



Techno-Economic Analysis of Kraft Pulp Production Through Compact Cooking and Lo-Solids Technology

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Abstract. Pulp and paper industry is one of the most important and growing industrial sectors in the world. Global pulp and paper production continues to increase along with rising demand from year to year. The pulp industry generally uses hardwood for Kraft pulp production which is also integrated with paper mills. The Kraft process uses a mixture of sodium hydroxide and sodium sulfide, which is known as white liquor. Improving productivity, pulp quality and cost efficiency is the main focus in facing global competition. Efforts to research and apply new technology continue to be carried out to increase pulp yield without reducing the quality. This study aims to evaluate the techno-economic performance of Kraft pulp production through Compact Cooking and Lo-Solids technologies. Techno-economic analysis (TEA) is carried out by using Microsoft Excel with the scope is started from pulp cooking until bleaching. It focuses on optimizing cooking conditions and analyzing variable costs like wood chips, chemicals and utilities to compare economic profitability. The finding suggests that Lo-Solids technology is more cost-effective than Compact Cooking, providing a basis for further process improvements. Kraft pulp production from Compact Cooking gives profit margin around 148 USD/ADt, while Lo-Solids give profit margin around 189 USD/ADt.

Keywords: Compact cooking, Cost efficiency, Kraft pulp, Lo-Solids, Techno-economic analysis.

1 INTRODUCTION

Pulp and paper industry plays an important role in the global economy. The demand of pulp is increasing annually. According to statistics from the Food and Agriculture Organization (FAO), pulp production in 2022 exceeded 197 million tons per annum. In 2021, Indonesia was the seventh largest pulp producer in the world [1]. Pulp is a raw material for paper making which contains cellulose and hemicellulose. The most widely used chemical pulping process is Kraft process [2]. More than two-thirds of the globally produced pulp comes from Kraft pulping mills [3]. The Kraft process uses a mixture of sodium hydroxide and sodium sulfide, which is known as white liquor [4]. Kraft process has some advantages, such as higher pulp strength and better chemicals and energy recovery system [5]. Improving production efficiency and pulp quality is the

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main focus in facing global competition. The challenge facing pulp and paper industry today is to develop process technology that can meet high product quality standards in the market, while minimizing operational cost [6].

Efforts to research and apply new technology continue to be carried out to increase pulp yield without reducing pulp bleachability or product quality. Several pulp production technologies for batch and continuous systems have been developed since the implementation of the Kraft process. The most commonly used commercial cooking technologies are Super Batch, Compact Cooking and Lo-Solids. Super Batch cooking combines a uniform chemical alkali profile and reuses heat in subsequent batches [7]. Compact Cooking and Lo-Solids are continuous modified Kraft pulp cooking technologies. The principle of Compact Cooking is to optimize cooking temperature and alkali used in impregnation process by utilizing black liquor recirculation [7,8]. Meanwhile, the basic principle of Lo-Solids is to minimize the number of dissolved solids in cooking liquor, especially at the end of the cooking process, by involving several stages of cooking liquor extraction [9].

Pulp and paper industry is currently also facing various economic challenges, such as increasingly global competitiveness and higher production cost. Production cost increment is mostly caused by the prices of raw material and energy [10]. According to FisherSolve in the fourth quarter of 2018, the five largest operational costs of pulp and paperboard production in the southeastern United States are respectively pulp fiber raw material cost, energy cost, labor cost, machine and maintenance cost and chemicals consumption cost [11]. These costs have impact on decreasing revenues and profit margins for the industry. In addition, fluctuations in demand for products can cause excess or less production, which can trigger financial losses. To overcome this challenge, pulp and paper mills need to improve factory operational efficiency and reduce waste to minimize production cost. Collaboration with technology companies can lead mills to develop efficient pulp production technology [12].

In line with the objectives to evaluate technoeconomic of Kraft pulp production, a study on Compact Cooking and Lo-Solids technologies was conducted to provide an internal view of the economic performance and profitability between these technologies. This study investigated and compared variable cost between Compact Cooking and Lo-Solids technologies.

