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Revamping of the long fiber line at PM6 Essity Valls

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ACRONYMS

BF	Broke fiber
CD	Short fiber
DAF	Dissolved air flotation system
DC	Dump chest
DOM	Daily operations meeting
HHT	Household towel (kitchen paper)
IRR	Internal rate of return
LF	Long fiber
MBU	Mini-business unit
MD	Machine direction
MES	Manufacturing Execution System
MPV	Maximum production velocity
NPV	Net present value
PM	Paper machine
PM6	Paper machine 6
SF	Short fiber
TOIPA	Toilet paper
WOM	Weekly operations meeting
WWTP	Waste water treatment plant

NOMENCLATURE

CEL	Cutting edge length [km/rev]
m_D	Dry mass [t]
\dot{m}_D	Dry mass flowrate [t/h]
P_A	Applied power in the refiner [kW]
P_N	Net power of the refiner [kW]
P_{NL}	No-load power of the refiner [kW]
SEC	Specific energy consumption [kWh/t]
SEL	Specific edge load [J/m]
V	Volume [m ³]
\dot{v}	Volumetric flowrate [m ³ /s]
w	Pulp consistency (mass fraction of dry pulp)
ρ	Density [kg/m ³]
ω	Refiner rotational speed [rev/s]

SUMMARY

This project focused on improving the long fiber (LF) line of Paper Machine 6 (PM6) at Essity Valls to reduce product variability and energy consumption, especially during kitchen towel production. The main issue identified was the oscillatory behaviour of Specific Energy Consumption (SEC), caused by the discontinuous discharges of the LF pulper into the dump chest. These oscillations were transmitted through the stock preparation process and affected machine direction (MD) tensile strength of the paper sheet and drying capacity of the machine.

To address this, a dynamic model was developed to simulate SEC behaviour across the stock preparation process. After evaluating several alternatives, the selected solution involved installing a new conical refiner after the LF mixing chest and constructing a pipeline to transfer short fiber pulp from the SF mixing chest to the LF machine chest. These modifications significantly reduced SEC oscillations from 144 to 83.2 kWh/t in the LF dump chest and from 16.5 to 4.03 kWh/t in the paper machine headbox.

The project showed strong economic viability caused by the promising expected savings due to the reduction of electrical energy consumption in the refining stage and the improve of the MD tensile strength variability.

1. INTRODUCTION

1.1. Papermaking process

This section describes the papermaking process to help the reader understand and become familiar with the main equipment in the mill and how tissue paper is formed. Note that the nomenclature used in this chapter will be used throughout the rest of this report.

1.1.1. Raw materials

The main raw material to produce paper is pulp or cellulose, and specifically at the Valls mill, only virgin fiber is used. The pulp is transported to the mill in 250 kg bales and stored under a roof before being introduced into the process. The combination of pulps, known as the recipe, varies according to the quality to be produced (toilet paper or kitchen towel).

Depending on the origin of the wood, celluloses can be classified as follows^[1]:

- **Hardwood pulp:** The cellulose is derived from hardwood trees (e.g. eucalyptus, birch or oak). The pulp is used to give the tissue paper a soft texture, which is due to its shorter fibers.
- **Softwood pulp:** The cellulose is extracted from softwood trees (e.g. pine or spruce). The fibers, which are longer, are responsible for the paper's strength.



Figure 1.1. Pulp bales storage. Own work.

On the other hand, cellulose can be differentiated due to the pulping process it has been submitted to convert wood to pulp^[1]:

- **Chemical:** Pulp is extracted from wood by a chemical process. Chemical pulp has a low content of lignin, this makes this type of pulp whiter and less prone to yellowing. Additionally, due to the bleaching process to whiten pulp, the efficiency is lower, and they are more expensive. The cellulose bales used in PM6 Valls are mostly chemical pulp.
- **Mechanical:** Pulp is extracted from wood by mechanical process, including thermal treatment. Mechanical pulp has a high content of lignin, which makes it less white and prone to yellowing. It is generally considered of lower quality and the price is cheaper.

Also in Valls Mill, it is used broken or waste pulp, which comes from paper reels that do not fulfill the quality specifications and edge cuts from paper machine and converting. This type of pulp is used to reduce both the environmental and cost impact of paper rolls produced.

1.1.2. Pulping

The pulping section prepares the pulp to be processed, converting dry cellulose into a water-pulp mixture. Pulp bales are transported to an agitated tank called pulper. Inside pulpers, the pulp is mixed with:

- Water: It gives the appropriate pulp consistency (7% in pulpers).
- Sodium hydroxide: It controls the pH of each line, which is expected to be neutral.
- Cationizing agent: It controls the charge of each line, which is expected to be slightly negative.
- Short and long fiber enzymes: They are added to fibrillate virgin pulp fibers reducing the energy consumption in refiners.
- Broke enzymes: They help to disintegrate broken pulp.

There are three pulpers in PM6, one for each line. They operate in batch mode in both filling and emptying actions. Pulp is transported from the pulper to another tank, called dump chest, which feeds the process in continuous mode.

1.1.3. Pulp preparation

The stock preparation phase prepares the pulp to be introduced into the paper machine, it takes from the outlet of the dump chest to the inlet of the paper machine. Cleaning, refining and mixing processes take place during stock preparation.

1.1.3.1. Pulp cleaning

Pulp shall contain impurities such as wood chips, sand or tree resin residue. Also, wires which are used to wrap the pulp bales and are extracted in the pulper automatically, however, they can be introduced to the process pipelines in some cases. These contaminants can damage process equipment like pumps or refiners.

That is why pulp being pumped from the three dump chests is deputed through wire traps, preventing the arrival of steel wires to the refiners and high-density cleaners or hydrocyclones which separate pulp from other impurities by density difference.

1.1.3.2. Virgin pulp refining

Once the pulp is free from the impurities mentioned before, the virgin pulp (only LF and SF lines) pass through refiners. This equipment is used to achieve the required mechanical strength to tissue paper. Inside refiners, the pulp flows between spinning disks and the cellulose is fibrillated, meaning that, the cellulose fibers to have more ends available to interact with near fibers, consequently the mechanical strength of the resulting paper increases.



Figure 1.2. Refiner 3 at PM6. Own work.

The long fiber line has two refiners in series. When producing kitchen paper both refiners are used as its strength specifications are higher, while producing toilet paper only one refiner is necessary. The short fiber line has only one refiner.

1.1.3.3. Broke deflaking

Broke pulp does not need to pass through refiners because it is a finished product that has already been refined before. As broke pulp may not be well disintegrated in the pulper, it passes through deflakers and the broke screen to eliminate impurities and make the broke pulp processable.

1.1.3.4. Pulp mixing and storage

Long and short fiber lines, separately, are mixed with broke pulp inside mixing chests with a specified ratio depending on the product produced. After that, both lines are pumped to machine chests, which are the last storage tank before entering to the paper machine.

In kitchen paper production, a wet strength aid is added after these chests to give paper wet resistance. Since the wet strength aid is an aqueous solution of a cationic polymer, a charge compensating anionic polymer solution is also added.

1.1.3.5. Fan pumps

After machine chests, the pulp consistency (% weight of dry pulp) is around 3.5%, but the consistency required at the inlet of the machine need to be between 0.1 to 0.5% in order to ensure a uniform paper sheet formation across the whole width of the machine^[1].



Figure 1.3. Fan pumps rotor^[1].

Virgin pulp lines are mixed with the silo's water to achieve the optimal consistency mentioned before in the fan pumps, which are responsible for diluting the slurry and pumping it into the forming section of the paper machine.

The silo's water and a major part of the water used in the process are internally recovered water. Paper solids present in machine wastewater are recovered through a flotation device used to separate solids by air injection and recirculated to the broke pulp dump chest. Water that can not be reused (hydrocyclone cleaning water, screening liquid phase and machine drainages) is sent to the wastewater treatment plant of the mill to be used again in the process.



Figure 1.4. Dissolved air flotation system. Own work.

1.1.3.6. Screening

After the fan pumps, both lines pass through the last pulp cleaning unit called screen. Screens have a cylindrical perforated basket and internal agitator to ensure that no small impurities are present in the inlet of the paper machine.

1.1.4. Paper machine

Paper machine 6 is a double-press crescent former tissue machine built by PMT Italy Spa. This type of machine needs two fabrics, a forming wire, and transport felt to create a wide and uniform paper sheet. The PM6 is a double-width machine because it produces two reels simultaneously with a machine speed between 1500 m/min and 2000 m/min. The paper machine has two sides known as the drive side (DS) (where there are the motors that drive the wire, the felt and the Yankee dryer) and the tender side (TS) (the other side where there are not the drives of the machine).

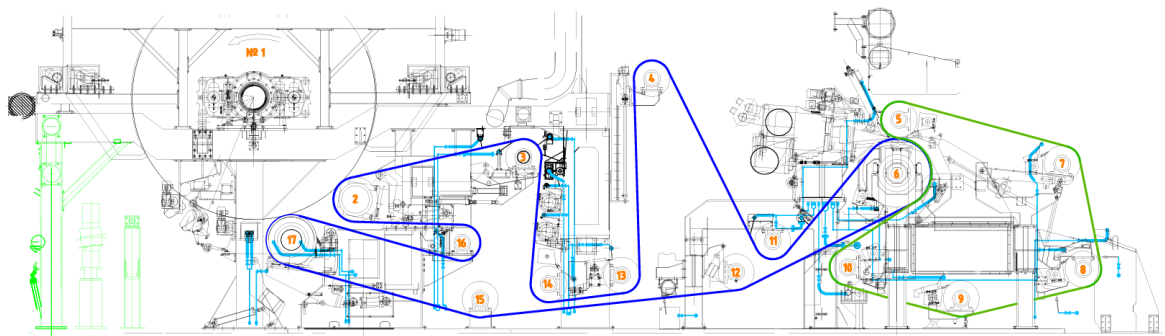


Figure 1.5. Paper machine TS view (see a copy at appendix A)^[1].

1.1.4.1. Paper formation

As said in section 1.1.3.5, a diluted pulp slurry is pumped to the machine's headbox, where the paper is formed at the outlet of it. The headbox projected the pulp between the crescent former roll (5) and the header roll (6) against the wire, where dewatering takes place because of the material and the mesh size and the paper sheet is stuck to the felt.

The headbox is the last piping section before the paper machine, it has square section that becomes smaller when approaching to the exit in order to keep and steady pressure in the cross-machine direction, the final part of the headbox, which is the thinner, is known as the lip. Two pulp lines enter the machine's headbox (long and short fiber) separately to create a paper sheet that is mechanically strong (long fiber line) and is soft enough (short fiber line).



Figure 1.6. Paper machine lip. Own work.

1.1.4.2. Pressing

Once the paper sheet is formed, it is transported to the pressing section of the machine through the felt. In this section, the machine presses the felt and paper sheet towards the dryer to remove excess water. The PM6 has two presses: the suction press (roll 17), with a perforated surface and vacuum pressure, extracts the maximum amount of water, and the blind press is used to increase the dryness of the paper to about 45% pulp and 55% water^[1].



Figure 1.7. Dewatering produced due to Yankee dryer – blind press contact. Own work

1.1.4.3. Drying

The paper sheet is transferred from the felt to the dryer (roll 1), known as the Yankee. The sheet is stuck to the dryer due to the chemical coating layer, an aqueous chemical mixture with three components that is sprayed before the press and dryer contact point^[2].

- **Coating:** a polymer that is used to stick the paper sheet to the dryer surface. It deactivates as the sheet is dried so it can be easily removed from the drying section.
- **Release:** an organic ester oil used to separate the paper from the dryer. During the initial drying phase, the coating chemistry takes the lead and ensures the adhesion of the sheet to the dryer. As the moisture decreases and the temperature increases during the drying process, the non-stick properties of the coating take the lead, allowing the sheet to release from the dryer surface.
- **Phosphate:** it creates a protective layer on the dryer surface, preventing it from corrosion and abrasion.

Drying of tissue sheet is carried out by two complementary processes: conduction drying and forced convection drying. Conduction drying takes place on the surface of the dryer. The heat generated by the condensation of 8 bar steam in the dryer is transferred to the tissue sheet by conduction.

The drying hood covers most of the circumference of the dryer and is responsible for the remainder of the drying process. It provides heat to the tissue web by blowing high-velocity hot air onto the tissue surface. It serves two purposes: it provides additional heat, and it is the only way to remove evaporated water from the drying system to the outside.

The moisture of the paper sheet is measured and controlled through a scanner that is moving towards the sheet's width. Consequently, the burner temperatures that heat the air that is projected to the paper sheet at the Yankee dryer surface are adjusted to achieve the moisture specification, which can be between 6 and 6.7% by weight.



Figure 1.8. Yankee dryer and drying hood. Own work.

1.1.4.4. Creping

The paper sheet is separated from the Yankee dryer surface using the creping blade, creating a uniform crepe pattern (small and regular ridges that run across the tissue paper surface) that increases the bulk and softness of the tissue paper. The angle of the blade, blade bevel (β), is varied depending on the quality produced in order to increase the paper softness.

Apart from the creping blade, the machine possesses two more blades. The skinning blade, which is before the creping blade, is used to separate the paper from the dryer, like the creping blade, when applying the skinning blade, the paper sheet is thrown on the under the machine pulper (UTM) and diluted and recirculated to the broke dump chest, this blade is used when the creping blade is being changed during production. The cleaning blade is situated before the coating spray boom and is not in contact with the paper sheet. This blade is used to remove and clean the coating layer before it is applied.

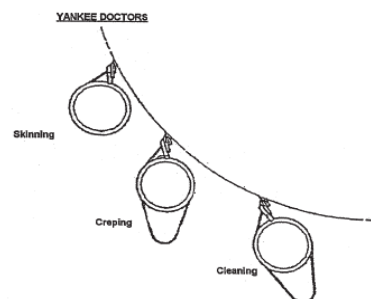


Figure 1.9. Cleaning, creping and skinning blades diagram^[1].

1.1.4.5. Reeler section

The paper sheet exiting the Yankee dryer is rolled in the pope reel roll, and the two paper reels are formed. This roll is moving at a lower linear velocity than the machine in order to keep the crepe pattern created in the creping blade, the percentage difference in speed between the dryer and the pope reel is known as the creping ratio.



Figure 1.10. Paper reeling at pope reel roll^[1].

Once both reels are finished, they are wrapped, labeled and transported to the semifinished product warehouse through an automatic system of roller belts. Finally, the paper reel is combined with others to create the final product in the converting lines.

