A *Kobetsu* approach to eliminate product waste in the biofuel industry

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Master Dissertation

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Resumo

A presente dissertação reflete um projeto desenvolvido numa das consultoras de topo de Excelência Operacional. O principal foco do trabalho é a aplicação da metodologia *Kobetsu* com vista a reduzir perdas de produto e a produção de águas residuais numa empresa de produção de biodiesel.

A empresa de biodiesel ambiciona liderar a transição energética em Portugal produzindo um produto de qualidade. Para tal, produz biodiesel sujeitando óleos de diferentes fontes a um processo dividido em três unidades. O projeto iniciou-se quando a administração identificou a consultora como capaz de melhorar o seu processo e trazer benefício económico. A consultora já tinha trabalho com a empresa de biodiesel nos últimos dois anos, e novos desafios surjiram enquanto os problemas foram sendo resolvidos. Tal levou a duas iniciativas de redução de desperdício.

A primeira iniciativa deu-se na unidade de neutralização da fábrica. Existiam perdas significativas de produto na unidade. Isto significa que a fábrica estava a descartar óleo que poderia ser comercializado, traduzindo-se em perda económica dupla. Os custos de expedição de águas ácidas e neutras eram significativos, sendo o custo de expedir águas ácidas maior. Reduzir ambas as águas residuais, enquanto se transforma água ácida em água neutra representa ganho económico. Igualmente, controlar a extração de água da fábrica representa ganho económica para a empresa por haver óleo a ser expedido como água.

As duas iniciativas foram transformadas em *workshops* liderados usando a metodologia *Kobetsu*. Esta é uma ferramenta de resolução de problemas estruturada, que almeja definir o âmbito do problema, os objetivos, as soluções e as contramedidas necessárias para sustentar as melhorias feitas.

Abstract

This dissertation reflects a project developed at one of the top consulting firms in Operational Excellence. The main focus of the work is the use of the *Kobetsu* methodology to reduce product losses and wastewater production in a biodiesel-producing company.

The biodiesel company aims to lead the energy transition in Portugal by producing a product of quality. It produces biodiesel by subjecting oils from different sources to a process divided into three different units. The project started when the board identified the consulting firm as capable of improving its process and bringing economic benefit. The consulting firm had already been working with the biodiesel company for two years, and new challenges arised as problems were being solved. This led to the two waste-reducing initiatives.

The first initiative is held at the neutralization unit of the plant. There were significant product losses in this unit. This means that the plant was disposing of oil that could be commercialized, translating to double economic loss. The second initiative aimed to reduce the production of wastewaters in the plant. The costs of shipping acid and neutral waters are significant, with the cost of shipping acid waters being higher. Reducing both wastewaters, while transforming some acid waters into neutral would represent an economic benefit. Also, controlling the water extraction of the plant would represent an economic benefit to the company as there was oil being shipped as water.

The two initiatives were transformed into workshops led using the *Kobetsu* methodology. This is a structured problem solving tool, that aims to define the scope of the problem, the goals, solutions, and countermeasures needed to sustain the improvements made.

Ackowledgements

This project marks the end of my academic journey, which shaped the adult I am today. I did not walk alone in the path leading to this moment, and thus would like to aknowledge to everyone that helped me reach this goal:

To my Parents for all the love and for showing me that resillience and sacrifices come before success.

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To my friends for showing me that it really does not matter what our background is. We can achieve anything we set our minds to.

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Contents

Nomenclature and Acronyms

3C – Case, Cause, Countermeasure. Structured problem-solving tool.

A3 – Structured problem-solving methodology that summarizes goals, solutions, and results in a single sheet of paper.

FAME – Fatty Acid Methyl Esters.

FFA – Free fatty acid.

Flowchart – Diagram that details the order of steps in a sequential process.

Gemba – Japanese word for *workfloor*; place where value is added.

GQDCM(I) – Growth, Delivery, Resource Efficiency, Flow Efficiency, Respect for People, Improvement.

IM – Industrial Manager.

Impact-Effort Matrix – Visual decision-making tool that prioritizes tasks by comparing its impact if executed and effort to execute.

JI – Job Instruction.

Kamishibai – Japanese word meaning *paper play*.

KBS - Kaizen™ Business System.

KICG – Kaizen™ Institute Consulting Group.

Kobetsu – Japanese word for *focused*.

MSA – Methanesulfonic acid

Muda – Japanese word for *waste*.

PDCA – Plan, Do, Check, Act. Improvement cycle.

PEBD – *Produção Específica de BioDiesel*. Plant unit where biodiesel production occurs.

PEEA – *Produção Específica de Esterificação Ácida*. Plant unit where the acid esterification occurs.

PEG – *Produção Específica de Glicerina*. Plant unit where the treatment of glycerin occurs.

PEN – *Produção Específica de Neutralização*. Plant unit where the neutralization occurs.

PERT – *Produção Específica de Retificação de Torre*. Plant unit where the rectification of alcohol occurs.

SIPOC – Supplier Input Process Output Costumer.

VOC – Voice of Costumer.

VSM – Visual Stream Mapping.

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1 Introduction

This dissertation was written under the Master in Mechanical Engineering at *Faculdade de Engenharia da Universidade do Porto* (FEUP). The project was developed by *Kaizen Institute Western Europe* (KIWE) and implemented at a Biodiesel (FAME) producing company which will be referred to throughout this essay as Company D, for confidentiality purposes.

Company D hired KIWE to improve its production processes, help define the company's strategy and change the organization culture as a whole. The project first started in 2020 and is now entering the 2nd quarter of its 3rd year. There have been significant improvements at different levels of the company: the production volume of Biodiesel, the daily management, the stability of production (reduction of unplanned stops), the process knowledge with the creation of norms, and the leadership culture.

As of today, other challenges emerged, new priorities have been selected and the project now aims to reduce the residues of both acid and neutral waters, the usage of Methanesulfonic acid (MSA) and Methanol in the production process and the losses in the Neutralization section (PEN) of the process.

In order to achieve these goals targets were set with Company D and a standardized way of structured problem-solving called *Kobetsu* was used. Along with this tool, other *Kaizen*™ tools were already implemented such as Team Boards and Meetings, 5S, Visual Management, amongst others.

This chapter gives an overview of *Kaizen Institute*'s history, purpose and working philosophy. It also digs deeper into the project scope and goals at Company D while also referring to the main obstacles identified and the tools used to overcome these challenges. Finally, it will have an outline of the structure of this dissertation.

1.1 Kaizen Institute

Kaizen Institute Consulting Group (KICG) is an Operations Consultancy company founded in Switzerland in 1985. The *Group* is a pioneer, and leader, in implementing (and coaching) its *Kaizen* methodology. *Kaizen* is the junction of two Japanese words: *kai* (change) and *zen* (better) and is defined by KICG's founder Masaaki Imai (2007) "as everyday improvement, everybody improvement and everywhere improvement".

The *Kaizen*™ *Business System* consists of three levels of implementation:

- *Strat Kaizen*™: Excellence in Strategic Revision.
- *Value Stream Kaizen*™: Excellence in Process Transformation.
- *Daily Kaizen*™: Excellence in Leadership and Problem Solving.

These levels of implementation aim to reach the *Kaizen*™ Growth Model Goals:

1. Growth
2. Quality
3. Cost
4. Delivery
5. Motivation

To finalize, KICG believes in a *Gemba* (Japanese word for workfloor)-orientated approach: on the factory floor and always close to the workers. This way, there is a better understanding of the process, everyday problems, and the real reason these problems occur leading to better employment of problem-solving and stability tools.

1.2 Project framework and motivation

Company D produces Biofuel using virgin and used neutral and acid oils from the food industry, residential use, or from vegetable and animal sources. The source of oils, combined with the production process used are important factors in the operating cost of the process (Gebremariam and Marchetti 2018). The final product can be used separately, or it can be incorporated into diesel.

The project in question focuses on two main challenges: the reduction of production of acid waters and the losses of PEN – the difference between flow input and flow output in this unit.

The production of acid waters is an issue because of its high transportation costs. The company could be reducing costs if the water being shipped was neutral instead of acid. As of today, most of the costs associated to wastewater production are from shipping acid waters.

The PEN is an area where a neutralization of oil occurs. By introducing a base to an acid fluid, a neutral pH is obtained. The goal in this area is to reduce the difference between input and output of oil whether caused by quality issues (reflux) or bad operation of equipment.

The project scope is defined above, Company D called on KIWE to tackle these issues, using its *Kaizen*™ methodology. The project was defined together with Company D to be aligned with its organizational priorities. KIWE intends to improve the current situation to increase its profit margin.

1.3 Biofuel sector and the company

The national biodiesel sector is still considerably small, with five big producers identified:

- Fábrica Torrejana de Biocombustíveis, SA;
- Iberol – Sociedade Ibérica de Biocombustíveis e Oleaginosas, SA;
- Prio Biocombustíveis, SA;
- Sovena Oilseeds Portugal, SA;
- Biovegetal – Combustíveis Biológicos e Vegetais, SA.

Although Company D is not listed as one of Portugal's biggest producers, it was still allocated a share of emissions of Titles of Biodiesel (TdB) by DGEG in 2011. (Direção-Geral de Energia e Geologia 2022b)There are also small, dedicated producers, but Company D's main competitors are those five companies mentioned before.

The production of Biofuel in Portugal is mainly aimed to incorporate into diesel. Diesel is still the most consumed type of fuel nationally and there is legislation in place to establish a percentage of biodiesel incorporated into diesel and gasoline. That value was fixed at 10% in 2020 (Direção-Geral de Energia e Geologia 2022a).

Company D was founded in 2006, started experimenting biodiesel producing in 2009, and, as stated before, started commercializing biodiesel in 2011. Its factory is in *Área Metropolitana do Porto*. The company's main goals are to become a reference in the biodiesel producing sector and to be part of the country's energetic transition. The operations and machines of its production process are in constant testing and improvement, and the team of workers is being built in accordance with the company's values and future vision.

There are 4 main teams: Production, Maintenance, Laboratory and Safety and Movements. The Production team works to ensure that all the operations and controls necessary to produce biodiesel are being executed. Maintenance works in a preventive and reactive way and supports the other teams. The Laboratory and Safety team is responsible for analyzing the quality of the product being produced and to ensure that all safety requirements and procedures are being met. Finally, the Movements team operates as the connector between the outside and the inside of the factory: all the raw materials that arrive, and all the products and residues that are shipped.

1.4 Project Goals

The priorities of the project were defined together with the team of Company D. The choice of initiatives to implement was based on the impact that they would have on the company's economical and operational goals. These initiatives were always set to be aligned with the Company's priorities at medium and long term.

Reducing the production of acid waters was set as one of those goals. The process produces waters, as a consequence of the chemical reactions happening throughout the process. Water is sometimes added in specific point to the stream of product to, mainly, help separate substances. Finally, it enters the flux when washing is needed in some of its machines. In the end, these waters need to be removed from the oil and, ultimately, from the factory. The shipping costs of water are considerable, especially those of acid waters. Controlling this production of acid and neutral wastewater would bring economic benefits to the company. The acidity of the water also increased the price of shipping as lower acidity waters would be shipped at a lower price. This is an opportunity to improve the process inputs, as a standardization of acid input would not only allow to have better shipping contracts, but also allow to save costs in acid material.

The losses in PEN represent the difference between the input and the output of material that goes into the unit. There are unavoidable losses such as unnecessary product that is removed, but sometimes in the process of waste removal, oil is also extracted, and this translates into economic losses to the company. After the process is done, there may be a need to reflux the oil as its quality is not up to par with the standard. If this happens, there is a loss that can still be recovered, but should not be happening. This will be explained in-depth latter.

1.5 Adopted Method

The main methodology used was *Kobetsu Kaizen*™. The main problems were identified with the team. To do so, an Impact-Difficulty Matrix was used. This tool allows to understand which are the priorities at moment zero and what ongoing initiatives should be put on hold. To then find and follow-up on solutions, several workshops were done, especially with the Industrial Manager (IM).

The initial status of the priorities was then designed, with the help of indicators, process mapping and flowcharts. This is fundamental to better understand the problems found and was done together with the Industrial Manager (IM) of the plant.

Having defined the *As Is* situation, the future vision was set, with goals that are *SMART*: Simple-Measurable-Achievable-Relevant-Timely. This means that the goals are easily trackable, they can be measured, they are realistic, relevant to the company and are set to be achieved in an established time frame.

Afterwards, the root causes were determined. Once again, together with the Industrial Manager of the plant, there was an analysis of the process as a whole to determine the biggest sources of instability. Then, the question was made: *Why is this happening?* The experience of the IM was of big usefulness as it allowed to quickly identify the obstacles in the process.

Finally, the design and testing of solutions were done. There was a big emphasis on standardizing operations as it was found that there was a lack of norms for common tasks. Also, the capacity to react to different process indicators was an improvement opportunity identified: the production team did not have the knowledge to implement countermeasures when deviations in the process occurred.

All these initiatives should then be monitored and always be revised to find improvement opportunities. This may be the most challenging part of the project as it requires a certain level of maturity of the company, and it requires that continuous improvement is embedded in the organization's culture.

1.6 Dissertation Structure

This dissertation has 6 chapters, structured according to the Mechanical Engineering department standard.

The first chapter gives a broad introduction to KICG and to the activity sector of Company D. The methodology and goals of the project are presented and finally, there is an outline of the dissertation Structure.

In chapter two, a thorough Theoretical Framework is done. Here, all the scientific reasoning behind the decisions made throughout the project will be presented. All the methods and tools used are described and the reason why they were used is given.

Chapter three focuses on a bigger and deeper characterization of the problem *As Is* situation. There is a total breakdown of the process and the improvement opportunities found.

Chapter number four gives insight into the method used to implement the improvement initiatives. All the steps of the implementation are described, from design to testing.

In the fifth chapter the results of the project are presented.

Finally, the sixth chapter draws conclusions about the project, while describing future works and improvement opportunities.

2 Theoretical Framework

The following chapter is a summary of all the theoretical concepts and tools used to support the dissertation. It will shed light on all the academic and theoretical background that led to the decisions made throughout the project and to better explain the tools implemented.

2.1 Kaizen™ Business System

The *Kaizen™ Business System* (KBS) is a management model which seeks Operational and Growth Excellence by implementing *Lean* foundations and tools in organizations. Every *Kaizen* project is ruled by five principles:

1. Creating value for the customer
2. Creating flow efficiency
3. *Gemba* effectiveness
4. People engagement
5. Being scientific and transparent

The long-term goal is to add value to companies by reaching GQCDM(I) goals, by following the guidelines aforementioned. Figure 1 shows the base model of KBS represented by a house, from its foundations to its ceiling.

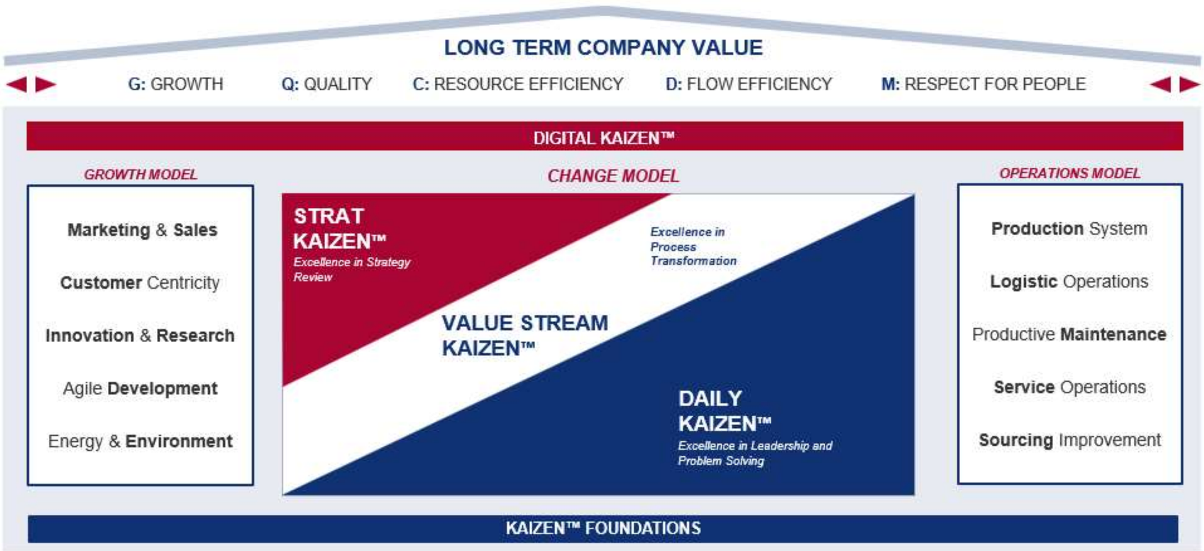

Figure 1 - Kaizen Business System graphical representation. (Kaizen Institute 2022b)

The KBS is driven by the GQCDM(I) goals, supported by *Strat Kaizen™* - Excellence in Strategic Revision-, *Value Stream Kaizen™* - Operational and Growth Excellence-, and *Daily Kaizen™* - Leadership and Problem-Solving Excellence. The *Digital Kaizen™* lays on top of the 3 three pillars mentioned and aims to implement the Digital transformation companies need to keep up with market demand. Finally, the KBS house settles on top of the *Kaizen™ Foundations:*

- Values and Principles
- *Kaizen™ Audits*
- *Kaizen™ Governance*
- Total Quality Management

2.2 Process Industry and Energy Challenges

The Process Industry increasingly faces more challenges. The competitive environment surrounding this industry makes continuous a must for growth. In parallel, the current global geo-political situation is extending the economic challenges faced: the energy crisis and the supply chain breaks are concerning points. Petroleum-based fuel prices have increased. This competitive and volatile environment requires organizations to deliver products, deploying the minimal (and optimal) amount of resources while delivering a high quality product with a low lead time (Panwar et al. 2015).

The world is facing serious climate changes that threat not only the environment, but also the health and safety of humans, local and global infrastructure, and total efficiency (Abbass et al. 2022). The Process Industry is responsible for 31% of emissions of greenhouse gases (GHG). Mitigation of these emissions is fundamental to keep the planet habitable and orderly. There is added responsibility for developed countries and their industries to have a responsible role in energy consumption and GHG emissions, as their action can have a global impact, with bigger consequences away from these regions.

Energy is a key topic when discussing development, growth and, of course, sustainability (Bilgen 2014). Energy consumption is attached to growth and progress and can be used as a measurement of the degree of development of a country/region/continent. The attachment of these variables can be seen in Figure 2, where, around 2007, there is a change in the growing tendency of consumption. This happens coincidently at the time of the Global Financial Crisis spanning from 2007 to 2009 (Bilgen 2014). Figure 2 also shows a decrease in global energy consumption in 2020, the first year of the Global Covid-19 Pandemic. Energy consumption decreased by 4.5% in 2020 and carbon emissions fell 6.3%. This tendency is already reversing, as lockdowns ease and travel restrictions are being abandoned (BP 2021). It is also observable that fossil fuels dominate energy consumption, so this ever-growing increase in energy consumption will ultimately lead to an increase in emissions of GHG.

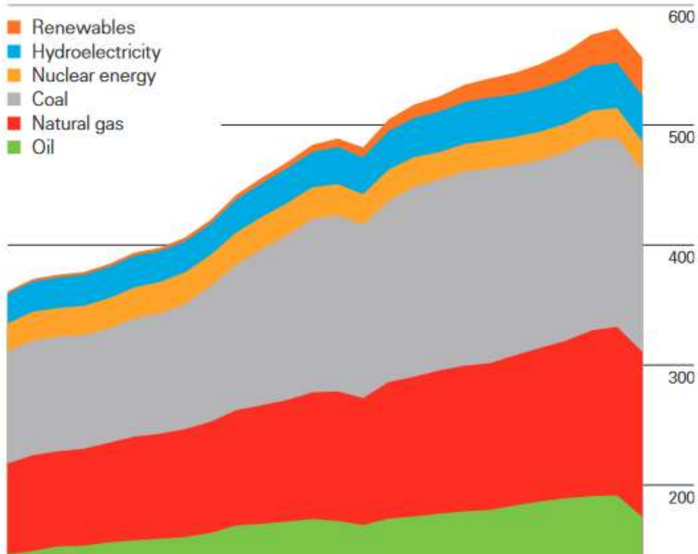

Figure 2 - World Energy consumption in exajoules from 1995 to 2021 (BP 2021).

The need to decrease fossil fuel consumption is widely spread, but there is still a lack of actual actions such as legislation and investment in research to increase renewable energy adoption and enhancement. These types of fuel seem to be the path to lead the world into a *sustainable* future. Sustainable development is defined in the World Commission on Environment and Development's 1987 Brutland Report named "Our Common Future" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Keeble 1988). This definition is important because it addresses the real goal of a greener planet: the possibility for future generations to enjoy at least the same opportunities as humans do now. It is important to restate the major role of developed countries in the coming years, as more energetic challenges arise. Many of these countries are heavily dependent on oil-based fuels, but they are not oil producers. This means, their economies are very vulnerable to increasing oil prices (Soytas and Sari 2006). The importance of a good energy system, with different sources and solutions seems evident. Planning regionally, nationally, and internationally is fundamental to a sustainable future. The energy problem has many variables from depleting fossil resources to deforestation and loss of agricultural land. It is why integrating different solutions is important: having different sources of energy avoids dependency on a single type of energy, keeps solutions connected to the environmental goals set and creates more opportunities for economic growth (Rudberg, Waldemarsson, and Lidestam 2013).

2.3 Biodiesel Industry

The Biodiesel Industry faces two environmental challenges: the production of green fuel and the mitigation of GHG emissions in its production process. Biodiesel is a renewable and clean fuel as it does not emit GHG, but its production process may release some of these gases into the atmosphere. As stated before, Portugal has a target of 10% of biodiesel incorporated in all fossil diesel. This goal pushes big petroleum-based fuel producers to buy biodiesel. These kinds of targets have been set by many countries worldwide, increasing the production of Biofuels: from 2001 to 2007 there was an increase from 0.8 to 4 billion liters of biodiesel produced worldwide (Bindraban, Bulte, and Conijn 2009). The main challenges this industry faces are the development of sustainable supply chains of biomass and the attraction of investment to develop large-scale production facilities (Energy Agency 2021). As seen in Figure 3, biofuel production had a growing tendency throughout almost all the 21st century until 2021. The Covid-19 Pandemic explains the sudden decrease entering the new decade. Even so, the data shows an increasing adoption of this alternative fuel, and with lockdown and restrictions being eased it is expected that the production numbers will be on the rise soon.

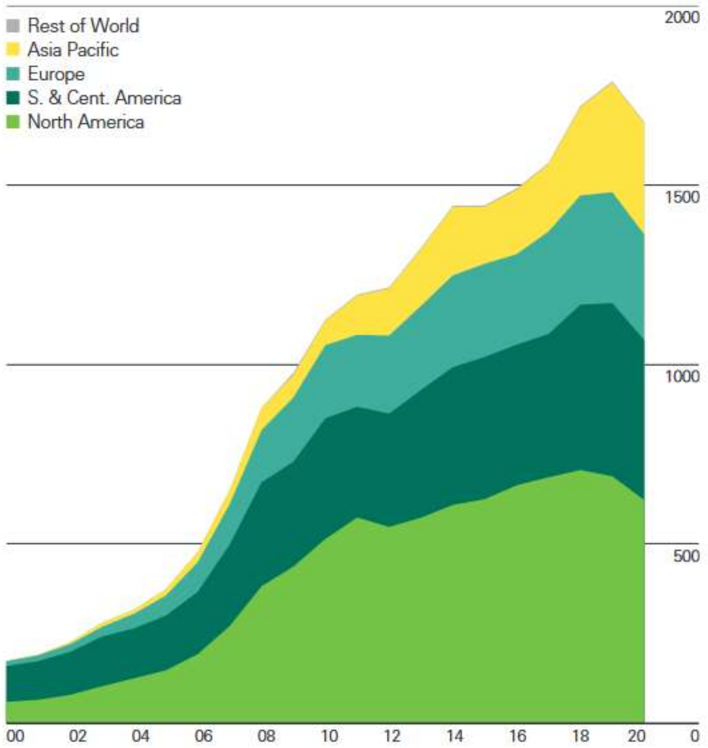

Figure 3 - World Biofuel production in thousands of barrels of oil equivalent per day from 2000 to 2021 (BP 2021)

2022 has been a year of changes at a geo-political level: as the Covid-19 Pandemic starts to slow down, the war in Ukraine started and stirred up the world. Portugal did not escape the consequences of this military attack and one of the consequences was the increase in fuel prices. From January 1st to April 1st diesel prices increased 34.5% and gasoline prices increased by 22.5% (Figure 4). This increase means more costs for the average citizen and, at a lower scale, profit losses for fuel producers.

