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Gestão de Resíduos em uma Unidade de Produção de Papel *Tissue*: Uma Abordagem Prática

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Resumo

Os princípios de sustentabilidade, juntamente com os Objetivos de Desenvolvimento Sustentável (ODS) definidos pela Organização das Nações Unidas (ONU), são ferramentas imprescindíveis para o alcance e manutenção da qualidade de vida para os próximos anos. O setor de produção de papel pode valer-se desses objetivos, podendo se tornar mais eficiente, com menor consumo de água e diminuição de resíduos. A indústria de papel tissue utiliza-se de fibra virgem de celulose de eucalipto ou de papel branco reciclável. Tem-se, ao final, um papel com características como a maciez, baixa gramatura e boa absorção de líquidos, típicas para uso como papel higiênico, guardanapo, entre outros. Dentro do processo fabril, diversos procedimentos podem ser responsáveis pelo surgimento de fiapos e poeira de papel, sendo um tipo de desperdício dessa indústria. Dentre esses, podem ser citados o aumento do teor dos finos, proveniente do processo de refino da fibra, tratamento mecânico inicial da matéria prima do papel, que propicia a resistência do produto. O procedimento da formação do crepe do papel é responsável por fazer com que a folha do *tissue* adquira características como a maciez e o volume, mas que pode proporcionar a criação dos resíduos. Por meio de uma abordagem simples relacionada ao balanço de materiais do processo, com a análise das entradas e saídas do processo, o intuito desse trabalho é estimar a quantidade de material perdido em uma máquina de papel *tissue*. Sendo uma avaliação preliminar fundamental para a tomada de decisões relativas ao gerenciamento de resíduos.

Palavras-chave: balanço de massa, papel sanitário, produção, sustentabilidade.

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Waste Management in a Tissue Paper Mill: a Practical Approach

Abstract

The principles of sustainability, together with the Sustainable Development Goals (SDGs) defined by the United Nations (UN), are essential tools for achieving and maintaining quality of life for the coming years. The sector can make use of these objectives, and the process can become more efficient, with less water consumption and reduced waste. Using virgin cellulose fiber derived from eucalyptus or even recyclable white paper as raw material, this production method is responsible for producing paper with characteristics such as softness, low grammage and good liquid absorption, with products such as toilet paper, napkin, among others. Within the manufacturing process, several procedures can be responsible for the appearance of lint and paper dust, being a type of waste in this industry. Among these, we can mention the increase in fines content, resulting from the fiber refining process, initial mechanical treatment of the paper raw material, which provides the product with resistance. The paper crepe formation procedure is responsible for making the tissue sheet acquire characteristics such as softness and volume, but which can lead to the creation of waste. Through a simple approach related to the balance of process materials, with the analysis of process inputs and outputs, the aim of this work is to estimate the amount of material lost in a tissue paper machine. It is a fundamental preliminary assessment for making decisions regarding waste management.
Keywords: material balance, hygienic paper, production, sustainability.

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1 Introduction

Tissue paper production is distinguished by the creation of a soft and voluminous product, which, due to the hydrophilic capacity linked to the cellulose fibers, resulting in a paper with a high capacity to absorb liquids (PERNG, TENG & CHANG, 2021). One of its primary characteristics is the application in cleaning processes and hygienic purposes (OLEJNIK, BLOCH & PELCZYNSKI, 2019).

The final characteristics are defined by the fiber mixture used as raw material and the parameters used in the process, where modifications are required for each type of expected product, which result in toilet paper, paper towels, napkins, among others (ISMAIL *et al*, 2020).

In terms of raw materials used in the early stages of the process, can be from virgin cellulose fiber or recyclable paper, each type of primary source necessitates a different set of mass preparation steps. Processing virgin fiber stock is easier than processing recycled source material, which requires a dedicated stock production plant (ASSIS *et al*, 2018). In addition to wood fibers, resources such as water and chemical products for standardizing and treating the paper mass during the liquid phase are heavily used in papermaking (AVŞAR & DEMIRER, 2008).

The initial refining process in both methos, involves compression of the fibers by stators and application of shear forces. Besides the fibrillation and fines formation stand out among the changes in material properties at this stage. The fines formed, one of the factors for the appearance of dust and paper lint, varies depending on how the mechanical treatment is carried out (DEBNATH *et al*, 2021).

