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Proposal for Improvements to Increase Production Flow in the Sodium Lactate Obtaining Process in the Food Industry

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Abstract: The industrial segment of the food industry represented approximately 10.6% of the Brazilian GDP in 2022, according to ABIA data. Within this context, food additives, including lactic acid, are found. The latest report from Mordor Intelligence estimates a 4.2% growth in demand for lactic acid by 2026. In order to meet this growth, this work was developed. The problem-solving analysis method was applied in conjunction with other market methodologies and tools, such as fault tree analysis, FMEA, and statistical tools. The main focus of the study was to increase sodium lactate productivity to ensure customer demand is met in the coming years. Thus, the research aimed to assist the company in achieving maximum production capacity in obtaining sodium lactate with a production flow of 2,900 L/h. An FMEA was applied to the heat exchangers in the process, resulting in the identification of three failures, which were addressed through association with fault tree analysis. In conclusion, it was found that the model proposed by the MASP methodology was a strong driver for identifying root causes and eliminating them.

Key words: sodium lactate, MASP, heat exchangers, continuous improvement
JEL codes: L0

1. Introduction

The food industrial segment is one of the largest in the country, representing approximately 10.6% of the GDP, according to the latest infographic released by the Brazilian Association of the Food Industry (ABIA) in 2022. Brazil is the second-largest food exporter globally. Roma et al. (2020) brings to light the issue of the microbiological quality of foods produced in this economic sector, as an important parameter to be evaluated. In this context, the food industry uses food additives, which, as elucidated by Honorato et al. (2013), have become mandatory in modern nutrition to maintain the quality and validity of products in supermarkets, being of fundamental importance for the national and international industry.

Teixeira (2018) states that food additives are intentionally added to foods for various reasons, such as improving taste, texture, and appearance, and extending the shelf life of processed foods. One of the additives used in the food industry is lactic acid, as described by Carioni et al. (2001). This organic compound lowers the food’s pH, thereby inhibiting the growth of pathogenic microorganisms and increasing the shelf life of processed products.

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According to Comex data (2022), from January to July 2022, Brazilian food industry exports reached US$ 194.251 million, representing a growth of 20.1% and a surplus of US$ 39.889.7 million. Brazilian exports of organic and inorganic compounds from January to July 2022 grew by 4.0% compared to the same period the previous year, amounting to US$ 5.5 billion (Comex, 2022).

During this period, exports of lactic acid totaled approximately US$ 29.7 million. The top five countries that exported this product were, in descending order, the Netherlands, Argentina, the United States, Uruguay, and Indonesia (Comex, 2022).

According to Mordor Intelligence (2021), a 4.2% growth in global lactic acid consumption is estimated by the year 2026. One of the factors responsible is the increasing application in the food and beverage market in emerging economies. One such market is the rapidly emerging Asian market due to the increased use of lactic acid as a food additive due to the growing consumption of meat and its derivatives.

In view of these needs, a continuous improvement study and the application of the problem-solving analysis method were developed in one of the processes of a company located in the northern state of Rio de Janeiro, which produces lactic acid and its derivatives. Due to the fact that sodium lactate follows the trend of increasing lactic acid productivity, as it is a derivative of this organic acid, the company needs to achieve the maximum utilization of its production capacity with a production of 2,900 L/h of the derivative.

Thus, the core of this work is to answer the following question: how to increase the production of sodium lactate?

2. Literature Review

According to IDEC (2022), the food industry has been of fundamental importance to humanity through the application of conservation techniques and the development of new processing methods, which help overcome food safety barriers. According to ABIA data (2022), exports of processed foods in Brazil amounted to R$244.1 billion in 2021, with a 16.9% increase in global revenue. Retail food represented R$493.3 billion in the same year, and the food industry employed approximately 1.7 million workers, a 1.2% increase from 2020

Lactic acid has been used as an important preservative in the food industry. According to Pizato et al. (2015), lactic acid (2-hydroxypropanoic acid, IUPAC name) is a natural organic compound with great versatility. It is used as an ingredient for pH adjustment or as a preservative because it acts as an inhibitor of pathogenic bacteria in bovine, swine, or poultry matrix foods (Jhon et al., 2008). Industrial production of lactic acid is based on microbial activity through the fermentation of carbohydrates (Inkinen et al., 2011).

In the lactic acid obtaining process, lactic acid bacteria are most frequently used (Jia et al., 2018). According to Ghanbari et al. (2013), one of the most important characteristics of lactic acid bacteria is their ability to resist stress, which is essential for their survival. For this reason, it is crucial to ensure optimal conditions for microbial growth within a fermenter for lactic acid production.