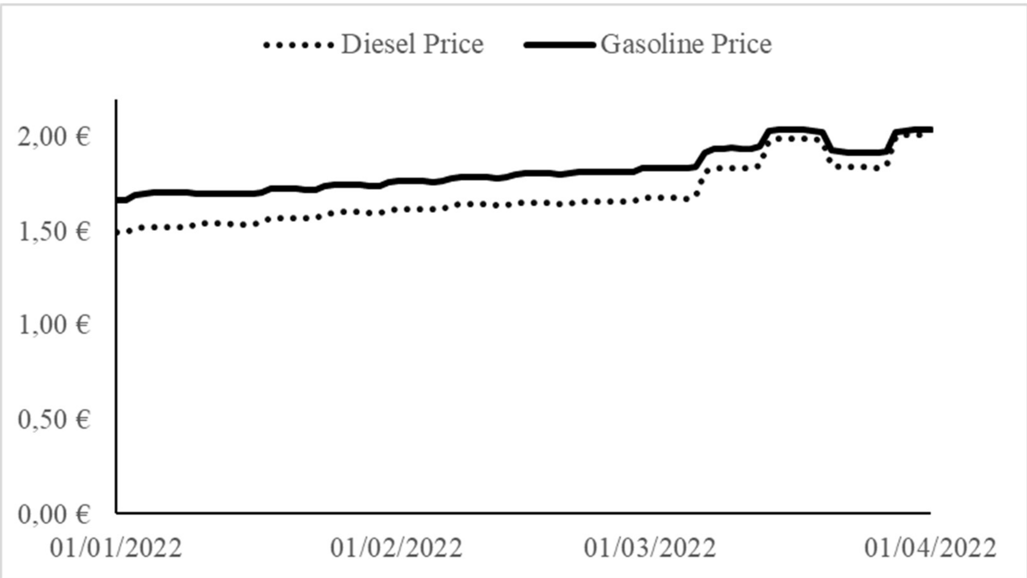

Figure 4 - Average Fuel Price evolution in Portugal through the first 3 months of 2022 (Direção-Geral de Energia e Geologia 2022c)

The cost of raw materials accounts for about 70 to 80% of the production costs of biofuel (Gui, Lee, and Bhatia 2008). This is very significant to the economic feasibility of biodiesel production, but it does not only affect the economic part of the process. There are two main types of biodiesel feedstock: edible and non-edible vegetable oils. Soybean, peanut, sunflower, palm, and coconut oil are examples of the first category while rapeseed, jatropha, jojoba, and used cooking oil are examples of the latter (Elgharbawy et al. 2021). The usage of food for energy raises concerns: the prices of food may increase, the land availability for food crops may decrease, and deforestation. The logical way to face these challenges is to use non-edible vegetable oils. The physical and chemical properties of biofuel vary according to its feedstock. One important type of property is the cold flow property type: these properties, such as the cloud and pour point, reflect the changes in crystallization, viscosity, and gelling in the fuel. This translates into the possibility or not of using biofuel in cold climate countries.

Biodiesel is a mixture of fatty acids alkyl esters. It is produced by transesterification, a reaction that transforms triglycerides and alcohol into ester (Ma and Hanna 1999). The process normally uses a catalyst to enhance the reaction and the alcohol is normally inserted in excess because of the reversibility of the reaction. The process transforms triglycerides into diglycerides, diglycerides into monoglycerides, and finally monoglycerides into glycerol. This final reaction also produces an ester molecule or a biodiesel molecule. Glycerol (or glycerin) has commercial value in pharmaceutical, food, cosmetics, textile, and more industries so a high level of purity of glycerol is relevant to Biofuel producers. The type of alcohol used in the transesterification defines the product obtained: when using methanol, the mixture obtained is fatty acid methyl ester (FAME) while ethanol usage produces a fatty acid ethyl ester (FAEE) (Ramos et al. 2019). Methanol is more commonly used has it has lower costs, higher accessibility, and better chemical properties: it is the shortest alcohol chain, and it is polar. In turn it is more toxic and volatile. Methanol is mostly obtained from natural gas and so biodiesel obtained from methanol is not considered fully renewable. Ethanol has a lower reactivity, and it is harder to separate from the glycose produced. Its main advantages are lower toxicity and lower cloud and pour point, allowing engines running with this fuel to start at lower temperatures. As ethanol is produced using natural products, biodiesel produced using this alcohol is considered fully renewable (Ma and Hanna 1999) (Ramos et al. 2019). To enhance the transesterification process, a catalyst is often used. Alkali catalysts are mostly used as they increase the velocity of the reaction the most and are less corrosive. The most used basic catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH). Sulphuric acid (H_2SO_4), hydrochloric acid (HCl), and sulfonic acid are commonly used acid catalysts. This type of catalysts is used when the glyceride group has more fatty acid content (Marchetti, Miguel, and Errazu 2007) (Ma and Hanna 1999).

2.4 *Kobetsu* Kaizen™

Kobetsu Kaizen™ is a structured problem-solving tool that follows the A3 methodology normally carried out on 5 consecutive days. It focuses on a problem, to be solved in a defined timeframe with a multidisciplinary team. The goals to be reached must be clear, the financial benefits must be tracked, and the countermeasures should be implemented rapidly to obtain results with low costs and investments. This methodology got its name from the A3 paper size in which normally the communication tool, displayed in Figure 5, is inserted.

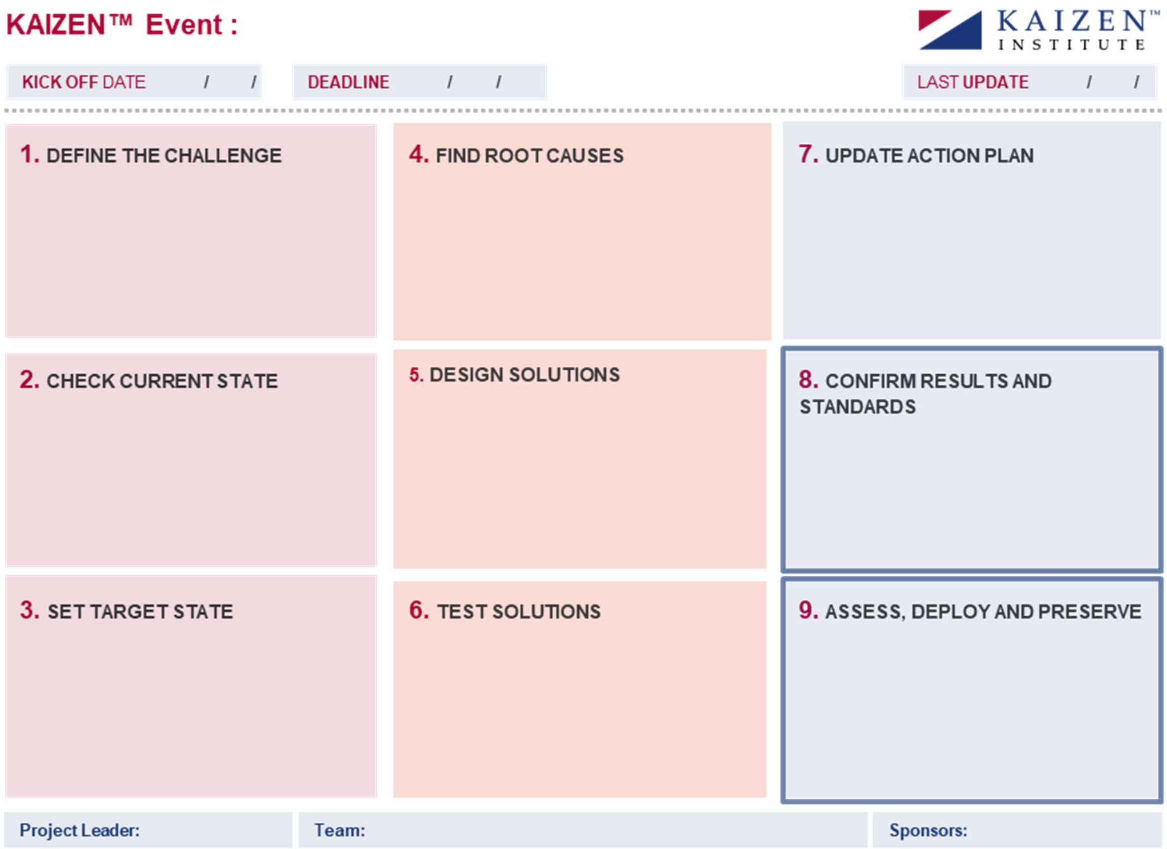

Figure 5 - A3 template.

The kick-off point of a *Kobetsu* Kaizen™ Event is the definition of a problem. This step will define the scope and will guide the roadmap of the Event. Problems can be hard to identify, and they may not be structured enough to be solved with software or quantitative tool. This type of problem calls for a simple and structured way to be solved. Organizations sometimes ignore problems, tend to normalize them, assume they are unsolvable, or they are too time-consuming. Other issues found are the lack of follow through on solutions adopted, the lack of information about the problem, the wrong people being involved, and tackling the problem instead of the root cause. All these topics cause stress, increased costs, increased delivery times, and resource misusage, in other words, the value chain loses agility. To start a *Kobetsu* Kaizen™ Event it is crucial to have a good preparation. Collecting and analyzing data is important as it gives a better understanding of the process and the problem. Also, understanding how the organization is structured and which teams will be involved gives good information about how to lead the Event.

The A3 methodology helps to simplify and standardize the improvement plan, can be used as a communication tool (Tortorella, Cauchick-Miguel, and Gaiardelli 2019), and empowers the organization both in terms of Organizational Knowledge and benefits tracking. A well-used A3 guarantees that results are obtained in 3 different areas (Kaizen Institute 2022d):

- **Quality:** Reaching improvement goals set.
- **Productivity:** Saving time that would be otherwise consumed replanning and reworking solutions, having meetings to check progress and adjust to miscommunication and misunderstandings, and preparing reports.
- **Leadtime:** Executing deadlines and using settled working days.

In conclusion, the A3 methodology reduces the number of communication moments during a project, structures the planning, executing, and closing phases of a project, and, above all, improves the organizational culture of improvement, something that is often overlooked in Continuous Improvement projects.

In some literature (Santos Filho and Simão 2022), the A3 is defined as a seven-step methodology. While there are variations to the number of steps and its denominations, the most important aspect of the A3 methodology is the thinking process and the embedding of the PDCA structure into the organization. Kaizen Institute defines the 9 steps of its A3 as:

1. **Defining the Challenge:**

A moment to settle the scope of the project, where the team finds a reachable goal. It is a moment to understand the necessity and the problem to improve. Usually a verb is used to clarify the goal: “increase x”, “decrease the time of y”.

2. **Checking Current State:**

In this stage, data is collected and analyzed to understand the current situation. A lot of tools can be used such as:

- Spaghetti diagram: visually shows the path of the unit of flow. Allows understanding of the distances covered in a process and how to reduce them.
- Checking sheet: Registers the number of occurrences in a time frame (hour/shift/day…).
- *Muda* Hunting: Registers the process’ Muda and classifies it.
- Shadowing: Observation of a certain task or process.
- *Yamazumi*: Helps balance the workload.
- DILO/WILO/Time Writing: Registers periodic tasks of the team leader (Day In Life Of/Week In Life Of) or of the team (Time Writing).

In the data analysis stage, the following tools can be used:

- Histogram: Represents the distribution of sets of data.
- Pareto’s Diagram: Shows what occurrences are most significant to the process, using the 80-20 approach (shown on Figure 6): 80 percent of outcomes are caused by 20 percent of causes.
- Scatter plot: Demonstrates how variables are related to each other.
- 5WH2: Identifies, deconstructs, and evaluates the problem. To do so 7 questions are asked: “What? Where? Why? Who? When? How? How much?”.
- VOC: Voice of Customer. Gathers all the needs and requests of the customer. A good VOC allows making better decisions regarding marketing, sales, product, planning, and strategy.

Finally, it can be important to map the process flow. For that, one can use:

- SIPOC: Supplier Input Process Output Customer. Allows for a better understanding of the connections between team processes and its suppliers and clients.
- VSM and Process Mapping: Visual Stream Mapping is used to map the flow of material while Process Mapping is used to map the flow of information and its exchanges between teams and departments.
- Flowchart: Details the flux of activities inside a process. Clearly details the start and finish point of a process as well as decision points (Figure 6).
- Influence Diagram: Used to understand dependencies between variables. Mostly used in hard-to-map processes.
- Meetings Waterfall: Describes the flux of meeting happening, from its duration to involved parts.
- Client Journey: Analyses the customer experience while in contact with the organization.

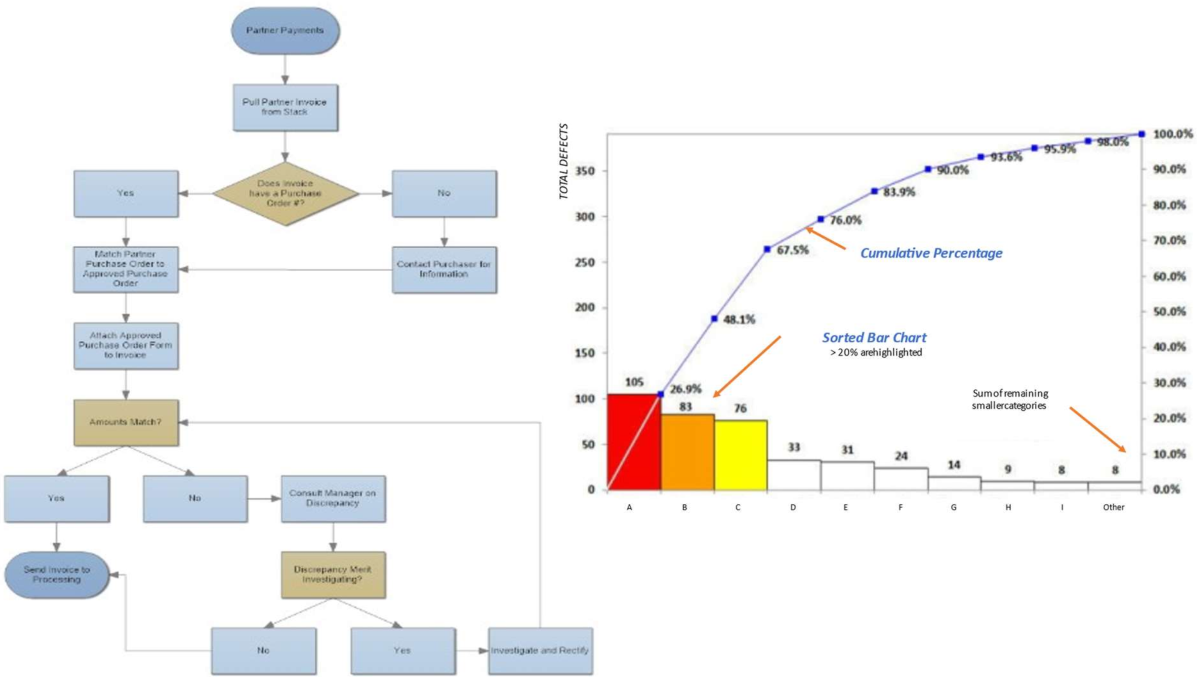

Figure 6 – Flowchart (left) and Pareto Diagram (right)

Another important aspect of this stage is going to Gemba and doing a critical view of the reality of the problem. Talking with the team involved and understanding their point of view is also relevant.

3. Setting target state

The target should have a metric, a timeframe, and a target value. For example: "The number of accidents should decrease to 0 until the end of the year". The goal must be SMART:

- Simple: Choose a specific target in a selected area.
- Measurable: Have ways to control the metric attacked.
- Achievable: The goal should be obtained with the team and should be aligned with the organization's priorities.
- Relevant: The goal should be impactful within the organization whether is it in monetary terms, decrease of time wasted or resources applied.
- Time bound: The goal should have a time frame to be achieved.

4. Finding Root Causes

To identify the root causes of the problem, a 4-step plan can be followed:

1. Identifying all possible causes using Ishikawa Diagrams (Figure 6), Process Mapping, Flowchart, or VOC.
2. Identifying root causes. For this the 5 Time Why methodology can be used or a Differential Analysis.
3. Prioritizing the strongest causes using data from step 2 of the A3 methodology.
4. Validating the root cause.

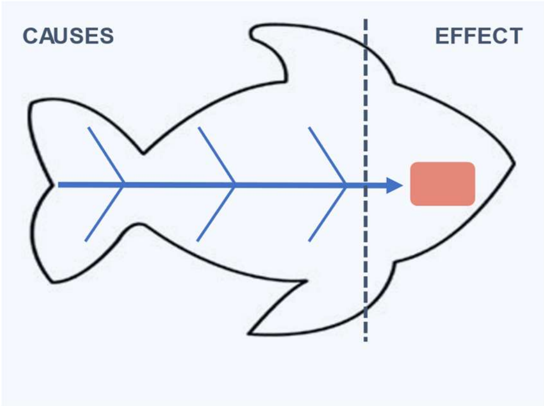

Figure 7 - Ishikawa Diagram: Usually split into 6 different sections (Material, Machine, Environment, Manpower, Method, Measure) it is a good brainstorming tool to identify causes. (Kaizen Institute 2022d)

5. **Designing Solutions**

In this stage, a macro vision of the improvement plan must be built. It is important to evaluate the solutions with better chances to positively impact the problem. A good tool to do so is the Impact-Effort Matrix. Using Figure 8 as an example, 3 and 7 are considered Quick Wins and are solutions to be adopted immediately. 8 and 9 should be discarded as they are unfruitful solutions. 2 and 4 are long term solutions and should be considered Key Projects – these normally need a good project management and follow up. Finally, 5 and 6 translate into barely anything and should not be considered as improvement priorities.

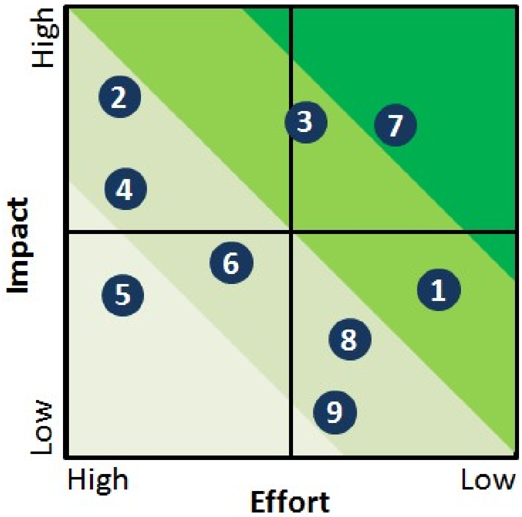

Figure 8 - Impact-Effort Matrix. (Kaizen Institute 2022d)

6. **Testing solutions**

To validate each solution, applying and testing them on the Gemba is fundamental. To test solutions, it is important to have a testing plan. To do so, it is important to establish which indicators should be monitored.

7. **Updating Action Plan**

The Action Plan should follow the 4 phases of the Deming Cycle, or PDCA cycle:

1. Plan – planning the activities to reach the target.
2. Do – executing said activities.
3. Check – validating the effectiveness of those activities.
4. Act – improving solutions or implementing tools to sustain previous solutions. The solutions or improvements found here should lead to phase 1.

The cycle is iterative and has a continuous improvement vision embedded in it. (Borys, Milosz, and Plechawska-Wojcik 2012)

For following up on Kobetsu Events, a PDCA template is used. In this document, the all the actions are listed and should be assigned to a problem/topic, have a responsible person or group, a starting and closing date, and in which phase of the cycle it is. This phase is important as it tracks all the improvement actions taking place. Figure 9 shows an example of a PDCA template.

PLANO AÇÕES

KAIZEN EVENT	AÇÃO	OBS	RESP.	DATA INICIO	DATA FIM	PDCA
Kaizen Diário	Definir plano de implementação e equipas		KI + PS	27/06/2022	27/06/2022	4 - Completed (A
Box Soldadura	Workshop definição Box		KI + PS	04/07/2022	04/07/2022	2- Doing (D)
Layout	Soldadura - criar espaço e mover máquinas portáteis		PS	04/07/2022	09/07/2022	1 - Planned (P)
Layout	Torre treliçada - mudar o serrote	Problema da alimentação (MP noutro sítio)	PS			
Layout	Ferragens - alterar o posicionamento das máquinas		PS	04/07/2022	09/07/2022	1 - Planned (P)
Layout	Postes - criação da celula de fluxo unitario (Plasma, furação, decapagem, quinagem)	Local definido, movimentação complicada	PS	11/07/2022	16/07/2022	1 - Planned (P)
Layout	Postes - multiplo lote: MC, Fresa, BLG, MF (máquina furação)	Local ainda não definido - DEFINIR Análise de dados (% A,B,C)	KI + PS			
Layout	Célula Máq. Vigas	Movimentação complicada, empresa externa, feita apos as outras mudanças	PS			
Kaizen Diário	Workshop Desenho quadro		KI + PS	27/06/2022	27/06/2022	4 - Completed (A
Kaizen Diário	Formação equipa Soldadura		KI	28/06/2022		4 - Completed (A
Kaizen Diário	Implementação e acompanhamento equipa Soldadura		KI	29/06/2022	04/07/2022	4 - Completed (A
Kaizen Diário	Formação equipa Prensas + Maquinagem		KI	05/07/2022		1 - Planned (P)
Kaizen Diário	Implementação e acompanhamento equipa		KI	06/07/2022	11/07/2022	1 - Planned (P)

Figure 9 - PDCA template, for follow-up on solutions

8. Confirming results and standards

A comparison of the previous situation and the current situation with indicators is essential. It is also important to describe the benefits brought by the improvement plan. If the results were not achieved, the project should return to step 2 of the A3 methodology.

In this step, all the standards are gathered and all the people who will use them are listed. A training plan should be created to make sure everyone is aware of the new standards created and how to apply them. Afterwards a skills matrix should be created and updated regularly to ensure that the team is fully capable of applying the new standards.

9. Assessing, Deploying and Preserving

Finally, it is good practice to show pictures of the before and after the improvement project, listing every improvement made and explaining how and why it was executed.

- Checking: Understanding what went well and what went wrong, identifying improvement opportunities for future projects, and checking all the financial and operational benefits.
- Spreading: Checking if it is possible to apply the same improvement to other machines/departments/teams of the company and, if so, creating tutorials on how to do it.
- Sustaining: Having documents and templates to insert all the improvement measures taken.

An A3 project is a powerful tool when well applied. The biggest hardship normally arises from steps 7 to 9 as sometimes improvement actions are not kept in the long term, do not have the right support from management, or are not updated when better solutions are found. The adoption and success of the project are always dependent on the team and organization, and one of the hardest things to do is change the organizational culture. This is a long and never-ending process of adopting Continuous Improvement every day, in every area by everyone in the organization.