As a result, the manufacturing methods used by the paper machines, which perform sheeting, drying, and creping of the paper, have a large influence on the final properties of tissue paper. For example, the crepe formation process causes the fibers to weaken and even break, resulting in buckling, distortion, and breakage of the fiber structure. There are also micro folds, which are stacked and give the softness appearance (ASSIS *et al*, 2018).

Because of crepe formation occurs a fiber breakage, dust and lint appear, remaining in suspension and possibly can accumulate on the structures and equipment of the manufacturing environment, causing safety problems, high costs, and low quality (FRAZIER *et al*, 2022).

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Although these residues are of organic origin, they carry inorganic substances from the conversion process, causing residues depending on the process. Tissue paper mills are subjected to concentrations of up to 10 mg/m^3 (ANDERSSON *et al*, 2019).

Depending on the method of management, these wastes can be reused in a variety of ways, such as reducing the consumption of virgin materials, being used in other processes, or generating electricity (ZHANG, YANG & LIU, 2020; OUADI, FIVGA, JAHANGIRI, SAGHIR & HORNUNG, 2019; HAILE *et al*, 2021).

In this sense, considering that one of the objectives of sustainable development is to “ensure sustainable production and consumption patterns”, it is essential for industrial practices to adopt management aimed at waste reduction.

To accomplish this, one technique used is mass balance as a methodology for planning and controlling the flow of materials, allowing the identification and monitoring of processes that generate environmental impacts to propose solutions for waste recycling, recovery, or reuse (CORCELLI, FIORENTINO, VEHMAS & ULGIATI, 2018).

The purpose of this article is to present the mass balance of the tissue paper manufacturing process, specifically in the tissue machine, which uses virgin cellulose fiber as raw material. This study intends to define how much of the raw material taken to the machine becomes waste due to losses related to the process, introducing aspects of crepe refining and formation that can cause the appearance of these residues.

2 Literature review

2.1 Sustainability and industry

Sustainable development addresses meeting the needs of the present generation without compromising the needs of future generations. Toward to this statement, the United Nations (UN) monitors the impacts across 17 categories, comprising of 169 targets and 248 indicators (United Nations [UN], 2015).

The main methods for sustainability management are based on reducing hazardous substances and waste generation, increasing energetic efficiency, improving in logistics and cost efficiency, designing products for recycling and biodegradable materials. In general, the quantification of energy and material flows in the processes involved should be managed to reach the UN levels by 2030 (REGO & CORRÊA, 2022).

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To produce recycled paper, several factors need to be considered, including carefully managing the process of collecting and sorting fibers and removing any chemical substances that could affect the quality of the final product during manufacturing (SUHR *et al*, 2015).

Recycling plays a significant role in the production process of paper, as cellulose fibers can be recycled multiple times (CORCELLI, FIORENTINO, VEHMAS & ULGIATI, 2018). In Europe, the production of paper has increased by an average annual rate of 1.15% between 1993 and 2021, while the consumption of recycled paper for paper production has grown at a rate of 2.34% per year, thanks to advancements in the recycling process. Resulting approximately half of the raw materials used in paper manufacturing come from recycling (FAO, 2020).

Although paper is often viewed as a sustainable product, companies should consider other factors within the sustainability framework, including environmental protection, social inclusion, and economic growth.

Globally, the consumption of raw materials in paper industry highlights the shift towards using more recycled paper instead of virgin materials (CEPI, 2022).

In Brazil, the paper sector stands out in reverse logistics practices, having achieved a recycling rate of just over 70% in the year 2020, higher than the global average, which is 59.1% according to data from the Empresa de Pesquisa Energética (2024).

The use of sustainable materials and resource management must be included in current agendas to avoid scarcity, given that demand for papers for domestic, sanitary, and packaging use is constant and growing due to population and income growth (FAO, 2020).

2.2 Tissue process and waste formation

Tissue paper production consists of several stages that define the final characteristics of the product. Such processes begin with the input of raw material, which can be virgin eucalyptus fiber or recyclable white paper; later in the mass preparation, the fiber is disaggregated and refined (MENDES *et al*, 2020). The material is then pumped to the paper machine, where the tissue paper sheet is formed, with a high concentration of water. Excess moisture is removed from the sheet paper in a controlled manner during drying, after which it is rolled in rolls and sent to conversion, where the final conformations of the product, such as roll preparation and packaging, are carried out. Finally, the last step is to prepare the rolls for logistical process to deliver the product (WANG *et al*, 2019).

