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Kinetic study of softwood cooking for bleached pulp production

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The partition of softwood pulp production worldwide is constantly decreasing. New plants are not being built, but are only being modernized, increasing their capacity. The timber harvesting of softwood in Bulgaria is significant, and after the closure of the Stamboliyski plant of Mondi, large quantities of wood remained available. This has led to interest in starting the production of softwood bleached pulp in Bulgaria, which is a marketable product and an indispensable raw material.

Industrial wood chips of softwood were cooked in the laboratory and the effect of the parameters: active alkali charge and duration of the cooking time were investigated. Total pulp yield, screening pulp yield, knots, residual alkali in the black liquor and Kappa number of the obtained pulp were determined. The optimal parameters of the active alkali charge and the duration of the process of producing pulp with the required Kappa number for bleaching were established. Based on the results of the cooking, the bleachability of the pulp and the possibility of obtaining high-quality bleached softwood pulp were determined.

Keywords: softwood, cooking, kinetics, bleachability, bleached pulp

INTRODUCTION

Wood is the main raw material used in pulp and paper production and represents the most significant cost component in pulp production. Consequently, the quality and price of wood have become critical factors in modern pulp production operations. The suitability of wood for pulp production varies not only between species, it also depends on the cutting location, growing conditions and age of the tree. The kinetics of Kraft pulping have been extensively studied and documented since the late 1950s [1]. There are numerous studies in the scientific literature examining individual softwood and hardwood species [2–5]. However, comparing results from different periods is often challenging, as analytical techniques, tools and interpretation methodologies have evolved over time. Since differences in cooking behavior between some species – especially softwoods – can be minor, it is often advantageous to rely on results obtained in a single laboratory using well-defined procedures. This complicates broad comparative evaluations of multiple types based on different literature sources [1].

The two main methods for producing chemical pulp are alkaline processes, such as the Kraft process, and acidic processes, such as the sulfite process. Historically, both wood and non-wood fibrous materials have been processed primarily by chemical pulping techniques. World production statistics show that the majority of chemical pulp is produced today by the Kraft process. Although the latter process yields stronger fibers, this method is increasingly affected by environmental regulations regarding emissions of total reduced sulfur (TRS) compounds, sulfur dioxide, suspended solids, and wastewater pollutants. In contrast, sulfite pulp production is continuously declining due to environmental concerns and the lower mechanical properties of the resulting pulp [6].

The Kraft process continues to be the leading method for producing paper pulp. Although softwood has long been the primary raw material in Northern Europe, recent years have seen growing interest in the use of hardwoods [7].

Alkaline pulping is generally divided into three distinct phases, each characterized by unique kinetic behavior. In the initial phase, delignification proceeds rapidly, accompanied by significant carbohydrate degradation [8]. The subsequent bulk delignification phase, characterized by slow reaction rates, is responsible for the removal of most of the lignin and shows higher selectivity – meaning that lignin is removed more efficiently than carbohydrates. During the residual delignification phase, all reaction rates decrease significantly, including those associated with carbohydrate degradation, resulting in reduced selectivity [9]. Therefore, to maximize carbohydrate yield, it is preferable to terminate the cooking process before

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residual delignification begins. The chemical reactions underlying delignification are very complex and remain only partially understood [10].

The parameters applied during Kraft cooking have a decisive influence on the subsequent bleaching step, shaping the total consumption of bleaching reagents, the environmental footprint of the wastewater, the stability of the whiteness and the mechanical properties of the resulting pulp. While extended delignification during cooking usually reduces the demand for bleaching chemicals, supports increased closure of bleaching plants and increases the calorific value of the black liquor, achieving deep delignification without concomitant carbohydrate degradation remains a significant technical limitation. As a result, significant amounts of chemicals are usually required in the bleaching sequence to compensate for the residual lignin content [12].

It is well-established that different types of alkaline pulps exhibit different bleaching profiles, usually quantified as the amount of bleaching chemicals required to achieve the target whiteness. Numerous studies have attempted to correlate the structural characteristics of residual lignin with pulp bleachability. Many studies have shown that residual lignin enriched with specific structural motifs exhibits increased reactivity to chlorine dioxide [13].