2.5 Digital Kaizen™

As technology progresses, the need to integrate digital systems in organizations seems obvious and increasingly challenging. Industry 4.0 came with challenges to all organizations as technology seems to become obsolete more and more rapidly. Digital Kaizen™ presents itself as a model to better implement management innovation (KBS) and technological innovation in organizations. As is KICG's prerogative, Digital Kaizen™ aims to reach GQCDM(I) goals (Coimbra and Kaizen Institute 2016), such as:

- Flexibility
- Efficiency
- Safety
- Quality
- Time to Market

It is important to keep in mind that digitalization is not the goal, but yes, the path to reach the goals and targets of the organization. Not only it is important to focus on technology, but also on people and processes. Before digitalizing, it is important to improve processes to ensure that waste is not being automatized, then choose the right technology and establish a strong change management process to guarantee that everyone at the company is taking the most out of the technology.

The Digital Kaizen™ Knowledge Model is structured in 4 different applications and 3 types of technologies. All of them, are consolidated by the foundations of Digital Kaizen™, as seen in Figure 8. (Kaizen Institute 2022a)

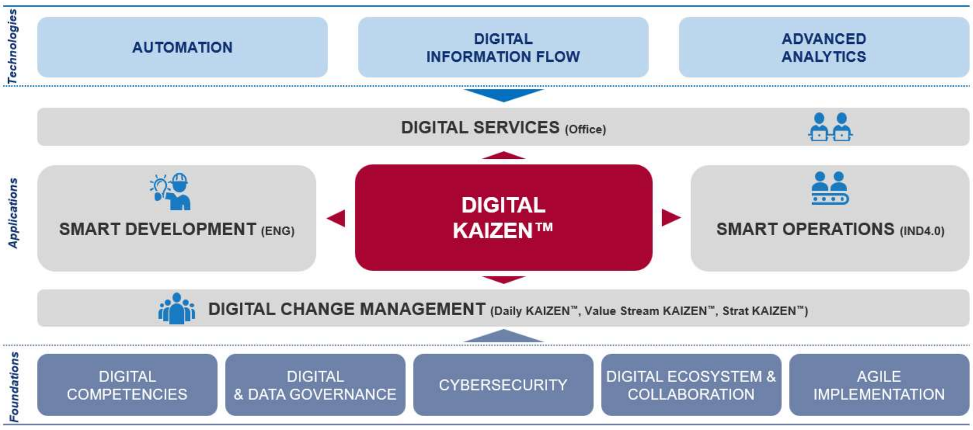

Figure 10 - Digital Kaizen™ Knowledge Model. (Kaizen Institute 2022a)

The areas of implementation are:

- Smart Development: Connected to engineering activities such as Research&Development.
- Smart Operations: Linked to industrial processes, internal and external (logistics, production, maintenance…).
- Digital Services: Related to support areas, mainly transactional processes like HR, Marketing, or Accounting.
- Digital Change Management: Strongly attached to Kaizen pillars, is used to support the Kaizen™ Business System's Strat, Value Stream, and Daily Kaizen™.

The 3 main types of technology identified are:

1. *Automation* of periodical tasks and processes.
2. Integration of *Digital Information Flow* systems to improve communication within the organization and with outside players such as customers and suppliers.

3. *Advanced Analytics* to manage, transform and display relevant data.

All these technologies and areas of adoption must be supported by the foundations of Digital Kaizen™. Defining digital skills and assembling a skills matrix and training program, having a digital governance model to manage data, adopting a strong cyber-security infrastructure, and having a good digital ecosystem with innovation partners and ongoing development are all crucial to having a digitally strong organization.

2.6 Standard Work

Standard Work is a combination between man, machine, and material, where the worker's focus is on value-added tasks (Coimbra and Kaizen Institute 2016). It can be obtained by observing and describing tasks being executed in the *Gemba*. By identifying hardships and improvement opportunities, Standard Work adoption aims to create standards and train workers to use them in their daily tasks to reduce waste, variability, and effort to obtain more consistent results and ultimately decrease costs to the organization. Standard Work can be adopted by most manufacturing companies, regardless of their level of automatization.

To implement Standard Work, at any level of an organization, the following 5 steps must be performed (Kaizen Institute 2022c):

1. Goals: Define SMART goals.
2. Study: Study the process in the Gemba with the help of tools like Spaghetti Diagrams, Muda Hunting, or Time Writing.
3. Improvement: Adoption of improvement ideas.
4. Standardization: Standardization of the process using visual elements.
5. Consolidation: Training the team and updating standards periodically.

Work Standardization often looks to reduce cycle times and increase productivity. Before observing the process, an analysis of what is going to be watched, which inputs and outputs are expected, what is the expected duration of the task, and what are the first and final step should be made. Once in the Gemba, the task should be detailed into micro-tasks, all times should be collected, and the micro-tasks should be classified as Value Added (VA) or Non-Value Added (NVA).

To improve the work, the team should be involved in the creation of solutions. Asking questions like "What is the goal of the task?" or "Why is it necessary?" are good starters for brainstorming solutions, looking to save time in the execution of tasks. Using an Effort-Impact Matrix can help to choose which measure should be taken first. Standards should come out of these brainstorming sessions. Standards are the easiest, most simple, and safe way of executing a task known at the moment of creation. They should be unique, visual, simple, accessible, and clear to have a transversal adoption. These standards help stabilize the process by removing recurring errors, creating a multidisciplinary team, and preserving the Organizational knowledge.

After the creation of the Standard, it should be presented to the team, asking for improvement opportunities. Also, the Standard should become visible in the workplace where it is being applied. When creating Standards for regular tasks, a good tool for checking if they are being used is the *Kamishibai* cards (Niederstadt 2013). These cards allow the team to see if the new tasks are being executed according to the Standard. They normally are two-sided with a green side and a red one. The cards, shown on Figure 11, contain a checklist with the new standards, if any non-compliance is found the card is visually presented to the team in the red side. In that case, the team leader should also look to implement countermeasures to guarantee that the Standards are being applied and are not obsolete. These routines of frequently auditing the work and improvements made is vital for the creation of a continuous improvement culture inside organizations, and all levels should have them.

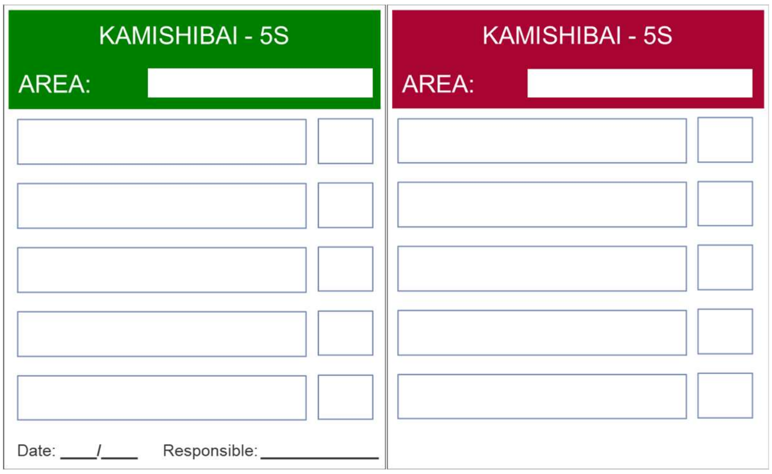

Figure 11 - *Kamishibai* cards.(Kaizen Institute 2022d)

3 Problem Context

This chapter will follow the first three steps of the A3 methodology, corresponding to the preparation phase of the workshop. As so, a global description of the production process will be first made, and, afterwards, the targets of the two workshops (reduction of losses in the PEN and reduction of residual waters).

Company D has three main units: the acid esterification unit, the neutralization unit, and the biodiesel production unit – PEBD. The first feeds the second unit and the second feeds the last unit. There is also a glycerin treatment unit, the PEG, that treats glycerin to then be commercialized and the alcohol rectification unit, that refines the used methanol in the process to then recycle it. All 5 units receive thermal energy from a furnace that is fed with biomass. There are monthly small maintenance stops, a week-long maintenance stop during the winter and a two-week maintenance stop during the Summer. These maintenance stops are sensible moments because they need to be done quickly to not disturb the expected production value, but they also need to be effective as the process wears the machine down significantly. To control the process and ensure every product complies with the needed quality standards, the plant has a laboratory. This laboratory receives samples taken by the Production team of various points in the process. From here, the samples are scanned for various parameters like composition, pH, and temperature. The analysis of these samples allows to understand if any changes to the process are needed. Finally, the Production team has a control room, where they can control process variables such as flux of product and water, open or close valves, and start or stop pumps. Figure 12 shows the three types of oils that Company D: acid raw materials, used materials, and virgin materials.

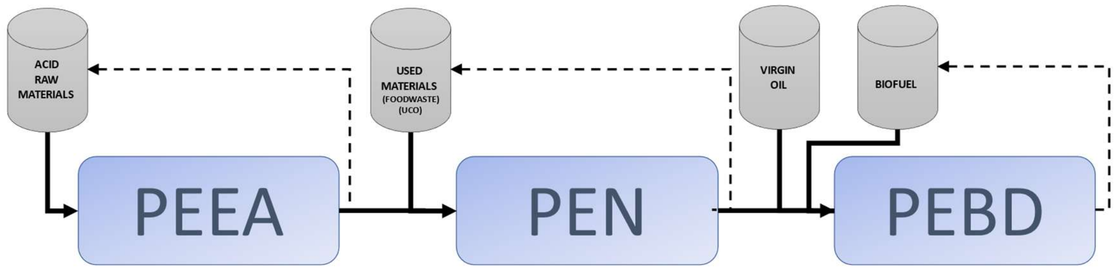

Figure 12 - Feedstock flowchart of the factory

Acid raw materials need to go through an acid esterification process in the acid esterification – PEEA - unit. This process takes place in a single reactor, the R10001, and it follows these steps:

1. **Replenishment** of the reactor with acid feedstock.
2. **Heating** of the material to ease the segregation of phases. This type of feedstock normally contains residue that solidifies at room temperature. The increase in temperature allows transforms solids into a paste.
3. **Acid addition** to clean the acid material. The oil will be cleaned throughout the whole process, with this being its first moment of waste removal. In this process, water is formed as it is a subproduct of the acid reaction.
4. The reactor is left **decanting** to let the waste settle in its bottom. This residue along with the water formed during the addition of acid is then **purged**.
5. **Alcohol** is then injected into the reactor followed by **acid**. The alcohol reacts with the FFA to create esters while the acid is added to act as a catalyst for the reaction.
6. The reactor is once again **decanted** to let the remaining waste and water settle at the bottom and then the tank is **purged** once more.
7. The product is then transferred to a **drying unit** where the alcohol is removed from the oil.
8. The oil is ready to be sent into PEN.

The reaction that takes place in this phase creates both acid and neutral waters in steps 3 and 5 because the acid addition produces water as a sub-product.

PEN is responsible for the neutralization phase of biodiesel production. It receives both oils treated in the PEEA and used neutral oils. It is responsible for removing impurities, to then feeding these oils along with virgin oils to the final phase of biodiesel production – the separation of esters and glycerol. Its process consists of the following phases, shown in Figure 13:

1. The oil entering PEN is pre-treated with an **acid**. This treatment aims to separate impurities from the oil and produce water. This also helps to avoid the forming of unnecessary soaps.
2. An **alkali** is then added to increase the pH of the oil, as very acid oils only produce water when put through an esterification process. This process also forms soaps – saponification. These soaps can help separate residue from oil but need to be removed.
3. The oil is then transferred to a **coalescent** tank where the separation of phases is promoted by gravitational forces. Oil has a lower density than water, soaps, waste, and pastes, and because so it stays afloat leaving the unnecessary products at the bottom of the tank. This equipment is **purged** when the horizontal decanter is not in-line, to remove soaps, mainly.
4. When in-line, the oil is transferred to the horizontal decanter where oil is **separated** from waste, soaps, and water using rotational force, induced by two engines with a torque differential. This equipment is put on- or off-stream depending on the quality of the oils entering PEN.
5. The oil is then **washed** again, using water to purify the oil. An acid is also injected into the tank to help separate pastes and soaps from oil, as it increases these substances' affinity with water.
6. A **vertical centrifuge** receives the washed oil and separates the water and soaps from the oil, using its different densities to keep unnecessary products at the bottom of the equipment. It is then **purged** to remove the excess products. In this equipment, water is inserted to promote the separation of phases of oil, soaps, and waste.
7. The oil is then transferred to SKID 4, a tank that acts as a **buffer** for the following equipment. This tank makes sure any flow fluctuation is absorbed and the output of PEN is not affected.
8. The final stage of PEN consists of a **dehydrator** that removes water from the oil. This is done through heating the mixture, evaporating the water, and finally extracting this steam from the oil.

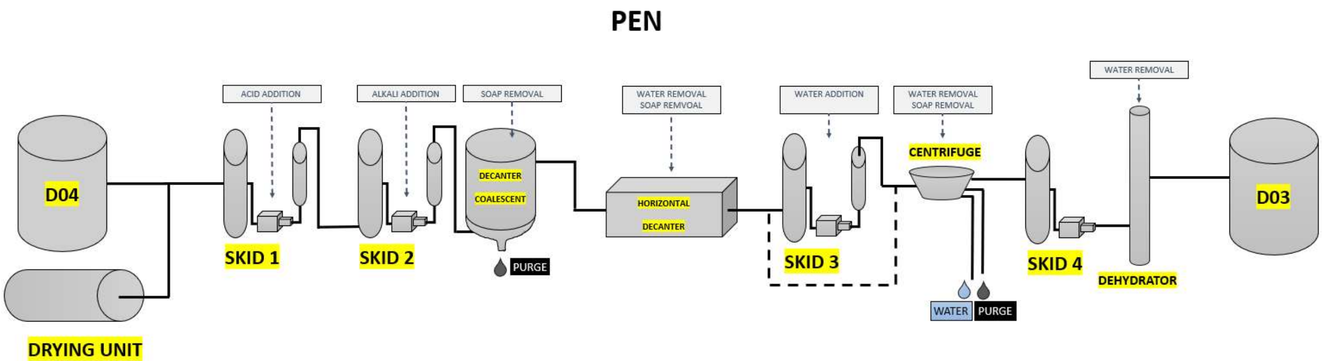

Figure 13 - PEN's flow diagram

The oil is then analyzed to determine if the pH, soap quantity, waste quantity, and water quantity are up to standard. If not, the oil is reprocessed in PEN. If the standard quality is met, then the oil is transferred to the final stage of biodiesel production, where esters are segregated from glycerol.

In PEN, the amount of product (input) inserted, and the amount of product extracted (output) is measured, both in total, and after moments of extraction (purging). These losses indicate the quality of purging being done, if the separation equipment is well setup, and if the purging in Gemba is being done correctly. If the oil needs reprocessing at PEN, it means that somewhere along the process, it was not treated correctly which also translates into a loss. If these losses are too high, it is most likely that oil is being removed, and an economic opportunity is being wasted.

There is water formation in the process that is unavoidable, whether it is formed as a subproduct of chemical reactions happening both at PEEA and PEN, cleaning water during PEN's process, or even water injected into separation equipment to wash it. Nonetheless, water quantity in the oil is often higher than expected. This represents a cost to the company as water shipping has a significant cost, especially acid water. It is important to state that acid water could be shipped at a lower price if the pH was not very low.

3.1 Defining the Challenge

After the two first years of Kaizen Institute's project at Company D, new priorities were defined as initial problems were solved. As so, two new goals were set:

- Reducing the percentage of losses in PEN in all its components.
- Reducing the production of acid waters, transforming them into neutral waters.

These goals were set together with the company's board and with its middle management team. In this step, it is common to try and look for causes and solutions but following the step-by-step is fundamental to a successful A3-led project.

Both the percentage of losses in PEN and the production of acid waters in cubic meters (m^3) will be the Key Performance Indicators (KPI's) of each initiative and will allow for evaluating the progress made. In *Kobetsu* Kaizen™ events it is fundamental to have indicators, as they show the progress made, positive or negative trends, and allow, above all, to launch countermeasures if there are deviations from the target.

3.2 Checking Current State

The goal of this step is to understand the process thoroughly, collect data, and define where the company is at the moment. Flowcharts helped understand the process as a whole for both challenges and, besides the KPI's defined in the last step, some micro indicators were defined to have more local visibility of the process. This allows to have a better grasp of where problems are occurring, their impact on the KPI, and to release more specific and oriented countermeasures.

First, regarding the losses in PEN, the flow diagram shown in Figure 13 helped to have a better perception of the process. Drawn with the help of the Industrial Manager, it gave a good understanding of where purging and product removal was happening in the process. These two moments are, obviously, responsible for losses – some avoidable, others unavoidable. Then, the baseline was drawn, using numbers from November and December of 2021. The losses were split into: total losses, effective losses, horizontal decanter losses, vertical centrifuge and dehydrator losses and reprocessing losses. Effective losses accounted for losses in the horizontal and vertical decanters and in the dehydrator. The total losses equaled to the sum of the effective losses and the reprocessing losses. The main focus was put into decreasing the effective losses as they translated how well the process is being controlled. The reprocessing losses should also be decreased but it is important to keep in my mind that this reprocessing could be due to the quality of the feedstock received, and therefore could not be controlled by the company. The baseline was then set:

- **Total Losses:** 28.27%
- **Effective Losses:** 20.49%
- **Horizontal Decanter Losses:** 10.72%
- **Vertical Decanter and Dehydrator Losses:** 9.77%
- **Reprocessing Losses:** 7.78%

These values permit a better comprehension of where the problems were centered, and some interpretations could already be made. The horizontal decanter had the highest percentage of losses meaning this machine was separating a lot of material. The losses in the vertical decanter and dehydrator also point towards a bad configuration of these two devices. The percentage of losses could not at the time be calculated separately as the company did not possess the machinery to do so. These values were made visible in a flip chart, Figure 14, posted in the Mission Control Room, and, further ahead in the project, where the tracking of the KPIs will be made.

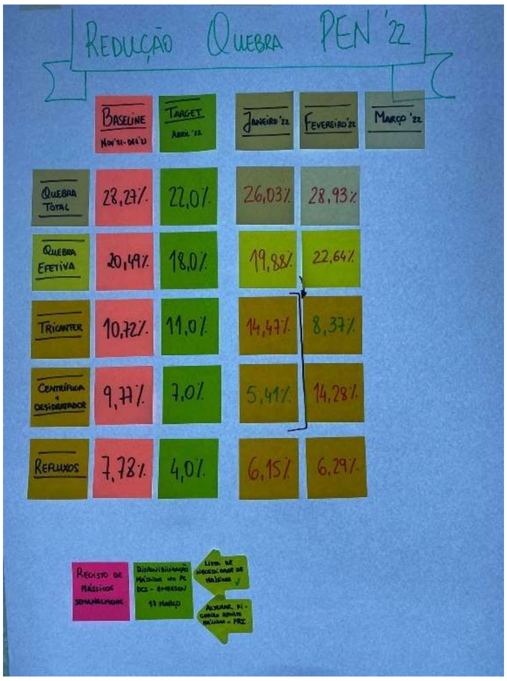

Figure 14 - Losses reduction flipchart.

The same analysis was done with the residual waters. The flux of water in the process was drawn with the Industrial Manager. Along with this tool, some micro indicators were set to, again, have local visibility of the process and to react better to fluctuations above the target – set in the next step. As shown in Figure 15, two fluxes of water happen in the process: one for neutral waters and the other for acid waters. The flowcharts were drawn in flipcharts placed in the Mission Control Room and they also contained the targets and monthly values of the indicators defined. They contained the stream of water, the tanks or equipment it went through, the insertion of acid, the purging of water, and the unit that was producing the water.

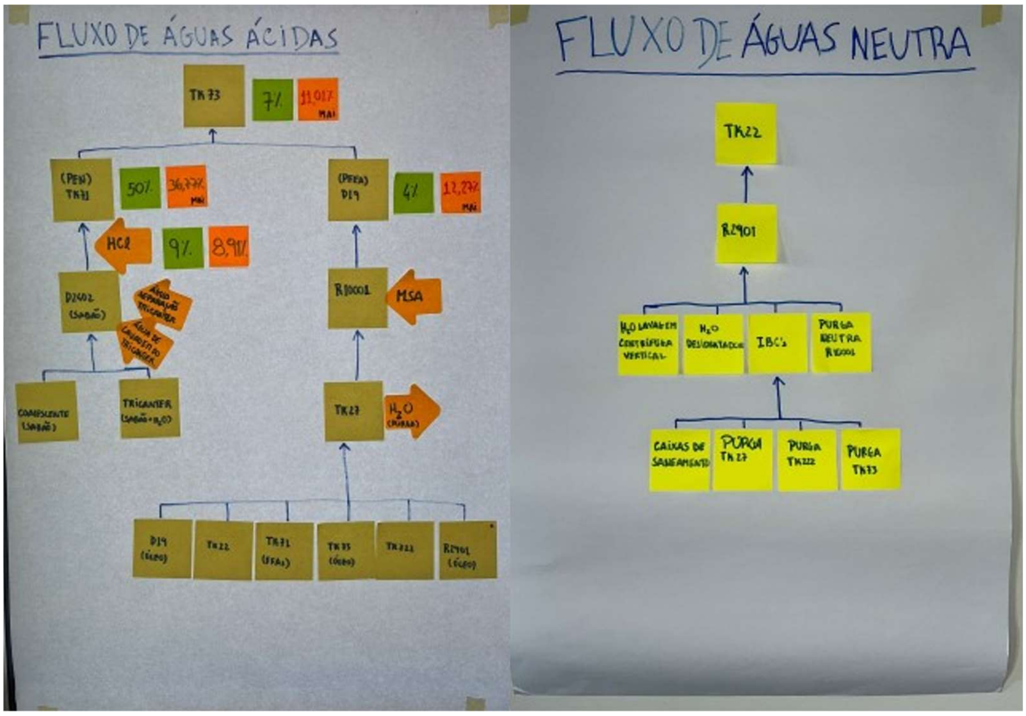

Figure 15 - Acid and neutral waters flowchart

To establish the baseline for residual waters, data from July 2021 to February 2022 was analyzed. The cost of shipment for neutral waters increased 5% in December 2021, reaching the value of 51975 [MU][1]. The cost of shipment for acid waters stayed at 384 [MU] per ton plus a 900 [MU] transport rate. The KPI for this workshop was calculated as the ratio between the number of tons of residual waters – acid or neutral – produced and tons of raw materials processed at PEN. The number of tons of residual waters produced would not be a good KPI, as this production is heavily linked to the amount of product that goes through PEN.

$$KPI = \frac{Amount\ of\ residual\ waters\ produced\ [ton]}{Amount\ of\ raw\ materials\ processed\ at\ PEN\ [ton]} \tag{1}$$

The average percentage of residual acid waters produced from July of 2021 to February 2022 was 11.25% and the percentage of neutral waters was 14.56%. Nonetheless, while the plant produced more neutral waters – 3.31 percentual points more– the costs of shipping acid waters accounted for 93.2% of the total costs of shipping residual waters. It is also important to address the fact that the low pH influences the shipping cost of acid waters. If the process was controlled in a way that no excessive amount of acid was added, then the acid waters would not have an extremely high acid value. In addition, the fact that the procedures surrounding the purges and transfers of product between the tanks were mostly not standardized. This means that oil is shipped as water, creating another problem: the company was paying for its selling product to be shipped. Solving this issue means that the company would be saving money in shipment costs and increasing its profit has it would have available more biodiesel to commercialize.

[1] Monetary Unit.