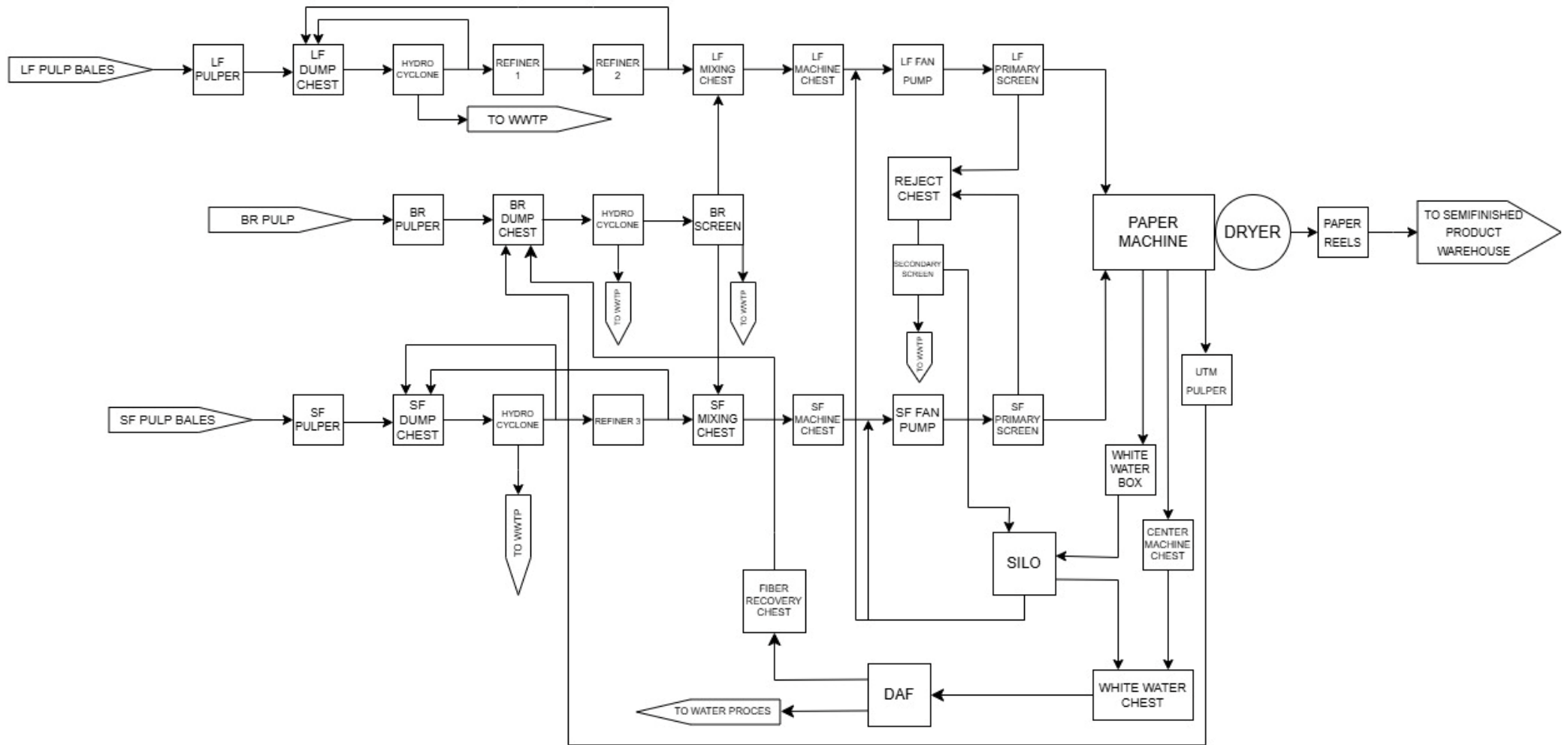


Figure 1.11. Block diagram of paper process (just pulp flows are shown see additional process machine for water block diagram). Own work.

1.2. Previous antecedents

1.2.1. Hood burner temperatures oscillatory behaviour

As A. Fernández found in his thesis *Debottlenecking of the drying process in PM6 at Essity Valls*^[3], there is an oscillatory behaviour in the hood burner temperatures that limits the performance of the paper machine because, due to the construction materials of the hood components, the temperature can not exceed 500°C.

Looking at the period of the oscillations, which is about one hour, suggests that there is a relationship between the burner temperatures and the long fiber pulping process. As described above, the pulps are discharged to the long fiber dump chest in batches, while the dump chest feeds the process continuously. The long fiber dump chest is fed with virgin pulp when the level is at 50%.

The refining process occurs at a constant rate, in other words, the flow rate out of the tower is always the same, which means that a part of the flow rate must be recirculated back to the dump chest. Consequently, the degree of pulp refining in the dump chest increases as it is discharged and decreases when virgin pulp is fed again. The more refined pulp the more energy is required to dry the paper sheet, because refined fibers have more hydroxyl groups that can interact with water, making highly refined pulp difficult to dry.

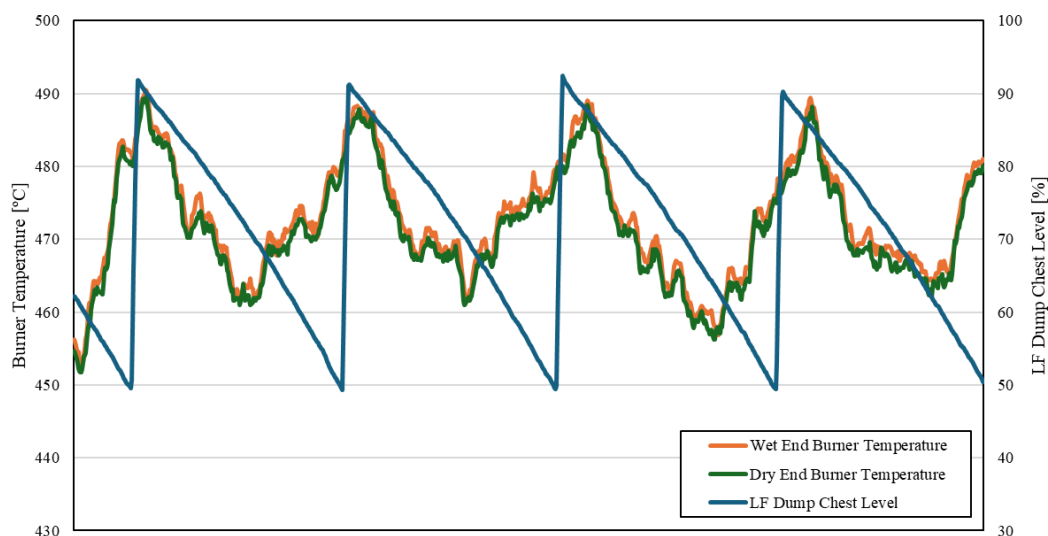


Figure 1.12. Burners' temperatures oscillations caused by discontinuous LF pulper discharges to LF dump chest.
Own work.

1.2.2. Long fiber and short fiber consumption

Originally the paper machine number six was designed to work with a long fiber percentage of 30%. Because the price of long fiber has historically been higher than that of short fiber (see Figure 1.13), the consumption of long fiber has been reduced in order to achieve an economically competitive product.

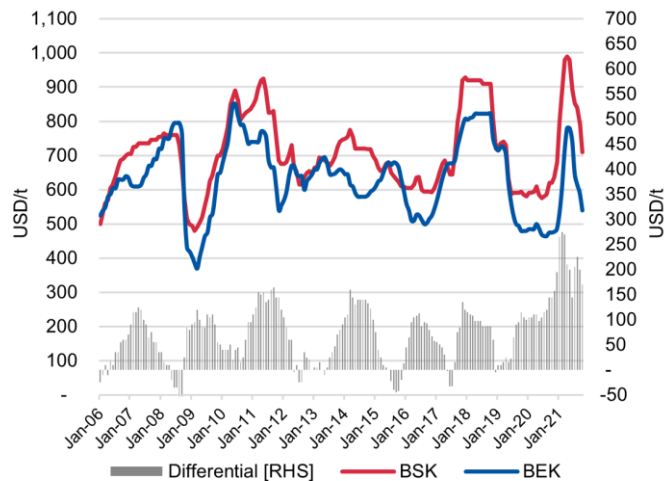


Figure 1.13. Price comparison between BSK, Bleached Softwood Kraft (long fiber pulp) and BEK, Bleached Eucalypt Kraft (short fiber pulp) from 2006 to 2022^[4].

This process modification has caused the flow rate of the long fiber circuit to be significantly reduced, affecting the temperature variability of the hood burners, the machine direction (MD) tensile strength of the paper and the formation of the sheet in the headbox.

Also, the ratio of broken pulp in the long-fibre circuit in the mixing chest is much higher than that of the short fiber, thus reducing the flow of virgin long fiber. In addition, the ratio of long fiber in the machine headbox is also considerably lower than that of short fiber.

2. OBJECTIVES

The long fiber line is a key part of paper machine process as it influences the strength of the final product. Variability in this line can lead to fluctuating paper properties, reduced runnability and higher operational costs.

This thesis aims to reduce product variability, specifically machine direction tensile strength by revamping the long fiber line through process analysis and targeted engineering improvements. The objectives described below define the scope of this work.

- Propose improvements to the long fiber line to reduce sources of product variability focusing on refining area.
- Quantify the impact of the proposed modifications by analysing changes in machine direction tensile strength and process stability.
- Evaluate economic feasibility through cost-benefit analysis, considering investment costs, operational savings and return on investment.

Because as both burner temperatures and machine direction tensile strength variations are accentuated during the production of kitchen towels, this work will focus on the two qualities that represent a major part of kitchen towel production.

Finally, although the work is centred on the proposed modifications to reduce product variability, it also describes the tests performed during the progress of the project to measure how process variables influence product variability.

3. STUDENT'S ROLE IN COMPANY

Essity is a leader company in the hygiene and health sector, with its headquarters in Stockholm, Sweden, whose purpose is focused in improving the well-being and contributing to a healthy, sustainable and circular society. Taking this into account, Essity develops, produces, commercializes and sells products and services among approximately 150 countries. Specifically in Spain, Essity has three production plants located in Valls (Tarragona), Allo (Navarra) and Telde (Gran Canaria) and two commercial offices in Madrid and Barcelona^[5].

Particularly, Essity Valls Mill has two paper machines, which are in charge of producing tissue paper reels of around 2750 kg, three converting buildings that have different lines where the paper reels are converted into the rolls that are then marketed, and two Personal Care buildings where nappies are manufactured.

In my case, I have become part of the Resource Support Team (RST) at Paper Machine 6 (PM6), formed by the Operations Leader, the Process Leader and the Graduate Engineer. In my case I am performing the role of a Graduate Engineer, my functions include participation in operation and maintenance meetings, revision and update procedures and standards, support production teams, tracking of Key Performance Indicators (KPI's), among others that will be explained detailly in the following sections of this chapter.

3.1. Operations meetings

As part of the RST team, operations meetings are an important part of our work. Most of the tasks are derived from these meetings. During the internship, the meetings I routinely attended were: Daily Operations Meeting (DOM), Weekly Operations Meeting (WOM) and Mini Business Unit (MBU).

3.1.1. Daily Operations Meeting (DOM)

Daily Operations Meeting (DOM) as its name indicates, is a daily meeting where the Process RST Team, a representative of Maintenance, Safety and Quality departments and the shift Team Leader participate. This is used to discuss the performance of the unit the day before following the SQDCM (Safety, Quality, Delivery, Cost, Moral) structure and plan the next 24 hours. As a Graduate Engineer, I am responsible for facilitating the meeting, gathering the most relevant information.

Before, the meeting, I refresh the DOM's SharePoint site to keep it up to date. Also, together with the process leader, the *Centrelining Local* is reviewed, where about 400 machine parameters, such as pressures, temperatures, flow rates, are captured every 10 minutes. To facilitate the review, the *Centrelining Local* is colour-coded: green means that the value of the variable is as expected, blue means that it is close to the limit and red means that it is out of limits. The objective of the review is to understand why the variables are out of limits and to decide if actions should be taken to correct them.

Before the meeting, I inspect the machine to check for possible defects such as leaks, paste, out of place elements, checking all three levels of the machine on the drive side and on the tender side. Any deviations found are photographed and shown to the shift Team Leader so that

they can be corrected during the day. If any serious deviations are encountered, they are discussed in the DOM to reach a consensus on how to proceed.

3.1.2. Weekly Operations Meeting (WOM)

Weekly Operations Meeting is done every week and the Process Leader and the Graduate Engineer from both machines together with the Paper Machine Continuous Improvement team attend. This meeting is used to discuss several topics regarding both paper machines. Knowledge and improvements are shared with the other machine in order to find the possibility to replicate them.

Using the *Centreline*, we discuss the most relevant changes in process behaviour during the week before, deviations found are analysed in the meeting by the whole team. Also, consumables (parts of the machine that need to be replaced regularly) and clean tasks (parts of the machine that need to be cleaned regularly) centrelines are reviewed there.

3.1.3. Mini Business Unit

Mini Business Unit is a weekly meeting with the whole RST of PM6, including Process and Maintenance. The purpose of the meeting is to organize and prioritize the tasks and projects that are being executed in the unit. Moreover, Process and Maintenance plans are discussed in case of a planned downtime in order to coordinate all the tasks that need to be done in a safety and effective way.

My role in this meeting is to inform the rest of the participants how my tasks are progressing and in case of absence of the Process Leader, I am also in charge of organizing the information before the meeting and updating the Planner page where all the tasks are displayed.

The principal projects and tasks I have reported in the MBU are the analysis of the reduction of broke pulp in the long fiber line and the improvements of the production teams. The first one is related to my thesis, because the purpose of the reduction mentioned was to reduce the variability of the MD tensile strength and the pulp morphology.

Related to the improvements of the production teams, every quarter the company organizes an internal site tour where every unit can present one improvement that has developed. During the MBU, I share which are the improvements that each shift is developing that can be presented in the next site tour.

3.2. Machine parameters analysis

During my internship, I have analysed several machine parameters in order to understand some process behaviours using Proficy Historian Administrator (PHA). This software enables the user to graph whatever machine parameter that has been captured at every timescale desired. It calculates some statistical data of every parameter selected such as the mean, and the standard deviation, these values are used to set the correct limits to each variable.

In this sense, I have set limits for each product of PM6 for five fiber morphology parameters. At the long fiber machine chest, there was installed an instrument, that gives information about

the fiber's morphology at real time. The purpose of this instrument in the long fiber line is to show fiber's behaviour with changes in refiners' power, machine velocity or recipes.

With the objective of keeping updated the Proficy system, every week I participate in a meeting with the Continuous Improvement Leader and the PM5 Graduate Engineer. During this meeting, it is discussed which variables need to be added and removed from the *Centreline* in order to provide the most valuable information about the machine's behaviour.

3.3. Safety investigations

As a Graduate Engineer, I have been in charge of organizing the safety investigations in case of an incident in PM6. My responsibilities were to group the PM Safety Technician (leader of the investigation), the affected person, the shift Team Leader, the PM6 Operations Leader and union representatives.

During the investigation of the incident, the affected person explains how the incident occurred and the whole team led by the Safety Technician try to identify the root cause. Once this is done, the team sets actions focused on the root cause found before. In case the incident was suffered realising a task that has associated a procedure, this is reviewed and modified if necessary to prevent the incident from occurring again.

3.4. Chemical and product traceability

Guarantee the chemical and product traceability of each reel produced in the paper machine is essential to assure the product's quality and safety and pass IFS accreditation and other audits. As for product traceability, I am responsible for posting in its folder all the recipes for the different products of PM6. The recipe contains the number of bales of every type of cellulose that need to be introduced into long and short fiber lines and the production's start date.

Regarding the traceability of chemicals, I oversee the operator reports, which include the batch numbers and expiration dates of the chemical products used in the process, with the objective of assuring that no expired product has been introduced. In case of an issue, for example no expiration date or batch number in the label, I contact with the supplier to solve.

Operators write down the information in the report manually, which produces many inconsistencies in the report and huge time consumption in the revision. That is why, during the year 2025, a work group was created to try to improve this process, in which I participate. The first measure we adopted was to move the chemical traceability information to the Manufacturing Execution System (MES), before it was stored in an Excel file. Now we are working on the automatization of the process with QR code for each product container containing the batch number and expiration date information.

3.5. Shutdown planning and participation

A periodical planned shutdown is carried out in PM6 because of the felt change, it needs to be replaced to obtain the paper quality expected and a good machinability. The tasks that will be performed during the shutdown are discussed and planned in the MBU meeting as mentioned above. In addition, three weeks before the shutdown PM6 Process and Maintenance teams meet with other departments like digitalization or general services to ask if they need to do some

tasks during the downtime, this meeting is repeated weekly until the date of the machine stoppage.

During the shutdown, I am in charge of reviewing and performing some of the operator tasks that appear in the planning, that are related with cleaning zones of the machine that can not be done when the machine is running. Also, as the replacement of the felt requires a lot of people, I help the operators to introduce it, guided by the Team Leader.

3.6. Site tour

During my internship I had the opportunity to explain the process and the paper machine to different groups, some of these tours were in English and others in Catalan depending on the dominant language of the audience.

On February, I took part in the *Experimenta Day*, organised by the university, where students from different degrees, masters and doctorates visited Essity with the aim of providing professional guidance.

In April, the tour was given to the students of team leadership practices of the chemical engineering degree, apart from the explanation of the process I was able to have a conversation and answer their questions since three years before I had been visiting Essity with the same subject.