The demand for bio-based packaging materials has increased in recent years due to the shift away from plastics. In 2023, global paperboard production is estimated to be approximately 55 million metric tons per year, with the United States accounting for 29% of this total, or nearly 14 million tons. Global production is projected to increase to 66 million metric tons by 2032. The Kraft process continues to be the predominant method of producing the fibers used in paperboard production [14].

The aim of the present study is to investigate the possibility of obtaining softwood pulp for bleaching under low sulfidity cooking and to establish the kinetic dependences of the process and the optimal active alkali charges.

MATERIALS AND METHODS

The experiments were carried out using industrial softwood chip. Wood chips were hand-sorted to remove knots and bark, and 100 g of absolutely dry chips were cooked in 2 L stainless steel laboratory autoclaves rotating at constant rate in a polyglycol heating bath. The liquor-to-wood ratio during cooking was 3.5:1, the sulfidity was 7.4% and the active alkali charge varied from 22% to 24% as NaOH. Cooking started at 80°C followed by heating to a maximum temperature of 172°C with a reaction time of 50 to 130 min at this temperature. Kappa number and residual active alkali were measured according to SCAN standards (SCAN-C 1:77 and SCAN-N 33:94).

RESULTS AND DISCUSSION

The results of the investigation of the influence of the duration of Kraft cooking and the active alkali (AA) charge on the Kappa number of softwood pulp are presented in Fig. 1. It is established that extending the duration of the cooking has a positive effect on the delignification process, but at AA charge of 22%, pulp with a Kappa number between 50 and 90 units is obtained. This means that only unbleached pulp for kraft paper or kraftliner can be produced under these conditions. At an AA charge of 23%, a Kappa number between 30 and 35 units is achieved, while the reaction time is from 110 to 130 min. These Kappa number values are considered optimal for standard softwood pulping for bleaching. 24% of AA leads to a much faster and extended delignification, as the optimal Kappa number can be achieved in just 70 min of reaction time (Fig. 1). It was found that a reaction time of 110 – 130 min leads to a Kappa number between 24 and 28 units. These Kappa numbers are typical for modified Kraft pulping methods of softwood, which are characterized by an impregnation stage with a solution with very high sulfide content, followed by main pulping at an optimal alkali concentration until the end of the process at relatively lower temperature.

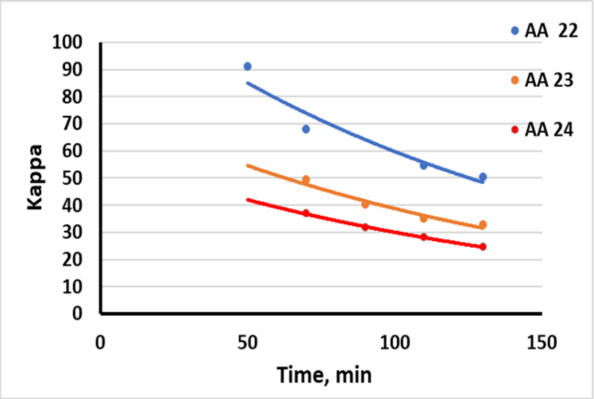

Fig. 1. Effect of the reaction time and active alkali charge on Kappa number

At a higher active alkali charge we have an increased content of residual alkali (Fig. 2), but the screening pulp yield remains practically the same. This is explained by the significant reduction of the duration of the pulping to the same Kappa number (Fig. 3).