Table 1 – Residual Waters Baseline

Date	% Acid Waters	% Neutral Waters	Number of Acid Cisterns	Number of Neutral Cisterns	Acid Waters Total Cost [MU]	Neutral Waters Total Cost [MU]
Jul/21	12.72%	18.78%	14	10	131 212.80	4 950.00
Aug/21	8.73%	16.47%	11	6	104 316.48	2 970.00
Sept/21	9.83%	14.58%	16	11	151 954.18	5 445.00
Oct/21	10.40%	10.84%	10	10	94 009.92	4 950.00
Nov/21	17.52%	14.10%	12	15	113 089.92	7 425.00
Dec/21	28.88%	17.66%	6	11	53 338.56	5 717.25
Jan/22	7.09%	13.74%	7	13	58 470.24	12 201.75
Fen/22	6.10%	13.44%	7	13	50 905.44	11 706.75
Baseline	11.25%	14.56%	-	-	94 662.19	6 920.72

Similar to what was done regarding the losses in PEN, micro indicators were defined. These gave visibility to where water was being over-produced or over-injected, and where acid was being added in excess. These indicators and their baseline, calculated using values from January to March 2022, were:

- **Percentage of Water Produced in PEEA:** 7.37%
- **Percentage of Water Produced in PEN:** 48.54%
- **Percentage of Acid Inserted in PEN's Waters:** 7.78%

The PEEA indicator shows if there is an oil with water in the esterification unit, or if the water coming out of there is solely produced by the chemical reactions. The second indicator shows if there is water being injected in excess into the neutralization process and/or if the acid waters tank is receiving oil. Finally, the acid indicator shows if the amount of acid being inserted in the waters removed from PEN is excessive, unnecessarily increasing the pH of these waters. This acid is added to a tank that receives the soaps, pastes, and waters extracted from the PEN's stream and serves as a facilitator for the separation of these products.

3.3 Setting Target State

The next step was to find a target goal. The goals set in this phase should be aligned with the company's view of its ideal state – or its True North. The True North is the direction the company should take to reach the ideal state. This is important because the goal of the initiatives should always be to improve the company to a standard of excellence all around. As stated before, this should be done with the help of the team involved, as their experience and knowledge of the process are very important to access a realistic goal. It is appropriate to stress the importance of this stage: the goal will guide the project in terms of what initiatives to start and what countermeasures to implement.

For the losses in PEN, the main goal is to keep the losses on the Horizontal Decanter, reducing all the others. The following targets were set:

Table 2 - Baseline and Targets for reducing the losses in PEN

	Baseline	Target	Percentual Point Decrease
Total Losses	28.27%	22.00%	6.27
Effective Losses	20.49%	18.00%	2.49
Horizontal Decanter Losses	10.72%	11.00%	-
Vertical Decanter and Dehydrator Losses	9.77%	7.00%	2.77
Reprocessing Losses	7.78%	4.00%	3.78

These targets for both the KPI and the micro indicators were obtained together with the Industrial Manager, and his experience and knowledge of the process were once again crucial in doing so. They were set looking to achieve a controlled process by only removing unnecessary processes from its stream.

One important aspect regarding the reduction of residual waters is that the actual goal is to transform acid waters into neutral waters. This transformation aims to keep neutral waters production at the same percentage, meaning that the total water production should be reduced. The economic gain is obvious and, as stated before, if the pH of acid waters was also increased, there would be an opportunity to renegotiate the shipping costs of acid waters. This was not a priority, but it was mentioned in this step as possible future step. Once again, the Industrial Manager helped define the targets. He was a key element in all the project as he had deep knowledge of the process and of the plant. The goal was defined as function of the production of acid waters. This means that the value set for that type of water then, obviously, influenced the target value for neutral waters. Finally, the values obtained were:

Table 3 - Baseline and Targets for reducing the wastewaters

	Baseline	Target	Percentual Point Decrease
% Acid Waters Produced	11.25%	7.00%	4.25
% Neutral Waters Produced	14.56%	19.00%	-
% Acid Waters Produced in PEEA	7.37%	5.00%	2.37
% Acid Water Produced in PEN	48.54%	50.00%	-
% Acid inserted in PEN Waters	7.78%	8.00%	-

This meant a reduction of 4.25 percentual points of the acid waters produced, compared to the raw materials processed in PEN. A similar increase is expected in the production of neutral waters, resulting in economic benefits for the company. To better understand this benefit, consider a month with 1000 tons of raw materials processed in PEN. Assuming the average rate from July 2021 to February at which a shipment occurs, with the values obtained in the baseline shipment cost would amount to 51 858.00 [MU]. In a month with the same 1000 tons processed, but with the goals of residual water production achieved, the company would pay 34 498.50

[MU] in shipment efforts. This translates to a 33.5% monthly saving and 208 314.00 [MU] saved yearly.

4 Solution Design

After the preparation phase of the A3, the design of solutions starts. In this phase, a root cause analysis is done, followed by designing solutions, and testing them. A great part of this stage was done through workshops with the Industrial Manager. Together with him and the Production Manager, the true causes of problems were identified, and the correspondent solutions were designed. The work done previously, collecting data and mapping the process helped structure this phase.

4.1 Root-cause analyzis

Before starting to design solutions, the true causes of problems need to be found. One of the biggest concerns leading this workshop was to really dig into the problems. The first Event was about losses in PEN. In good Kaizen fashion, a flipchart was posted in the Mission Control Room, as shown in Figure 16. The standard Kaizen color code was used: yellow for equipment/departments/persons/…; pink for problems; green for solutions; orange for the status of the action. The sources of problems were then listed:

1. Coalescent
2. Horizontal Decanter
3. Vertical Decanter and Dehydrator
4. Refluxes

These sources were identified as they were the point of removal of matter from the stream. The Industrial Manager and the Production manager were challenged to dive into the unit's problems throughout this workshop. The goal was to understand the real reason why oil was being extracted from the process.

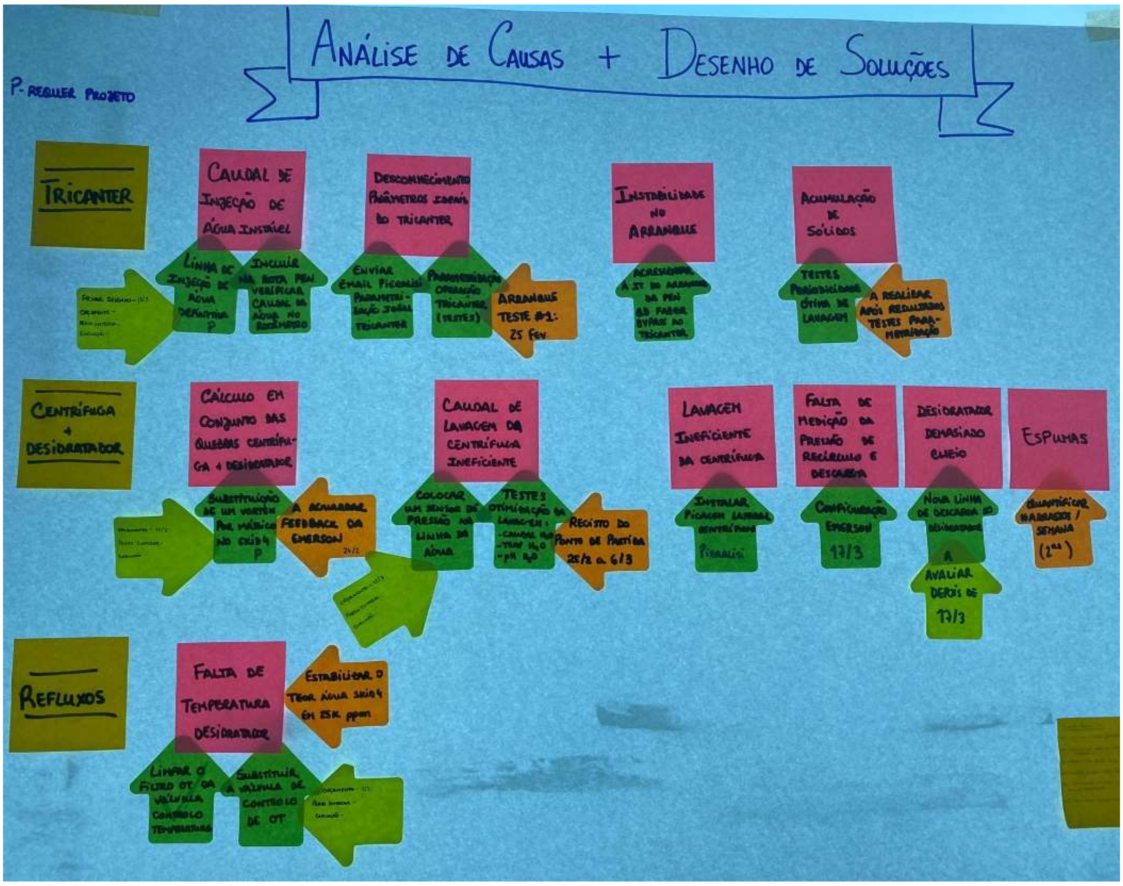

Figure 16 - Flipchart used to do the root-cause analysis of losses in PEN.

The sources identified are listed in Table 4. Starting with the coalescent, the two problems found were the unstandardized quantity of purged soap and the inefficient separation in the equipment. When the horizontal decanter is in-line, the coalescent is not used as a separating device. However, when the horizontal decanter is bypassed, the coalescent acts as a vertical centrifuge and is used to remove soaps, and other residues. The purging of this waste was not standardized and could lead to the removal of oil along with residue. Also, the separation of phases on this equipment proved to be inefficient at times, with the oil still having a considerable amount of soap, water, and solids mixed in it. Regarding the horizontal decanter, the unstable injection of water flux means that it was harder to separate the remaining solids in the product, deregulating the machine. The decanter would then start to send oil to the residue tank, and in more extreme situations the whole unit had to be stopped for it to be recalibrated. Another significant problem found was that the horizontal decanter was not projected specifically to separate biofuel products or even to process similar substances. The machine supplier could not give any input on what the ideal working parameters were because of their lack of experience in this field and all the knowledge was obtained in an empirical way. The variability of the product that was fed into the unit exacerbates this issue. When PEN is restarted after a stop, the decanter works poorly during this initial phase, extracting not only water and waste but also oil, having an unstable performance. Finally, one of the root causes found was the accumulation of solid waste. The machine should not receive a large amount of solid waste, but there is still an amount that goes into the decanter, jamming both oil and residue outlets. Looking at the vertical decanter and dehydrator, the first problem identified was that the losses of the two machines were calculated as one due to the equipment used. This proved to be a problem, because of the impossibility of comprehending what was the relative weight of each equipment to the losses. It was not possible to analytically confirm if either the vertical decanter or the dehydrator contributed much more to the unit's losses. The washing flow of the vertical decanter was also identified as a problem. The flux of water was considered insufficient by the team, while the optimal pH and temperature of the washing water were also considered. This machine accumulated a considerable amount of residue and if not cleaned properly, it could underperform. As so, the next issue found was that the vertical centrifuge was not being washed often enough. The working cycle of the machine would last 12 minutes followed by a 2 minutes wash, but this periodicity was found to be insufficient. This frequency should also consider the product's composition. Another issue regarding the vertical centrifuge was the lack of measurement of the reflux and transfer pressure. The reflux outlet is fed with oil that needs to go through PEN once again. The transfer outlet sends oil upstream to SKID 4, before entering the dehydrator. If the pressures of both outlets are not known, the Production team will have no visibility of the flow of water going into each, consequently not knowing if the machine is properly separating oil from waste. The accumulation of product inside the dehydrator was also marked as a problem. The excessive volume inside the equipment prevents it from executing its function correctly. This equipment also formed waste foams inside which deregulated it, and, consequently, prevented it from working properly. Finally, regarding refluxes – the reprocessing part of losses – the main issue found was the low temperatures inside the dehydrator. Because of this, water stopped being removed from oil hence the need for reprocessing. As the quality of oil entering the final biodiesel production cannot be compromised, this was also identified as a problem.

Table 4 - Problems found for each source of losses

	Horizontal Decanter	Vertical Decanter and Dehydrator	Refluxes	Coalescent
Problems	Unstable injection of water flux	Losses calculated together	Low temperatures in the Dehydrator	Quantity of soap purge is not standardized
	Optimal parameters not known	Vertical Decanter's washing flux insufficient		Inefficient separation
	Instability on start	Vertical Decanter washed insufficient times		
	Solid waste jamming	Lack of measurement of reflux and flush pressure		
		Dehydrator too full		
		Foams formed in the Dehydrator		

Looking at the wastewater reduction a similar approach was followed. Figure 17 shows the flipchart that was used to connect tanks to the problems related to residual waters. The same color code was used and the main focus of the workshop was to use the knowledge of the Industrial Manager to find the root causes of problems in this matter.

Figure 17 - Flipchart used to do the root-cause analysis of residual waters.

The following issues were found:

- D19: the oil purge of this tank was not standardized. This tank receives water from both purges of the R10001 during the acid esterification reaction. These waters could sometimes also contain some oil, hence the need for a purge.
- Tk 22: the oil purge of this tank was not standardized. This tank's function is to receive neutral wastewaters and store them until shipment. Sometimes, the water has oil in it from upstream sources, hence the need for a purge.
- Tk 71: the oil purge of this tank was not standardized. This tank receives the acid waters produced and inserted into PEN. Once again, sometimes oil is mixed with the water, due to bad operation upstream, so there is a need for a purge.
- Tk 222: the water purge of this tank was not standardized. This tank received oil and unwanted waste from the Alcohol Rectification unit of the plan, to then feed this oil into the PEEA unit. If done incorrectly, this purge would send oil, but also water to the PEEA increasing acid water production.
- R2901: the oil purge of this tank was not standardized; there is no acidulation of the product. This tank receives residual waters from multiple sources. There should be a separation of the water from the waste mixed in it and the remaining oil. The need for a purge, comes from the possibility of oil being mixed with water. If the purge was controlled in this tank, it would avoid oil being shipped as wastewater. Also, if done correctly, the purge would prevent the water to be acidulated because of being reinserted in the process, and therefore shipped at a higher cost. The acid insertion would help separate the three phases to better flux them.
- Tk 27: the water purge of this tank was not standardized. This tank feeds the PEEA unit with oil. The purge of water should be done uniformly to avoid purging oil and also to avoid the water to go upstream, meaning it would be acidulated and being transported as acid water, instead of being shipped as neutral water at a lower cost.
- R10001: the neutral purge of this reactor was not standardized; the acid purge of this reactor was not standardized; the acid consumption of this reactor was not standardized. As explained before, this reactor represents the esterification part of the process, and as said before two purges occur. These purges should only remove water, but sometimes oil maybe extracted. If a surplus of acid is injected during both the pre-treatment and the actual esterification reaction, the water removed can be excessively acid.
- Horizontal Decanter: the washing water was streamed to the start-up of PEN; the optimal quantity of washing water. This water is sent to the D2402, a deposit that receives this water and the one injected into the decanter, the soaps from the Coalescent, and the product that goes through PEN in its initial phase (this product is sent here as a buffer to start the whole unit, and then is reprocessed). If the washing water of this decanter was sent to the R2901, as it happens with the washing water of the vertical centrifuge, then it would not be shipped as acid water, lowering the shipment costs of the biodiesel company.
- D2402: the acid consumption of this tank was not standardized. The acid insertion aims to separate water from soaps, which this tank receives from the coalescent and the horizontal decanter at PEN.
- Tk 73: loads to shipment companies are not standardized. This tank stores acid waters before shipment. The loading of waters should be controlled to ensure that the water being shipped does not contain oil.

Finally, during the workshops, another problem was identified. As stated before, the Industrial Manager's knowledge of the process was an important contribution to the workshops. However, either before or even at the start of the workshops, the IM spent an excessive amount of time calculating KPI's. It was clear that a valuable member of the team could not be spending time in this Non-Value-Added task.

4.2 Design of Solutions

After identifying the root causes of problems, solutions were then debated. There were solutions that could be rapidly implemented while others had longer execution times, either because of the solution's complexity and/or because it was dependent on external suppliers or companies.

For the losses in PEN, starting with the Coalescent the solutions for each problem were:

1. **Standardization of the quantity of soap purged.** This eliminates the variability from the process, and, if designed correctly, stops the extraction of oil when purging. If every time the purge is done, the standard procedure is followed, then the process could be controlled. A Job Instruction (JI) was designed, with the procedure step by step along with pictures to facilitate the interpretation of this document – depicted in Figure 18. This solution was designed together with the Production Manager and passed onto the Production team.
2. **Injection of water into the equipment.** Water helps the separation of phases, between oil and soap. This way, when purging the Coalescent, no oil would be extracted. A line of water at the inlet of the tank was proposed.

PEN | **Coalescent purge**

Revision Date: **13/05/2022** KAIZEN INSTITUTE

Intr.	PEN is where the oil is neutralized by inserting acid in Skid 1 and an alkali in Skid2. This will creat a subproduct: soap. A purge is done in the Coalescent to keep the unit stable.
1	The purge should be done to keep the losses between 6 to 8% of the Coalescent volume (this information can be found in PEN's file)
2	The control valve Lic 2401 is opened or closed in order too keep the losses between 6 and 8%.
3	If the control valve Lic 2401 is totally opened and the losses are still below 6%, the Bypass should be open.
4	If with both Lic2401 and Bypass totally opened, the losses are still below 6%, then the coalescent's reflux pump should be connected between the purging and sample outlets, close valve y, open both x valves and turn on the pump.
5	Confirm if the purge started.

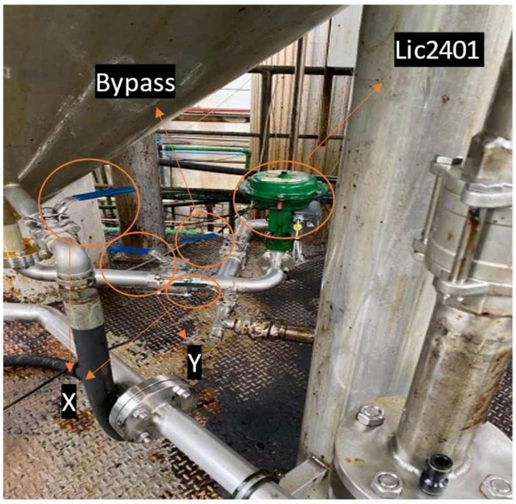

Figure 18 - Job Instruction for the Coalescent Purge.

In order to tackle the unstable flux of water of the Horizontal Decanter, the following solutions were found:

1. Installing **a dedicated, permanent line** for water injection. This would likely solve this issue, but it is yet to be taken forward as it is not a priority of the company at the moment.
2. Including **checking the water flux in PEN's route**. This route intends to be an autonomous maintenance check-up done by the Production team to the neutralization unit. As the horizontal decanter has a rotameter, this device should be checked regularly to ensure the current flux of water is being injected.

To find the optimal parameters of the horizontal decanter two initiatives were defined:

1. Contacting the **machine supplier**. Their knowledge about the machine and from other users' experience can provide important information.
2. Conducting **internal tests** to understand what the optimal parameters of the machine are. As the feedstock's quality can vary, this knowledge will be important.

Regarding the instability during the restart of the unit, the following solution was designed:

1. Adding to the Job Instruction of PEN's restart that the **horizontal decanter should be bypassed**, during the initial phase. This was an important Job Instruction as the topic of when to put the Horizontal Decanter in line was defined as critical issue. PEN was very unstable when the workshop started, especially the Horizontal Decanter. Figure 19 shows the JI created that was then used to train the Production team to apply it.

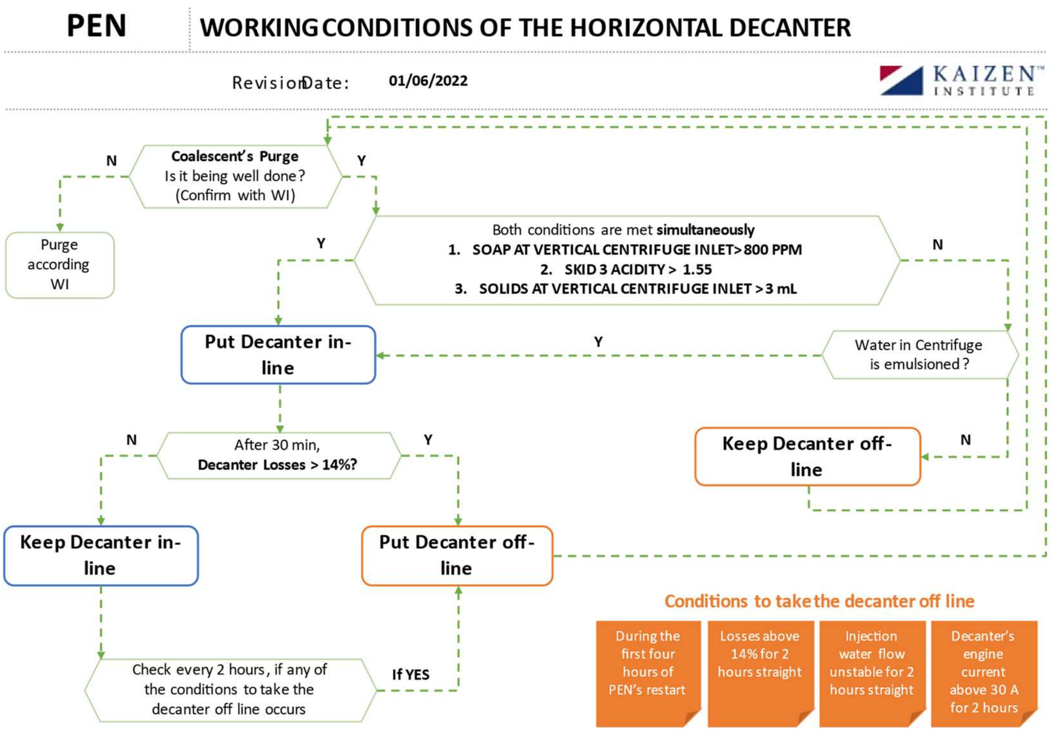

Figure 19 - Job Instruction to decide when the Horizontal Decanter should be bypassed.

Finally, to mitigate the solid waste jamming in the horizontal decanter:

- **Testing** the optimal periodicity between washings. Understanding when the right time to wash the machine would reduce the number of jamming occurrences.

Onto the losses of the Vertical Centrifuge and the Dehydrator, to separate the values of losses for each machine the following initiative was planned:

- **Changing the current flowmeter for a vortex flowmeter** in the outlet of the vertical decanter. The current equipment is a mechanical flowmeter and does not allow to separately calculate the losses of each equipment. This initiative was not taken forward as this was not a priority for the company.

To achieve an efficient washing water flow in the vertical centrifuge the solutions designed were:

- **Installing a pressure sensor** in the water line, to evaluate the flux of water in real time.
- **Conducting internal tests** of the washing water. These tests were designed to study the influence of the flux, temperature, and pH of the washing water. To do so, the Production team was instructed to collect this data while doing their round of samples of the product. A Job Instruction - Figure 20 - was also created for this sake, to guarantee that the samples would not vary.

