Industrial Ecology and Knots Solid Waste of a Pulp Mill

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Os rejeitos de nós são inevitáveis durante a conversão da madeira em polpa dentro do digestor contínuo no processo kraft. No estágio de cozimento ocorre impregnação parcial e consequentemente perda de fibras, assim como danos ambientais. Este trabalho analisa a viabilidade da mistura dos nós com cavacos virgens na alimentação do digestor, aumentando a vida útil do aterro industrial, provendo ganho econômico e ambiental, com base nos princípios da ecologia industrial e produção mais limpa. O sistema de reuso proporcionou um ganho de 781.87 quilogramas por hora de fibras, demonstrando a viabilidade para o reuso dos nós.

Palavras-chave: *cavacos de madeira; celulose; fibras.*

Knots wastes are inevitable during the wood convertion in pulp inside the continuous digester of kraft process. In cooking stage, partial impregnation occurs and consequently lose fibers, as well as environmental damage. This work analyzed the feasibility of knots and virgin chips mixing to continuous digester feed, increasing the useful life of the landfill, providing economic and environmental gains, based in industrial ecology and cleaner production principles. The reuse system provides a gain of 781.87 kilograms per hour of fibers, demonstrating the feasibility for knots reuse.

Keywords: *wood chips; cellulose; fibers.*

Introduction

The production process of cellulose pulp worldwide called Kraft is characterized by the continuous cooking. Through delignification of wood chips from solution with sodium hydroxide and sodium sulfide, Asahel Knowlton Eaton obtained in 1870 and 1871 the first patents of this process[1].In comparison with other methods, better mechanical properties of the pulp were observed. The first evidence of use in a factory goes back to 1885 in Sweden with wood from Scandinavia, the resulting paper presented greater resistance, receiving the name Kraft derived from the Swedish word resistance[2].

The process shows maximum energy efficiency capacity and minimum chemical losses, mostly incorporated into the solids wastes during the process, with 96% to 97% recovery of chemical reagents. Likewise, a modern cellulose mill can be self-sufficient energetically, from wood dissolved in black liquor (liquor resulting from cooking), because the dissolution of fiber can be converted into biofuel[3].

During the continuous cooking process, part of the wood chips has little impregnation and consequently difficulty in delignification, originating the solid wastes known as knots. Due to the presence of black liquor from cooking, reuse to be reincorporated in the digester is economically viable4. This article aims to study the fibers and environmental gain from the reuse of knots instead of discarding it in the industrial landfill, increasing the useful life of the landfill and consequently contributing to the conservation of natural resources.

INDUSTRIAL ECOLOGY

Some productive strategies are being incorporated in the industries in order to reduce the negative effects of their activities on the environment, even allowing, for financial opportunities through these new processes[5]. A new direction for manufacturing, prioritizing waste minimization, the efficient use of raw materials is seen as one of the main alternatives, and industrial ecology can help new productive dynamics[5,6].

The work developed by Jay Forrester at Massachusetts Institute of Technology can be considered as one of the pioneers in terms of industrial ecology. Started between the 1960 and 1970, this work was one of the precursors, analyzing the world as a series of connected systems and simulating trends of environmental degradation. Which allowed observing the current industrial model as unsustainable[7].

In the late of 80s, Robert Ayres used the concept of industrial metabolism to define the process composed of inputs and outputs. Presenting materials and energy as input, and products and waste as output. Applying the input and output flowchart methodology, the existence of some inefficient industrial processes was detected, and these resulted in waste and pollution[7].

Influenced by industrial metabolism, from 1990, industrial ecology became an important topic, gaining a prominent place in industrial decisions[8]. Even presenting good indicators when implemented in the industry, industrial ecology can encounter institutional obstacles during the process operationalization phase, thus, inadequate procedures must be avoided to obtain satisfactory results[9].

Currently industrial ecology has been incorporated into industries with other environmental-based streams, including cleaner production. Although defined by some authors as complementary and convergent, both currents present some differences[8].

Cleaner production aims to decrease waste generation and manufacture products with less environmental impact at the end of their life cycle. Conventional technologies, also called end-of-pipe, seek to understand waste management after your generation, with no efficiency[5]. Cleaner production has contributed to waste management during industrial processes, directly contributing to industrial ecology.

Industrial ecology has been presented as an alternative for sustainable development in the productive sector5. The main goals inherent to sustainable development include, the sustainable use of resources, the preservation of human and ecological health (the maintenance of the structure and function of ecosystems) and the promotion of environmental equity[10].

Industrial ecology, cleaner production, and other tools inserted into closed processes are fundamental for the industry, showing favorable results, mainly the reduction of environmental degradation at different levels (local, regional and global) and the expansion of financial gains[11].