Sodium lactate is a product derived from lactic acid that, according to Kuo & Chen (2004), has the ability to increase the shelf life of pork and poultry by suppressing meat oxidation and promoting increased stability of animal fat, reducing the action of deteriorating microorganisms. The production process of obtaining sodium lactate begins with the supply of raw materials, lactic acid, and caustic soda (NaOH), to the reactor. The reaction to produce this additive is a neutralization reaction, where lactic acid releases an H+ ion and binds to the hydroxide (OH^{-}) of caustic soda, forming water (H_2O). Sodium ions (Na^+) and lactate ions ($C_3H_5O_3^-$) combine to form sodium lactate ($C_3H_5O_3Na$)

$$CH_3CHOHCOOH + NaOH\ CH_3CHOHCOONa + H_2O \tag{1}$$

The process for obtaining sodium lactate in the company where this work was applied follows the flowchart illustrated in Figure 1.

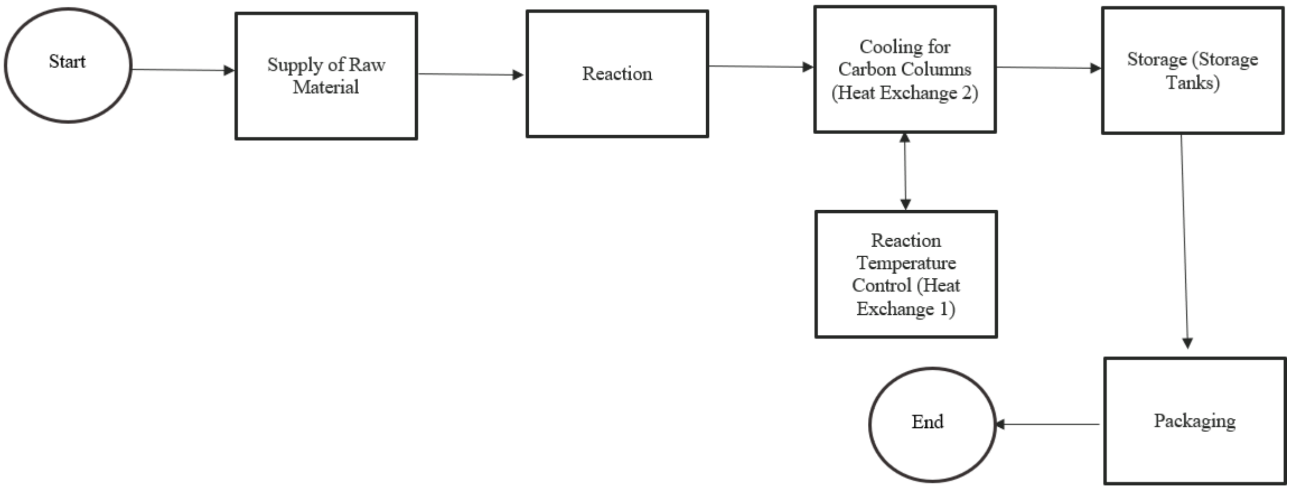

Figure 1 Flowchart of the sodium Lactate Production Process

Due to the issue being related to temperature control in the production process, both in the reaction and in the processing (entry into coal columns), the analysis methodology was applied to the heat exchangers. Al-Dawery et al. (2012) state that plate heat exchangers are the most common types and are applied in operations involving wide temperature and pressure ranges. Additionally, these devices are more compact and consequently occupy less physical space. Another point is that their process capacity can be expanded more practically (Prado et al., 2011).

According to Laube & Madergan (2018), to size a heat exchanger, it is necessary to define the initial data of the fluid. These include the mechanical measurements of the heat exchanger, the mass flow rate of the cold and hot fluids, the inlet temperature of both fluids, the viscosity of both, the specific mass, and the thermal conductivity of the cold and hot fluids.

2.1 Applied Tools

To understand the applied tools, it is necessary to conceptualize the process, which, according to Crivellato & Vitoriano (2022), is a set of routine activities with a beginning, middle, and end. They are classified into three categories: primary or business-related, linked to the generation of organization revenue through the manufacturing of products or execution of services; support and administrative.

When it comes to process modeling, Lobo et al. (2018) explain that initially, it is necessary to know the current state of the process, known as “as is”. This allows understanding what is happening and why the purpose of the process is not being fulfilled. Through the understanding of the process and the use of process engineering, it is transformed into something new through improvements, reaching a future state, called “to be”.

Pareto Diagram: Silva & Souza Junior (2022) explain that the Pareto Chart was initially conceived by the economist and engineer Vilfredo Pareto, who analyzed the wealth in his country and saw that most of the wealth was concentrated in 20% of the population. For Barbosa & Rangel (2018), the Pareto diagram is based on the 80/20 concept, meaning that few causes generate significant problems, representing about 20%. For this reason, it is necessary to focus on these main causes.