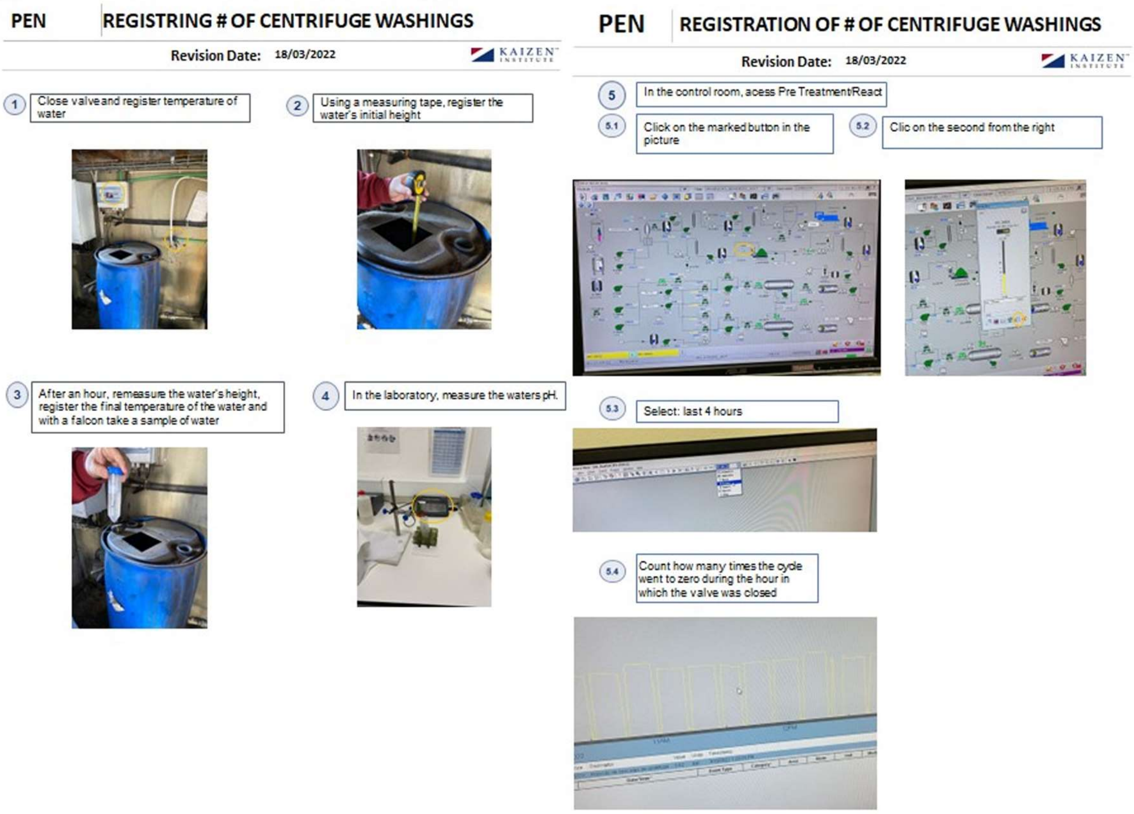

Figure 20 - Job Instruction to register the number of washings done in an hour.

- **Installing a sample point** in the centrifuge to evaluate the quality and composition of the oil. This way the Production team can have a better perception of the timing to wash the equipment.

Looking at the Dehydrator, 3 initiatives were started:

- **Programming the software in the control room** to start measuring the pressures of both reflux and flush.
- **Installing a new flush line** in the dehydrator, to prevent it from being too full,
- **Registering the number of drags** weekly and crossing the numbers with values from the laboratory. These drags happened when the oil going into this machine does not have the right parameters. If so, the machine will start extracting oil along with the water, something that should be avoided.

This last initiative started a workshop of its own. After collecting data from January through April of 2022, the data from the laboratory was crossed with the number of drags. Together with the Industrial Manager, the root cause of the drags was analyzed. Once more, a flip-chart, shown in Figure 22 was used, to visually translate the workshop.

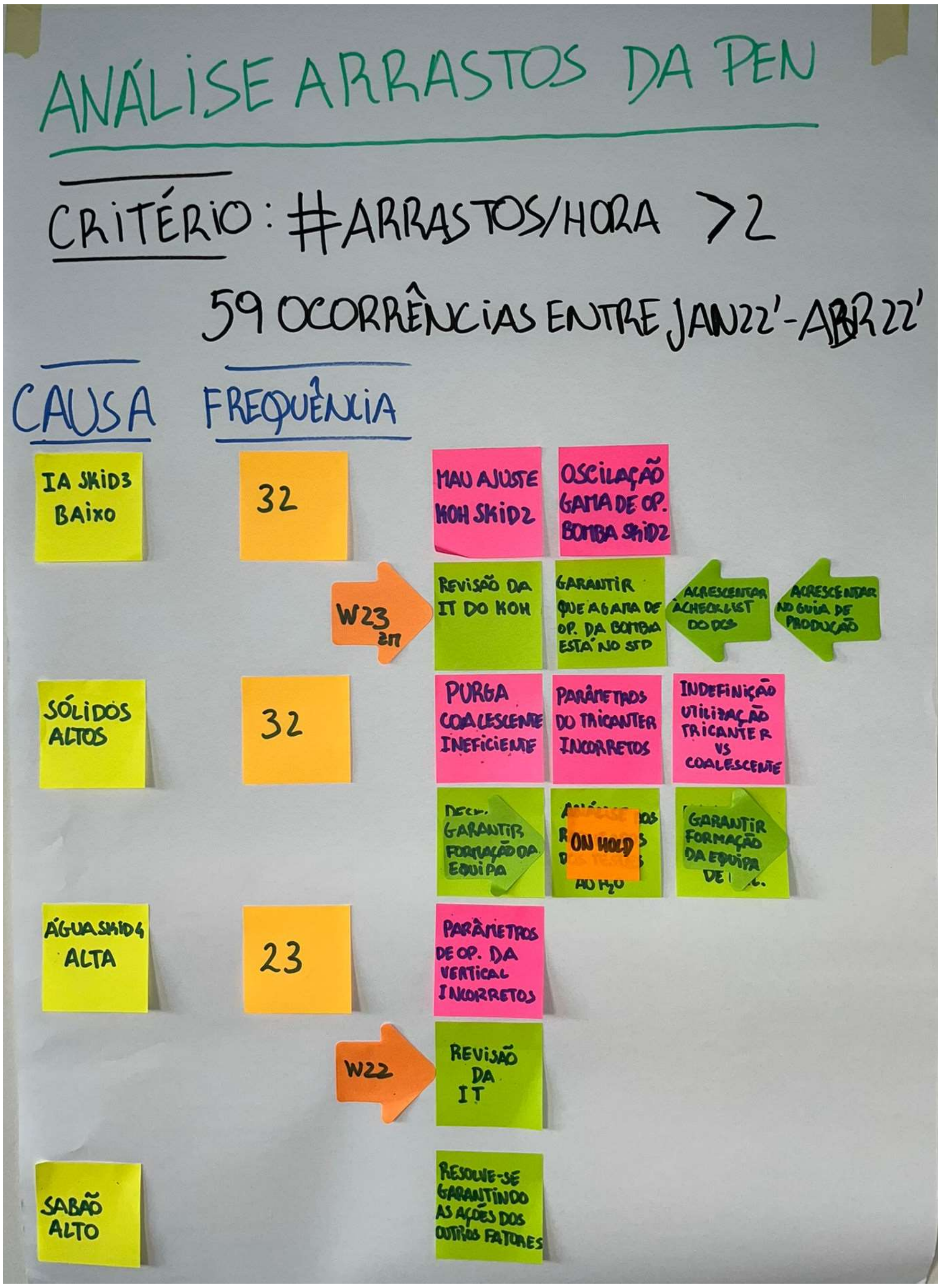

Figure 21 – Flipchart used in the workshop to reduce the number of drags in the Dehydrator. A 3C approach was used.

An occurrence was studied when more than two drags per hour occurred. 59 occurrences were identified from January through April 15th. The four causes pointed out by the IM were: low acidity at the inlet of SKID 3; high solid waste quantity in the outlet of the vertical centrifuge; high water quantity in the outlet of the vertical centrifuge; high soap quantity in the outlet of the vertical centrifuge. This workshop was led using the 3C model – a structured problem-solving tool that identifies a Case, or problem, its Cause, and the Countermeasure to be adopted. The initiatives launched are presented in Table 5.

Table 5 - 3C for the reduction of the number of drags in the dehydrator

Case	Cause	Countermeasure
Low acidity at the inlet of Skid 3	Bad alkali adjustment at Skid 2	Updating the Alkali Insertion Job Instruction – Figure 22
		Training the Production team accordingly
	Oscillation of frequency of Skid 2's pump	Updating the Skid 2 Job Instruction, to contemplate the frequency adjustment of the pump
		Training the Production team accordingly
High solid waste quantity in the outlet of the vertical centrifuge	Inefficient Coalescent Purge	Creating a Job Instruction for this
		Training the Production team accordingly
	Incorrect Horizontal Decanter Parameters	Conducting internal tests to find the optimal parameters
	Incorrect definition of usage or not of the Horizontal Decanter	Defining when to put the Horizontal Decanter in line and when to bypass it
		Training the Production team accordingly
High water quantity in the outlet of the vertical centrifuge	Incorrect operating parameters of the Vertical Decanter	Updating the Vertical Decanter Job Instruction
		Training the Production team accordingly
High soap quantity in the outlet of vertical centrifuge	All of the Above	Is corrected by conducting all the other countermeasures

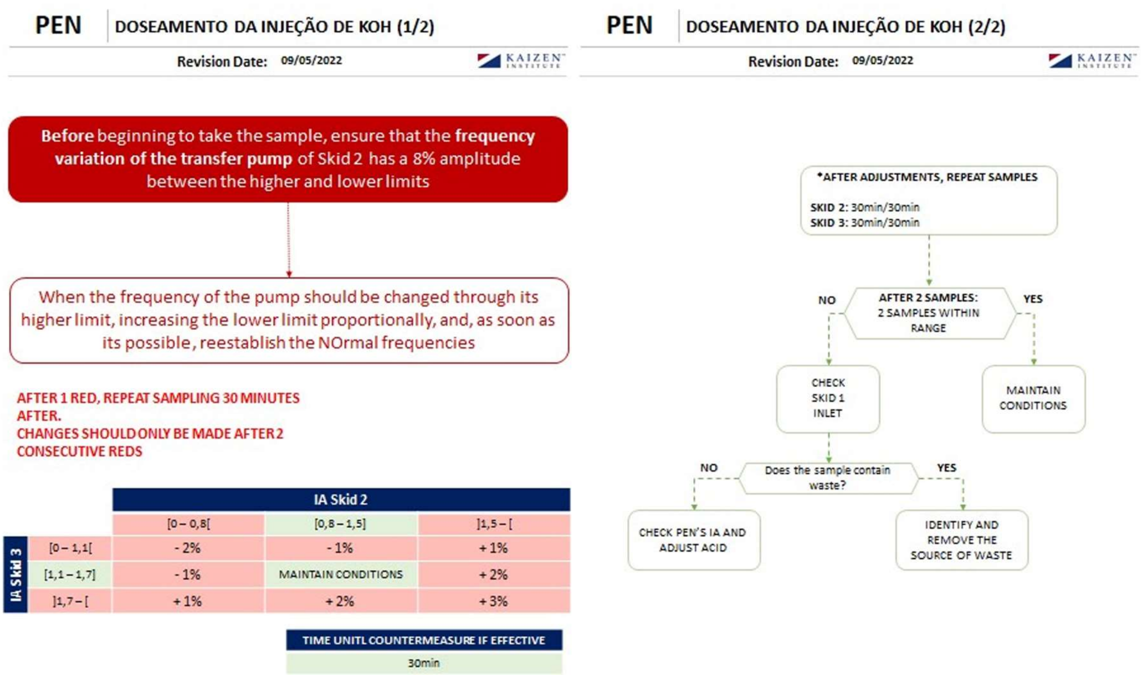

Figure 22 - Job Instruction for the alkali adjustment.

Finally, for diminishing the refluxes and guaranteeing the Dehydrator working temperature, two solutions were implemented:

- **Cleaning the thermal fluid valve** to ensure that the thermal oil is reaching the dehydrator at the desired temperature.
- After cleaning the valve, the team concluded that it needed **to be replaced**. So, an external company was contacted. A budget was given, which was approved by the board, and the valve was ordered and then installed.

In parallel with all the initiatives taken, another improvement opportunity was found. Having the mass entering and leaving PEN visible in the Production control room would mean that the team could more rapidly identify deviations from the standard and be more agile to intervene. To do so, the company that provided the software for the Production control was contacted to update the program. The team is still in a data gathering stage so there can be a better understanding and comprehension of the results given by the software.

For the reduction of wastewater, starting with the horizontal decanter's washing water, the solutions found were:

- **Bypassing the flush line** to avoid these waters being sent to the acid waters stream. If these waters did not mix with acid waters, they could be shipped as neutral waters at a lower cost.
- **Conducting internal tests**, as said in the reduction of losses in PEN section, to find the optimal water flow to be injected into the oil. If done correctly, the water intake of the plant would be controlled and, probably, decreased.

Looking at Tk 27, a tank that feeds oil into the PEEA, the initiatives taken were:

- **Standardizing the water purge** of this tank. The focus doing this Job Instruction, shown in Figure 23, was not only on the procedure of the Gemba, but also linking the percentage of water inside a tank that, in theory, should mainly contain oil. To do this connection, a series of tests is planned, for the laboratory to analyze samples from this tank and obtain the percentage of water in it. This test will allow the team to understand if there needs to be a change in the criteria to fill the R10001. If the percentage of water in the Tk 27 is higher than 1% then Tk 27 still needs purging, before sending the product to the PEEA unit.

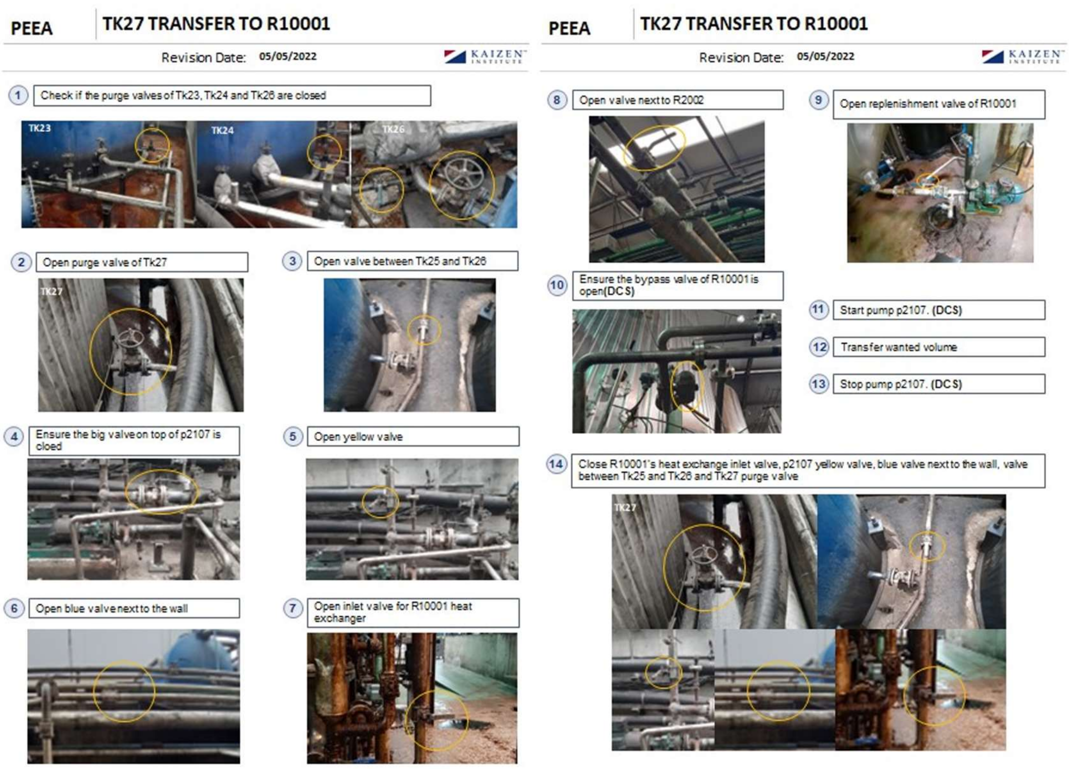

Figure 23 - Job Instruction for the water purge of Tk 27

In the PEEA unit, three actions were planned for the R10001:

- **Optimizing the acid consumption.** To do so, a study ought to be conducted, to understand the optimal amounts of acid to be inserted during the pre-treatment and the reaction itself. This study should focus on the influence of the composition of the feedstock received by the company, especially the FFA composition and the water percentage.
- **Standardizing the neutral purge** of R10001, by creating a Job Instruction for this task – as depicted in Figure 24. This way, the Production team will have a standard procedure for this task and variability will be eliminated from the process. By doing so, neutral water could be extracted efficiently during this step, avoiding shipping it as acid water while also avoiding shipping oil as water. Finally, this will allow having a better understanding of the water quantity at the end of the pre-treatment, helping solution number 1 for the R10001. Together with the creation of the Job Instruction, ensuring the team knows the JI and is trained to perform it.
- **Standardizing the acid purge** of R10001, by creating a Job Instruction for this task – also depicted in Figure 24. Once again, this will give the Production team a standard procedure for this task, eliminating variability and avoiding shipping oil as water. A conductivity meter is installed in this tank. This device allows the team to check when to stop both the neutral and acid purge, by analyzing the conductivity change in the screen. This was an important step put in the Job Instruction created for this task. Together with the creation of the Job Instruction, it should ensure that the team knows the JI and is trained to perform it.

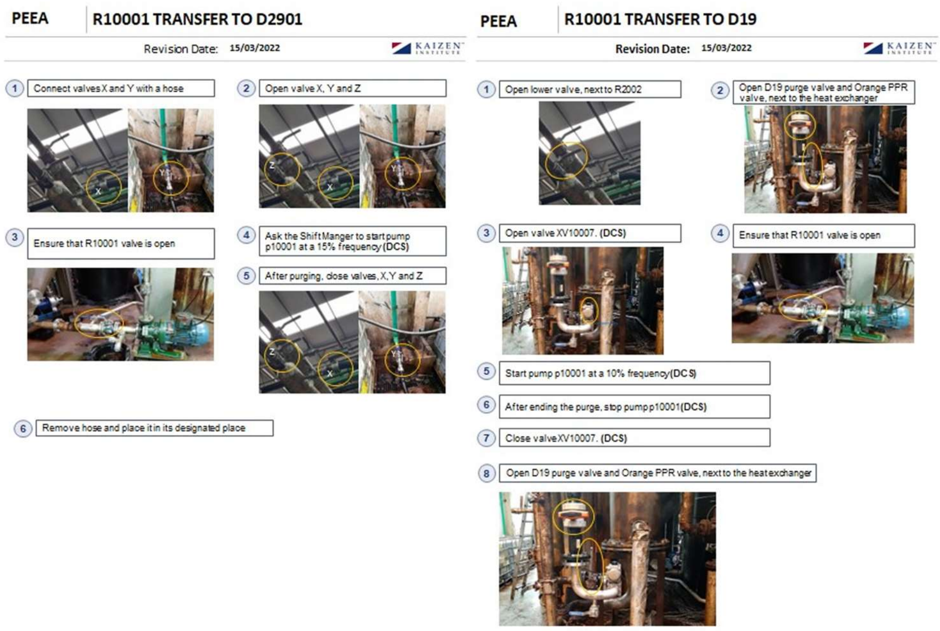

Figure 24 - Job Instructions for the neutral (left) and acid (right) purges of R10001.

In the D2402, the tank receiving soaps and water from the Coalescent and the Horizontal Decanter, the solution found was:

- **Optimizing the acid consumption** of this tank. This way, water will not be excessively acid, contributing to the renegotiation of shipping taxes.

For Tk 222 and Tk 22 the same solution was found:

- **Standardizing the purge** of both tanks, by creating Job Instructions for each task. This way, the Production team will have a standard procedure for these tasks and variability will be eliminated from the process. Together with the creation of the Job Instructions, ensuring the team knows the JI and is trained to perform it is required. This solution is especially important in the Tk 22 as it is the last stop before neutral water is shipped. For the Tk 222 it is important to do correctly do the water purge, to ensure that the PEEA does not receive excess water, that could be shipped as neutral water instead of acid water. This last JI is shown in Figure 25.

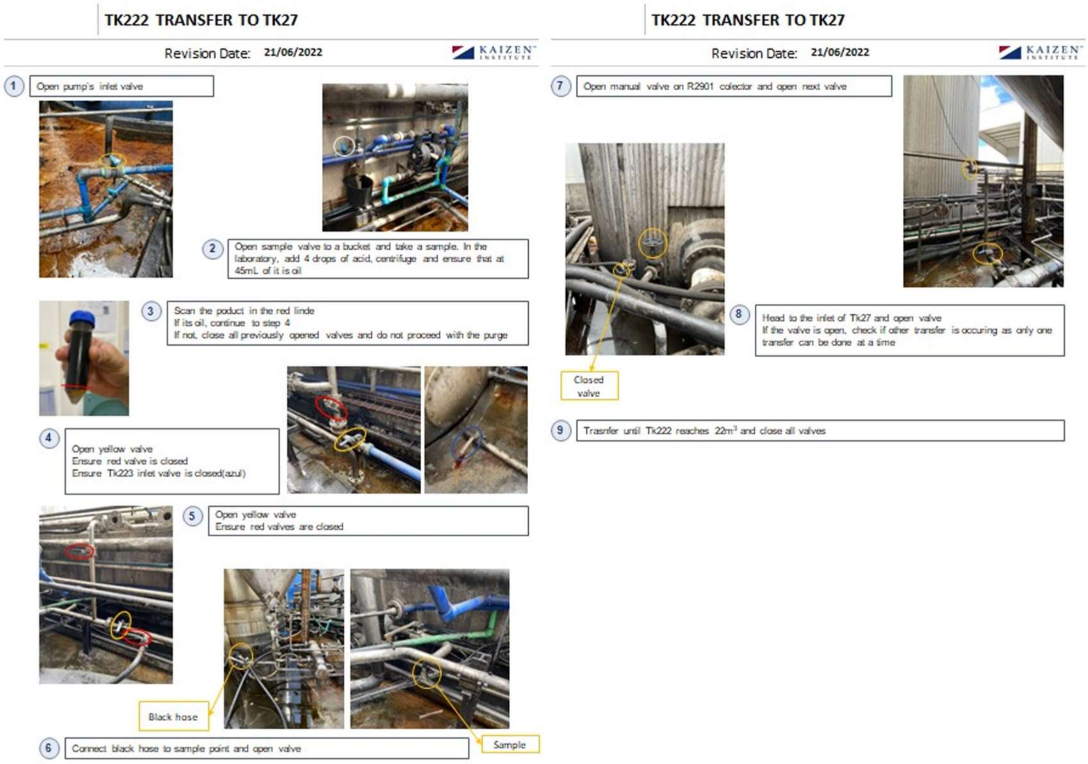

Figure 25 - Job Instruction of the purge of the Tk 222.

The R2901 tank receives water from several sources, from purges of tanks, to washing water from the vertical centrifuge, to even rainwater mixed with oil. Before sending the neutral water it receives to Tk 73, it needs purging to remove any oil left in it. Having this in mind, the team found the following initiatives to reduce wastewater:

- **Standardizing the purge** of this tank by creating a Job Instruction for this task. Once again, this will give the Production team a standard procedure for this task, eliminating variability and avoiding shipping oil as water. A conductivity meter is installed in this tank. This device allows the team to check when to stop the purge, by analyzing the conductivity change in the screen. This was an important step that was put in the Job Instruction created for this task. Together with the creation of the Job Instruction, depicted in Figure 26, ensuring the team knows the JI and is trained to perform it is required.
- **Controlling the samples** of purge taken in this tank. This will provide information to the team regarding the need of inserting acid to promote the separation of phases. That separation is crucial, as this tank represents 50% of oil intake in Tk 27. If the team could guarantee that the oil is removed fully from the tank, it would prevent oil from being sent to Tk 22 and shipped as neutral water, thus translating into economic gain to the biodiesel company.