Industrial Mill Processes

KRAFT PULPING

The origin of the kraft pulping process is attributed to two patents by Asahel Knowlton Eaton in 1870 and 1871 for delignification of wood with sodium hydroxide and sodium sulfide[12]. In this process, all commercial types of wood can be used to produce a cellulosic pulp characterized with superior mechanical properties compared to other production processes[13].

FIBER LINE

The main stages of the pulp production process happen along the fiber line.

WOOD TRANSPORT AND PEELERS

The transport of raw material is carried out by trucks through highways, being taken in wood logs form to the mill for following processes.

Depending on the industry, the log may arrive with bark or not. If necessary, the wood will be destined primarily to peelers, because the barks do not have a significant amount of cellulose, consume a large amount of chemical reagents and the final quality of pulp is impaired. After peelers stage, the logs go to the chippers and then sieving, aiming to separate the wood chips with regular dimensions and super or under dimensioning. The sized wood chips go to the wooden patio, while the rejects can be burned in the boiler to generate steam.

DIGESTER AND BLEACHING PROCESS

The chips are carried by conveyors to the digester, where they will be mixed with the cooking liquor also known as white liquor. Such liquor is an aqueous composition of: sodium hydroxide and sodium sulfide forming the active compounds; sodium carbonate, sodium sulfate, sodium sulfite and sodium thiosulfate are compounds known as dead charge. Basically the white liquor varies due to the recovery cycle of the chemical compounds, but following the percentage[14]:

Table 1: White licor composition.

Compound	Percentage (%)
Active	
NaOH	53
Na2S	21
Dead Charge	
Na2CO3	14
Na2SO4	6
Na2SO3	3
Na2S2O3	3

In a continuous digester, the mixture between wood chips and white liquor occurs, followed by the impregnation stage. The insertion of high-pressure water vapor allows the cooking liquor to penetrate the wood, increasing the efficiency of the separation process between cellulose and lignin.

The mixture is transported to the cooking stage, remaining for 1 to 2 hours at a 150 to 170 ºC. As can be seen in the following diagram[15,16].

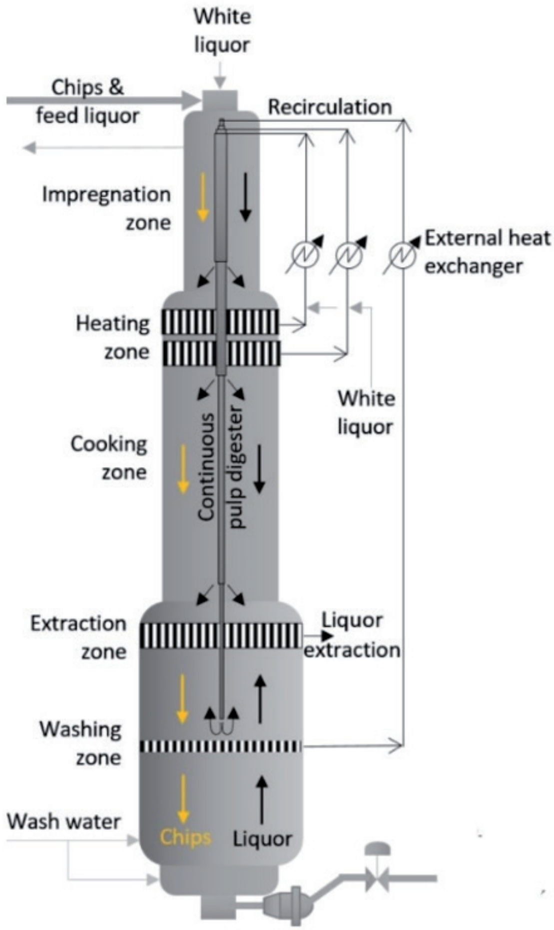

Figure 1: Continuous digester flow diagram[17].

After the cooking process, the pulp is diluted in blow tanks to follow the washing, delignification and depuration[18]. Bleaching aims to remove residual lignin and hexenuronic acids from cooking to bring the white characteristic to celulose. To avoid the use of chemical compounds with chlorine ("Total Chlorine-Free" bleaching), modern cellulose industries normally use oxygen as the first stage of bleaching[19].

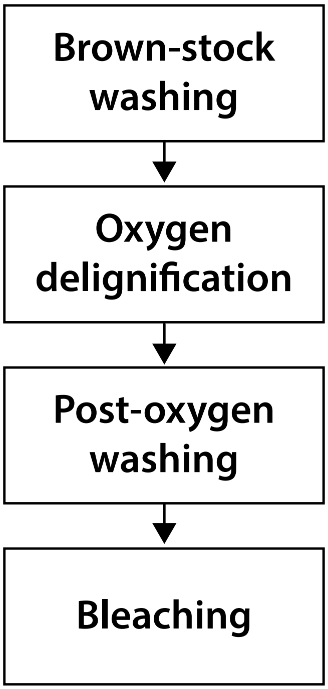

Figura 2: Delignification to bleaching processes[20].