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The tendency to release particulates and fines not properly bonded or with low cohesion to the sheet during the manufacturing process or in the finished product line is related to the residues formation such as paper dust and lint. According to Frazier, Zambrano, Pawlak, & Gonzalez (2022), and as shown in Table 1, this waste can be produced by a variety of sources.

Table 1: Main sources of paper dust and lint in the tissue process.

Process	**Source**
Fiber Selection	Thermomechanical pulps, Fines content, Fiber source, Recycled fibers, Ash Content
Sheet Mechanical Integrity	Sheet density, Bonding, Sheet strength
Drying	Reduced final sheet moisture, Creping, Yankee cylinder accumulation
Converting Operation	Electrostatic charge, Printing, Reeling and Rewinding

Source: Adapted from Frazier, Zambrano, Pawlak and Gonzalez (2022).

During refining, the fibers are reduced, resulting in fines content. This material is detached from the wire and felt during the initial stages of paper formation and at the end of production through the crepe process, resulting in particulate waste that remains suspended and accumulates in difficult-to-access areas of the machine or building.

The virgin cellulose fiber is modified during the refining stage of tissue paper production, which is responsible for adding strength but also results in the loss of softness and absorption capacity to the paper, which are essential for the final product (MORAIS, CARTA, AMARAL & CURTO, 2021).

The Figure 1 depicts the mechanical action of the fiber between the two disks (KUMAR JAIN, DUTT & JAIN, 2021). The degree of refining, one of the relevant information in this process, is monitored through the Schopper-Riegler degree classification (SERRA-PARAREDA *et al*, 2022).

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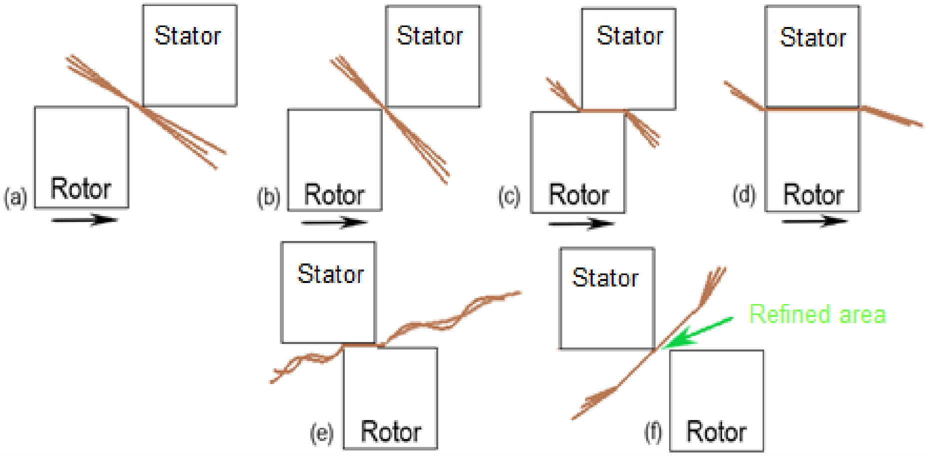
Figure 1: Fiber refining process.

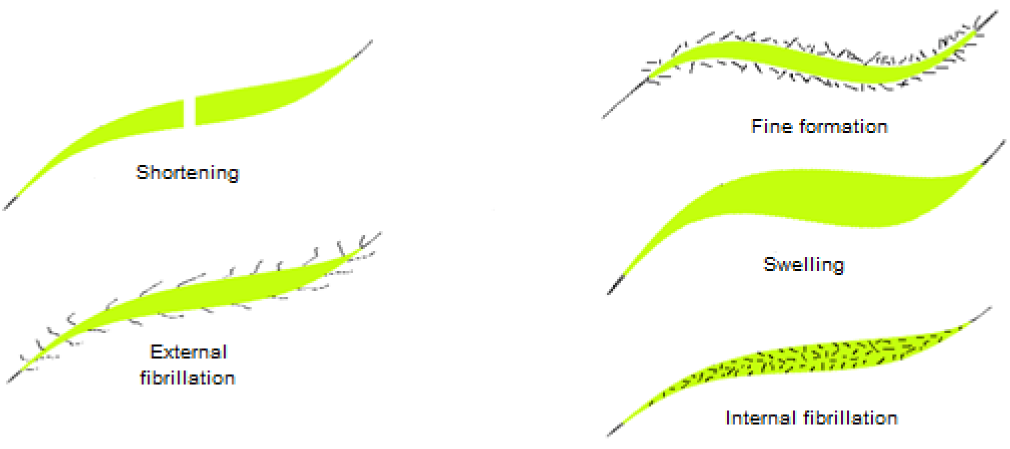


Source: Adapted from Kumar Jain, Dutt and Jain (2021).