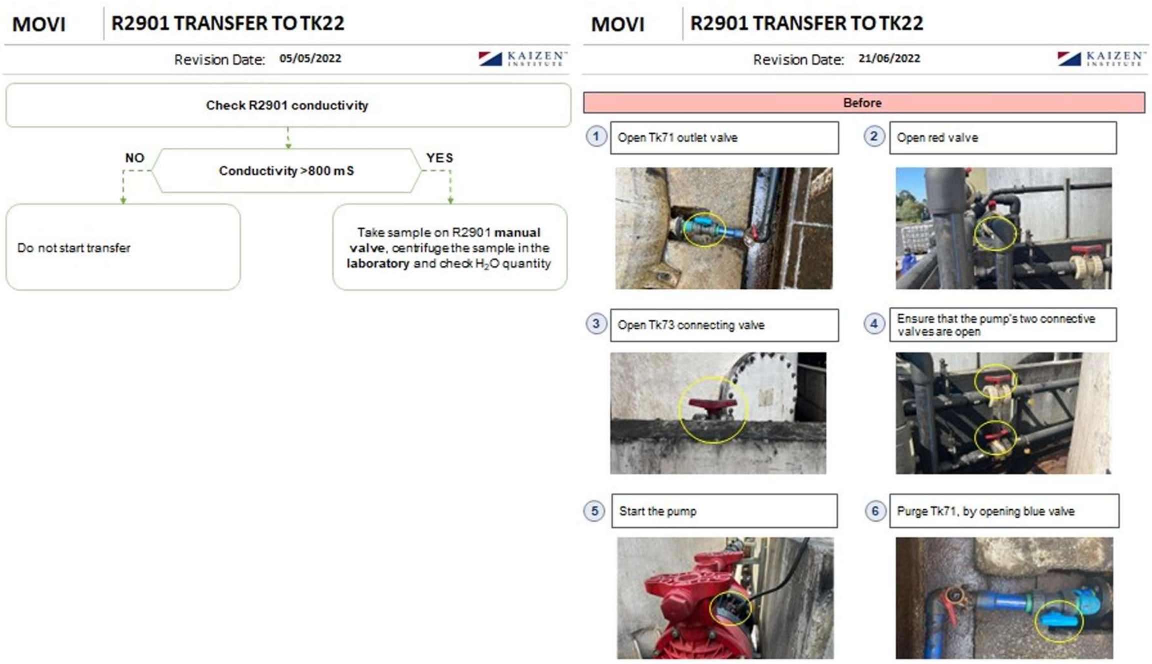

Figure 26 – Job Instruction for the water purging of the R2901

For D19, the tank that receives wastewater produced in the PEEA unit, the main solution found was:

- **Standardizing the purge** of this tank by creating a Job Instruction, show in Figure 27, for this task. Once again, this will give the Production team a standard procedure for this task, eliminating variability and avoiding sending oil to Tk 73 and shipping it as water. Together with the creation of the Job Instruction, ensuring the team knows the JI and is trained to perform it.
- **Standardizing the transfer** of water to Tk 73. The main issue with this transfer was the team not checking regularly the product being transferred. By periodically purging the tank during the transfer, the team should evaluate if the product being purged is water or oil. If the purge revealed oil, the transfer should be stopped, thus avoiding mixing oil in a tank that should only contain water to be shipped.

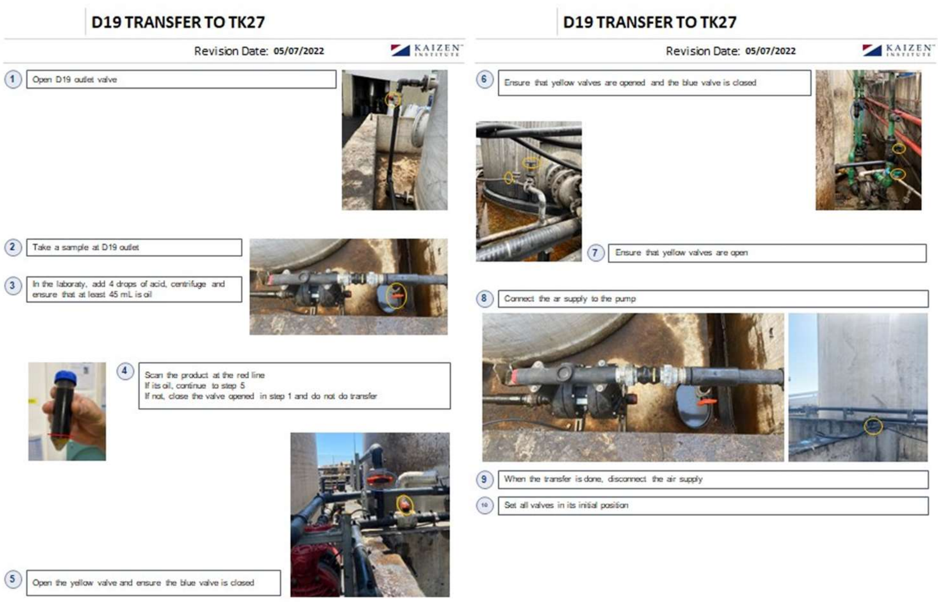

Figure 27 – Job Instruction to purge oil from the D19 to the Tk 27

Regarding the Tk 71 tank, the tank receiving wastewater coming from PEN, the solutions found were:

- **Standardizing the purge** of this tank. Figure 28 shows the JI done for this procedure. Once again, this will give the Production team a standard procedure for this task, eliminating variability and avoiding sending oil to Tk 73 and shipping it as water. Together with the creation of the Job Instruction, ensuring the team knows the JI and is trained to perform it.
- **Standardizing the transfer** of water to Tk 73. Figure 29 shows this JI. The main issue with this transfer was the team not checking regularly the product being transferred. By periodically purging the tank during the transfer, the team should evaluate if the product being purged is water or oil. If the purge revealed oil, the transfer should be stopped, thus avoiding mixing oil in a tank that should only contain water to be shipped.

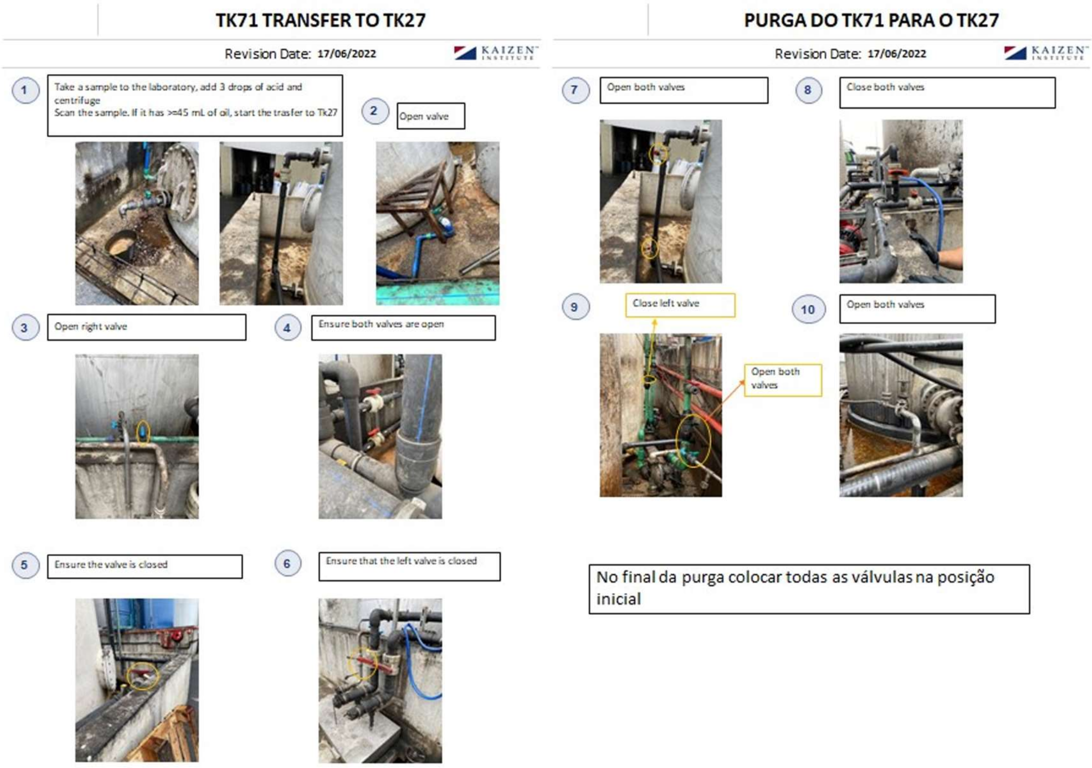

Figure 28 - Job instruction for the purge of the Tk 71.

Figure 29 – Job Instruction for the transfer of water from the Tk 71 to Tk 73

Finally, for the last stop for acid waters before being shipped, the Tk 73, the following initiative was conducted:

- **Standardizing the loading** of acid waters to external companies, by periodically checking that the product being shipped is, in fact, water. This would create a checking routine in the Movements team, to guarantee that no oil is being shipped as water.

As shown above, for both workshops, a big part of the solutions aim to reduce variability in tasks performed by the team in Gemba. This was a big part of the challenge during the project, along with the training of the team. A lot of variability in task performance, process knowledge, and overall decision-making among the team. To make the Job Instructions there were generally three phases of the process:

- Gathering all the necessary steps to execute the task properly, together with the Production Manager. This meant that he used his process knowledge both empirical and theoretical to give input on how the tasks should be performed whether it was the sequence of tasks, the values to be attentive to, or which team should be executing this work.
- Going in the Gemba to follow the team while they explain the task, taking photos of the procedure to insert in the Job Instructions, and better understand the process and problems faced by team members while executing them.
- Validation of the Job Instructions and sharing improvement opportunities found in the Gemba with the Industrial and Production Managers.

After undergoing these steps, the JI is added to the Job Instruction Index, shared with the team via email, and put visually in a selected zone in the control room.

As stated before, the amount of time the Industrial Manager spent calculating KPI's is not acceptable. He is a very important member of the company and he should not be spending this time in this Non-Value-Added activities. Combined with the goal of digitalizing Company D, a tool was developed to automatically calculate these indicators. Power BI, a multifunctional software focused on business intelligence was used. Using Power BI, all the Excel files containing relevant data to the KPI's were transformed to calculate the KPI's. Power BI works with column and row calculation, and allows the transformations done to be carried to newly inserted values in the spreadsheets. To transform the data, mathematical operations were performed between different columns, data was grouped by month or week, other necessary steps were taken like removing duplicates based on week or month of insertion, and a SQL code was used to calculate the weekly and monthly variation of tank volumes. After calculating the tables with the weekly and monthly indicators, a dashboard was designed to automatically return the indicators, with a color formatting. Red means over the target, green means below the target, the target visible by a constant line, the name of the indicators and an automatic update of the values to show (a 5-month visibility and 10-week visibility). This not only relieved the Industrial Manager of the Non-Value-Added task of calculating indicators, but also offered a visual way to see trends and performance of the KPI's allowing for a more agile and local intervention when needed. Finally, this dashboard was saved in a shared file so every member of the team could have access to this information. Figure 30 depicts the dashboard designed for the reduction of wastewater.

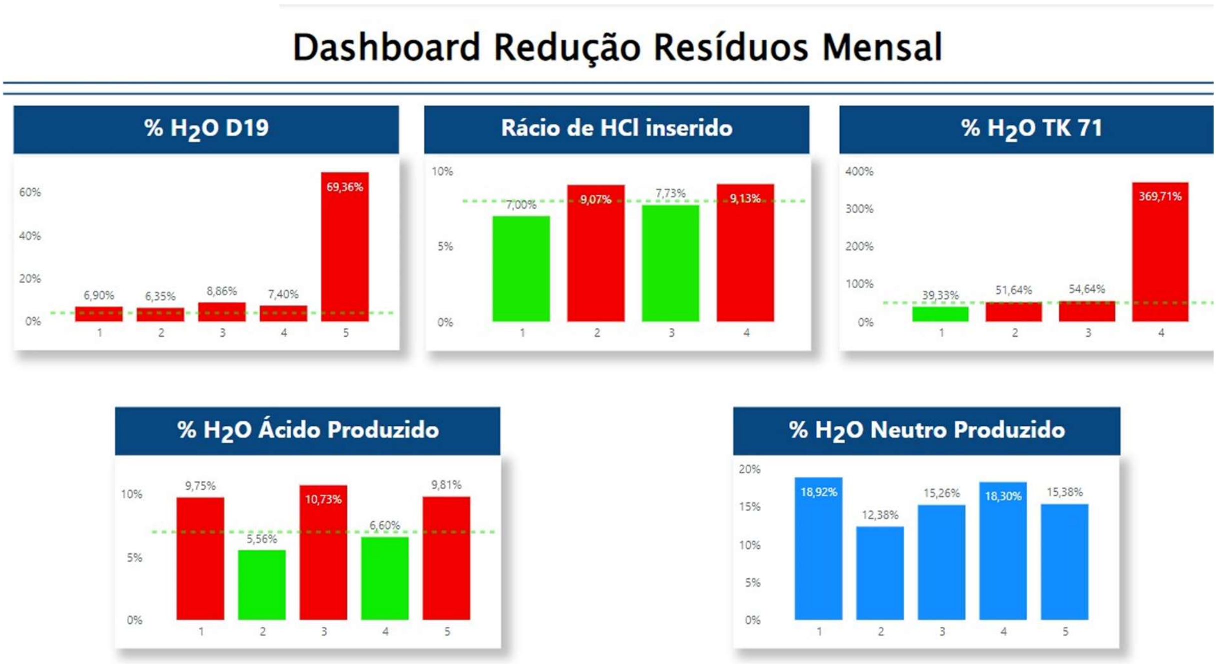

Figure 30 - Dashboard of the reduction of wastewater in a development phase.

Some of the solutions found in the reduction of PEN's losses affect the workshop for the reduction of wastewaters. Understanding the optimal amount of water injected into the horizontal decanter and the periodicity between washings, the amount of water and the periodicity to wash the vertical decanter affect the water consumption and, logically, the wastewater to be shipped.

4.3 Solution testing

Most of the solutions found were focused on the standardization of the process. To test these solutions the Production team was followed while executing the tasks described in the Job Instructions. It was then evaluated if any changes were needed whether because of missing steps or because improved ways of executing the tasks were found. These tests went in line with the Kaizen principle of being Gemba oriented. The proximity to the Production team helped identify improvement opportunities that translated into better Job Instructions. It is also important to state that the Job Instructions made are not static documents: they should always be improved and updated when needed. Therefore, it is important to check on the team for improvement opportunities, and create a culture of continuous improvement so the workers actively participate in the bettering of the organization, especially in processes they regularly take part in.

With that in mind, some tests were done. For the Horizontal Decanter, the water flux injected into the equipment is being tested. However, these tests are difficult to conduct because the Horizontal Decanter is often bypassed due to the quality of the feedstock that arrives at Company D. Connected to that, the tests on the periodicity between washings of this equipment are on hold, as they are dependent on the results of parameters assessment. Finally, the team is gathering data to access the validity of the Job Instruction for the bypass of the Horizontal Decanter. This will allow to check if the value limits defined in the JI are well established or if any change is needed.

Currently, the Vertical Decanter is being tested for the optimal flux, pH, temperature of the water, and the number of times to be washed. Figure 31 shows the data that is being gathered in order to understand which are the optimal parameters for this procedure.

Date	Hour	Temperature i	Temperature f	Temperatura	pH	Height i	Height f	# Washings	Flow	Flow/Washing
02/03/2022	09:54	47,40	47,40	47,40	6,20	9	47	7	90,28	12,90
03/03/2022	15:25	46,00	47,50	46,75	5,23	11	58	9	111,66	12,41
18/03/2022	12:18	45,10	47,90	46,50	5,39	9	46	5	87,91	17,58
30/03/2022	14:50	39,30	22,10	30,70	5,75	8	86	9	185,31	20,59
05/04/2022	16:25	34,00	43,00	38,50	4,30	12,5	51	4	91,47	22,87
06/04/2022	16:25	36,00	42,00	39,00	5,30	9,5	51	4	98,60	24,65
07/04/2022	18:50	35,20	41,20	38,20	5,70	11,5	46	4	81,97	20,49
12/04/2022	13:30	30,50	31,20	30,85	5,63	10	9	2	-2,38	-1,19
12/04/2022	14:30	32,40	32,40	32,40	5,60	9	10	2	2,38	1,19
12/04/2022	15:30	33,30	33,60	33,45	5,60	14	8,5	3	-13,07	-4,36
12/04/2022	16:30	33,50	33,90	33,70	5,66	9	8	2	-2,38	-1,19
12/04/2022	17:30	34,00	33,50	33,75	5,72	11	8	2	-7,13	-3,56
12/04/2022	18:30	33,30	33,60	33,45	5,66	10	6	2	-9,50	-4,75
12/04/2022	19:30	32,30	32,60	32,45	5,60	9	10	2	2,38	1,19
15/04/2022	15:00	37,00	37,50	37,25	5,20	11	9	5	-4,75	-0,95
15/04/2022	16:00	37,50	38,70	38,10	5,25	9	8	4	-2,38	-0,59
15/04/2022	17:00	38,70	38,00	38,35	5,18	8	11	4	7,13	1,78
15/04/2022	18:00	38,00	38,10	38,05	5,13	11	9	4	-4,75	-1,19
15/04/2022	19:00	38,10	37,80	37,95	5,10	9	11	4	4,75	1,19

Figure 31 - Data table with the information being gather regarding the washing of the Vertical Decanter.

The number of drags in the Dehydrator is being followed to ensure that the preventive actions taken are being effective. The spreadsheet – Figure 32 -also includes a section to mark the reason for the drag, so the frequency of root causes is analyzed, and, if needed, countermeasures can be taken specifically for those problems.

Date	Week	Hour i	Hour f	Interval	Drag/h	#Drag	Low IA Skid 3	High Solids VC IN	High Solids VC OUT	High Water Skid 4
27/01/2022	4	07:48	09:31	1,72	2,91	5	1			1
07/02/2022	6	14:59	15:14	0,25	4,00	1	1			1
07/02/2022	6	17:11	17:40	0,48	2,07	1	1			1
08/02/2022	6	02:59	03:46	0,78	2,55	2	1			1
08/02/2022	6	06:34	07:51	1,28	3,90	5	1			1
08/02/2022	6	12:03	14:04	2,02	2,98	6	1			1
15/02/2022	7	12:27	00:00	11,55	2,34	27	1			1
03/03/2022	9	17:42	19:00	1,30	3,08	4	1	1		1
16/03/2022	11	03:12	04:52	1,67	3,60	6	1	1		1
19/03/2022	11	17:17	18:03	0,77	2,61	2	1	1		1
27/03/2022	13	14:40	15:17	0,62	4,86	3	1	1		1
28/03/2022	13	21:28	21:57	0,48	2,07	1	1	1		1
28/03/2022	13	22:53	23:06	0,22	4,62	1	1	1		1
06/04/2022	14	23:45	23:59	0,23	4,29	1	1	1		1
07/04/2022	14	01:52	02:11	0,32	3,16	1	1	1		1
30/04/2022	17	01:18	02:24	1,10	3,64	4	1			1
30/04/2022	17	03:00	03:20	0,33	3,00	1	1			1
30/04/2022	17	03:35	05:02	1,45	3,45	5	1			1
16/05/2022	20	03:16	04:12	0,93	4,29	4	1	1		1

Figure 32 - Spreadsheet containing data related to the number of Drags in the Dehydrator.

Regarding the optimal consumption of acid in the R10001 and D2402, the tests are yet to start as there has been a shortage of the acids used in the plant. This situation can be explained by the current difficulties felt all around the world due to supply chain problems and the current geopolitical situation in Europe. Company D has resorted to different acids that are not as good for the process, because they increase the waste production and decrease the process efficiency. These alternative acids are not a perfect solution but constitute a better solution than not inserting acid in the process at all. Concluding, until the acid suppliance improves the tests cannot be conducted.

Finally, the laboratory is collecting data regarding the samples of oil from R2901 to understand if inserting acid in this take to promote the separation of oil and water is needed.

5 Implementation of a Tracking System

5.1 Updating the Plan of Action

After finding the solutions and planning the confirmation tests needed, the Plan of Action needs to be updated. This Plan of Action follows the PDCA cycle: Plan, Do, Check, Act. Each initiative of the plan has a starting date, a planned conclusion date, a person responsible for it, the problem, and the workshop in which they were done, and additional notes to add information besides the status of the initiative. PDCAs normally have four statuses corresponding to each stage of the cycle, but the one used in both workshops, shown in Figure 33, has more to better describe the state of each task. The stages are the following:

- Planned (P) – Action planned for a certain date with a responsible assigned.
- Dimensioning (Dim) – Action in technical dimensioning phase
- Procurement (PO) – Action in budgeting and buying phase.
- Ready to Install (Ins) – Action ready to be installed.
- Doing (D) – Ongoing Action.
- Validation (C) – Action in validation phase.
- Completed (A) – Completed Action. Needs to be shared with the workshop team.
- Delayed – Delayed action.
- Canceled – Canceled Action.
- Pending – Action with no conclusion date.

The document also contains a trust curve, Figure 34, that gives a visual representation of the macro status of the workshop, giving the PDCA an important communication function. This document serves as a follow-up to all initiatives and its structure should be embedded in the organizational culture. It is something Kaizen Institute is implementing in Company D, specifically in the daily team meetings.

DEPARTMENT:	PRODUCTION	Leader/Sponsor:	Industrial Manager
AREA:	PEN	Starting Date	10/03/2022
KAIZEN EVENT:	**Reduction of PEN'S losses**		

#	Topic/Opportunity	Problem	Action	Comments	Responsible	Starting Date	Conclusion Date	PDCA
1	Coalescent	Soap purge is not standardized	Standardization of the purge		IM	05/04/2022	13/05/2022	Completed (A)
2	Coalescent	Inefficient Separation	Evaluation of injecting water into the tank	Defined as non-priority by the team	IM	05/04/2022		Canceled
3	Horizontal Decanter	Unstable Water Injection Flux	Definite water injecting line	Defined as non-priority by the team	IM and MM	10/03/2022		Canceled
4	Horizontal Decanter	Unstable Water Injection Flux	Inclusion of a checkpoint to see the water flux in the rotamenter into PEN's route		IM and KI	10/03/2022	17/03/2022	Completed (A)
5	Horizontal Decanter	Optimal Working Parameters unknown	Contacting machine supplier to obtain information about optimal parameters	Machine supplier contacted multiple times with no answer	IM	17/03/2022		Canceled
6	Horizontal Decanter	Optimal Working Parameters unknown	Parametrization tests	Tests with 100L and 150L completed Tests with 200L waiting for the Decanter to be back in-line	IM	10/03/2022		Delayed
7	Horizontal Decanter	Instability at restart	Standardization of when to bypass the Horizontal Decanter		IM	10/03/2022	01/06/2022	Completed (A)
8	Horizontal Decanter	Solid Waste Jamming	Testing the optimal periodicity between washings	Waiting for the Parameters' to end	IM	10/03/2022		Delayed
9	Vertical Decanter + Dehydrator	Vertical Decanter and Dehydrator losses calculated together	Replacing the massic flowmeter for a vortex flowmeter	Defined as non-priority by the board	IM and MM	10/03/2022		Canceled
10	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Installing pressure sensors		IM and MM	10/03/2022	24/05/2022	Completed (A)
11	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Testes de Otimização da Lavagem (caudal, temperatura e pH)	Data is still being collected	IM	10/03/2022	01/08/2022	Doing (D)
12	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Installing sample point	Waiting for external supplier to evaluate the solution Evalution planned for the Summer Maintenance Stop	IM and MM	10/03/2022	10/08/2022	Planned (P)
13	Dehydrator	Flush and reflux pressure not measured	Installing pressure sensors		IM	10/03/2022	24/05/2022	Completed (A)
14	Dehydrator	Dehydrator too full	New flush line	Not needed at the moment	IM and MM	10/03/2022	02/06/2022	Planned (P)
15	Dehydrator	Foams	Quantify the number of drags per week	Data collected Workshopped started All the solutions in the Workshop are concluded	IM	10/03/2022	01/06/2022	Completed (A)
19	Refluxes	Lack of temperature in the Dehydrator	Cleaning the thermofluid filter of the temperature controlling valve		IM	10/03/2022	17/03/2022	Completed (A)
20	Refluxes	Lack of temperature in the Dehydrator	Replacing the temperature controlling valve	New valve will be installed in the Summer Maintenance Stop	IM and MM	10/03/2022	01/08/2022	Ready to Install (Ins)

Figure 33 - PDCA used to follow-up on the initiatives of the Reduction of PEN's losses workshop

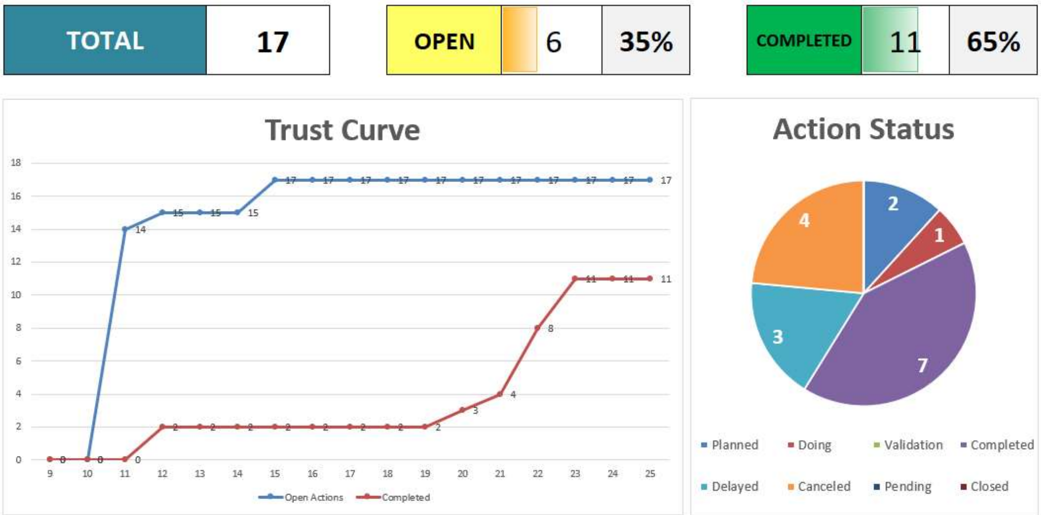

Figure 34 - Trust Curve of the PDCA related to the reduction of losses at PEN.