2 METHODOLOGY

2.1 Kraft Pulp Production Process

In general, Kraft pulp production in existing Fiber line mill includes wood chips cooking stage in digester, pulp screening and washing stage, oxygen delignification stage and pulp bleaching stage. Wood chips are obtained from wood debarking and chipping process. Wood chips cooking process is carried out using a pressurized reactor called a digester and chips enter from the top of digester. Continuous digesters have a volume of thousands of cubic meters with the largest digester capacity being able to produce more than 3,000 tons of pulp per day. The main stages of cooking in a continuous digester consist of preheating the chips, impregnation and cooking. Preheating the chips using steam aims to remove air from chips as much as possible.

During impregnation, white liquor will be distributed into the chips. Impregnation time must be sufficient and carried out at a low temperature ($120 \pm 5^\circ\text{C}$). The good impregnation process will result uniform cooking and low number of rejects. After impregnation stage, chips cooking begins by replacing the liquor from impregnation with hot white liquor. Cooking temperature is increased to 150°C . As the chips move towards the bottom of digester, the alkaline condition, temperature and solids content in the digester can be adjusted so that the cooking process takes place optimally [4].

After cooking process, brown pulp will be washed to remove unwanted dissolved materials and maximize recovery of organic materials for further processing in the recovery boiler. Oxygen delignification is carried out in pressurized and high temperature reactors by adding caustic and oxygen. After washing and oxygen delignification stage, unbleached pulp will be processed in bleaching stage. The purpose of pulp bleaching is to remove residual lignin and increase brightness of the pulp to meet the quality of final product. In the Elemental Chlorine Free (ECF) method, pulp bleaching process is carried out using chlorine dioxide in acidic environment and caustic, oxygen and hydrogen peroxide in alkaline environment to increase lignin extraction and oxidation [4]. The bleached pulp will be sent both to drying machine and paper machine. The schematic diagram process scheme of Kraft pulp production is presented in Fig. 1.

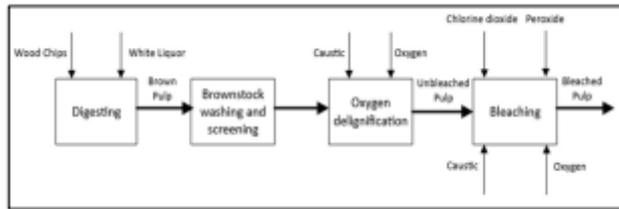


Fig. 1. Diagram process scheme of Kraft pulp production.

2.2 Data Collection and Processing

Kraft pulp production and wood chips, chemicals and utilities consumption data collection were conducted during a 6-month sampling (1 October 2023 to 31 March 2024). All process parameter, daily consumption and production data coming from field instrumentation equipment in the plant. The data will be processed in the distributed control system (DCS) database and recorded in a PI ProcessBook software. The historical data will be collected as information about plant and saved in PI ProcessBook. The saved data will be utilized as back up data for process parameter evaluation, equipment performance analysis and troubleshooting. The historical data also will be extracted into Microsoft Excel to be used for daily production and consumption report. The data that has been extracted into Microsoft Excel will be used for as a calculation of production variable cost between Compact Cooking and Lo-Solids technologies.

Wood chips and chemicals consumption will be classified as raw material consumption. Specific wood chips consumption data will be used to calculate pulp yield. Chemicals consumption includes white liquor consumption in digester, caustic

soda consumption in oxygen delignification and bleaching, chlorine dioxide and hydrogen peroxide in bleaching. Utilities consumption consists of power, process water and steam consumption. Pulp production cost will be calculated as combination of raw materials and utilities costs. Economic profitability analysis is conducted by calculating margin between pulp price and production cost.

3 RESULTS AND DISCUSSIONS

3.1 Determination of Kraft Pulp Yield

Wood chips consumption is calculated based on comparison between gross metric tonnes (GMT) of the wood chips fed to the digester and air-dry tonnes (ADt) of pulp produced. Table 1 summarizes the results of Kraft pulp yield and Kappa number between Compact Cooking and Lo-Solids technologies.

Table 1. Comparison between present work and literature.