3.7. Standard procedures and operator's tasks optimization

During my internship, I have created and improved standard procedures with to ease new operator's training and keep them up to date. Procedures for cleaning, start-up and shut-down of paper machine were the most important ones, as they allowed me to acquire a better knowledge of the machine's operation as well as to get to know the staff of the production team, by asking how their shift performed these operations and commenting on the differences between the other shifts and the old procedure.

Operators carry out preventive maintenance tasks in different parts of the process and paper machine equipment, called *Cleaning, Inspection and Lubrication* (CIL) tasks. These tasks can be organized with different frequency depending on the criticality of them using Rubik. In this sense, we created a work team with the Process Leader and a machine tender apprentice, who was also doing her internship, to review all machine tender's tasks with the operators.

As a result of this project, about 30 tasks were deleted because of being obsolete or repeated, also, about 20 CIL documents (short and visual procedure of the task) were created or improved. Finally, once the list of tasks was corrected, we have restructured the tasks in the different shifts and weekdays so that the workload is balanced and the tasks can be performed correctly.

4. MATERIALS AND METHODS

4.1. Process data gathering

Process data has been extracted using the digital tool Proficiency Historian, which about 5000 most important control system signals (measured values, controller actions, PID parameters, output signal...) such as pressures, flows, consistency, levels control loops are captured every second. This has been extracted to a *csv* file to be treated and plotted.

4.2. Specific energy consumption (SEC) model

A model based in energy and mass balances was defined to understand how refiner's energy was distributed through the process streams and chests. A first order differential equation was proposed because of the influence of the LF pulper discharges to the LF dump chest. Below it is shown the example of the dump chest (equation 4.1) and the general formula used for all the process chests (equation 4.2).

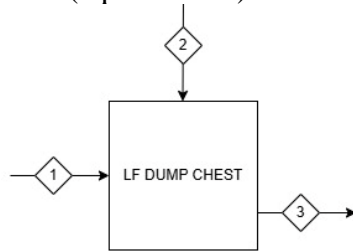


Figure 4.1. LF Dump chest block diagram. Own work.

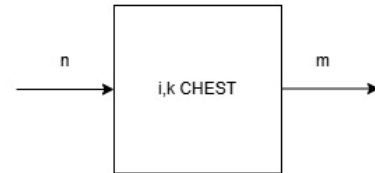


Figure 4.2. General process chest block diagram. Own work

$$\frac{dV_{LF,DC}}{dt} = \dot{v}_1 + \dot{v}_2 - \dot{v}_3 \quad (4.1)$$

Where:

$V_{LF,DC}$: Long fiber dump chest volume [m^3], \dot{v} : Stream volumetric flow rate [m^3/s].

$$\frac{dV_{i,k}}{dt} = \sum_1^n \dot{v}_n - \sum_1^m \dot{v}_m \quad (4.2)$$

Where:

i: Pulp line (long or short fiber), k: Process chest (dump, mixing or machine chests), n: Chest inlet stream, m: Chest outlet stream.

According to the specific energy consumption (SEC) it has been modelled with a first order differential equation based on the dry mass balances (dry pulp flow rates) as the specific energy consumption is calculated the quotient of the net power applied in the refiner in kilowatts (kW) and the dry pulp flowrate in tonnes per hour (t/h).

$$\frac{d(\text{SEC}_{LF,DC} \dot{m}_{D,LF,DC})}{dt} = \text{SEC}_1 \cdot \dot{m}_{D1} + \text{SEC}_2 \cdot \dot{m}_{D2} - \text{SEC}_3 \cdot \dot{m}_{D3} \quad (4.3)$$

Where:

SEC: Specific energy consumption [kWh/t], m: Dry pulp mass [kg], \dot{m}_D : Dry pulp mass flowrate [kg/s].

Considering an ideal mixture inside the chest it could be supposed that specific energy consumption value of the chest is the same as in its outlet stream. Then:

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = \text{SEC}_1 \cdot \dot{m}_{\text{D1}} + \text{SEC}_2 \cdot \dot{m}_{\text{D2}} - \text{SEC}_{\text{LF,DC}} \cdot \dot{m}_{\text{D3}} \quad (4.4)$$

From the left-hand side part of the equation.

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = m_{\text{D,LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} \frac{dm_{\text{D,LF,DC}}}{dt} \quad (4.5)$$

The dry mass of pulp inside the dump chest can be converted to the volume using the consistency and the density in the dump chest.

$$m_{\text{D,LF,DC}} = V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \quad (4.6)$$

Where:

ρ : Pulp density [kg/m^3], w : Pulp consistency or pulp mass concentration.

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} \frac{d(V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}})}{dt} \quad (4.7)$$

Then, in order to simplify the model, density and consistency of the chests had been considered constants.

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{dV_{\text{LF,DC}}}{dt} \quad (4.8)$$

The volume differential can be substituted by equation 4.1.

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \cdot (\dot{v}_1 + \dot{v}_2 - \dot{v}_3) \quad (4.9)$$

And applying equation 4.6.

$$\frac{d(\text{SEC}_{\text{LF,DC}} m_{\text{D,LF,DC}})}{dt} = V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} (\dot{m}_{\text{D,1}} + \dot{m}_{\text{D,2}} - \dot{m}_{\text{D,3}}) \quad (4.10)$$

Then grouping left hand side part of equations 4.4 and 4.10.

$$V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} + \text{SEC}_{\text{LF,DC}} (\dot{m}_{\text{D,1}} + \dot{m}_{\text{D,2}} - \dot{m}_{\text{D,3}}) = \text{SEC}_1 \cdot \dot{m}_{\text{D1}} + \text{SEC}_2 \cdot \dot{m}_{\text{D2}} - \text{SEC}_{\text{LF,DC}} \cdot \dot{m}_{\text{D3}} \quad (4.11)$$

$$V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}} \frac{d\text{SEC}_{\text{LF,DC}}}{dt} = \dot{m}_{\text{D1}} (\text{SEC}_1 - \text{SEC}_{\text{LF,DC}}) + \dot{m}_{\text{D2}} (\text{SEC}_2 - \text{SEC}_{\text{LF,DC}}) \quad (4.12)$$

$$\frac{d\text{SEC}_{\text{LF,DC}}}{dt} = \frac{\dot{m}_{\text{D1}} (\text{SEC}_1 - \text{SEC}_{\text{LF,DC}}) + \dot{m}_{\text{D2}} (\text{SEC}_2 - \text{SEC}_{\text{LF,DC}})}{V_{\text{LF,DC}} \cdot \rho_{\text{LF,DC}} \cdot w_{\text{LF,DC}}} \quad (4.13)$$

Finally, equation 4.14 is the general equation used for all the process chests.

$$\frac{d\text{SEC}_{i,k}}{dt} = \frac{\sum_n^1 \dot{m}_{\text{Dn}} (\text{SEC}_n - \text{SEC}_{i,k})}{V_{i,k} \cdot \rho_{i,k} \cdot w_{i,k}} \quad (4.14)$$

Further details of the model are explained in appendix B.

5. REFINING

The purpose of this section is to discuss the fundamentals of the refining process, because the work will be focused in how the pulp is refined in the mill.

The role of the refining process is to develop sheet strength; however, it can also have significant effect on sheet drainage, bulk, porosity and formation. While refining has a positive impact on sheet strength, it has a negative impact on softness and absorbency.

The primary piece of equipment in the refining process is the refiner, which consist of two or more internal plates, some of which rotate (rotators), and others are stationary (stators). These plates are very closely spaced and as the pulp is pumped between the rotor and stator, the bars on the surfaces of the plates cut, split and brush the fibers. This increases the surface area of the fibers, promoting better fiber-to-fiber bonding and strength development.

5.1. Fibers

In order to discuss refining principles, it is important to understand fiber morphology. Fibers are long and hollow cylinders, its hollow portion is named lumen, and the wall is known as cell wall, which contains the bulk of fiber's material. Fibers are bonded by the middle lamella that contains about 50-70% of the total lignin content of the wood. Lignin bonds individual fibers together.

The fiber wall is made up of several layers: the primary wall, the secondary walls. The chemical composition varies between these different layers as it can be seen in the following table.

Table 5.1. Thickness and chemical composition of different layers of the fiber's cell wall^[6].

Layer	Thickness [μm]	Cellulose	Hemicellulose	Lignin
Primary	0.03-0.10	10%	20%	70%
S1	0.10-0.20	35%	25%	40%
S2	0.05-0.20	55%	30%	15%
S3	0.07-0.10	55%	30%	25%
M. Lamella	1.00-2.00	0%	10%	90%

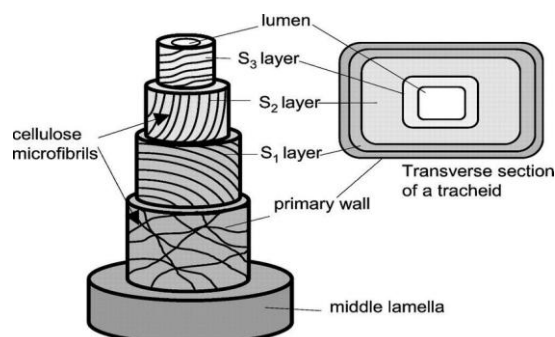


Figure 5.1. Composition of the different layers of wood fiber^[7].

Inside refiners, the primary wall and the first layer of the secondary wall (S1) are removed, exposing the inner secondary layers which are rich in cellulose and hemicellulose, whose hydroxyl groups promote fiber-to-fiber bonding and strength development.

5.2. Refining principles

The refining process involves the treatment of fibers in the presence of water with metallic bars. The plates are grooved so that the bars that treat fibers and the grooves between bars allow fiber transportation through the refining machine.

The refining principles consist of several stages. Initially, fiber flocs are collected on the leading edges of the metallic bars, known as pick-up stage. As the leading edge of the rotor bar approaches the leading edge of the stator bar, fiber flocs are compressed. This results in a strong hit that presses most of the water is compressed out of the flocs. At this point, shorter fibers may separate from the main floc and flow away with the expelled water into the grooves between bars. The remaining fibers stay compressed between the bar edges and receive refining.

After this, both leading edges slide along the fiber floc and press it against the flat bar surface. Most refining is performed during this edge-to-surface stage when bar edges give mechanical treatment and friction between fibers gives fiber-to-fiber treatment inside the floc. This stage continues until the leading edges reach the tailing edges of the opposite bars.

After the edge-to-surface stage, the fiber floc is still pressed between the flat bar surfaces until the tailing edge of the rotor bar has passed the tailing edge of the stator bar.

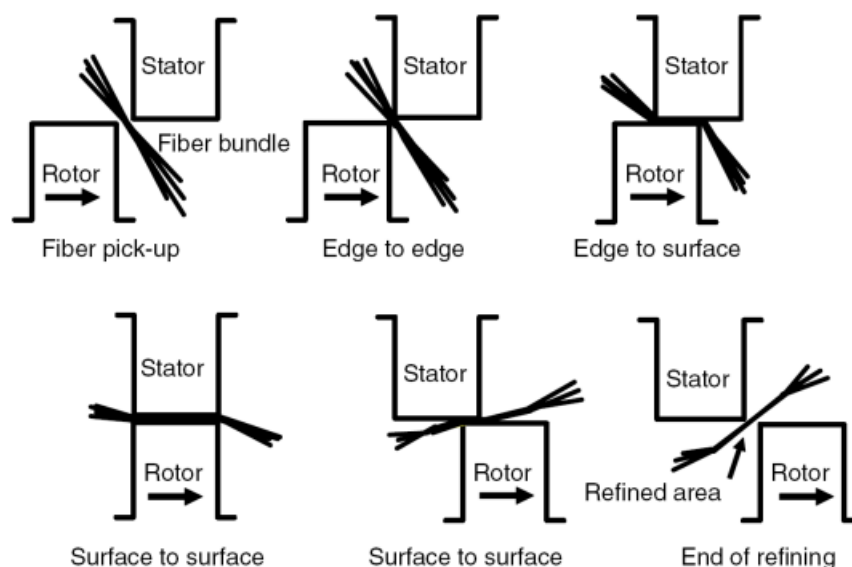


Figure 5.2. Refining mechanism^[8].

5.3. Refining variables

In order to simplify and model the behaviour of the fibres within the refiner, the industry has defined variables based on intensity of the hits between the fibres and the plate bars. These calculated parameters depend on the power applied to the fibers, the plate design and the rotational speed^[8].

Specific Energy Consumption (SEC) represents the magnitude of energy applied to the pulp is calculated using the equation 5.1:

$$SEC = \frac{P_A - P_{NL}}{\dot{m}_D} \quad (5.1.)$$

Where:

SEC: Specific energy consumption [kWh/t]

P_A : Applied power in the refiner [kW]

P_{NL} : No-load power [kW]

\dot{m}_D : Dry mass flowrate that pass through the refiner [t/h]

No-load power is defined as the power required to rotate the unit, full of pulp, at its operating speed, with the plates completely open.

The intensity of the hits is named Specific Edge Load (SEL) and can be calculated using the equation 5.2.

$$SEL = \frac{P_A - P_{NL}}{CEL \cdot \omega} \quad (5.2.)$$

Where:

SEL: Specific edge load [J/m]

CEL: Cutting edge length [km/rev]

ω : Rotational speed of the refiner [rev/s]

The cutting edge length is the total length of all bar edges and depends on the plate design.

5.4. Types of refiner

As mentioned before, refiners consist in two grooved plates with metallic bars. Most used refiners used in tissue production are:

- **Double disc refiner:** Double disc refiner consists in four plates, two outer plates on the refiner walls are the stators and two inner plates located on the floating disc are the rotors. Pulp is introduced and refined in both gaps between refiner walls and floating disc.
- **Conical refiner:** Conical refiner is formed by two plates, the stator is located at the external wall of the refiner and the rotor is the inner cone. Pulp enters conical refiner at the lower section part of the cone and flows along the plates surface, finally it leaves the refiner at the cone end with larger section.



Figure 5.3. Double disc refiner^[9].



Figure 5.4. Conical refiner^[10].

5.5. Refining control systems

The amount of power applied to fibers inside the refiner depends on the clearance between the rotor and the stator. In this sense, there are several types of control systems used in the industry to control the position and power input to a refiner in the process:

- Power control:** This scheme uses an operator-input set point to maintain the refiner motor power at a desired value. The refiner plates are mechanically positioned according to the motor kilowatts. The disadvantage of this type of control is the lack of response to process changes and dependence on the operator to adjust the set point for process changes. To be applied successfully, the refiners should receive a steady flow and consistency.
- Specific energy consumption control:** This scheme calculates the Specific energy consumption (using the formula 5.1) and compares it to the set point and adjusts the plate clearance. This type of control systems requires measuring flow and consistency before entering the refiner.

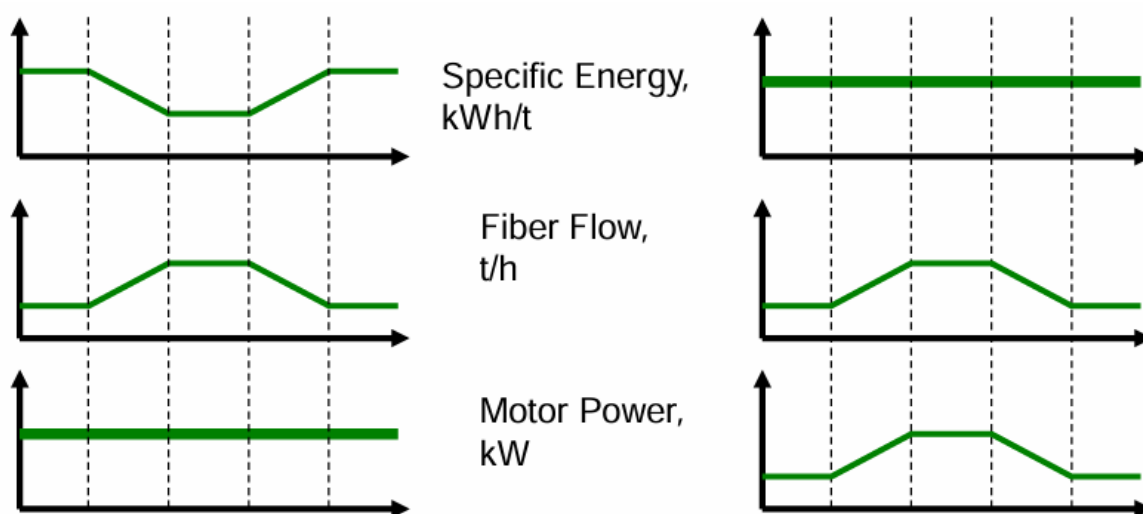


Figure 5.5. Comparison between power (at left hand side) and SEC (at right hand side) control schemes^[11].