In the paper industry, the measurement of the Schopper-Riegler degree is related to the classification of mass refining, where the capacities of the fibers to perform water drainage are evaluated, the higher the value of the Schopper-Riegler degree, the lower is the water drainage capacity through the fiber, because the mechanical effect of refining causes the fibers to have fewer spacings through which water can flow (NADER, BROSSE, DAAS & MAURET, 2022).

Internal and external fibrillation, fiber breakage, fines formation, and fiber deformation are some of the major changes that occur in the fiber, and these changes affect the final properties of the paper (DEBNATH *et al*, 2021). Figure 2 depicts what happens to the fiber during the refining process.

Figure 2: Fiber changes during the refining process.



Source: Adapted from Debnath *et al* (2021).

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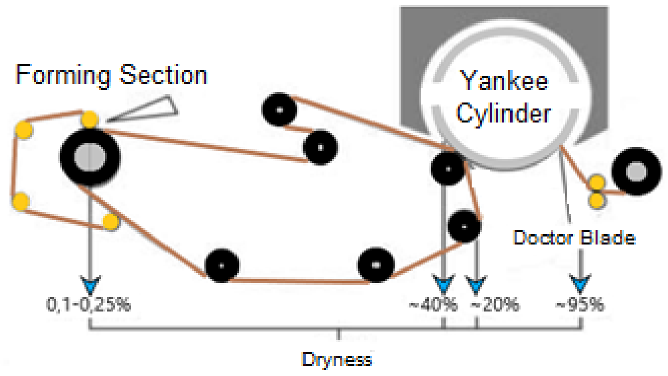
Fines are defined as the percentage of pulp that exceeds a 76 m aperture in a solid-liquid separation process with a particle length of less than 0.2 mm (BJÖRK, BOUVENG, VOMHOFF & ENGSTRAND, 2021).

According to Mayeli (2018), the presence of fines in the paper composition has a direct influence on the density and tensile strength because it improves the connection between the fibers, resulting in a more resistant sheet.

The presence of short cellulose fiber and the low grammage of the paper produced with values ranging from 15 to 50 g/m² distinguish the tissue machine from those that produce other types of paper. After refining, the fiber will enter the machine uniformly through the headbox in the forming section, and the format and type of paper produced (toilet paper, towel, napkin, among others) will be adjusted through the screen section's jet mass and velocity ratio. The sheet will then proceed to the felt section, where it will be pressed and dried by the action of the Yankee cylinder (a pressure vessel heated and pressurized by water steam), before proceeding to the crepe process, as shown in Figure 3 (ASSIS *et al*, 2018). These processes' primary characteristics are smoothness and softness (PAWLAK, FRAZIER, VERA, WANG & GONZALEZ, 2022).

Figure 3: Tissue paper machine.



Source: Assis *et al* (2018).

2.5 Mass balance

In general, increased production efficiency means less input consumption, because process instability necessitates more raw material consumption due to the necessary adjustments to stabilize the process and maintain product quality. Xia *et al* (2020) emphasized

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the importance of mass balance for two reasons: first, to compare and analyze performance parameters based on mass, and second, to evaluate parameters such as energy consumption, water, emissions, and environmental impacts.

As shown in Figure 4, the basic scheme for mass balance consists of analyzing the quantity at inputs, during processing, and outputs in relation to the mass of raw materials, products consumed, or generated. This evaluation, for example, allows for the identification of variations in the manufacturing process, the quantification of material losses, and the quality of finished and semi-finished products by monitoring and controlling the input mass proportionally to the output mass (NILO, 2013).

Figure 4: Basic model for mass balance analysis.

Source: Nilo (2013).

Mählkvist & Pontus (2018) developed a mass balance application for a pulp processing plant, focusing on the processing of wood chips and evaluating the chip silos, steam boilers, high pressure feeders, and biodigester. To complete the work, the data collected via sensors was evaluated, establishing the physical metrics of the process, evaluating with this information, and in addition to the mass balance, evaluating the energy balance.