The sequential steps to reach the final product include evaporation, recovery boiler and drying.

KNOTS SOLID WASTE

They are unavoidable residues from the conversion of wood into cellulose and are found in the depuration stage, after cooking process and before the bleaching process. It comes from the difficulty of cooking and under or oversized eucalyptus wood chips, containing little impregnation and consequently partially delignification in cooking process.

The content of knots depends directly of Kappa number of the pulp resulting from cooking. For numbers between 14 and 16 the content is much lower than cooking with numbers between 17 and 19. With these usual ranges, in modern continuous digesters, the content can vary from 0.4 to 1%. The knots still contain amounts of residual alkali and due to partial cooking, losses of fractions of the lignin contained in wood were released. As the waste is partially delignified, reuse for cooking is benefited[4].

Low alkaline charges and short periods of time during cooking are sufficient for the release of the fibers, causing the transformation of knots into cellulose before wood chips inside the digester. If the knots are not well mixed with the virgin chips, knot accumulation may occur in certain areas. The fibers are released quickly due to the transformation of the knots into cellulose, occurs a difference in volume and the wood chips column can change in your displacement, causing clogging.

KNOTS REUSE WITH VIRGIN WOOD CHIPS

Due to residual impregnation the cooking yield is high, in the range of 60 to 70%, varying according to alkaline charges and cooking conditions. The Kappa number of knot pulp is low (10 to 12), but close to the pulp number with virgin wood chips (16 to 19)[21].

The solubility in 5% NaOH (S5) for a virgin wood chips pulp after cooking is between 11 to 13%, while the pulp resulting from cooking the knots is between 9 to 10%. Although cellulose degradation of knots in a large concentration of alkali causes yield loss, cellulose is able to resist the excess[21].

With the re-cooking process with virgin wood chips, the final cellulose has no altered quality. The pulp originated has less viscosity and greater apparent specific volume, however, due to the low percentage the results of cellulose tests are not affected.

Material and Methods

During the process the knots was sent from depuration to wood chips pile to feed the continuous digester, between January/2016 and August/2017. At first, mechanical problems were observed with the conveyor belt, the presence of two straps generated instability and one skirt under the other. To solve the problem, the knots were mixed with the pile wood chips.

Knots from depuration were purged for one hour in an empty bucket, quantified at 1760 kilograms, which had a production of 3980 ADT per day, 5% consistency on line 1 and line 2, as well as a rejection rate of 13.5%. Laboratory cooking was designed to determine: depurated yield, waste, total yield, Kappa, viscosity, solids, residual alkali and pH.

The fiber gain for each hour of discarded knots solid waste can be expressed as:

$$\textit{Fiber gain} = \textit{Yield} \times \textit{Mass} \times \textit{Loss} \qquad (1)$$

Where, Fiber gain = fiber gain after the cooking; Yield = percentage of depurated yield after the cooking; Mass = Amount purged for one hour;Loss = System loss percentage.

Results and Discussion

Table 2 presents the results after cooking in laboratory, comparing the data of virgin chips and knots. Yield is understood as the efficiency of continuous cooking due to cellulosic degradation. Kappa number is the amount of residual lignin contained in the cellulose fiber. Viscosity refers to the degree of fiber degradation. Residual alkali concentration is important to keep compounds dissolved, your variation extends the cooking time or impairs uniformity.

Table 2: Laboratory cooking.

	Knots	**Virgin Chips**
depurated yield %	47.26	53.11
Waste %	0.1453	0.0105
Total yield %	47.40	53.12
Kappa	10.83	13.31
Viscosity cm^3/g	771	1176
Solids %	26.65	23.56
Residual alkali g/L	23.08	4.78
pH	13.51	12.73

FIBER GAIN

The loss of efficiency in a cellulose plant is approximately 6% in all short fiber kraft cooking, being calculated in the drying stage. With the yield observed at 47.26% and the amount of knots from depuration at 1760 kilograms per hour, the gain in fibers was 781.87 kilograms per hour.

DISCARDED VOLUME

The volume expressed in m^3 of the knots solid waste generated between January 2016 and August 2017 can be seen below.

Table 3: Discarded volume between 2016 and 2017.

Month	2016	2017
January	105.43	0.0
February	75.95	40.24
March	117.85	110.94
April	124.30	39.80
May	155.56	23.63
June	92.94	13.01
July	73.93	2.02
August	84.91	2.74
September	99.05	
October	53.91	

Conclusion

Due to the tropical climate, the cultivation of wood species to feed the system is favorable, however, brings greater production of solid wastes, such as knots, which were addressed in this article. From January 2016 to August 2017, 1216.21 m^3 of knots were sent to feed the continuous digester, showing effective reuse instead of landfill disposal.

The methodology industrial waste reuse is part of the industrial ecology and cleaner production principles, observing the industrial ecosystem and the interaction with the surrounding environment. At the same time generates economic return, brings consertion to environment.

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