6. PROPOSED PROCESS MODIFICATIONS

In this chapter, some process modifications will be proposed to reduce the oscillations in Specific Energy Consumption in long fiber line, which are mainly caused by the discontinuous discharges from the LF pulper. These oscillations are thought to affect the MD tensile strength and drying capacity of the paper machine hood.

Using the dynamic model, described in section 4.2, both current and future situations were analysed in order to compare both.

6.1. Initial situation

Before proposing the different modifications described in sections 6.2 and 6.3, an initial analysis of the process is performed in order to check if the model is behaving as it should according to what happens in the mill and to compare the results between the simulation of the current situation and modified one.

The following Figure 6.1 depicts a simplified block diagram of long, short and broke fiber with the process equipment that affects the Specific Energy Consumption of the pulp, where deflakers, hydrocleaners and screen have been removed, and chests and refiners have been considered.

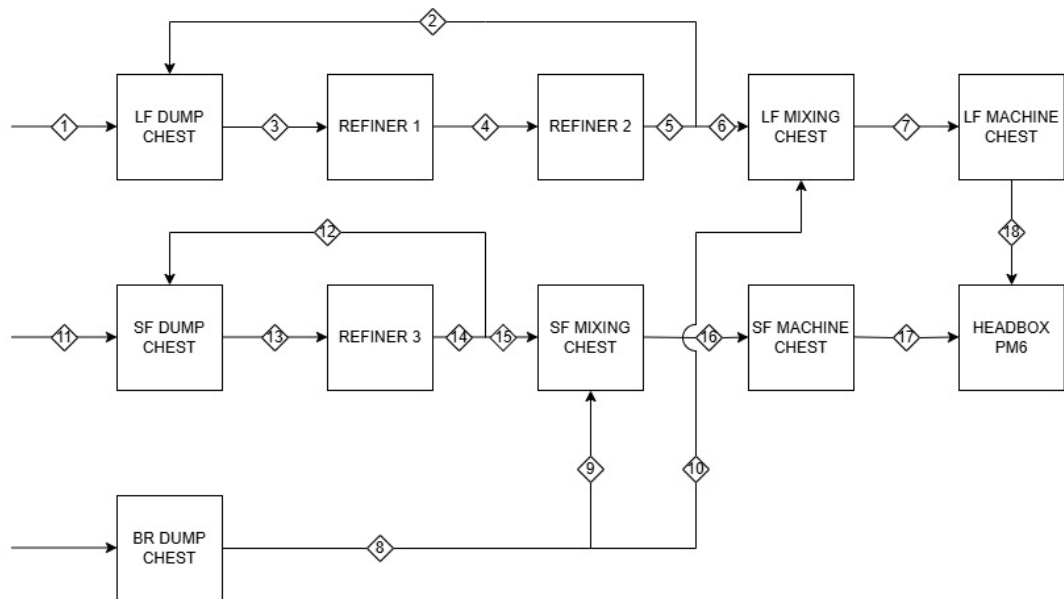


Figure 6.1. Simplified block diagram of stock preparation process part. Own work.

Once the mass balance has been completed, the simulation of the process is calculated, see additional assumptions used in chapter B of annexes. As introduced in section 1.2, burner temperature showed oscillations in line with the LF dump chest level, this behaviour can also be seen in the Specific Energy Consumption in the LF dump chest and transmitted to the mixing and machine chests. Following Figures 6.2, 6.3 and 6.4 shows how SEC behaves at the different process chests and in the headbox.

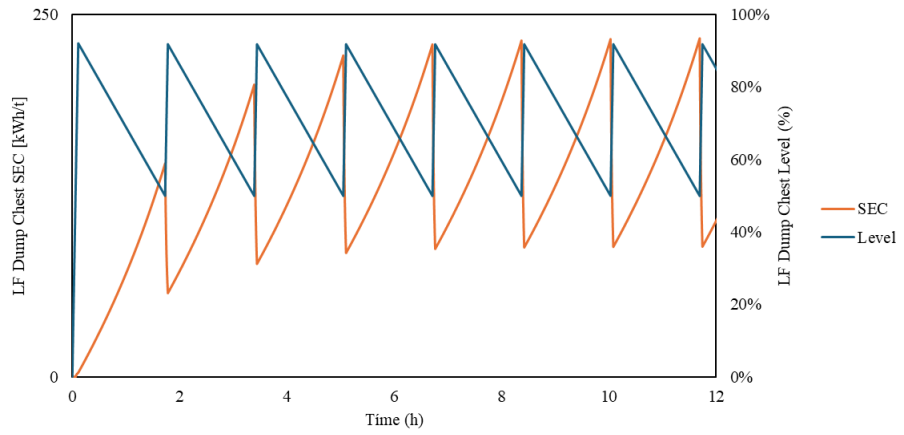


Figure 6.2. LF dump chest SEC oscillations due to LF dump chest level changes. Own work.

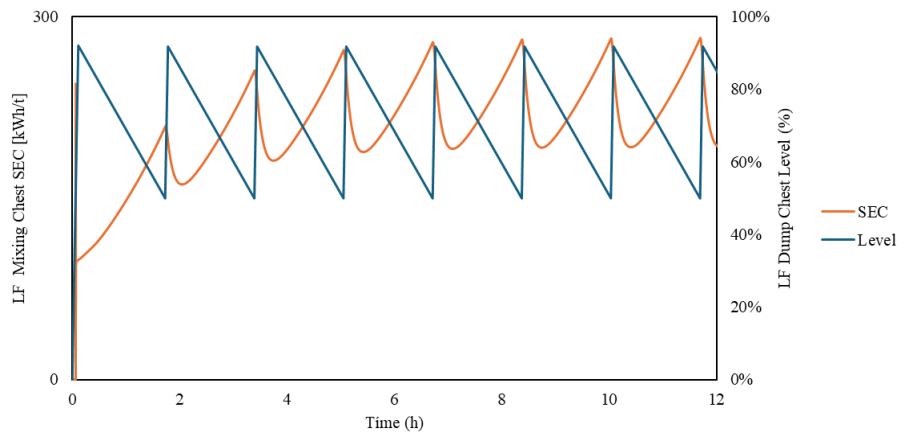


Figure 6.3. Transmitted LF mixing chest SEC oscillations. Own work.

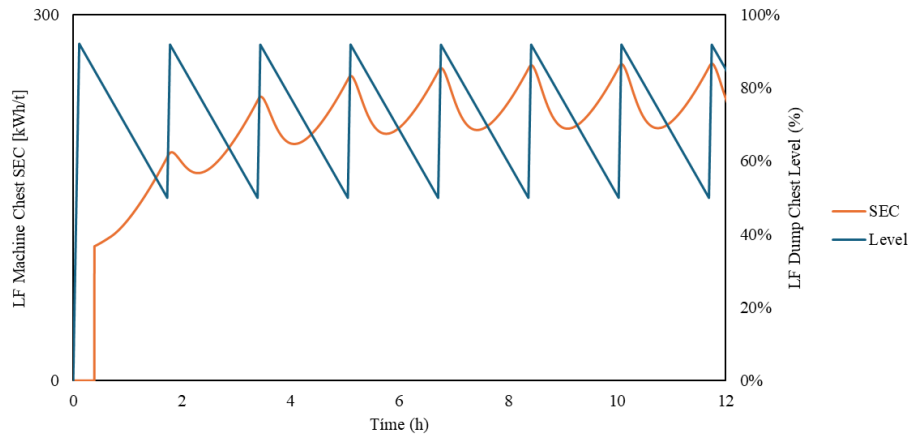


Figure 6.4. Transmitted LF machine chest SEC oscillations. Own work.

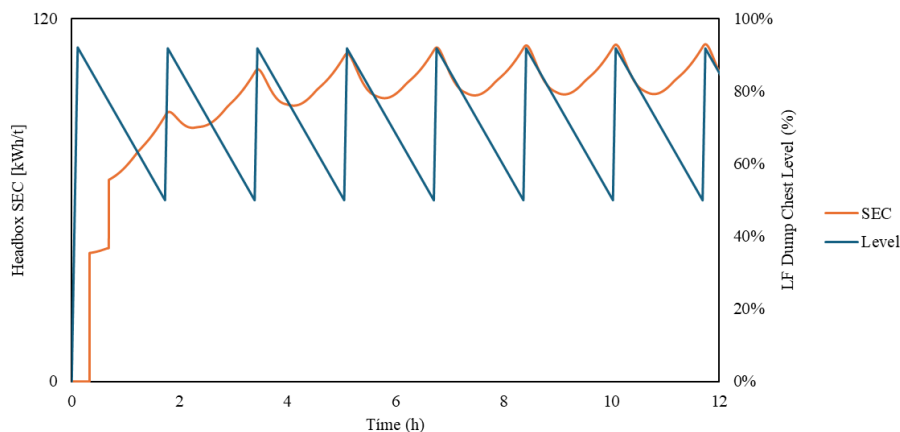


Figure 6.5. Transmitted headbox SEC oscillations. Own work.

Table 6.1. SEC variation at the different chests of the LF line at steady state.

Process chest	Δ SEC between LF pulper discharges [kWh/t]
LF Dump Chest	144
LF Mixing Chest	90.3
LF Machine Chest	52.8
Headbox	16.5

Changes in SEC inside the chest are produced due to the difference between the SEC of pulp inside the chest and the SEC of the inlets of the chest (see formula 4.14). When virgin pulp is introduced to the dump chest (the level of the chest increases from 50 to 90%), there is a decrease of SEC, but while the chest is being discharged, the chest's SEC increases because refined pulp coming from the refiner's recirculation is entering. As the refiner's recirculation flow rate is higher than the flow rate going to the mixing chest, SEC oscillations are accentuated.

As supposed, the model calculations support the idea that the LF dump chest level can affect the machine direction strength variability and the burner temperatures because more refined pulp (higher SEC) has a higher value of tensile strength and needs more energy to be dried. It is important to remark, that SF line also behaves like LF line, but as the total net power of the refiner is smaller (only one refiner whit less applied power) than in LF line it does not affect other variables.

6.1.1. Stock process design limitations

As observed before, the high recirculation after the LF refiners is causing the SEC oscillations in kitchen towel productions, however the current design of the stock process has some limitations that hinder the reduction of this stream:

- Maximum allowable pressure:** When working in good conditions refiners work as a pump, in fact, differential pressure inside the refiner is measured as an indicator of the wear of the discs. Refiners maximum working pressure is 6 bar^[12]. Working with the two refiners in series now means that the outlet pressure at the last refiner is between 4.5 and 5.5 bar. Reducing the flow through the refiners would increase the line pressure, which would exceed the maximum value and shut down the line.

- **Oversized refiners:** Current LF refiners are oversized for the throughput that currently needs to be refined in kitchen towel production, as due to the price difference between long and short fiber, consumption has been reduced in order to reduce the cost of production..
- **Other qualities productions:** The paper machine produces both kitchen and toilet products, with different recipes and pulp ratios, consequently stock process design must allow the product to be changes without stopping the line.

6.2. Specific energy consumption oscillations reduction

The following alternatives focus on decreasing the oscillations in SEC in the long fiber line. It is important to emphasize that modifications to the process must be compatible with the circuit for all qualities, even though the SEC oscillations are greater for kitchen towels.

6.2.1. Intermediate storage tank

This alternative consists in the installation of an additional intermediate storage tank between the long fiber pulper and the long fiber dump chest, as shown in Figure 6.6. The new tank would be fed by the long fiber pulper discontinuously and would discharge the pulp to the dump chest continuously, decoupling the pulper discharge from the refining process.

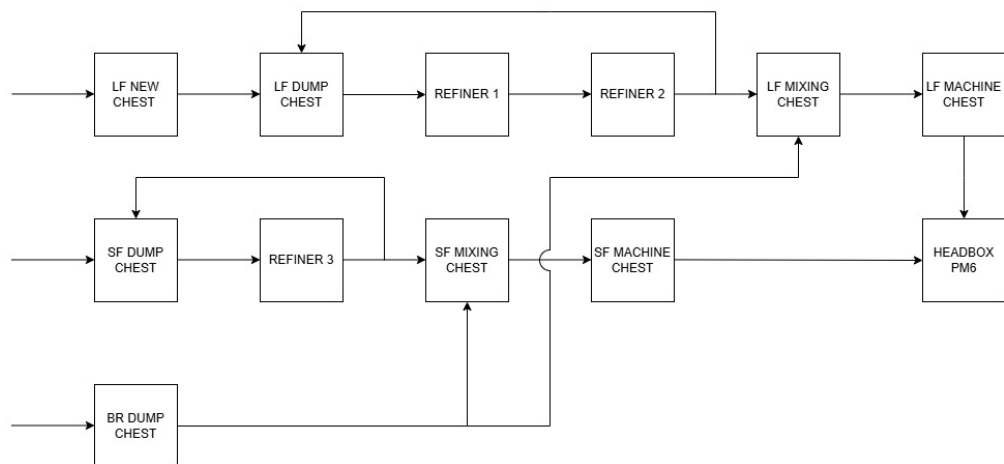


Figure 6.6. Simplified block diagram of stock preparation with the intermediate storage tank. Own work.

On the one hand, this new chest would eliminate the SEC oscillations in the LF line due to the constant feeding of virgin pulp by maintain a steady flow of virgin pulp to the dump chest. On the other hand, transitions between different products would increase as the tank would increase the residence time of the pulp from the pulper to the headbox. Moreover, it must be considered that the chest would require a volume of 1.5 pulper discharges which it is around 75 m³, in this sense it would be difficult to place it in the mill due to lack of space.

Although technically sound in terms of SEC stabilization, this alternative was discarded due to its high spatial and economic constraints, making it less feasible compared to other solutions.

6.2.2. New refiner at the outlet of mixing chest

This alternative consists in the installation of a new refiner at the exit of the LF mixing chest. In this configuration, only one of the existing two LF refiners would be used during kitchen towel productions, significantly decreasing the energy introduced into the dump chest. The new refiner would be sized to apply the remaining energy directly before the machine chest without the need of a high recirculation.

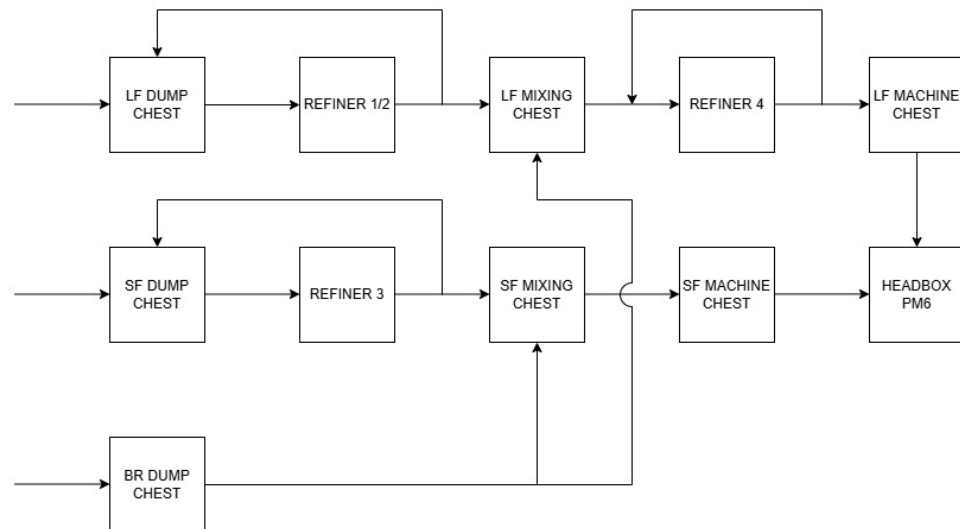


Figure 6.7. Block diagram of stock preparation with the new refiner. Own work.