5W2H: As exemplified by Ribeiro et al. (2021), one of the useful tools for building an action plan is 5W2H. According to Yang et al. (2021), the method is based on answering 7 questions with initials in English: what, who, when, where, why, and how. These questions have a specific connotation in building the action plan.

Fault Tree Analysis (FTA): According to Kabir (2017), Fault Tree Analysis (FTA) was invented in 1961 at Bell Laboratories by H. A. Watson with the support of M. A. Mearns. The goal of this invention was to assist in the design of the Minuteman missile for the U.S. Air Force. The fault tree is a qualitative technique used to identify and analyze factors related to the occurrence of a problem. Through it, it is possible to identify potential causes and failure paths (Zagidullin et al., 2021).

FMEA: It is an analysis method that uses a bottom-up evaluation mental model to identify possible failure modes with their causes. Its main objective is to identify potential problems in the process that may affect its safety or performance. Thus, the methodology allows introducing countermeasures to minimize or mitigate the effects of the potential problems mapped (Sulaman et al., 2017). According to Peeters et al. (2018), the application of the method should involve a multidisciplinary team, as this increases the likelihood of identifying all possible failures and their effects. In addition, a variation of FMEA is FMECA, where the criticality component is added, giving the tool a quantitative character. In this variation, the Risk Priority Number (RPN) is added.

3. Case Study

3.1 Applied Methodology

The research is a case study of a real problem in the fictitious company "Walt", where the Problem-Solving Analysis Method was used as the main tool for study and proposition of mitigating actions for the problem. Figure 2 illustrates the method used in this work.

Figure 2 Representation of MASP. Source: Adapted Campos, 2004 (Translated).

3.2 Analysis and Discussion of Results

The first step of the work was to characterize the problem based on the data provided by the company. For this purpose, the information from the sales department about the increased demand for the years 2023 and 2024 was taken into account as a premise. Based on this information from the sales department, an average production flow of sodium lactate of 2,900 L/h was projected.

During the problem characterization stage, the average daily flows for all 365 days of 2021 were collected. The collected values were entered and processed in the Minitab software. The first graph constructed was the time series, presented in Figure 3, where the obtained values of average production flows were compared with the target.

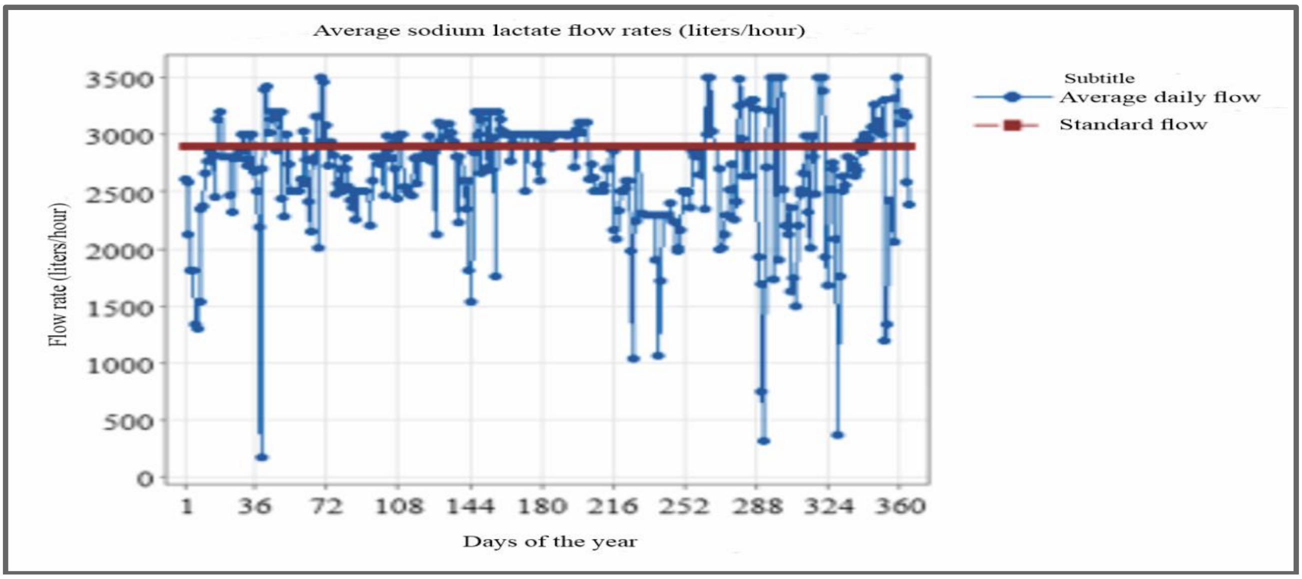

Figure 3 Time Series Graph of Average Daily Flows (Year 2021) in Relation to the Standard Flow to Serve the Market (Translated)

Based on the results obtained, it was possible to observe a significant fluctuation in the production flow. The company has a database where operators record all production stops with the reason and duration. The software automatically calculates the equivalent product loss in tons for that time interval. The data for the year 2021 was extracted, and a Pareto chart was constructed, as illustrated in Figure 4.