Compact Cooking			Lo-Solids		
Specific wood chips consumption (GMT/ADt)	Pulp yield (%)	Kappa number	Specific wood chips consumption (GMT/ADt)	Pulp yield (%)	Kappa number
3.34	47%	15.2	3.25	49%	17.1
3.33	48%	15.3	3.24	50%	17.2
3.15	52%	15.8	3.11	52%	17.1
3.01	54%	16.3	2.91	56%	17.5
3.18	51%	15.6	2.86	56%	17.4
3.26	49%	15.5	2.92	54%	17.4

Lower specific wood chips consumption indicates an increment in pulp yield. The cooked pulp yield resulted from Compact Cooking technology is between 47-54%, while Lo-Solids gives pulp yield between 49-56%. Pulp yield can also be indicated from Kappa number. Lower Kappa number indicates lower pulp yield due to degradation of pulp fibers during cooking process, even though the amount of lignin remains in pulp is also lower. Kappa number of the brown pulp from Lo-Solids tends to be higher than Compact Cooking. The amount of lignin remains in pulp from Compact Cooking is in the range of 2.2-2.4%. Meanwhile, the amount of lignin remains in pulp from Lo-Solids is in the range of 2.5- 2.6%.

3.2 Effect of Temperature on Kraft Pulp Yield in Compact Cooking

Kraft pulp cooking system with Compact Cooking technology uses impregnation vessel and digester. Impregnation vessel is an atmospheric vessel, where the initial heating and impregnation process takes place. Impregnation process is done with by inserting steam or hot black liquor into the wood chips [14]. The temperature of black liquor entering impregnation vessel is around 130-135°C. Meanwhile, the digester is a pressure vessel into which medium pressure steam is injected. The cooking temperature in the digester is in the range of 140-150°C. White liquor is also mixed with chips from impregnation process and fed to the top of digester. Fig. 2 and Fig. 3 display yield of

Kraft pulp at various impregnation temperature and cooking temperature respectively. Impregnation temperature and cooking temperature influence pulp yield and Kappa number. The higher impregnation temperature and cooking temperature, the lower pulp yield and Kappa number. This happens because too high cooking temperature can increase the degradation of cellulose and hemicellulose in pulp [7]. Increment in cooking temperature by 1°C causes a decrement $\pm 1.5\%$ in pulp yield.

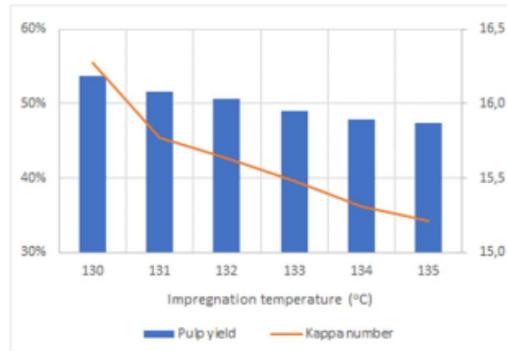


Fig. 2. Kraft pulp yield at various impregnation temperature in Compact Cooking

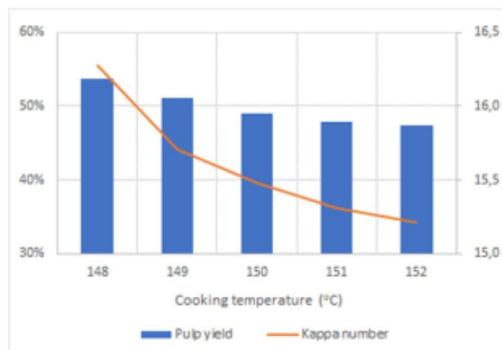


Fig. 3. Kraft pulp yield at various cooking temperature in Compact Cooking

3.3 Effect of Temperature on Kraft Pulp Yield in Lo-Solids

Kraft pulp cooking system with Lo-Solids technology consists of impregnation and cooking process in a digester. The impregnation process occurs at the top of digester. Wood chips are mixed with liquor and fed through the top of digester. The liquor temperature at the top of digester is around 130-135°C. Medium pressure steam is also injected through the top of digester. The cooking process occurs in the middle to bottom of digester. Fig. 4 displays yield of Kraft pulp at various cooking temperature. Similar with Compact Cooking technology, cooking temperature in Lo-Solids influences pulp yield and Kappa number. The higher cooking temperature, the lower pulp yield and Kappa number because of higher degradation of cellulose and hemicellulose in pulp. Increment in cooking temperature by 1°C causes a decrement $\pm 1.5\%$ in pulp yield and Kappa number decrement by 1.3%.