Donmezoglu Olmez & Aksoy (2021) presented a mass balance model in which the inputs were materials and inputs used in the manufacturing process and the outputs were processing residues and the finished product. The primary data required to perform the material balance was obtained from production software. However, some mass estimates for the final products had to be performed. As a result, several waste-reduction strategies were demonstrated, ranging from raw material qualification to process improvements.

3 Materials and methods

A macro scheme of the tissue paper manufacturing was established in the development of this research, and the direct and indirect stages of production were separated, as shown in

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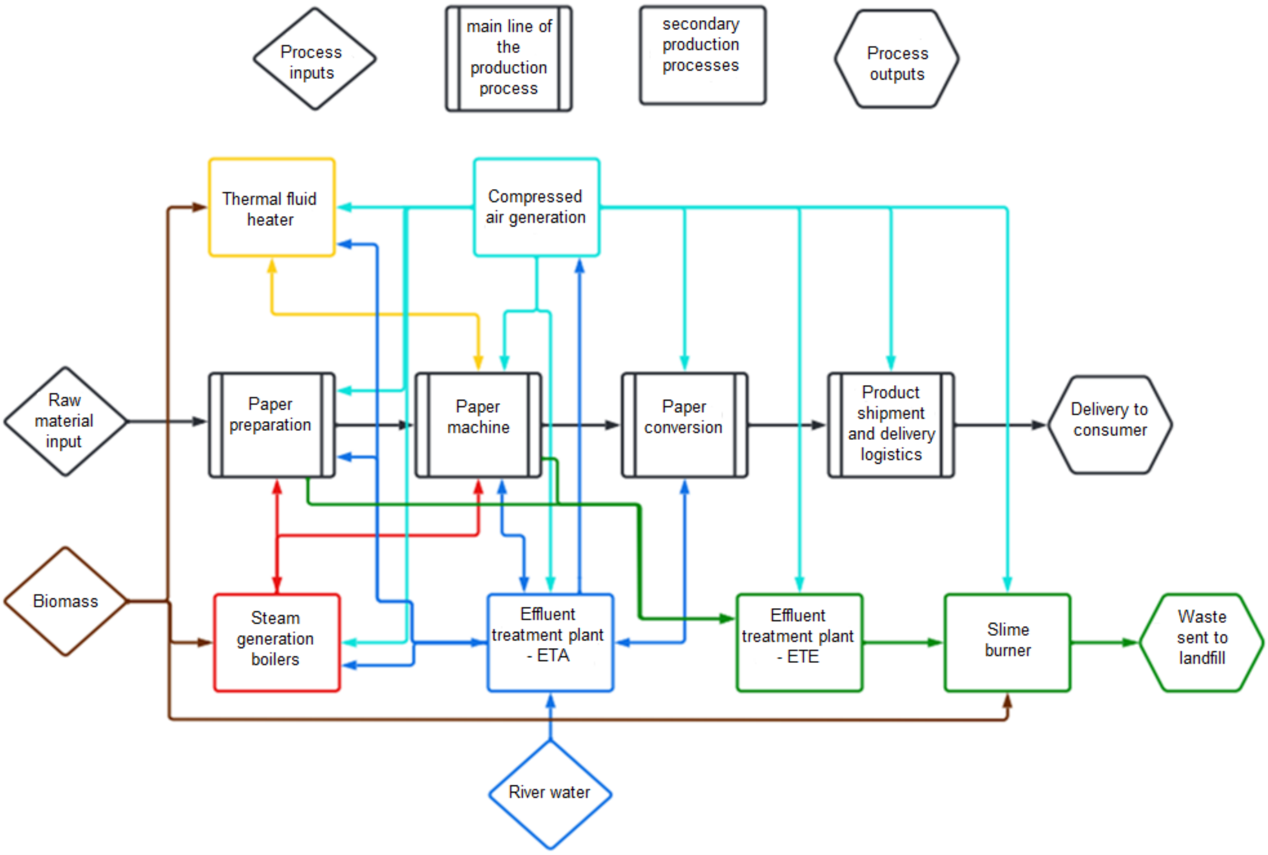
Figure 5. The central line, which begins with raw material entry and ends with consumer delivery, is the main path, and the adjacent processes, which are made up of consumables, were assigned to the lateral lines.

Figure 5: Tissue paper productive flow.