This modification would significantly reduce the oscillations in the SEC of the LF dump chest as the applied energy would be lower, since it would only be working with one refiner. The recirculation flow rate would also be reduced, because the total flow through the existing refiner could be decreased.

6.3. Short and long fiber lines balancing

This proposal will focus on balancing the machine chests output streams to ensure that the consistency in the different channels of the headbox are equal while maintaining the current long, short and broken fiber consumptions.

6.3.1. Piping at short fiber refiner outlet to long fiber machine chest

This proposal involves modifying an existing, unused pipeline that connects the short fiber (SF) refiner outlet to the long fiber (LF) mixing chest. The goal is to extend and repurpose this line to feed SF pulp directly into the LF machine chest.

Currently, to reduce long fiber consumption, the LF pulper recipe includes a percentage of short fiber. This short fiber is refined using LF refiner discs, which are not designed for it. Since LF refiners operate at higher intensity, this results in over-refinement of the SF pulp and unnecessary energy consumption.

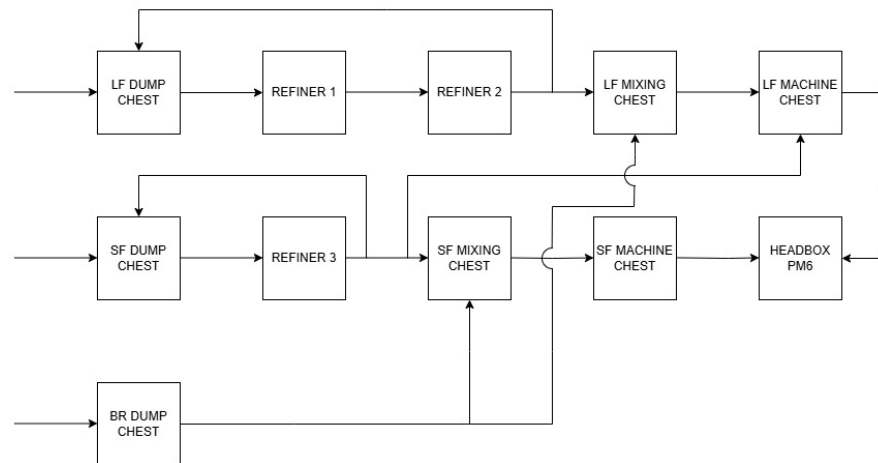


Figure 6.8. Simplified block diagram with the pipe between SF and LF lines at SF refiner outlet. Own work.

By redirecting a portion of the already-refined SF pulp directly from the SF circuit to the LF machine chest, this solution eliminates the need to refine SF with LF equipment. It also helps balance the flow between the two machine chests, improving sheet formation at the headbox by equalizing the consistency and stability of both fiber streams. This modification requires the installation of a control valve and a flow meter to regulate the SF flowrate going to LF line.

6.3.2. Piping at short fiber mixing chest outlet to long fiber machine chest

Similarly to the previous modification, this new pipe would feed long fiber line with short fiber in order to make both long and short fiber streams entering the headbox become the same.

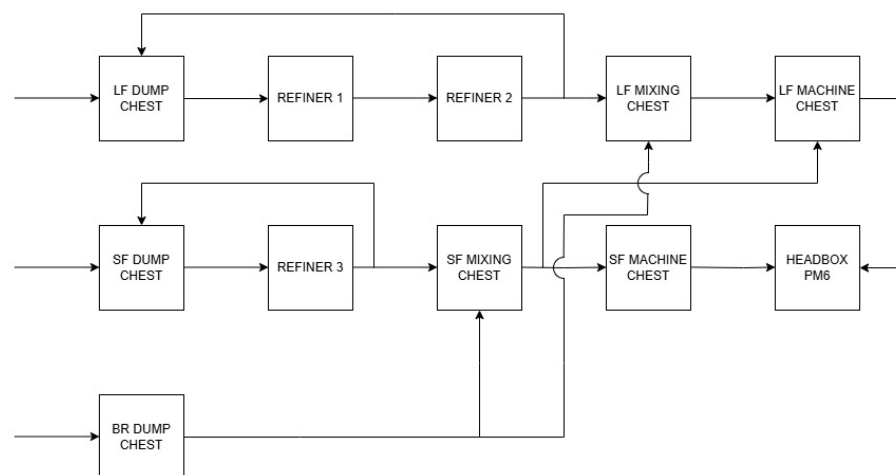


Figure 6.9. Simplified block diagram with the pipe between SF and LF lines at SF mixing chest outlet. Own work.

Both solutions are similar in terms of cost as they require the construction of a new pipe and the needed instruments to regulate the flow passing through. However, the second one would be better in terms of machinability as the shorter pipe would reduce the possibility of clogging the line when it is not in use during toilet paper production.

6.4. Final solution

Considering advantages, disadvantages and feasibility, the solution chosen was to implement the new refiner between LF mixing chest and LF machine chest as well as construct the pipe that connects SF mixing chest outlet with LF machine chest. Additionally, it is necessary to move the inlet of the broke fiber in the long fiber line to the machine chest in order to avoid refining broke with the new refiner.

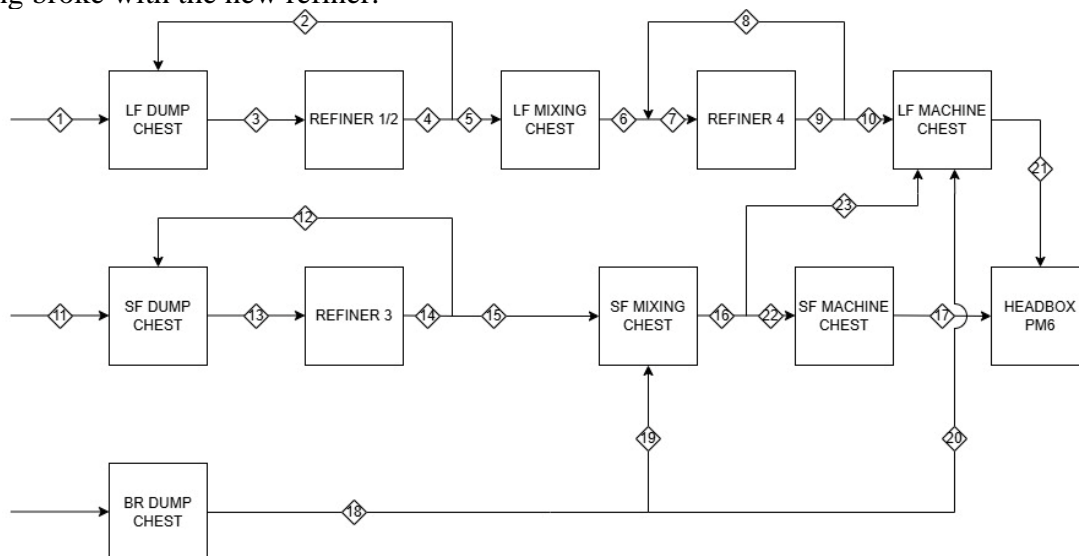


Figure 6.10. Simplified block diagram of stock preparation with the final solution adopted. Own work.

The mass balance, has been recalculated so that the material flowing from long and short fiber streams (21 and 17) into the headbox are the same, keeping the consumption of long, short and broken fiber as at present. The Specific Energy Consumption of each stream has also been recalculated for the new design, so that the SEC in the headbox is the same as the current one. To this end, the applied powers, of refiner 1 or 2 have been maintained, and the power required to achieve the same headbox SEC than in current situation has been determined with refiner 4 for the long fiber line and refiner 3 for the short fiber line. Finally, the no-load power of refiner 4 is lower as it is a smaller conical refiner.

Table 6.2 and Figures 6.11, 6.12 and 6.13 shows the SEC oscillations at the different process chests obtained with the simulation.

Table 6.2. SEC variation at the different chests of the LF line at steady state.

Process chest	Δ SEC between LF pulper discharges [kWh/t]
LF Dump Chest	83.2
LF Mixing Chest	29.1
LF Machine Chest	7.60
Headbox	4.03

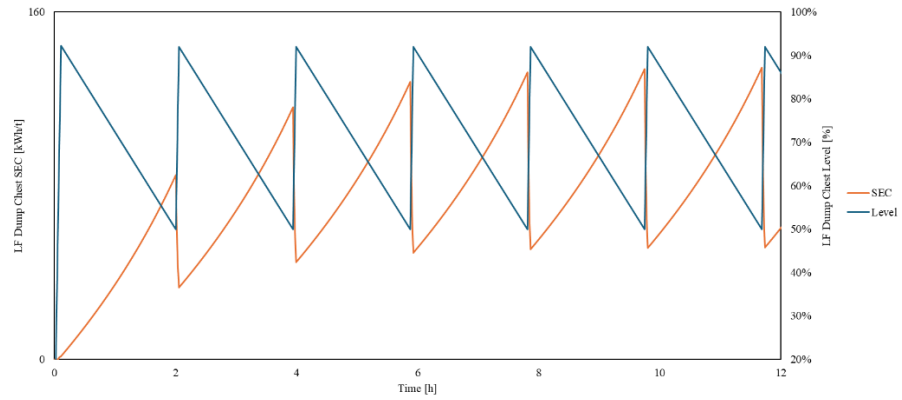


Figure 6.11. LF dump chest SEC oscillations due to changes with the proposed modifications. Own work.

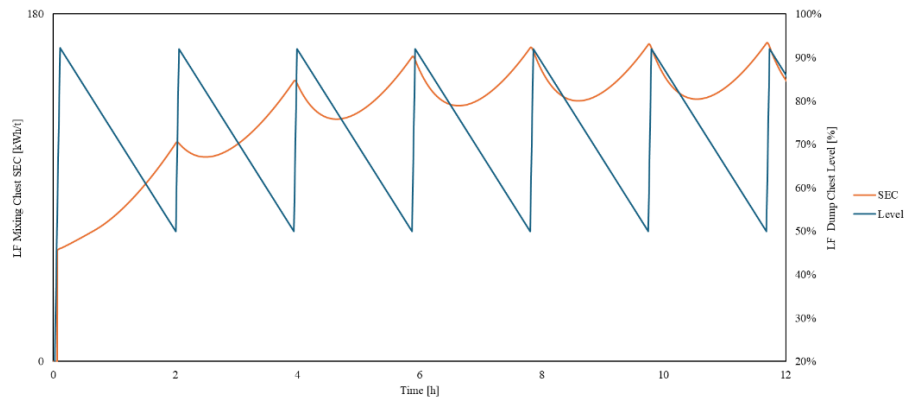


Figure 6.12. LF mixing chest SEC oscillations with the proposed modifications. Own work.

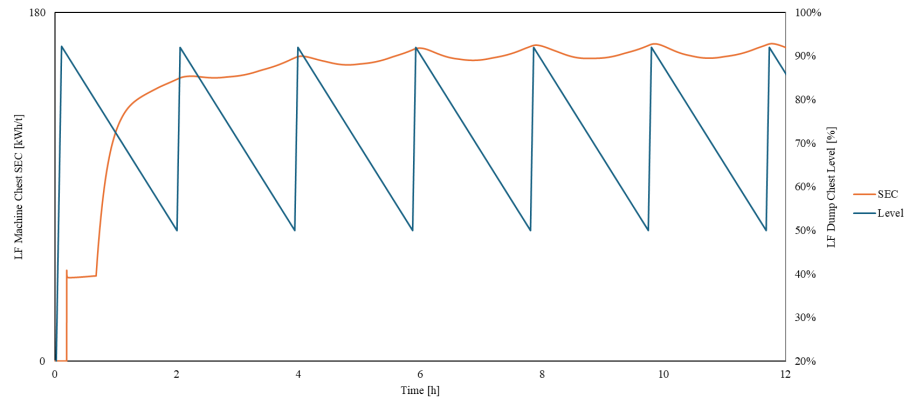


Figure 6.13. LF machine chest SEC oscillations with the proposed modifications. Own work.

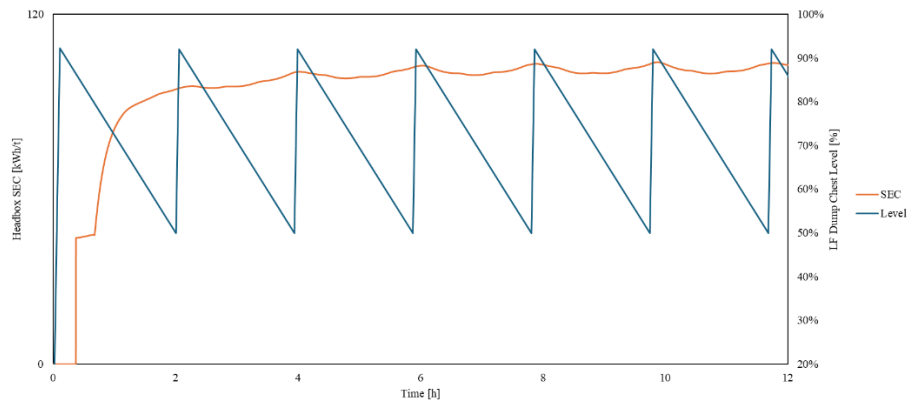


Figure 6.14. Headbox SEC oscillations with the proposed modifications. Own work.

6.4.1. Control strategy

The control strategy of the stock preparation process is discussed:

- **Pulper discharge to dump chest:** Pulp from pulpers is discharged to dump chest discontinuously using the level transmitter when the level is under 50%.
- **Consistency control:** Consistency controllers are situated after the process chests. They measure the consistency and add water when needed from the auxiliary consistency water line.
- **LF and SF line pressure:** LF and short fiber line pressure is controlled by the recirculation from the hydrocyclones, when pressure is under the set point the control valve closes to increase the pressure of the line and contrary when the pressure is above the set point the valve opens.
- **LF and SF refiner's recirculation:** LF and SF refiner's (1, 2 and 3) recirculation is controlled by flow controllers.
- **Refiner 4 inlet pressure:** Refiner 4 inlet pressure is controlled by the LF mixing chest pump. When the pressure is lower than the set point the speed of the pump motor will increase and when it is higher it will decrease.
- **Refiner's applied power:** All refiners applied power set point is set by the operator in order to achieve the desired tensile strength depending on the quality of the paper produced. When the applied power set point is increased the refiner discs get closer to each other increasing the power required to move them and consequently the tensile strength of the paper sheet increases. All refiners also have pressure transmitters at the inlet and the outlet because the differential pressure of the refiner is a measure of the wear of the discs.
- **Broke ratio to SF line:** Broke pulp is added at the SF mixing chest using a fixed ratio that the operator can change. The flow transmitter at the SF mixing chest inlet pipe send the information to the flow controller at the broke line in order to maintain the ratios desired.
- **Broke ratio to LF line:** Broke pulp added to the LF line will vary depending on the product that is being produced. When producing toilet paper, the broke pulp will be added to the mixing chest like in the SF line. When producing kitchen paper, the broke pulp will be added to the LF machine chest, the control strategy will be the same as in the SF line.
- **SF flow to LF machine chest:** The SF stream that goes to the LF machine chest will be calculated in order to maintain the LF and SF machine chest outlet flow rates equal to get a better formation.
- **Level of LF and SF mixing and machine chests:** LF and SF mixing and machine chests levels are controlled using a cascade control scheme. The measured value

obtained with a level transmitter is compared with the level set point and recalculates the set point for the inlet flow rate of the chest. When the level is lower than the set point the flow rate of the inlet stream is increased and contrary when the level is higher than the set point the flow rate is decreased.

6.5. Comparison between current and future situation

As mentioned before, the objective stock preparation process modifications were proposed to reduce the impact of the LF pulper discharges to the LF dump chest which were causing oscillations in the Specific Energy applied to the pulp. The reduction of these oscillations can be achieved by reducing the energy that is being accumulated in the dump chest and using a new refiner (well-sized) that can provide enough energy to the pulp without recirculating much of the flow that passes through the refiner. Regarding the paper sheet formation, modifications seek to balance the pulp flow rates in order to have the same consistency in the headbox in LF and SF circuits.