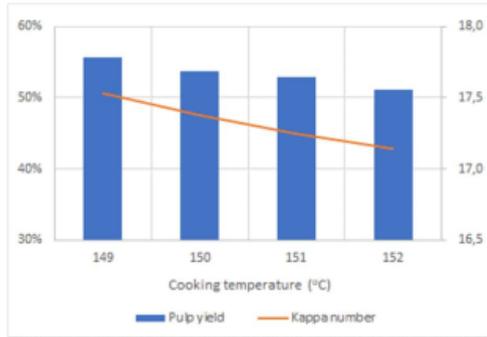


Fig. 4. Kraft pulp yield at various cooking temperature in Lo-Solids

3.4 Determination of White Liquor Consumption

White liquor is the main chemical used in Kraft pulp cooking process. Specific white liquor consumption is calculated based on the ratio between white liquor consumption fed to digester and air-dry tonnes (ADt) of pulp produced. Fig. 5 and Fig. 6 display specific white liquor consumption in Compact Cooking and Lo-Solids technologies respectively. The higher specific white liquor consumption, pulp yield tends to decrease. Specific white liquor consumption in Compact Cooking is in the range of 3.12-3.32 m3 per ADt pulp. Meanwhile, specific white liquor consumption in LoSolids is in the range of 3.06-3.21 m3 per ADt pulp. The higher specific white liquor consumption in Compact Cooking gives lower pulp yield compared to Lo-Solids. In Lo-Solids technology, several stages of white liquor extraction and circulation create a uniform alkali profile and low concentration of dissolved solids including lignin and extractive compounds until the end of cooking process [8]. Kappa number standard deviation of pulp produced using Lo-Solids technology is also lower than Compact Cooking.

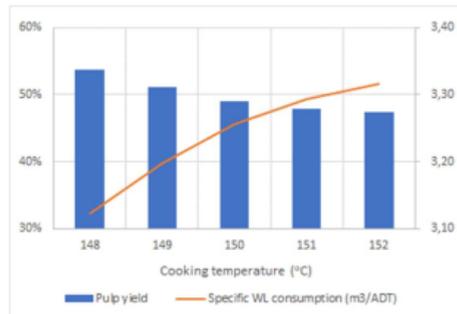


Fig. 5. Kraft pulp consumption at various cooking temperature in compact Cooking

white liquor

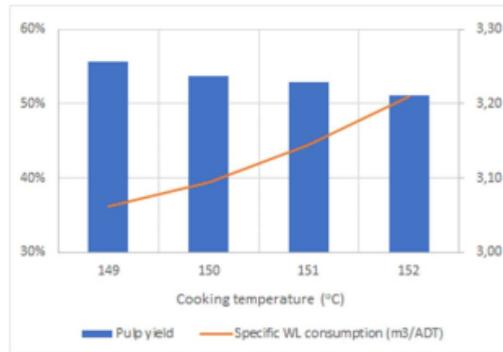


Fig. 6. Kraft pulp white liquor consumption at various cooking temperature in Lo-Solids

3.5 Determination of H-Factor and Cooking Time

H-factor is one parameter in Kraft pulp cooking process which combines temperature and cooking time. These parameters are very important in controlling the cooking process to achieve a certain pulp yield or Kappa number. Table 2 summarizes the results of H-factor and temperature between Compact Cooking and Lo-Solids technologies. Cooking time can be calculated using Arrhenius equation. Pulp cooking time in Compact Cooking is in the range between 2.9-3.6 hours. Meanwhile, the pulp cooking time in Lo-Solids is in the range between 3.9-4.4 hours. Cooking time is influenced by retention time and digester volume.

Table 2. Kraft pulp H-factor in Compact Cooking and Lo-Solids technologies.

