$_2$ flow rates requires meticulous attention to ClO$_2$ consumption and bleaching production, ensuring the pulp reacts optimally to attain prescribed brightness standards. Additionally, it is noteworthy that higher kappa number values correspond to elevated viscosity but lower pulp brightness, further emphasizing the intricate relationship between process parameters and pulp quality.

In light of these findings, it is imperative for the pulp industry to adopt sustainable practices that prioritize environmental conservation without compromising product quality. By leveraging insights from this study, stakeholders can develop strategies to mitigate environmental impact while maintaining operational efficiency in ClO$_2$ bleaching processes, thereby advancing towards a more sustainable future for the pulp industry.

**Suggestion**

Bleaching process, especially at stage D0, has an important role in processing chips into pulp and removing lignin content and improving pulp quality. Therefore, the author suggests that before using ClO$_2$, you should calculate the use of ClO$_2$ theoretically and control it in the DCS Room, so that the desired brightness value is achieved and do not use ClO$_2$ excessively. Checking samples must go through
an accurate process and in accordance with procedures so that there are no errors in data collection which can cause errors in taking action. Analysis of the amount of ClO₂ used is very necessary, because if not enough ClO₂ is used in the bleaching process, the brightness target will not be achieved, thereby reducing the quality of the pulp. Excessive use of ClO₂ will affect the amount of residue that is wasted too much and can also have an impact on fiber damage in the pulp.

REFERENCES