Following Figures 6.15 and 6.16 show the SEC of the SF and LF streams exiting the machine chest (streams 17 and 18 for the current situation and 17 and 21 for the future situation). Figure 6.17 shows the SEC of the headbox which is the mixture of the SF and LF machine chest outlet streams.

Short fiber line would reduce its SEC oscillations because in order to balance both lines' flow rates less recirculation in refiner 3 is needed. Despite more applied power is needed to achieve the same SEC average value in the SF machine chest, SEC oscillations are slightly smothered. It should be noticed that the oscillations in the SF line are much smaller than the LF oscillations, so balancing LF line with SF pulp will also help to reduce the LF oscillations.

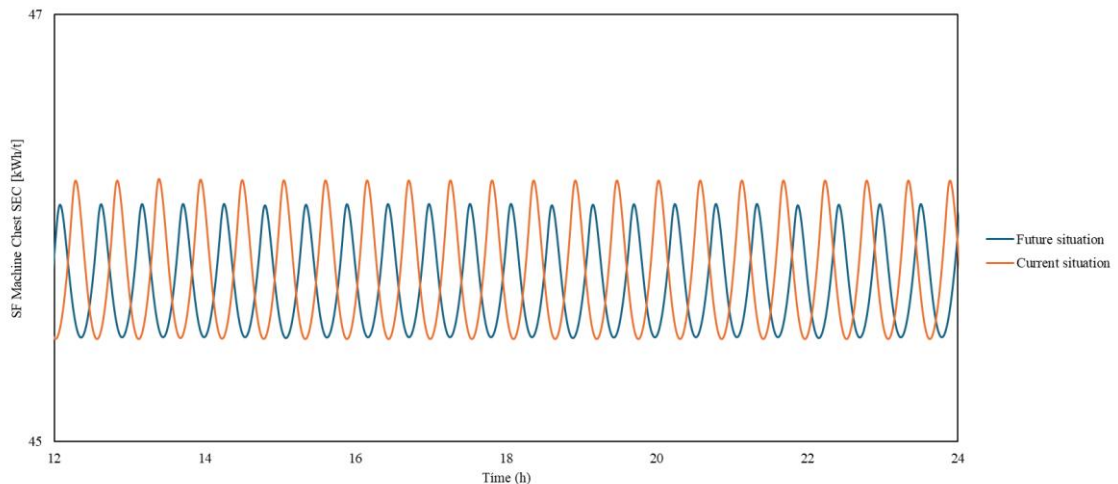


Figure 6.15. SF Machine chest SEC behaviour with current and future situation. Own work.

Long fiber line presented more changes than short fiber line. Firstly, the reduction of the SEC oscillations is caused by two phenomena:

- Refining optimization:** LF dump chest is acting as an accumulator of SEC due to the high recirculation in the current situation, the future situation proposes to work with only one of the refiners between the LF line and the SF line which will help to reduce the SEC in the LF dump chest because the applied power of the recirculated pulp will be halved, moreover working with only one refiner will allow the line to work with a lower flow rate crossing the refiners without exceed the pressure that stops the line (refiners have pump effect when working in good conditions). The new refiner, between the LF mixing chest and the LF machine chest will provide enough power to achieve the desired SEC in the LF machine chest, without having to recirculate the pulp (the recirculation of the refiner will be at the pump suction which also eliminates SEC oscillations^[13]). That is why the total net power applied with the refiners in the future situation is 10 kW higher than in current situation.
- Short fiber mixing at LF machine chest:** The pipe connecting the SF line with the LF line will avoid mixing SF pulp in the LF line before the refiner, which will help to improve the refining. Also as said before, the SF pulp presented less SEC oscillations so mixing part of them with the LF pulp will help to smooth the SEC oscillations of the LF line

Secondly, the reduction of the SEC average value is caused by the balancing of the LF and SF line. In the current situation a higher SEC is needed in the LF line because the LF stream flow rate that enters to the machine headbox is a third part of the total flow, while SF is the rest. In the future situation as the flow rates will be the same LF SEC value can be reduced (see appendix B to see how headbox SEC is calculated).

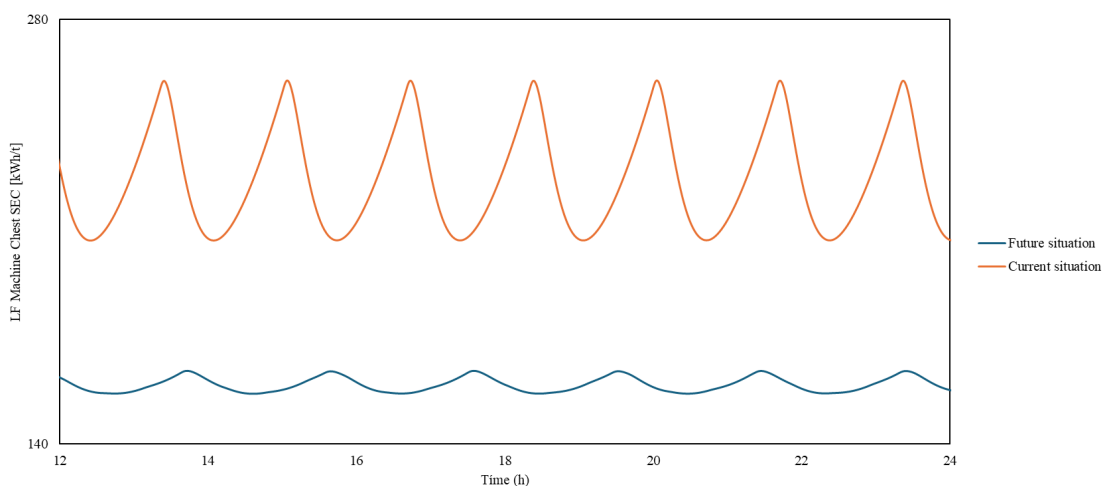


Figure 6.16. LF Machine chest SEC behaviour with current and future situation. Own work.

As a result of the modifications, headbox SEC oscillations will be reduced while maintaining the same average value to achieve the desired paper strength properties. Finally, Table 6.9 compares the SEC oscillations in the LF process chests and in the paper machine headbox (SF are not showed because the effect of SF line oscillations is insignificant compared to the LF line).

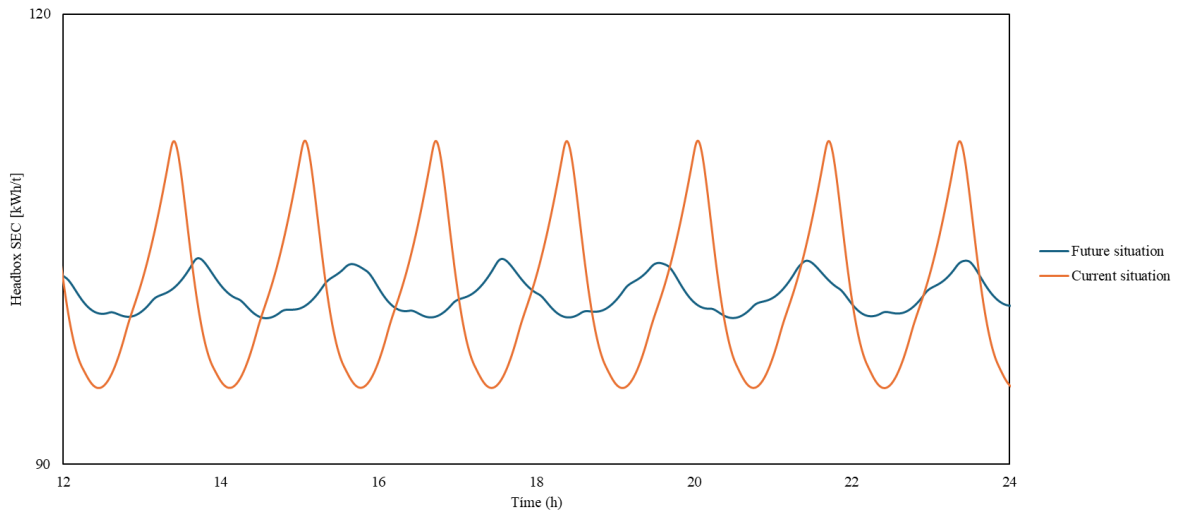


Figure 6.17. Headbox SEC behaviour with current and future situation. Own work.

Table 6.8. Comparison of Specific Energy Consumption at the different process chest and the headbox between the current and the future situations.

Process chest	Current situation Δ SEC [kWh/t]	Future situation Δ SEC [kWh/t]
LF Dump Chest	144	83.2
LF Mixing Chest	90.3	29.1
LF Machine Chest	52.8	7.60
Headbox	16.5	4.03

The simulation results clearly demonstrate that the proposed modifications significantly reduce SEC variability throughout the long fiber line, with improvements observed from the dump chest to the headbox. These reductions in energy fluctuation correlate directly with the reduction of the MD tensile strength variability. Also, the balancing of both pulp flow rates at the outlet of the machine chest would result in better sheet formation, as the dilution degree of pulp at the headbox will be the same.

7. ECONOMIC ANALYSIS

This chapter will discuss the economic profitability of the project considering the expected costs and benefits. The following sections of this chapter describe the expected costs and expected benefits. Finally, detailed information on the calculations performed can be found in appendix D.

7.1. Expected initial cost

The expected initial cost has considered direct cost coming from main components' acquisition, such as the new conical refiner, motors and velocity speed drives (VSD), the new piping supply, new instruments and valves, like flow and pressure meters and control valves, electrical and pneumatic installation, software installation and indirect costs coming from delivery, packaging, travelling and start up.

7.2. Expected savings

The expected savings of the project are calculated taking into account the reduction of the electrical consumption in the refining stage and the increase of reels produced during a year due to reducing the waste (reels out of specification) of the PM6 in both kitchen paper productions studied.

7.2.1. Electrical energy consumption reduction in refining stage

As a result of sizing the correct refiner after the machine chest, less recirculation will be needed, and therefore, less applied power will be needed to achieve the same Specific Energy Consumption in the headbox of the paper machine. Additionally, the no-load power of the new refiner is notably lower than the no-load power of the existing refiners of the long fiber line, which also helps to reduce the electrical energy consumption of the refining stage.

The modifications proposed in stock preparation lines would result in a reduction of 208.7 MWh/year.

7.2.2. Variability reduction in machine direction tensile strength

The variability reduction also would give savings due to a reduction in the number of reels that can not be consumed in converting due to not achieving the product quality specifications, particularly for exceeding the limits of the MD tensile strength in kitchen towel productions.

The normal distribution for both qualities was studied, these had been calculated using the average value and the standard deviation of all analysed reels of each production during 2024. Regarding the future situation, the standard deviation to build the normal distribution has been estimated using trial described in C.2 (for further details see appendix D).

The modifications proposed in stock preparation lines would result in a reduction of 484 t/year of waste.

7.2.3. Other expected improvements

Additional improvements in the machinability can be expected:

- Achieve higher MPV for kitchen paper productions: Smothering SEC oscillations in the headbox of the machine would provide a reduction of the burner oscillation temperatures, which would improve the drying capacity in the hood system and consequently, it would enable to increase the paper machine speed, in other words, increase the production capacity (A productions with the broke ratio modification, and respectively less SEC variation, achieved the maximum machine velocity more time than those with the original broke ratio standard, see appendix C).
- Reduce transition time between different qualities: As only LF machine chest would receive refined pulp with two refiners, transition time between kitchen paper and toilet paper would be halved as the volume of the mixing and machine chests is the same.
- Improve refiner centrelining: For SF line, the applied power in refiner 3 is always maintained constant, and the value is varied only depending on the quality produced. Contrary, both LF line refiners applied power vary during a production in order to achieve the specification requirements of each product. In this sense, as refiners would be separated by the mixing chest, refiner 1 applied power after the LF dump chest could be kept constant while only adjusting refiner 4 applied power.
- Spare refiner at LF line: Adding the new refiner at the LF line would provide a spare. In the event of a breakdown at one of the three LF refiners, the production of kitchen towels (and machine speed) would not be affected.

8. CONCLUSIONS

The revamping of the long fiber (LF) line at PM6 Essity Valls has proven effective in reducing process variability and enhancing paper quality, especially for kitchen towel production where machine direction (MD) tensile strength is a critical parameter. Through in-depth analysis, the project identified the discontinuous discharges from the LF pulper into the dump chest as a key source of variability in specific energy consumption (SEC), which in turn affected product quality parameters and drying performance of the hood.

A significant outcome of the project was the development of a dynamic model that simulated SEC behaviour throughout the stock preparation process. This model not only provided insight into the distribution of refining energy but also validated the original hypothesis, that the discontinuous feeding of virgin pulp into the LF dump chest led to oscillations in SEC values, causing a variation in SEC from 89.9 to 234 kWh/t. These oscillations were shown to propagate downstream through the mixing chest and machine chest, impacting the headbox and influencing tensile strength variability in the final product.

To further support this hypothesis, some production trials were carried out. These trials involved reducing the broke fiber ratio in the long fiber line to observe how refining behaviour and pulp consistency changed in response. The results closely aligned with the model's predictions, confirming that process instability was linked to the batch behaviour of the pulper discharges, and that stock process could be significantly improved by altering the distribution of virgin and broke pulp in the process chests while keeping the same consumptions.

The final solution implemented consisted of installing a new conical refiner after the LF mixing chest and constructing a pipeline to introduce short fiber pulp from the SF mixing chest directly into the LF machine chest. This redesign allowed for reduced recirculation in the original refiners, optimized energy input, and better balance between the LF and SF lines. As a result, SEC oscillations in the LF machine chest decreased from 52.8 kWh/t to just 7.6 kWh/t, and headbox SEC variability dropped from 16.5 kWh/t to 4.03 kWh/t. These improvements translated into more stable MD tensile strength and a reduced number of reels falling outside quality specifications. In terms of energy efficiency, the total applied power in the refining stage decreased 64 kW, leading to an annual energy savings of approximately 208.7 MWh.

From an economic perspective, the proposed modifications were demonstrated to be cost-effective. The estimated investment was justified by the savings achieved through energy efficiency and reduced product waste due to MD tensile strength variability reduction.

In conclusion, this work provided a successful technical solution to the variability issue but as well as validated the process hypothesis through both modelling and experimentation. The combination of modelling, experimental validation, and targeted process modifications resulted in measurable improvements in product quality, energy consumption, and operational stability.

9. REFERENCES

- [1] Valls Mill, *Curso de tecnología tissue*. YPE & GO! Program, SCA, 2014.
- [2] S. Archer, G. Furman, *Yankee Coating Systems – The Functional Interface*. Coating Space, Ecolab, Nalco, 2014.
- [3] A. Fernández, *Debottlenecking of the drying system in the paper machine number six at Essity Valls*. Master's thesis, Universitat Rovira i Virgili, 2024.
- [4] Industry Edge, *Pulp: Bottom nears for hardwood pulp, but is there further to go for softwood?*. 2021.
- [5] Essity, *Essity en España*. 2024. Available at: <https://www.essity.es/compania/essity-en-espana/> [Accessed January 2025].
- [6] Learning Compass, *MA Refiner (Basic)*. Essity, 1995.
- [7] A.R. Elbarbary, *Pectin Breaker (biotechnology approach for cleaner wastewater in retting flax process)*. Ministry of Water Resources & Irrigation, Cairo Water Week (2021).
- [8] J. Lumianinen, *Chapter 4 – Refining of chemical pulp*. Book 8, Papermaking Part 1, Stock Preparation and Wet End. Available at: <https://turbulence-initiated.sites.olt.ubc.ca/files/2013/01/1998-Lumiainen-Ch4.pdf> [Accessed June 2025].
- [9] AFT. *AWE Disc Refiner*. 2025. Available at: <https://aft-global.com/en/products/refining-equipment> [Accessed March 2025].
- [10] Valmet. *Valmet Conical Refiner Conflo*. 2025. Available at: <https://www.valmet.com/board-and-paper/stock-preparation/refining/refining/axial-flow-refiners/> [Accessed March 2025].