The team could not implement all the initiatives propose in the workshops. This was due to external factors – such as executing dates from external suppliers- and because the board did not find the budget space to execute them still. This means that the goals may not be totally achieved. However, the number of initiatives completed hints to at least some level of improvement.

In a more advanced phase of the project, when a certain level of maturity is reached inside Company, the teams should adopt the SDCA cycle: Sustain – Do – Check – Act. This cycle follows the same structure as the PDCA but is more focused on sustaining and maintaining the improvements made. This is an important step towards building a continuous improvement culture within the company as it ensures that the initiatives and improvements are not abandoned.

5.2 Confirming Results and Standards

Regarding the workshop to reduce PEN's losses the goals set in the A3 are yet to be achieved. Using data until June 2022, displayed in figure 35, there has been an increase in the refluxes, causing an increase in the Total Losses. The losses in the Vertical Centrifuge and Dehydrator decreased slightly, whilst the increase of the losses in the Horizontal Decanter had a similar increase. This data shows that there is still work to do in this matter, however, there are certain situations that can help explain some of these results. First, the refluxes had an increase that can be explained by the lack of temperature of the Dehydrator. The plant's furnace had been underperforming the whole month of June, because of both poor-quality biomass and jamming of the air ventilators. This means that the Dehydrator could not work at an acceptable level for a long time. Also, the acid inserted in the process changed, bringing unwanted side effects. As stated before, the company was having difficulties finding the acid usually put in the process. This means that an alternative had to be found. The new acid put formed foams in the Coalescent and in the Dehydrator and decreased the quality of the oil. The team had to deal with this as time went on, and mostly learned by experiencing. This ongoing adaptation period also made it hard for positive changes to be seen in the KPIs. Finally, the last few months were synonymous with multiple maintenance stops. PEN was especially affected by this, and the overall quality of the oil and performance of the unit decreased. However, looking at the values from May, there significant improvements up until that month. The plant was stable, and acid shortage was still not a problem. This indicates that the measures were being effective, and that they should be maintained. When the plant recovers its process stability, both from fixing the furnace problems, and adjusting the process to new acid inserted, it is expected that these values once again improve.

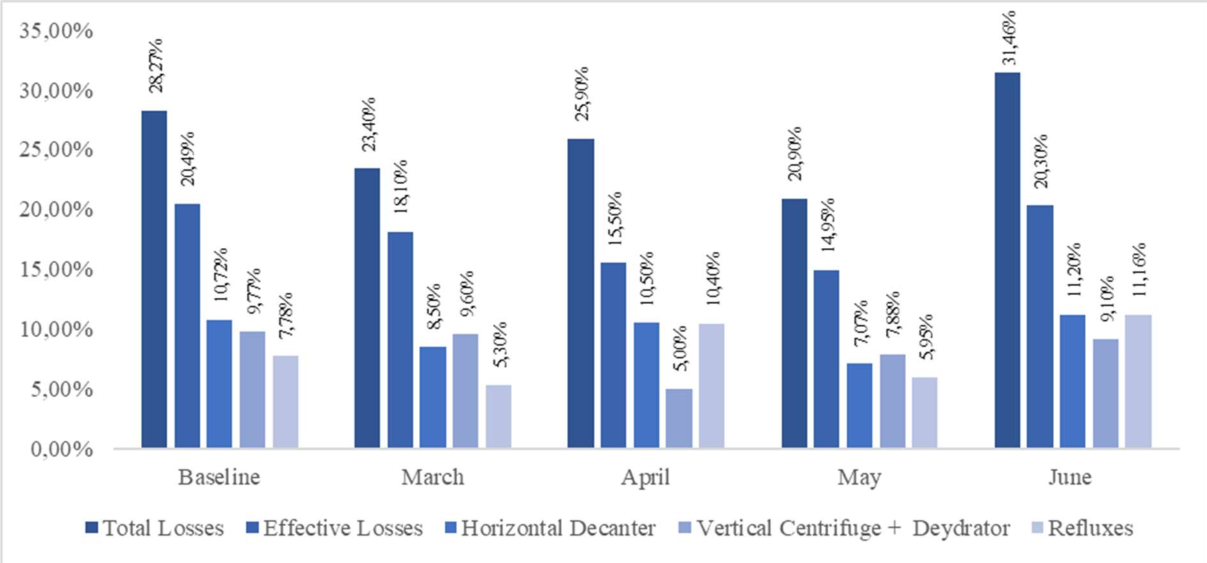

Figure 35 - Evolution from March through June of the 5 KPI's controled in the reduction of PEN's losses workshop.

Looking at the values from March to June of the KPIs of the reduction of wastewaters, shown on Figure 36, more promising results appear. In the month of June 6 cisterns loaded acid water, and the neutralization unit processed 644 units of mass. With this data, it was calculated that the company spent 23353.69 [MU] shipping acid waters and 24300.60 [MU] shipping neutral waters. A straightforward comparison with the baseline would not be realistic as June was a month of lower processed tons in PEN, meaning fewer waters were produced. However, if looking at relative numbers the acid water production decreased 35.5% relative to the Baseline, while the neutral water production fell 8.8%. Compared to a month with the same production and baseline percentages, June showed 30% saving on acid water transportation and 35% saving on neutral water transportation. These results are encouraging, although there are still improvement opportunities. The acid water KPI is still above target, and there should be a push to decrease this value. Regarding the other KPIs, only the acid water coming from PEN increased, but both the acid insertion and the water produced in the PEEA are not below target. This indicates that there is still work to be done and that the workshop needs to be followed-up. Finally, the increase in the waters produced in PEN can be explained by the poor performance of the unit in May and in June.

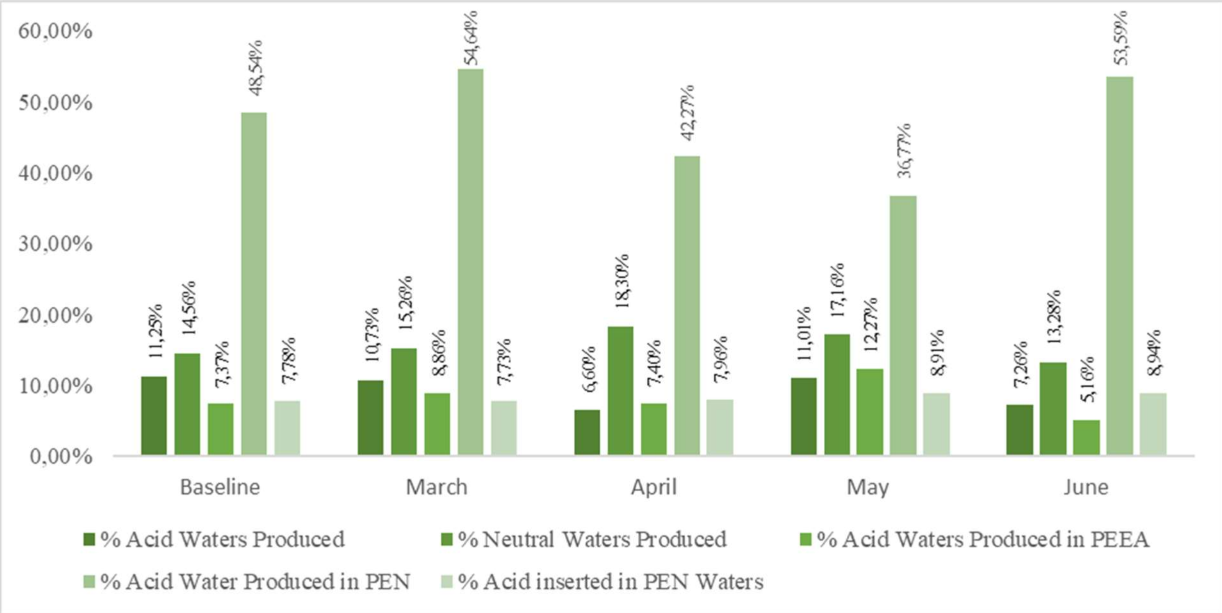

Figure 36 - KPI's of the reduction of wastewater workshop.

Besides the economic benefits, the company also acquired a considerable amount of Organization Knowledge. This was done in many ways. First with the creation of the Job Instructions, which represent an important archive of process knowledge. Preventing the company from having a big gap in knowledge between team members is fundamental. This way the Company is not dependent on individuals and has a strong core. If a member of the team leaves, the Company should not lose any capacity of working properly. The knowledge should be gathered and shared with the team. A digital Index was created to compile all the Job Instructions created, their date of creation, and if they need to be updated. That is an ongoing process to sustain the continuous improvement culture at the company, and one that should be ever ending. In parallel with this document, a Skills Matrix was designed – Figure 37 - to evaluate the workers' proficiency at each task. This was an important step in the project, as there was a big learning curve for newcomers to the Production team. Having this visibility of the teams' capacity not only showed who needed more training but also showed which workers could give training to their colleagues. To reduce the gap of knowledge among more senior team members, a Training Plan is underway, at the moment of writing – July 2022 - to ensure everyone in the team can execute properly their tasks. In the weekly project meeting, the status of Training Plan and the schedule of each training session is shared. This communication moment is important because the board has shown concern about the Production team skill set and so this ensure a continuous follow-up on this matter. Training Plan intends to ensure that all the Production and Movements team members know the Job Instructions and know how to apply them. This will also allow reducing the adaptation period of newcomers. The Production team members have a significant period of learning, as there is a considerable number of tasks to be performed and critical judgment is a very important part of this work, one that can only be acquired by experience. This is an important step towards the success of the project because it was identified by both the Industrial and Project Managers and Kaizen Institute that, in part due to the rotativity of the team, the team members showed unfamiliarity with the Job Instructions.

- 0 Não tem conhecimento
- 1 Tem conhecimento, mas não tem autonomia
- 2 Tem conhecimento e é autónomo
- 3 Tem capacidade de formação

	PRODUÇÃO	Chefes de Turnc										Técnicos											MANUTENÇÃO			MOVIMENTAÇÕ			LABORATÓRIO					
LABORATÓRIO			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A		N/A	N/A		0%	0%	0%	0%	0%
PEBD			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
PEN			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Paragem PEN																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Alterações de Caudal | Setpoints																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
pH Skid 1																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
IA Entrada PEN																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
IA Skid 2																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
IA Skid 3																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Doseamento da Injeção do KOH																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Caudal da Purga do Decantador																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Ácido Cítrico																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Pressão Centrífuga																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Teor de água do Desidratador																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Temperatura Desidratador																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Troca Filtros Alimentação PEN																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Purga do Coalescente																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Transferência R2001 (dos Arranques) para TK71																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Registo do Número de Lavagens da Centrífuga																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Transferência TK24 para D04																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Troca de H20 do barrilete de vácuo do desidratador																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
Arranque Desidratador																								N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
PEEA			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
PEG			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
PERT			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		N/A	N/A		N/A	N/A	N/A	N/A	N/A
PROCEDIMENTOS			0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A	N/A		0%	0%		N/A	N/A	N/A	N/A	N/A

Figure 37 - Skills Matrix. This document groups the Job Instructions by unit and the workers by team. There was also a selection of Job Instruction that each team should be able to execute.

Finally, the creation of the Power BI dashboard achieved its intended goal. The Industrial Manager gained 3 hours per week to perform Value-Added tasks as they no longer need that time to calculate KPIs. This also improved the fluidity of workshops as they would often spend the initial part of workshops finishing the calculations of the KPIs relevant to the workshops.

5.3 Assessing, Deploying, and Preserving

To close the A3, the assessment done is overall positive for both workshops. The team did not fulfill all the deliverables, both because some initiatives were not aligned with the board's priorities and because of external factors. This can in part explain the project not achieving all the goals defined. Although not all goals were achieved, there was still a relevant benefit for the company. There could have been more expressive results, but the plant had significant issues during the workshop that required long periods of stoppage and, sometimes, the full attention of the team.

The A3 methodology should be deployed in every future workshop conducted at Company D. The structure leads to a more concise approach and allows for check-ups on the solutions and status of the workshops. The team should also always aim to standardize all the tasks of the factory to decrease the variability in the execution of said tasks. Finally, the team should keep on using Power BI. The software is a powerful data treatment tool, with good graphic capabilities which promotes two of the core Kaizen values: to be scientific and transparent. It enables data analysis to be in a visual way and eliminate Muda, as it relieves team members of the task of calculating KPIs. This software should be one of the many advances implemented to digitalize Company D and take this organization amongst the industry's leaders in innovation and digitalization. The company should also look into installing conductivity meters in more tanks, as this device provides accurate information to when to stop the purging.

Finally, to preserve the solutions designed, there are initiatives already in progress and some that can be done. A communication wall, shown in Figure 38, was created to inform, especially the Production team, of new or updated Job Instructions. This will be complementing the Training Program and is also a way to already prepare the team when training time arrives. A newsletter was also created with the intent to improve communication between teams. The newsletter informs of new Job Instruction, equipment changes, Standard changes, future training, and so on. In parallel with the two workshops presented in this Dissertation, Kaizen Institute is actively pushing to change the organizational culture of Company D. This intends to create a continuous improvement culture that will enable its workers to sustain the improvements done, and to design, plan, and execute new improvements. This will also create routines that will prevent improvements to be lost. Updating Job Instructions and creating new ones, defining daily routines of management and improvement, and creating autonomous maintenance plans are all goals for the Future of the Company, and ones that are believed to be the best path to preserving the improvements done in this workshop.

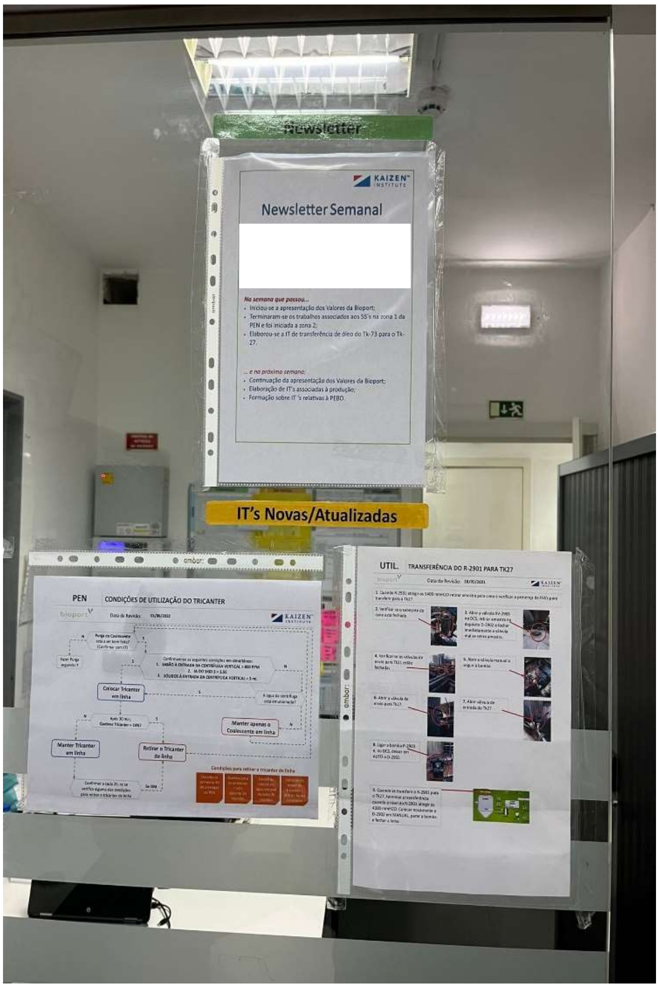

Figure 38 - Communication wall created on the control room to improve the connection between Kaizen Events and the daily activities of the plant.

6 Conclusions and Future Works

To close this dissertation, some conclusions are ought to be drawn. Starting with the project goals, a positive assessment must be made, especially in terms of implementation. The project looked to have a positive impact in several aspects of the organization. The benefits for the company were more than economic. The economic benefits were mainly achieved through the reduction of wastewaters, but that once the plant finds stability both in equipment maintenance and supply of materials, there can be a more realistic assessment of the success of the initiatives done to reduce the losses in PEN. On the other hand, the company benefited greatly from the production of the Job Instructions, the Skills Matrix, the Training Plan, and the Power BI dashboard, as well as all the other solutions found. All of these contribute to the organizational change that Kaizen Institute is promoting at Company D. There has been a great focus on, not only creating these tools, but ensuring that the teams know, and use them. This has been a challenge at Company D, as they have been facing several challenges related to the rotativity of the team. It was an important initiative to create training plans, reducing the learning period of new team members seems to be a big improvement opportunity.

The energy sector has been facing an increasing number of challenges for the last few decades. The energy demand has increased at an alarming rate, and governments and people no longer accept the path that was being taken until the end of the last century. Renewable Energies need investment and development to be a real alternative to fossil fuels. Closely working with a biofuel-producing company led to a number of elations that will be here stated. First, that renewable energy production is still far from being completely green. The number of trucks coming in and out of the factory is a good example of that. The goal of the Company is to produce a renewable source of energy but to do so, has to buy feedstock, sell the biodiesel produced, and ship wastes that are all transported through vehicles running on fossil fuels. It is also relevant to point out that the likely source of electricity that feeds the plant is not renewable. So, for a truly green transition, an integrated clean energy system needs to be drawn. Governments and companies need to commit to common goals and act coherently, concisely, and precisely. On the topic of the future of energy solutions, one conclusion drawn during this project was that even though biofuels may not be the future of renewables, they play an important role in the green energy transition. Biofuel can be seen as a halfway solution, but in reality, it is improbable that internal combustion engine cars are fully replaced by electric (or another renewable source) vehicles in the next 10 to 20 years. This means that there is still time, need and place for biofuels, and development should continue to be done and receive investment as this energy source will continue to be relevant. Aviation could be an area of interest for this fuel. There is still little progress in electrifying airplanes, and these vehicles have already proved to work with biofuels. Continuing, to underline the need to keep developing and producing biofuel, it is important to understand that electric vehicles reduce greenhouse gas emissions, but hurt the environment in others – i.e., the production and disposal of its batteries. This means that there can be a point in the future, where the transition to electric stops due to new and better solutions being found. This goes in line with Kaizen's philosophy, the continuous search for improvement and better solutions. Once again, if biodiesel keeps on being developed, incorporation rates increase, and other government actions are taken, this renewable source of energy can hold its market share. Finally, the recent world events showed that energetic dependence of outside countries and energetic centralization are serious threats to dependent countries. These two situations are liabilities to the economic sustainability of a country, in case of supply decreases or total cuts. Thus, countries should aim to have a considerable amount of energetic independence. As it is known, not every country has oil reserves. However, virtually any country has internal access to the raw materials used to produce biofuel. This reinforces the need to have diverse external sources, and significant sustainable and diverse sources of energy.

On the topic of future works, starting with digitalization, there are improvement opportunities worth to be mentioned. First, something that is already being done, is the creation of singular centralized Power BI dashboard. This will allow for a monthly, weekly and daily tracking of all the organizational KPIs. The goal is to have a screen with these values displayed in the Mission Control Room, with formatting that will allow quick evaluation of the status of each indicator through visual management. An improvement opportunity also found was the translation of KPI improvement into economic benefits for Company D. This will give even more purpose to the project and draw a path for the team.

On the topic of acid waters, one big improvement opportunity is having the acid wastewater act as the acids that are inserted into the process. This would mean obviously economic benefits as acid would be substantially less needed, as well as acid water shipments would almost vanish. There is a planned project to create a line that will feed the process with acid wastewater, and it is something that can change the production process for the better, while also converting waste into value for the company. This initiative also contributes to a sustainable future, as circularity is a very important aspect of green processes. The team is also planning to change the destination of the washing waters of the horizontal decanter. Instead of sending them to the D2402 and consequently acidulating these waters, the team is planning to assemble a line to send these wastewaters to the R2901 and ship them as neutral waters, saving shipment costs.

Passing on to the neutral waters, the major improvement opportunity found is the opportunity to treat waters internally. The reason this water is shipped as waste is that it needs treatment as it contains various unwanted substances. Company D has a water treatment station that at the moment is not being used. If this unit was reactivated, it could mean significant economic benefits as well as the opportunity to use this water to inject, where needed, in the process. This way the parameters of the water would be internally controlled, and variability would be reduced.

Focusing on the production process, Kaizen Institute is developing a workshop with Company D to increase the new product inserted in the PEEA. This type of product is the one that arrives at the plant in a rawer form, and therefore it has the biggest potential to add value. This way, Company D would be adopting a greener strategy as it would be using materials that arrived with no prior refinement or treatment.

All the new standards and tasks introduced by the workshops should be regularly checked. Kaizen Institute is planning to introduce Kamishibai cards to confirm these processes. These cards will serve for the team leaders to verify that the new processes are assimilated by the team and should be done in Gemba walks (regular previously defined routes to confirm processes and find improvement opportunities). This routine is very important to ensure that the improvements are not lost.