Source: The Author (2022).

Water transports raw materials in the main production line between raw material input, stock preparation, and processing in the papermaking machine. Following reel formation, the paper is mechanically transported using forklifts or conveyor belts.

In this study, the double disc refiner was considered, which is made up of a fixed stator disc and a rotor that performs the rotation movement. The raw material for this study will be short fiber eucalyptus pulp, as it is the main raw material processed in the industrial unit analyzed.

The waste generating points identified in the process were those originating in the refining processes, fines generation, located in the paper preparation stage, and machine

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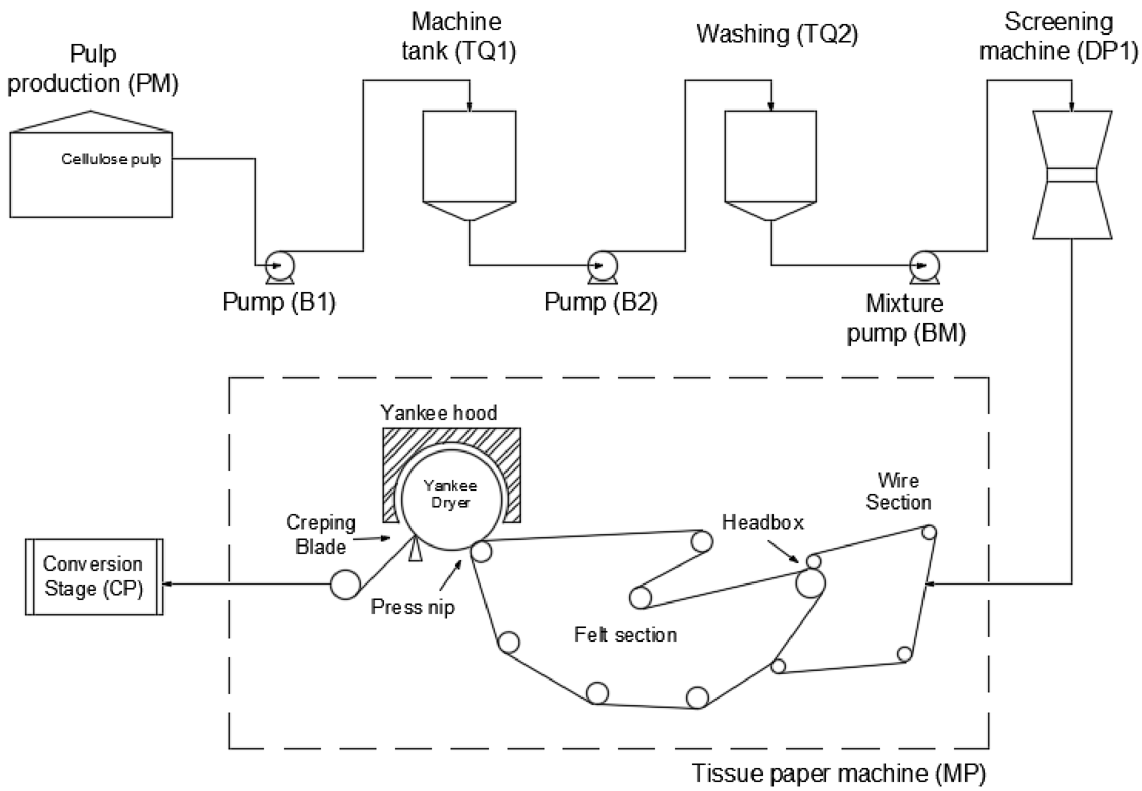
processing. Because both processes represented losses in the paper machine processing stage, mass balancing was performed at this point in the study.

The tissue production process model used is represented in Figure 6, where cellulose pulp starts the mass preparation cycle, being pumped to the machine tank (TQ1). Then to the hydromix, where the mixing pump will transport it to the screening machine (DP1), where the final separation of impurities from the paper mass will take place before entering the paper machine, where the formatting process will take place in the wire section, the drain in the felt section, pressing and drying section through the Yankee cylinder, then being detached from it through the creping blade, resulting in paper reels that will later be converted into finished paper.

Figure 6: Tissue paper production section selected for the mass balance analysis.



Source: The Author (2022).