- [11] R. Muñoz, *Refinig theories*. Technicelpa Valmet, 2015. Available at: https://tecnicelpa.com/files/20151127_Valmet_%20Refining%20Theories.pdf [Accessed May 2025].
- [12] PMT, *Refino DD-4000 Instrucciones*. M4000-1 (ES), PMT Italia SpA, 2004.
- [13] P. Soini, M. Partanen, *The effect of recirculation on pulp properties in refining of bleached hardwood and softwood pulp with conical refiner*. Sunds Defibrator, 1999. Available at: https://www.eucalyptus.com.br/artigos/1999_Recirculation+on+Refiners.pdf [Accessed April 2025].
- [14] The Engineering Toolbox, *How to Calculate the Density of Slurries: Formula and Examples*. Available at: https://www.engineeringtoolbox.com/slurry-density-calculate-d_1188.html [Accessed November 2024]
- [15] R. J. Trepanier. *Pulp fiber quality and the relationship with paper tissue properties*. Tappi Tissue, 2017. Available at: https://www.tappi.org/content/Events/Tissue%202017/Conference%20Proceedings/REV_3B.1_Trepanier.M.pdf [Accessed May 2025].
- [16] M. A. Hubbe, *Fines Management for Increased Paper Machine Productivity*. Proc. Sci. Tech. Advan. Wet End Chemistry, 2002. Available at: <https://repository.lib.ncsu.edu/server/api/core/bitstreams/b233a504-1933-4e82-9a89-33586648339f/content> [Accessed May 2025].
- [17] L. Sundstrom, A. Brolin, N. Hartler, *Fibrillation and its importance for the properties of mechanical pulp fiber sheets*. Nordic Pulp & Paper Research Journal, 8. 379-383. 10.3183/NPPRJ-1993-08-04-p379-383, 1993.

APPENDIX

A. PAPER PROCESS AND MACHINE ADDITIONAL DIAGRAMS

Figure A.1 shows the block diagram of the water circuit of the PM6.

Figure A.2 depicts the paper machine tender side of the PM6.

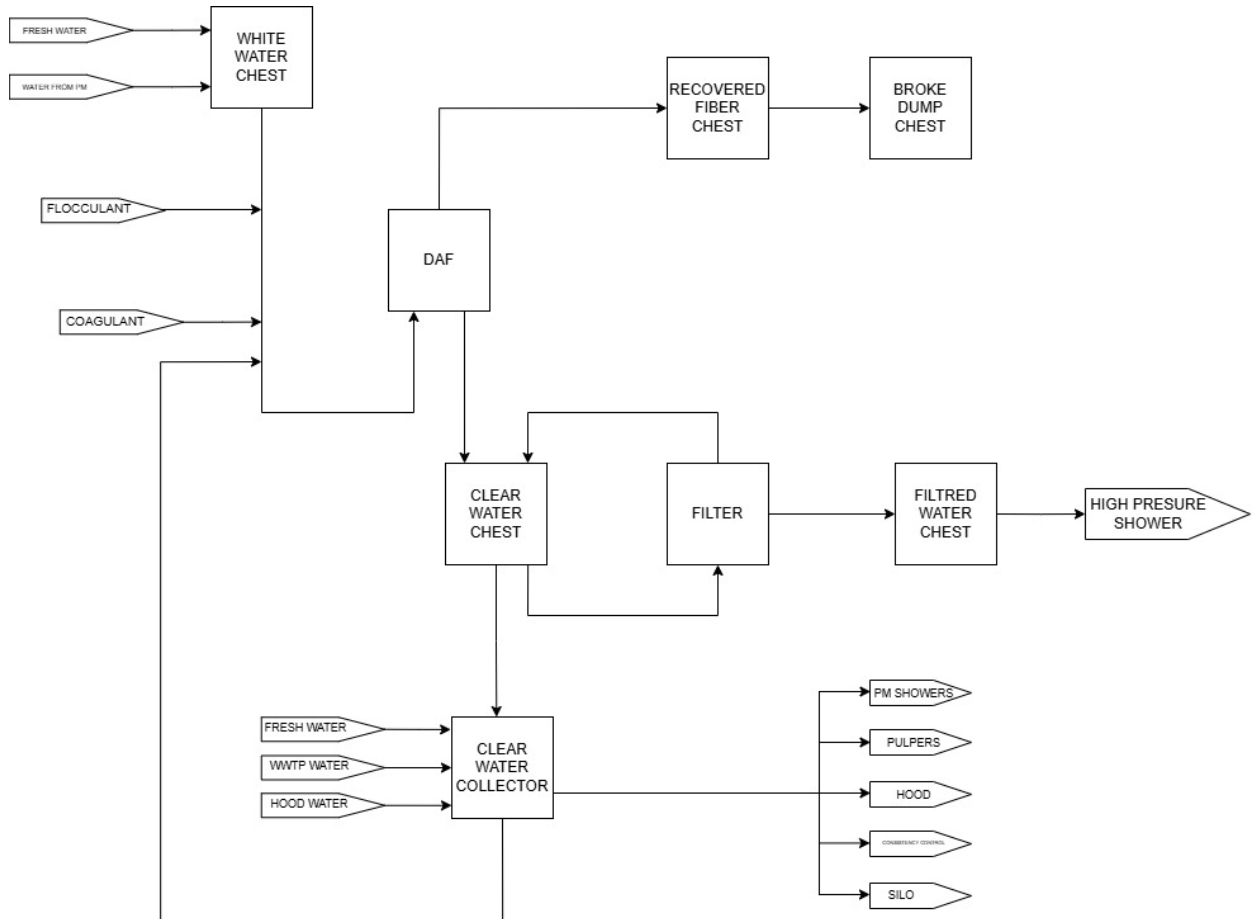


Figure A.1. Block diagram of water circuit of PM6. Own work

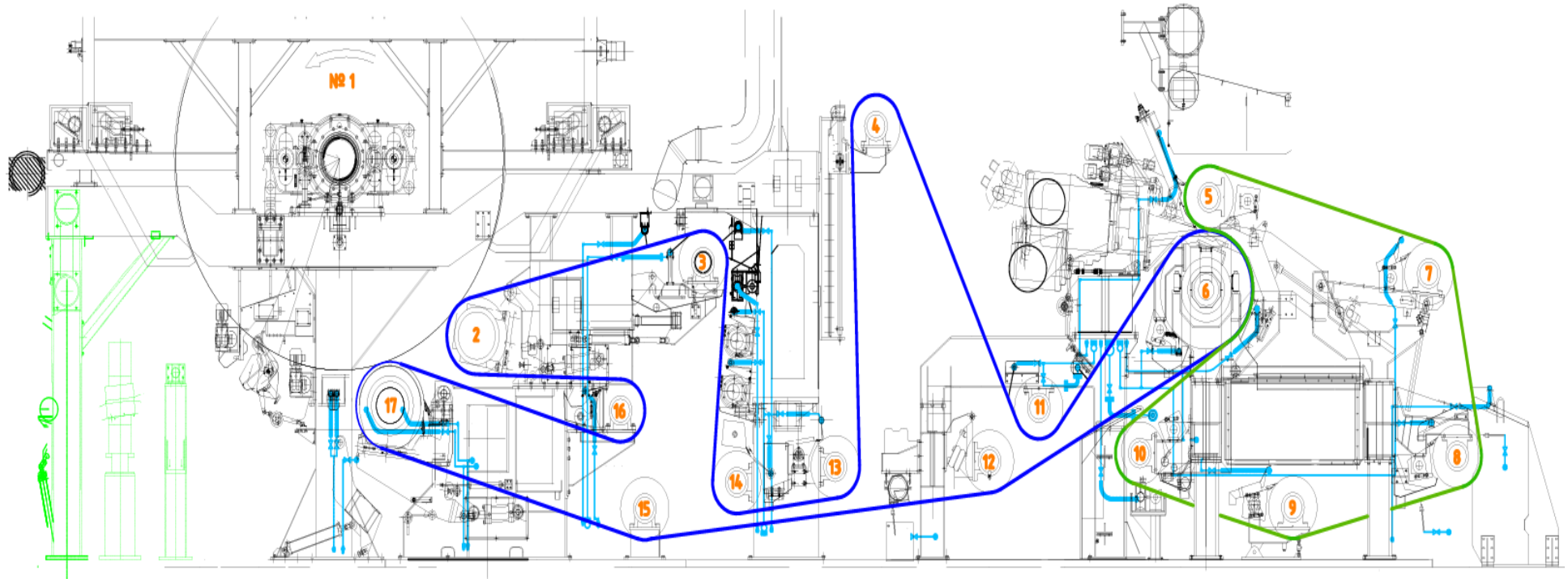


Figure A.2. Paper machine 6 TS view^[1].

B. MODEL ASSUMPTIONS

B.1. Pulp density

The following formula B.1^[14] has been used to find the density of the pulp depending on the consistency of it.

$$\rho_m = \frac{100}{\frac{w}{\rho_{DP}} + \frac{100-w}{\rho_w}} \quad (\text{B.1})$$

Where:

ρ_m : Mixture density [kg/m³], w : Pulp consistency [%], ρ_{DP} : Dry pulp density [kg/m³] and ρ_w : Water density [kg/m³]

Table B.1. Mixture components densities used for calculation.

Mixture component	Density [kg/m ³]
Dry pulp	740
Water	1000

B.2. Stream mixture

When two or more streams converge, it has been treated as an ideal mixture, thus formula B.2 has been used to calculate the resulting SEC:

$$SEC_R = \frac{\sum SEC_i \cdot \dot{m}_{D,i}}{\dot{m}_{D,i}} \quad (\text{B.2})$$

Where:

SEC_R : Resulting SEC [kWh/t], SEC_i : Individual converging streams SEC [kWh/t] and $\dot{m}_{D,i}$: Individual converging streams dry mass flowrate [t/h].

B.3. SEC increase in a refiner

When a stream passes through a refiner it increases its SEC depending on the net power and the dry pulp mass flowrate:

$$SEC_O = SEC_I + \frac{P_N}{\dot{m}_{D,I}} \quad (\text{B.3})$$

Where:

SEC_O : SEC at the refiner outlet [kWh/t], SEC_I : SEC at the refiner inlet [kWh/t], P_N : Refiner net power [kW] and $\dot{m}_{D,I}$: Dry mass flowrate passing through the refiner[t/h].

B.4. Headbox SEC

SEC at headbox has been calculated using formula B.2, where the converging streams are the outlets of LF and SF machine chests.

B.5. Simulation details

The conditions considered in the simulations to recreate the process behaviour are listed below:

- Simulation start point:** As there is no reference of the SEC, the simulation has been started with all chests empty of pulp. Feed from pulper starts feeding dump chests, when the level of the dump chests is 50%, they start to feed the mixing chest. At the same time virgin pulp is arriving to mixing chest, broke pulp stream feeds the mixing chest at the specified ratio. Then, when the mixing chests level is 50%, they start to fill machine chests. Finally, when that machine chests are filled at 50% they start to feed paper machine headbox.
- Dump chests:** LF and SF dump chests are being feed discontinuously, in the mill, both dump chests are fed with pulp when the level of the tank is below 50%, the discharge of pulp coming from the pulper accounts for 40% of the level of the tank, in other words the dump chests are filled to a 90% of them level.
 The formula used for feeding the dump chests in the excel file is:

$$=IF(AND(DumpChestLevel<0.9,DumpChestLevel>0.5),PulperStreamFlowrate,IF(DumpChestLevel>=0.9,0,IF(DumpChestLevel<=0.5, PulperStreamFlowrate,"ERROR"))$$
 The formula used for the outlet streams of the dump chests in the excel file is:

$$=IF(DumpChestLevel<0.5,0,DumpChestOutletStreamFlowrate)$$
- Mixing and machine chests:** LF and SF mixing and machine chests operates normally at the 50% of them level in the mill, in order to follow this behaviour the formula used for the outlet stream flowrate of each chest is:

$$=IF(ChestLevel<0.5,0,ChestOutletStreamFlowrate)$$
- Simulation period:** All simulations have been executed for a time period of 48 hours with time increments of 5 seconds. In order to obtain the steady state average, maximum and minimum values only the last 24 hours have been considered.
- Virgin pulp and broke pulp SEC:** Virgin pulp SEC is considered to be 0 kWh/t, while broke pulp SEC is considered to have the average value at the headbox which is 101.4 kWh/t.

C. PRODUCTION TRIALS

Two trials were developed to confirm the hypothesis that the burner temperatures and the MD tensile strength could be smoothed by decreasing the SEC of the pulp in the LF line. Results from these trials were used to calculate the expected savings of the project.

C.1. Reduction of broke fiber ratio in long fiber mixing chest during a production

This trial was done on 18th October 2024 and consisted in reducing the broken fiber ratio in the LF mixing chest, while increasing the broken ratio in the SF mixing chest in order to maintain the waste consumption.

The objective of the reduction of broke fiber was to increase the LF flow going to the LF mixing chest and, consequently, decrease the recirculation to the LF dump chest.

As expected, burners temperature oscillation decreased when reducing the broke fiber ratio in the long fiber line. Also, a reduction of the mean temperature of the burners was observed, which could be explained by the reduction of the power applied in the refiners and the increase of the long fiber consumption which facilitates to achieve the product tensile strength required while using less refiner power.

Regarding MD tensile strength variability, it was observed an improvement due to the reduction of LF refiners' recirculation. It should be noted that the MD tensile measurements are done every three reels are produced so it can not be concluded that the reduction of broken fiber improved MD tensile strength variability due to lack of data despite results obtained were in line with the hypothesis.

Table C.1. Burners' temperatures and MD tensile strength standard deviation during the two parts of the trial.

Analysed parameters	From start to half of production	From half to end of the production
Dry end burner temperature variation [°C]	8.02	5.98
Wet end burner temperature variation [°C]	7.88	5.93
MD tensile strength variation [kN/m]	14.9	6.82

Finally, morphology variables of LF line were also analysed with a morphology analyzer at the exit of the LF mixing chest. All three morphology variables analysed presented changes when changing the broke ratio at the LF mixing chest, as supposed all three variables presented oscillatory behaviour influenced by the LF pulper discharges which was smothered when reducing the broke ratio:

- **Fiber length:** Fiber length influences paper sheet properties, longer fibers generally increase the tensile strength of the paper as they provide more bonding opportunities, increasing the strength of the sheet^[15]. During the trial, it was observed an increase in the fiber length of the LF line pulp, which could be explained with the fact that when reducing the broke ratio more LF virgin pulp was entering to the LF mixing chest, consequently refiner applied power was reduced to achieve the target tensile strength

required for the paper that was being produced. Also, the oscillation in the fiber length were reduced indicating that the reduction of the refiner's recirculation enhanced the uniformity of the refining process.

- **Content of fines:** Fines are referred to small particles and fibers. High fines content can impede dewatering during the papermaking process, affecting the drainage and formation of the paper sheet^[16]. During the trial, a reduction of the content of fines was observed which is beneficial from both paper formation and drying. Also, a reduction of the variability of the content of fines was observed when the broke ratio in the LF mixing chest was reduced.
- **Fibrillation index:** The fibrillation index is a measure of the degree of external fibrillation of the fibers related with the bonding area of the fibers, higher fibrillated fibers are supposed to present with stronger sheet strength, however they can affect drainage and formation^[17]. In the trial, the fibrillation index decreased after reducing the broke ratio because the applied power in the refiners and the recirculation were reduced.

C.2. Reduction of broke fiber ratio in long fiber line during the whole production

This second trial consisted of applying the reduction of the broke fiber ratio in the long fiber mixing chest, done in the trial described in C.1, to the entire production. The machine parameters used in the second half of the 18th of October production were used in some productions in order to see if the results of the first trial were repeatable.

As observed in Tables C.2 and C.3, productions (from both qualities) applying a lower broke ratio in LF line showed less variability (fewer standard deviation) in MD tensile strength and burner temperatures than those that used a higher ratio.

Table C.2. Resume of different productions of A.

Production date	10/2024-12/2024	01/2025-02/2025	03/2025-04/2025
σ MD tensile strength [kN/m]	13.48	10.66	11.52
σ Dry end burner temp. [°C]	13.71	11.14	10.84
σ Wet end burner temp. [°C]	13.75	11.07	10.79

Table C.3. Resume of different productions of B.