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APPENDIX A: A3 of the Reduction of PEN's losses

Evento KAIZEN ™: Redução da Quebra na PEN

KAIZEN™ INSTITUTE

KICK OFF DATE 10 / 03 / 2022 | DEADLINE 31/07/2022 | LAST UPDATE 10 / 07 / 2022

1. DEFINE THE CHALLENGE

Reduce all losses in PEN:

- HorizontalLosses
- Centrifuge + Dehydrator Losses
- Refluxes

2. CHECK CURRENT STATE

Total Losses = 28,27%

Effective Losses = 20,49%

HorizontalDecanterr= 10,72%

Centrifuge+ Dehydrator= 9,77%

Refluxes= 7,78%

Baseline from November 2021 to December 2021

3. SET TARGET STATE

Total Loss = 22,0%

Effective Loss = 18,0%

Horizontal Decanter= 11,0%

Centrifuge + Dehydrator= 7,0%

Refluxes= 4,0%

4. FIND ROOT CAUSES

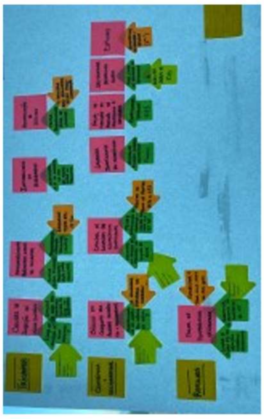
Horizontal Decanter: 4 causes

Centrifuge: 2 causes

DEHYDRATOR: 3 causes

REFLUXES: 1 CAUSES

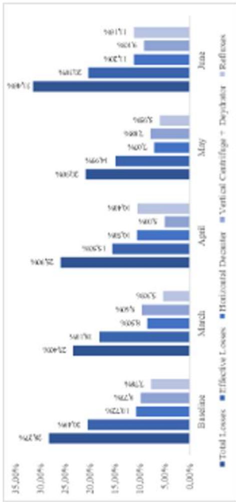
5. DESIGN SOLUTIONS



6. TEST SOLUTIONS

7. UPDATE ACTON PLAN

8. CONFIRM RESULTS AND STANDARDS



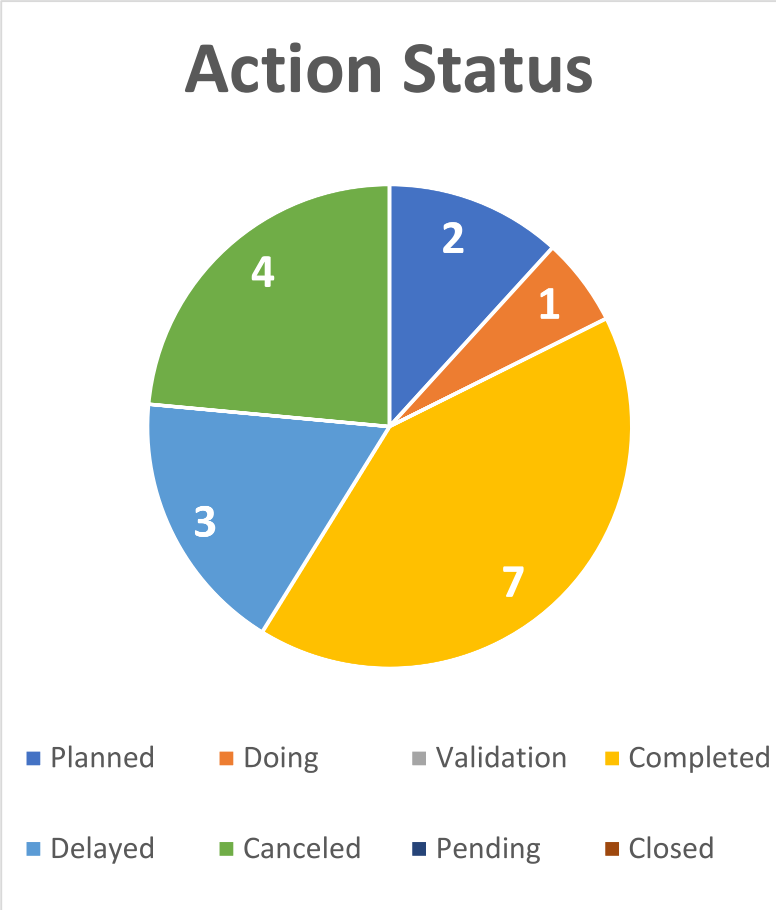
9. ASSESS, DEPLOY AND PRESERVE

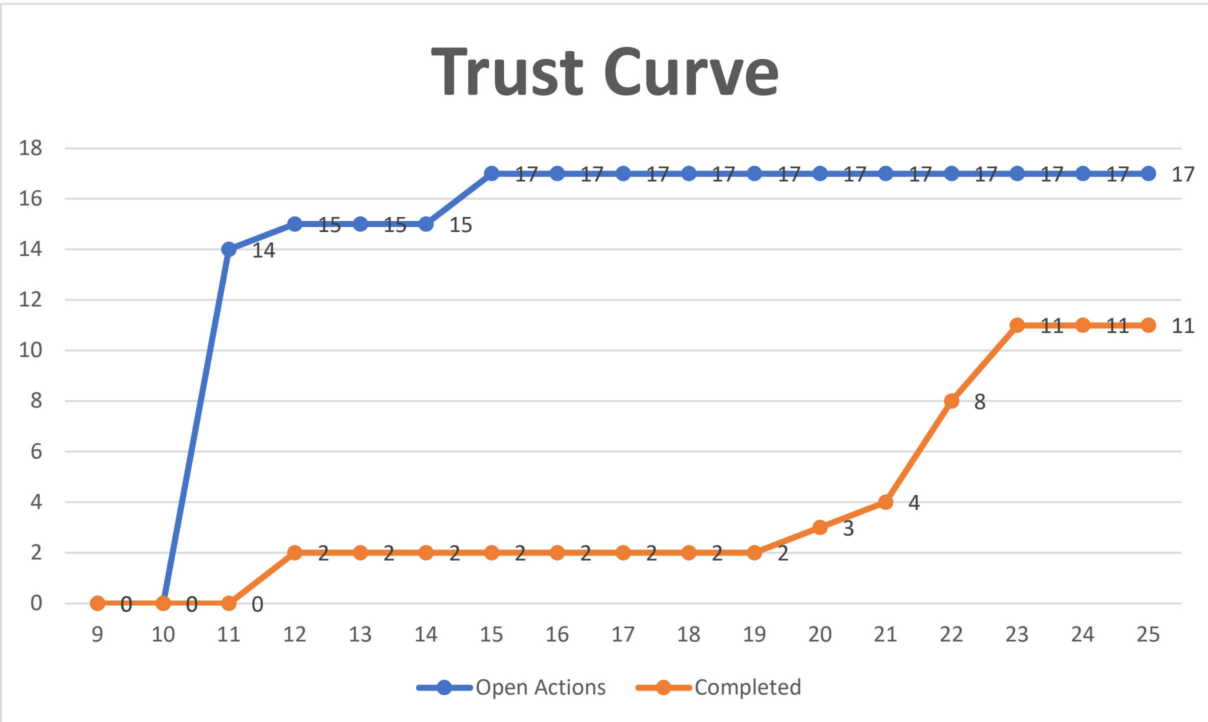
Create a dedicated line for the washing water of the Horizontal Decanter

Project Leader: Industrial Manager | Team: Production Team | Sponsor: CompanyD board

APPENDIX B: PDCA of the Reduction of PEN's losses

#	Topic/Opportunity	Problem	Action	Comments	Responsible	Starting Date	Conclusion Date	PDCA
1	Coalescent	Soap purge is not standardized	Standardization of the purge		IM	05/04/2022	13/05/2022	Completed (A)
2	Coalescent	Inefficient Separation	Evaluation of injecting water into the tank	Defined as non-priority by the team	IM	05/04/2022	23/05/2022	~~Canceled~~
3	Horizontal Decanter	Unstable Water Injection Flux	Definite water injecting line	Will be discussed on the 5th of July	IM and MM	10/03/2022	05/07/2022	Delayed
4	Horizontal Decanter	Unstable Water Injection Flux	Inclusion of a checkpoint to see the water flux in the rotamenter into PEN's route		IM and KI	10/03/2022	17/03/2022	Completed (A)
5	Horizontal Decanter	Optimal Working Parameters unknown	Contacting machine supplier to obtain information about optimal parameters	Machine supplier contacted multiple times with no answer	IM	17/03/2022	23/05/2022	~~Canceled~~
6	Horizontal Decanter	Optimal Working Parameters unknown	Parametrization tests	Tests with 100L and 150L completed Tests with 200L waiting for the Decanter to be back in-line	IM	10/03/2022		Delayed
7	Horizontal Decanter	Instability at restart	Standardization of when to bypass the Horizontal Decanter		IM	10/03/2022	01/06/2022	Completed (A)
8	Horizontal Decanter	Solid Waste Jamming	Testing the optimal periodicity between washings	Waiting for the Parameters' to end	IM	10/03/2022		Delayed
9	Vertical Decanter + Dehydrator	Vertical Decanter and Dehydrator losses calculated together	Replacing the massic flowmeter for a vortex flowmeter	Defined as non-priority by the board	IM and MM	10/03/2022	16/05/2022	~~Canceled~~
10	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Installing pressure sensors		IM and MM	10/03/2022	24/05/2022	Completed (A)
11	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Testes de Otimização da Lavagem (caudal, temperatura e pH)	Data is still being collected	IM	10/03/2022	01/08/2022	Doing (D)
12	Vertical Decanter	Insufficient Vertical Decanter's washing flux	Installing sample point	Waiting for external supplier to evaluate the solution Evalution planned for the Summer Maintenance Stop	IM and MM	10/03/2022	10/08/2022	Planned (P)
13	Dehydrator	Flush and reflux pressure not measured	Installing pressure sensors		IM	10/03/2022	24/05/2022	Completed (A)
14	Dehydrator	Dehydrator too full	New flush line	Not needed at the moment	IM and MM	10/03/2022	02/06/2022	~~Canceled~~
15	Dehydrator	Foams	Quantify the number of drags per week	Data collected Workshopped started All the solutions in the Workshop are concluded	IM	10/03/2022	01/06/2022	Completed (A)
16	Refluxes	Lack of temperature in the Dehydrator	Cleaning the thermofluid filter of the temperature controlling valve		IM	10/03/2022	17/03/2022	Completed (A)
17	Refluxes	Lack of temperature in the Dehydrator	Replacing the temperature controlling valve	New valve will be installed in the Summer Maintenance Stop	IM and MM	10/03/2022	01/08/2022	Planned (P)


Action Status
2
1
7
3
4
Planned
Doing
Validation
Completed
Delayed
Canceled
Pending
Closed


Trust Curve
Open Actions
Completed

APPENDIX C: A3 of the Reduction of wastewaters

KAIZEN ™ Event: Waste Reduction

KAIZEN INSTITUTE

KICK OFF DATE 23 / 03 / 2022 | DEADLINE 31/07/2022 | LAST UPDATE 10 / 07 / 2022

1. DEFINE THE CHALLENGE

Reduce the production of acid waters transforming them into neutral waters, and costs associated to its treatment

2. CHECK CURRENT STATE

Produção Resíduos / Entrada na PEN
% Acid Waters= 11,25%
% Neutral Waters= 14,56%
Monthly Shipping Costs:
Acid Waters = 94,5 k [MU]
Neutral Waters= 6,9 k [MU]
Shipping Costs per ton:
Acid Waters =385€/ton
Baselinebetween07/21 and 01/22

3. SET TARGET STATE

Acid Waters / Processed Material at PEN
% Acid Waters = 7%

4. FIND ROOT CAUSES

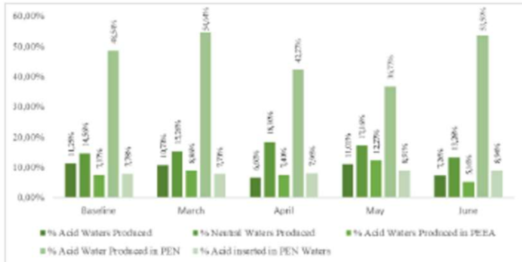
Tk 27 purge not standardized.
Upstream purges not standardized
R10001 Neutral Purge not standardized
Excessive acid consumption
Tricanter'swashing water is sent to the acid tank
Excessive water consumption in theTricanter

5. DESIGN SOLUTIONS

6. TEST SOLUTIONS

7. UPDATE ACTION PLAN

8. CONFIRM RESULTS AND STANDARDS



9. ASSES, DEPLOY AND PRESERVE

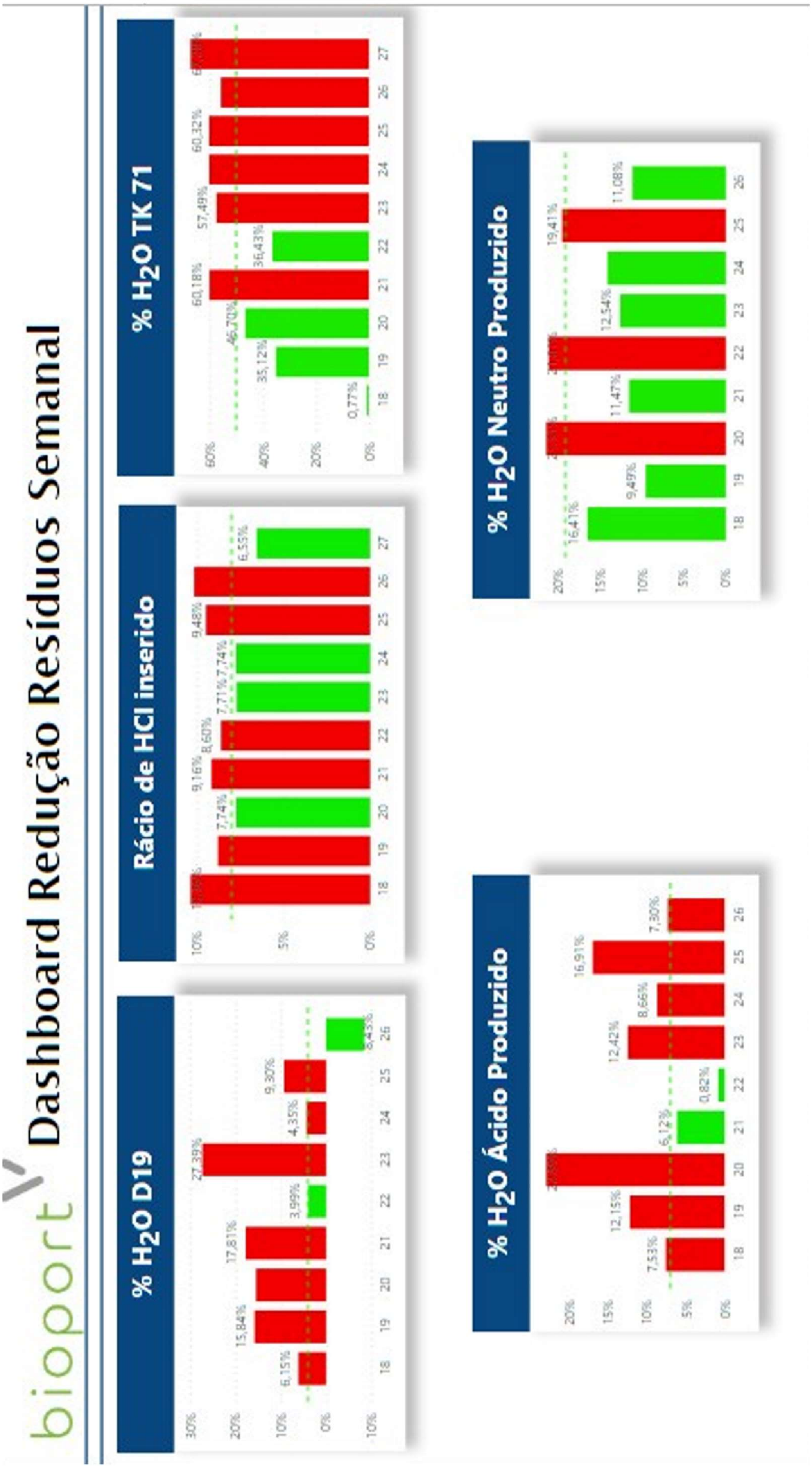
Usage of a conductivity meter in more tanks

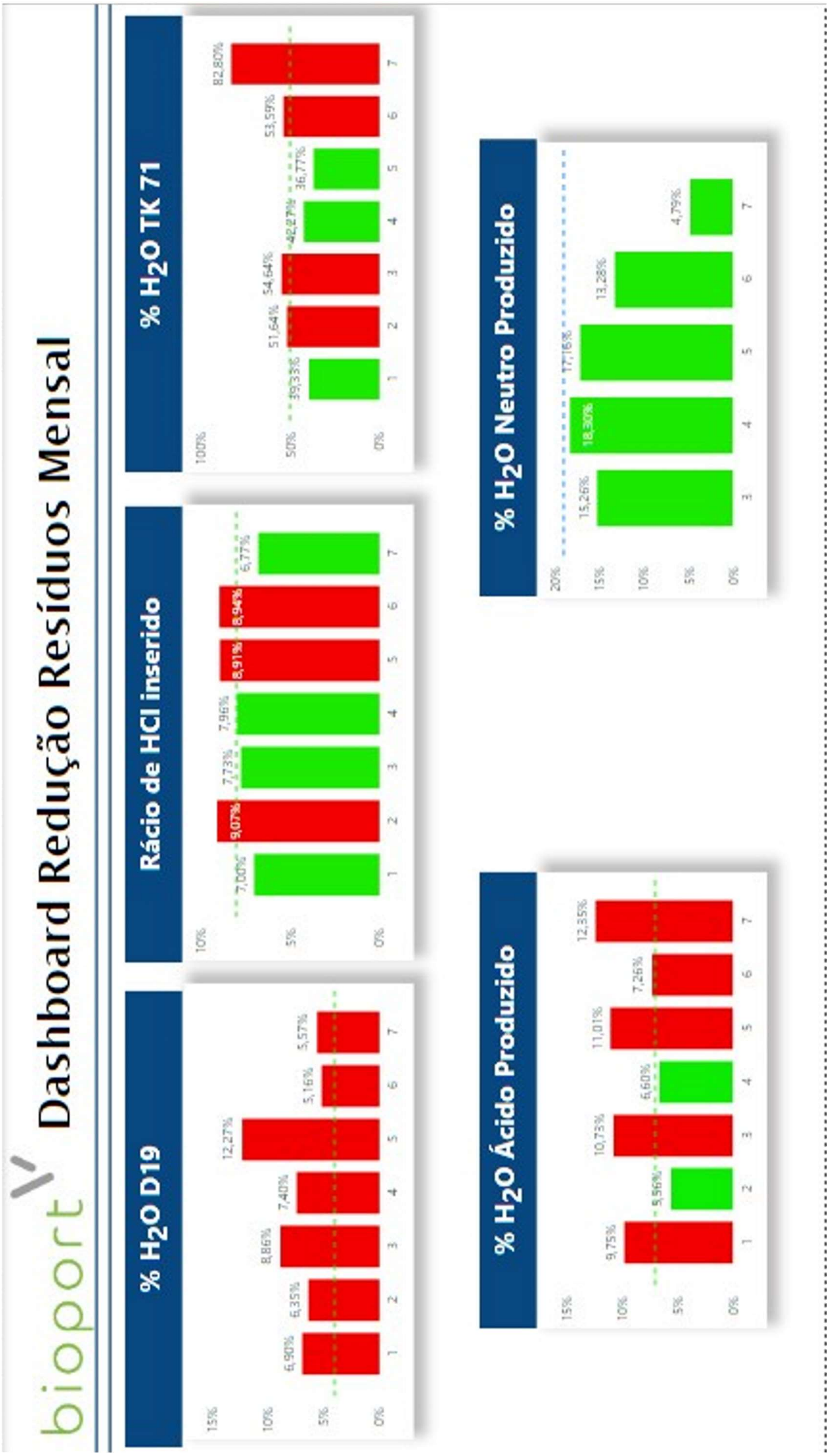
Project Leader: Industrial Manager | Team: Movements and Production | Sponsor: CompanyD Board

APPENDIX D: PDCA of the Reduction of wastewaters

#	Topic/Opportunity	Problem	Action	Comments	Responsible	Start Date	Conclusion Date	PDCA
1	Acid Water Flow	Horizontal Decanter washing water goes to acid water tank	Meeting with Maintenance Manager to assess solution		Industrial Manager	10/03/2022	31/07/2022	Delayed
2	Acid Water Flow	Horizontal Decanter washing water goes to acid water tank	Line design		Industrial Manager	10/03/2022	31/07/2022	Delayed
3	Acid Water Flow	Purge TK71	Job Instruction		Industrial Manager	10/03/2022	17/06/2022	Completed (A)
4	Acid Water Flow	Purge TK71	Job Instruction		Industrial Manager	10/03/2022	05/05/2022	Completed (A)
5	Acid Water Flow	Purge TK 73	Job Instruction		Industrial Manager	10/03/2022	13/07/2022	Planned (P)
6	Acid Water Flow	Purge D19	Job Instruction		Industrial Manager	10/03/2022	04/07/2022	Completed (A)
7	Acid Water Flow	Purge TK27	Job Instruction	Check with % water in TK 27	Industrial Manager	10/03/2022	05/05/2022	Completed (A)
8	Acid Water Flow	Acid Purge R10001	Job Instruction	Check with % water in pre treatment	Industrial Manager	10/03/2022	15/03/2020	Completed (A)
9	Acid Water Flow	Purge TK22	Job Instruction		Industrial Manager	10/03/2022	06/07/2022	Completed (A)
10	Acid Water Flow	Neutral Purge R10001	Job Instruction		Industrial Manager	10/03/2022	15/03/2020	Completed (A)
11	Acid Water Flow	Purge D19	Job Instruction		Industrial Manager	10/03/2022	31/07/2022	Completed (A)
12	Acid Water Flow	Purge TK222	Job Instruction		Industrial Manager	10/03/2022	21/06/2022	Completed (A)
13	Acid Water Flow	Purge R2901	Job Instruction		Industrial Manager	10/03/2022	05/05/2022	Completed (A)
14	Acid Water Flow	KPI Calculation	Power BI Dashboard		Kaizen	10/03/2022	04/07/2022	Completed (A)
15	Acid Water Flow	Purge TK 73	Job Instruction		Industrial Manager	10/03/2022	04/07/2022	Completed (A)

APPENDIX E: Dashboard of the Reduction of wastewaters




bioport
Dashboard Redução Resíduos Mensal
% H2O D19
6,90%
6,35%
8,86%
7,40%
12,27%
5,16%
5,57%
Rácio de HCl inserido
7,00%
9,07%
7,73%
7,96%
8,91%
8,94%
6,77%
% H2O TK 71
39,33%
51,64%
54,64%
42,27%
36,77%
53,59%
82,80%
% H2O Ácido Produzido
9,75%
5,56%
10,73%
6,60%
11,01%
7,26%
12,35%
% H2O Neutro Produzido
15,26%
18,30%
17,16%
13,28%
4,79%

APPENDIX F: Skills Matrix

- 0 Não tem conhecimento
- 1 Tem conhecimento, mas não tem autonomia
- 2 Tem conhecimento e é autónomo
- 3 Tem capacidade de formação

PRODUÇÃO	Chefe de Turno									Técnicos										MANUTENÇÃO / MOVIMENTAÇÕES		LABORATÓRIO
LABORATÓRIO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
PEBD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	N/A	
PEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	N/A	
Paragem PEN																				N/A	N/A	
Alterações de Caudal | Setpoints																				N/A	N/A	
pH Skid 1																				N/A	N/A	
IA Entrada PEN																				N/A	N/A	
IA Skid 2																				N/A	N/A	
IA Skid 3																				N/A	N/A	
Doseamento da Injeção do KOH																				N/A	N/A	
Caudal da Purga do Decantador																				N/A	N/A	
Ácido Cítrico																				N/A	N/A	
Pressão Centrifuga																				N/A	N/A	
Teor de água do Desidratador																				N/A	N/A	
Temperatura Desidratador																				N/A	N/A	
Troca Filtros Alimentação PEN																				N/A	N/A	
Purga do Coalescente																				N/A	N/A	
Transferência R2001 (dos Arranques) para TK71																				N/A	N/A	
Registo do Número de Lavagens da Centrifuga																				N/A	N/A	
Transferência TK24 para D04																				N/A	N/A	
Troca de H2O do barrilete de vácuo do desidratador																				N/A	N/A	
Arranque Desidratador																				N/A	N/A	
PEEA	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	N/A	
PEG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	N/A	
PERT	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	N/A	
PROCEDIMENTOS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	