Using the paper machine model presented in the previous chapter, data on raw material inputs (mass of paper made from virgin cellulosic fiber) were collected in order to perform loss comparisons. The parameters were collected at the exit of Pump B1 and later at the exit of the Paper Machines. Data was collected over three days of production, and

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calculations for three paper machines performed using the arithmetic mean of these parameters.

The process input data is the data collected after Pump B1 by mass balancing. The process variables used to estimate average passage of mass of paper and water, were measured by the flow meter of the paper machine in liters per minute (L/min), and the average percentage (%) of mass carried by water to the machine, as measured by consistency meters in the process. For this point, data on the machine's average speed in meters per minute (m/min) was gathered.

The estimate of ideal paper mass disregarding process losses, that is, the amount of planned finished material related to the masses of raw materials in the inputs, can be obtained by Equation (1). The expected mass (Me), in kg, is equal to the production time (Tp), in minutes, with an average of 50 minutes for the analyzed processes, multiplied by the mass flow rate (Vm), in L/min, and by the percentage of paper mass (Pp), expressed in %, present in this transported fluid.

4 Results and Discussions

4.1 Tissue machine runnability analysis

The Table 2 shows the average values obtained in the three processes studied over the course of three days of data collection.

Table 2: Average data collected in the input process.

Processes	Flow rate (l/min)	Paper mass rate (%)	Production speed (m/min)
Process 1	1,333.03	3.61	1,640
Process 2	1,511.33	3.53	1,733.33
Process 3	1,581.82	3.54	1,860

Source: The Author (2022).

At the end of the process, data on the mass of the paper reels leaving the machine in kilograms (kg), the moisture content of the paper in percentage (%), and the weight of the

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paper in grams per square centimeter (g/cm²) were collected. The Table 3 shows the average values obtained during three days of data analysis from distinct three processes.

Table 3: Average data collected in the output process.

Processes	Mass (kg)	Paper moisture (%)	Grammage (g/cm²)
Process 1	2,776.67	6	14.85
Process 2	2,696.67	5	15.21
Process 3	2,724.4	6	14.74

Source: The Author (2022).

$$Me = Tp \text{ x } Vm \text{ x } Pp \quad (1)$$

The results of this analysis are represented in Table 4, by the average mass values and the theoretical percentage of mass loss used for the calculations.

Table 4: Paper average mass and theoretical loss.

Processes	Avg. mass (kg)	Theoretical loss (%)
Process 1	2,855.46	4.34%
Process 2	2,934.02	7.95%
Process 3	2,724.4	4.83%

Source: The Author (2022).

The losses of machine inputs in relation to outputs were estimated to range between 4.34% and 7.95%, with Process 2 having the highest percentage of losses. The particulate in question is detached from the screen sections, felt sections, and during the crepe formation process of the paper, all of which are processes that result from the sheet formation in the paper machine.

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Some analyzes may require greater detail and increased sampling period. To meet these needs, it is suggested to expand monitoring at various stages of the production process, for example, in the fabric, felt and crepe process section. Eventually, techniques for measuring losses in these stages must be implemented, considering the difficulty of monitoring and the relevance of lost material. Longer observation times are also recommended, enabling the identification of process deviations and variance reduction. Another impact factor in this mass balance assessment is the characteristics of the final product, which may vary according to the raw material used, such as recyclable white paper.

In light of this, methods to reuse these losses can be used, as these percentages discovered end up becoming significant values for the production process over a one-month production period. To improve processes, systems to separate and reuse the mass of paper that falls from the felt and screen, as well as exhaust systems to collect dust in suspension, could be used, with the latter also preventing the accumulation of paper dust in the manufacturing environment.

Thus, in addition to improving the efficiency of the analyzed industry, there is also the introduction of sustainable practices, because losses are transformed into waste in the process, resulting in negative environmental impacts.

5 Conclusion

Recently, the environmental theme has been discussed in relation to sustainability subjects, particularly those that address project development in the area of industrial processes. In these courses, the use of mass balance concepts can aid in the discussion of a sustainable project by allowing the engineer to identify the main units within an industrial plant that are responsible for emissions and waste generation.

The data collected during the period and in the analyzed processes enabled the mass balance to quantify the flow of raw materials at the entrances as well as the process efficiency by identifying losses. The mass estimates were performed using the arithmetic mean of the process values, allowing the percentage of raw material lost during the formation of paper reels to be estimated.

The application model produced acceptable results for the parameters investigated, and the systematics become more accurate when analyzing data collected over longer time periods.

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