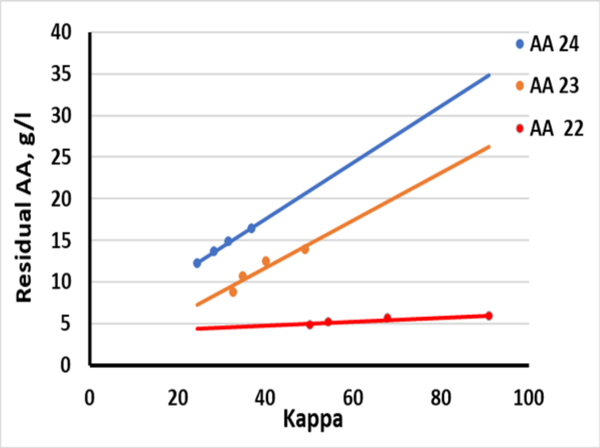

Fig. 2. Correlation between residual alkali and Kappa number

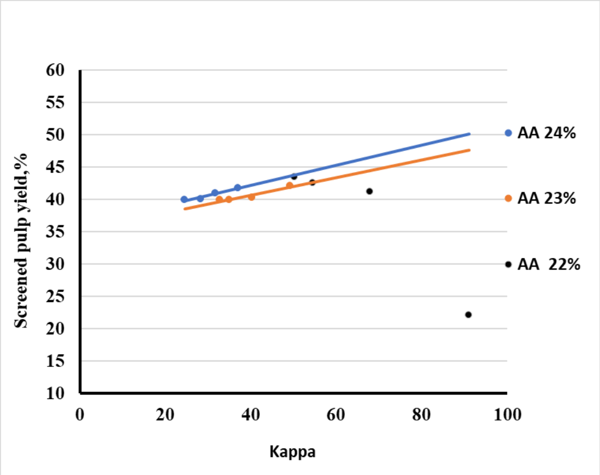

Fig. 3. Correlation between pulp screening yield and Kappa number

As a result, cellulose degradation is reduced, and the pulp yield remains relatively high (Table 1). The well-known advantage of fast pulping regime in terms of process selectivity and pulp yield is confirmed by these results.

It should be noted that owing to the very low sulfidity of the cooking liquor, which is close to natron pulping, all yield values are below the optimum (Table 1).

The general relationships between the pulp parameters after the cooking process with an AA charge of 24%, presented in Fig. 4, show that under these conditions, softwood pulp with a low Kappa number can be obtained. This will improve the efficiency of the bleaching process and reduce the need of expensive chemicals but will also slightly reduce the pulp yield.

Table 1. Effect of alkali charge on pulp yield

Active alkali charge as NaOH - 22% and sulfidity as Na_2S – 7.4%					
Time, min	50	70	90	110	120
Screened pulp yield, %	22.1	41.2	-	42.5	43.4
Screening reject, %	-	3.8	-	2.3	1.2
Total yield, %	-	45.0	-	44,8	44.6
Active alkali charge as NaOH - 23% and sulfidity as Na_2S – 7.4%					
Time, min	50	70	90	110	120
Screened pulp yield, %	-	42.1	40.2	39.9	39.7
Screening reject, %	-	0.4	1.3	0.3	0.3
Total yield, %	-	42.5	41.5	40.2	39.9
Active alkali charge as NaOH - 24% and sulfidity as Na_2S – 7.4%					
Time, min	50	70	90	110	120
Screened pulp yield, %	-	41.7	40.9	40.0	39.9
Screening reject, %	-	0.3	0.2	0.1	0.0
Total yield, %	-	42.0	41.1	40.1	39.9

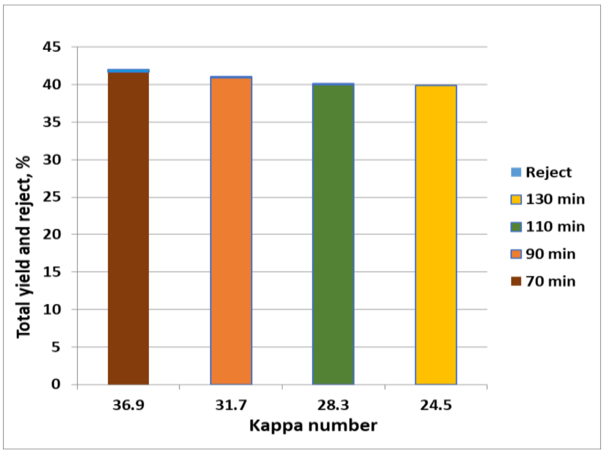

Fig. 4. Relationships between pulp parameters after 24% AA cooking

CONCLUSIONS

The results of this investigation show that at conditions of "Svilocell" EAD – Svishtov low sulfidity cooking of softwood, the active alkali charge of 23 % is optimal for obtaining a pulp for bleaching. It is established that at active alkaline charge of 24%, pulp with a lower Kappa number is obtained, which will increase the efficiency of the bleaching process. At the same time, the pulp screening yield remains practically unchanged, due to both significant reduction in cooking reaction time and improvement in its selectivity. By softwood cooking with an active charge of less than 23%, unbleached pulp with a Kappa number of more than 50 units is obtained, which can be used in the production of kraft paper or kraftliner.

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