<i>Compact Cooking</i>		<i>Lo-Solids</i>	
H-factor	Average temperature (°C)	H-factor	Cooking temperature (°C)
342	143	800	151
307	142	766	152
343	141	843	152
325	140	915	149
311	141	769	151
321	142	822	150

3.6 Evaluation of Kraft Pulp Production Cost and Profit Margin

Kraft pulp production cost can be estimated from variable cost. Pulp variable cost shows costs of material that changes proportionally according to the number of pulp production. Kraft pulp production cost includes raw material cost which are wood chips and chemicals cost, and utilities cost for water, electricity and steam. Table 3

summarizes Kraft pulp production cost between Compact Cooking and Lo-Solids technologies.

Table 3. Kraft pulp production cost comparison between Compact Cooking and Lo-Solids technologies

Input Operation	Unit	Price (USD)	Compact Cooking		Lo-Solids	
			Qty per ADt pulp	Cost (USD)	Qty per ADt pulp	Cost (USD)
Raw Material						
Wood chips	ton	112	3.210	359	3.048	341
White liquor	m ³	5	3.230	16	3.144	16
Caustic soda (as 50%)	ton	366	0.041	15	0.029	11
Chlorine dioxide	ton	1700	0.017	30	0.011	19
Hydrogen peroxide (as 50%)	ton	580	0.010	6	0.007	4
Utility						
Process Water	m ³	0,2	15.70	3	12.07	3
Power	MWh	78	0.18	14	0.13	10
Steam	ton	9	1.01	9	0.80	7
Total Cost				452		411

The highest cost is wood chips, which is affected by pulp yield and Kappa number target in cooking process. The chemical with highest cost is chlorine dioxide, which is used in bleaching stages. The cost of white liquor in both Kraft pulp production technologies is almost the same. Meanwhile, caustic soda and hydrogen peroxide cost in Compact Cooking is slightly higher than Lo-Solids. This can occur because of the differences in the performance of oxygen delignification process and efficiency of pulp washing and bleaching. Caustic soda or sodium hydroxide solution is used in oxygen delignification stage and hydrogen peroxide is used for whitening the pulp. The highest utility cost is electricity, which is used as energy source for process equipment. Specific electricity and steam are affected by pulp productivity and production capacity. Therefore, the higher pulp production capacity in Lo-Solids technology has impact on reducing specific electricity and steam consumption. Meanwhile, cost of water in both technologies are similar. In terms of production cost, Lo-Solids technology provides lower cost and more efficient compared to Compact Cooking. Profit margin can be calculated from the difference between pulp price and production cost. Kraft pulp price is 600 USD/ADt. Kraft pulp production from Compact Cooking gives profit margin around 148 USD/ADt, while Lo-Solids give profit margin around 189 USD/ADt.

4 CONCLUSION

This study evaluated techno-economic of Kraft pulp production through assessing economic performance based on technical, technological and financial aspects and compare profitability between Compact Cooking and Lo-Solids technologies. The main objective of this study was to determine Kraft pulp yield, white liquor consumption and pulp production cost through two cooking technologies: Compact Cooking and LoSolids.

The data collected from a 6-month sampling showed that Lo-Solids have better pulp yield with higher Kappa number and lower specific wood chips consumption compared to Compact Cooking. Higher pulp yield indicates less degradation of cellulose and hemicellulose during cooking process. Pulp yield is affected by cooking temperature. The higher cooking temperature, the lower pulp yield and Kappa number.

In term of chemicals consumption, Lo-Solids also have lower specific white liquor consumption. Lo-Solids cooking technology have several stages of white liquor extraction and circulation, to create a uniform alkali profile and low concentration of dissolved solids until the end of cooking process. H-factor is one parameter in Kraft pulp cooking process which combines temperature and cooking time. These parameters are very important in controlling the cooking process to achieve a certain pulp yield or Kappa number. Cooking time is influenced by retention time and digester volume.

The highest raw material cost in Kraft pulp production is wood chips, followed by chemicals cost such as chlorine dioxide, hydrogen peroxide, caustic soda and white liquor. The highest utility cost is electricity, which is used as energy source for process equipment. Specific electricity and steam are affected by pulp productivity and production capacity. Higher pulp production capacity in Lo-Solids technology has impact on reducing specific electricity and steam consumption. Accordingly, Lo-Solids cooking technology provides lower production cost and more efficient compared to Compact Cooking. Kraft pulp production from Compact Cooking gives profit margin around 148 USD/ADt, while Lo-Solids give profit margin around 189 USD/ADt.

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