Production date	10/2024-12/2024	01/2025-02/2025	03/2025-04/2025
σ MD tensile strength [kN/m]	9.487	8.106	9.000
σ Dry end burner temp. [°C]	11.83	11.29	11.24
σ Wet end burner temp. [°C]	11.84	11.28	11.32

The trial parameters were simulated using the model developed to compare the SEC oscillations between the trial and the current situation and link it to the MD tensile strength standard deviation in order to obtain the standard deviation of it for the new stock preparation design.

The applied power, of refiner 3 have been maintained, and the power required to achieve the same headbox SEC as in current situation was adjusted with refiners 1 and 2. Table C.4 shows the SEC oscillations at the different process chests.

Table C.4. SEC variation at the different chests of the LF line at steady state.

Process chest	Δ SEC between LF pulper discharges [kWh/t]
LF Dump Chest	106
LF Mixing Chest	64.8
LF Machine Chest	32.2
Headbox	10.7

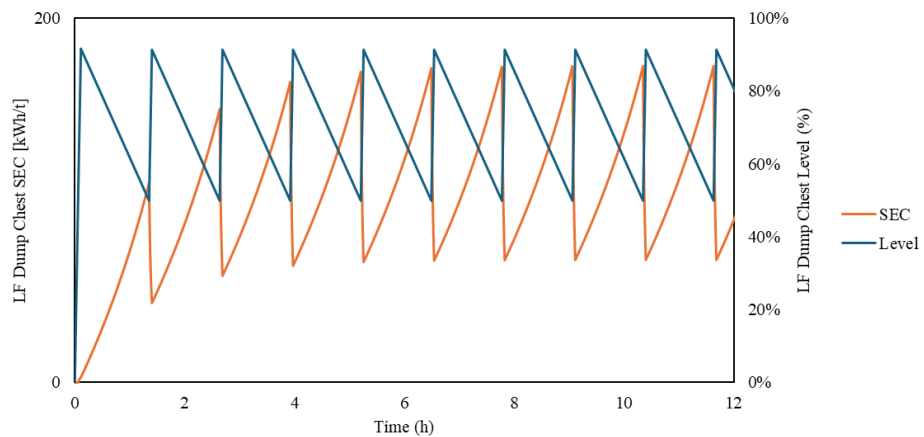


Figure C.4. LF dump chest SEC oscillations with the trial parameters. Own work.

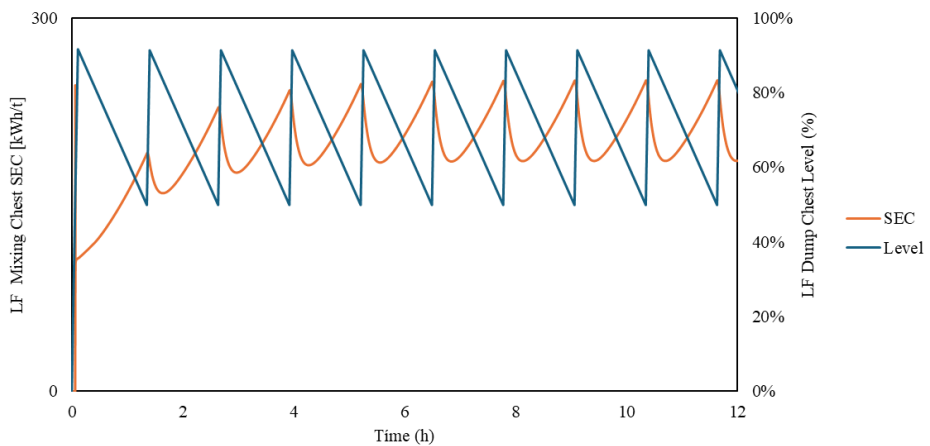


Figure C.5. LF mixing chest SEC oscillations with the trial parameters. Own work.

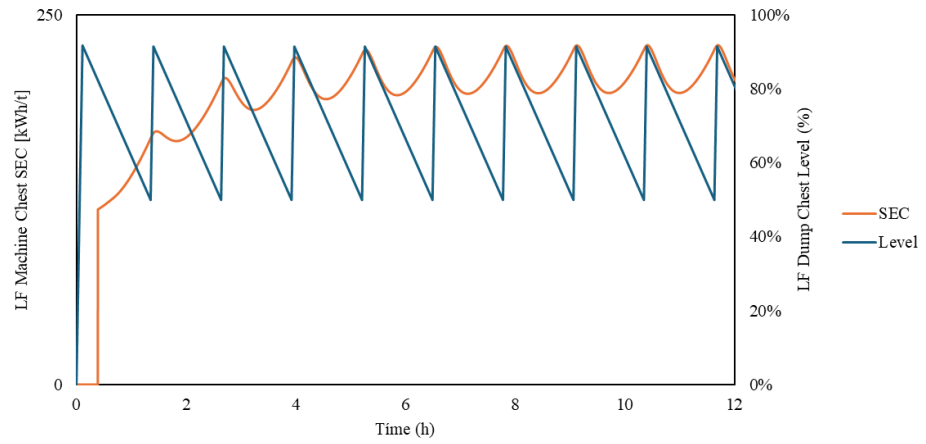


Figure C.6. LF machine chest SEC oscillations with the trial parameters. Own work

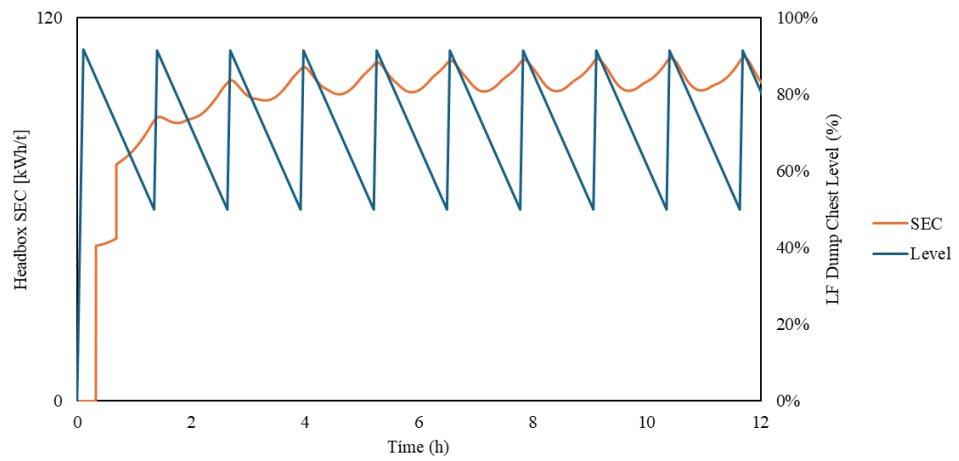


Figure C.7. Headbox SEC oscillations with the trial parameters. Own work

D. ECONOMIC ANALYSIS DETAILS

D.1. MD tensile strength standard deviation estimation

In order to estimate the standard deviation of MD tensile strength for each quality following calculations have been executed. First, average and standard deviation were calculated using all data available of 2024 (not all reels produced in the paper machine are analysed in the quality laboratory).

Using the results of the trial described in C.2, the potential decrease in the standard deviation was calculated by extrapolating the reduction in the standard deviation observed in the trials with the reduction in the headbox SEC oscillations (see Table D.1). Once these reductions were calculated, the potential reduction of MD strength was estimated based in the headbox SEC oscillations (see Table D.2).

Table D.1. Reductions of headbox SEC and MD tensile strength standard deviation observed in the trials.

Quality	Product A	Product B
Δ SEC Headbox [kWh/t] (std. parameters)	16.5	16.5
Δ SEC Headbox [kWh/t] (broke ratio trial)	10.7	10.7
Δ SEC Headbox reduction [%]	35.2	35.2
MD tensile strength standard deviation reduction [%]	14.5	5.13

Table D.2. Potential MD tensile strength standard deviation estimation.

Quality	Product A	Product B
Δ SEC Headbox [kWh/t]	4.03	4.03
Δ SEC Headbox reduction [%]	75.7	75.7
MD tensile strength standard deviation reduction [%]	31.3	11.1

To calculate the potential reduction of reels out of specification produced a normal distribution of the reels produced for each quality was constructed with the averages and standard deviations. The number of reels in each MD tensile strength value has been obtained by multiplying the cumulative probability for each strength value and the total number of reels produced in 2024 for each quality.

E. SELF-EVALUATION QUESTIONNAIRE

Degree Competences		Task in which you have observed the competence	Self evaluation [Rank 1 to 10]	Aspects to be improved
SPECIFIC COMPETENCES				
A1.1	Effectively apply knowledge of basic, scientific and technological materials pertaining to engineering.	During DOM meetings, when process variables are out of the expected range be able to identify and choose corrective actions	8	Improve my knowledge about papermaking process and paper machine.
A1.2	Design, execute and analyze experiments related to engineering	Two trials performed in this thesis, were designed, executed and analyzed. After that, the trial was used as standard.	10	
A1.3	Be able to analyze and synthesize the continuous progress of products, processes, systems and services, whilst applying criteria of safety, economic viability, quality and environmental management. (G6)	During DOM, when process performance is analysed and corrective or preventive actions are adopted.	9	
A1.4	Know how to establish and develop mathematical models by using the appropriate software in order to provide the scientific and technological basis for the design of new products, processes, systems and services and for the optimization of existing ones. (G5)	In this work with the SEC model developed, also I participate in calculating the consistencies of the papermachine headbox and discussions about hood optimization	10	
A2.1	Be able to apply the scientific method and the principles of engineering and economics to formulate and solve complex problems that arise in processes, equipment, installations and services, in which the material undergoes changes to its composition, state or energy content, these changes being characteristic of industrial chemistry and other related sectors such as pharmacology, biotechnology, materials sciences, energy, food and the environment. (G1)	-	-	
A2.2	Conceive, project, calculate and design processes, equipment, industrial installations and services in the field of chemical engineering and related industrial sectors in terms of quality, safety, economics, the rational and efficient use of natural resources and the conservation of the environment. (G2)	SEC model and trials were used to calculate the profitability of the future installation	9	

A2.3	Lead and technically and economically manage projects, installations, plants, companies and technological centres in the ambit of chemical engineering and related industrial sectors. (G3)	During the internship, when process leader was out of the office I was in charge of leading production team	8	Despite I have improved my soft skills during the internship, I think it is an area that I can improve further.
A3.1	Apply knowledge of mathematics, physics, chemistry, biology and other natural sciences by means of study, experience, practice and critical reasoning in order to establish economically viable solutions for technical problems (I1).	SEC model and simulations proved that hypothesis were correct	10	
A3.2	Design and optimize products, processes, systems and services for the chemical industry on the basis of various areas of chemical engineering, including processes, transport, separation operations, and chemical, nuclear, electrochemical and biochemical reactions engineering (I2).	Optimization of the centerlining process. Morphology equipment set of limits for different PM6 products	10	
A3.3	Conceptualize engineering models and apply innovative problems solving methods and appropriate IT applications to the design, simulation, optimization and control of processes and systems (I3).	Use of Proficy Historian tool to determine RCA of problems	10	
A3.4	Be able to solve unfamiliar and ill-defined problems by taking into account all possible solutions and selecting the most innovative. (I4)	Chemical traceability proposal, any problem solving process related to paper machine and process	8	Still need too much time as my background in papermaking process and paper machine is limited and more knowledge need to be acquired.
A3.5	Lead and supervise all types of installation, process, system and service in the different industrial areas related to chemical engineering (I5).	Daily machine inspections as well as process variables analysis	10	
A3.6	Design, construct and implement methods, processes and installations for the integrated management of waste, solids, liquids and gases, whilst also taking into account the impacts and risks of these products (I6).	Design and selection of alternatives for LF line	9	
A4.1	Lead and organize companies and production and service systems by applying knowledge and abilities regarding industrial organization, commercial strategy, planning and logistics, mercantile and labour legislation, and financial and costs accounting (P1).	Contact with chemical suppliers in case of traceability issues detected, reviewing work permits during planned shutdowns	9	
A4.2	Lead and manage the organization of work and human resources by applying criteria regarding industrial safety, quality management, occupation risk prevention, sustainability and environmental management (P2).	Daily work prioritization in DOM	8	Need to improve my communication skills to be more efficient.
A4.3	Manage research, development and technological innovation whilst ensuring the transfer of technology and taking into account property and patent rights (P3).	-	-	

A4.4	Adapt to structural changes in society caused by economic, energy or natural factors so as to be able to solve any resulting problems and to contribute technological solutions with a high commitment to sustainability (P4).	Energy and water consumptions are reviewed every day at DOM.	9	
A4.5	Lead and monitor the control of installations, processes, products, certification, auditing, verification, testing and reports (P5).	When reviewing operator tasks, supervising critical process variables. Participation in ISO and IFS audits in the plan.	10	
A5.1	Carry out, present and defend (once all the curriculum credits have been obtained) an original individually produced piece of work before a university panel. The work will consist of a professional integrated Chemical Engineering project that synthesizes (TFM1)	Development of this work and presentation in to different colleagues at Graduate Session.	7	Need to improve my communication skills
TRANSVERSAL COMPETENCES				
B1.1	Communicate and discuss proposals and conclusions in a clear and unambiguous manner in specialized and non-specialized multilingual forums (G9).	At any DOM, WOM or MBU	9	Need to improve my communication skills
B1.2	Adapt to changes and be able to apply new and advanced technologies and other important developments with initiative and entrepreneurial spirit. (G10)	Change of LF recipe	9	Sometimes I am slow at taking decisions as I prefer to analyse different perspectives
B2.1	Lead and define multidisciplinary teams that are able to make technical changes and address management needs in national and international contexts. (G8)	Defining corrective actions during Safety plant audits	9	
B3.1	Work in a team with responsibilities shared among multidisciplinary, multilingual and multicultural teams	Most work in PM department is conducted by a multidisciplinary team.	10	
B4.1	Be able to learn autonomously in order to maintain and improve the competences pertaining to chemical engineering that enable continuous professional development. (G11)	Most of my papermaking process knowledge was learned autonomously by paying attention at meetings and doing formations,	9	Limited time in production atmosphere to do formations
B5.1	Carry out and lead the appropriate research, design and development of engineering solutions in new or little understood areas, whilst applying criteria of creativity, originality, innovation and technology transfer. (G4)	During the development of this work	9	Research was limited by the continuously operating process
B5.2	Bring together knowledge, make judgements and take decisions on the basis of incomplete or limited knowledge whilst taking into account the social and ethical responsibilities of professional practice. (G7)	When making decisions in the absence of the process leader. Developed broke dump chest flow model with the process limited data	8	Deeper knowledge and experience in papermaking would help me to make decisions.

		as supplier needed information of the process		
NUCLEAR COMPETENCES				
C1.1	Have an intermediate mastery of a foreign language, preferably English	Developing project, attendance to meetings with external suppliers and formations	8	Improve my speaking skills
C1.2	Be advanced users of the information and communication technologies	Proficiency centerlining meetings, Rubik Pro pilot test	10	
C1.3	Be able to manage information and knowledge	Use correct company's database, optimization of machine tender's tasks project	10	
C1.4	Be able to express themselves correctly both orally and in writing in one of the two official languages of the URV	Every day in DOM meetings	10	
C2.1	Be committed to ethics and social responsibility as citizens and professionals	Safety culture of company	10	
C2.2	Be able to define and develop their academic and professional project	During the development of this work.	7	Better self-organization and communication would improve the development of the project

b) Evaluate the final master project and suggest improvements.

Key steps	Evaluation [Mark 1 to 10]	Improvement proposed
Selection/assignment of the project (dissemination, communication, assignment requirements...)	9	The assigned project was complex and open and well-adapted to the requirements.
Stay (welcome, length, relationship, follow-up made by the company...)	9	PM6 work environment is excellent, both RST and production team. Daily operations work hinder formation of basic aspects of papermaking process, but everybody was open to explain me any doubt I had.
Follow-up made by URV tutor	10	URV tutor gives feedback and questions that help me to improve the quality of this work
Other aspects to be considered (which ones...)	-	-