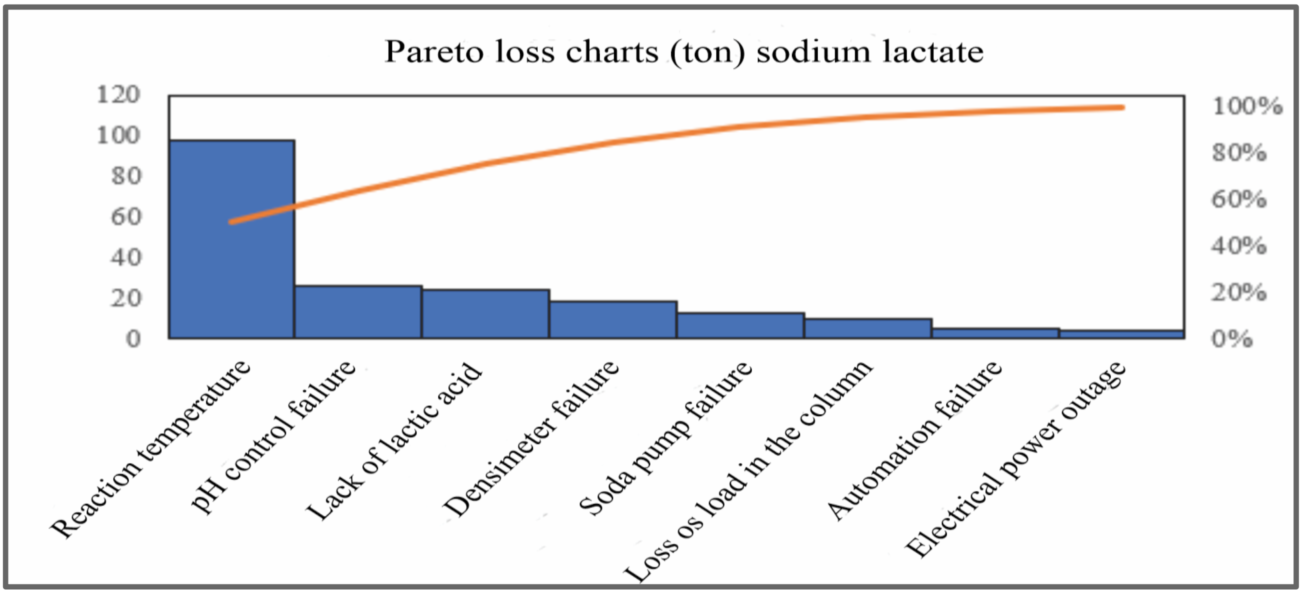

Figure 4 Pareto Chart of Losses, in Tons, of Sodium Lactate in 2021 (Translated).

The Pareto chart revealed to the team that the main issue in 2021 was the reaction temperature, accounting for approximately 50% of the losses that year, equivalent to 98 tons. To better understand the problem, interviews were conducted with the operators involved in this process. These interviews revealed that the reaction temperature involved working at a lower temperature than the lower specification limit. This reduction occurred because if the operation worked with temperatures within the control limits, the cooling in the second heat exchanger was not sufficient to cool the product for passage through the charcoal columns.

The specification limits for the reaction temperature range between 80ºC and 90ºC. However, an average working temperature of 76.03ºC was observed. When the process operates at a lower reaction temperature, the reaction yield decreases, and to compensate for this decrease, it is necessary to work with lower flow rates, leading to production losses.

In the production process for obtaining sodium lactate, there are two plate heat exchangers involved. The first heat exchanger is responsible for cooling the product during the reaction, as this reaction is exothermic (releases heat). The second heat exchanger, also a plate heat exchanger, is responsible for cooling the final product before it enters the activated charcoal columns.

With a focus on understanding the failure modes for these heat exchangers, a brainstorming session was conducted with the operators. During this brainstorming, the following questions were asked:

- What are the reasons for the “Reaction Temperature” failure?
- Why do we work with a reaction temperature below the specification limit?

Based on the answers to these questions, an Ishikawa diagram was constructed, revealing that the majority of issues were linked to the heat exchangers involved in the process. Using these results, a Failure Modes and Effects Analysis (FMEA) was applied to understand the failure modes of these equipment.

From the FMEA application, three main causes were identified for the problem:

- Adjustment of the reaction temperature below the specification limit made as a way to compensate for the inefficiency of the second heat exchanger.
- Presence of impurities in lactic acid, mainly fatty material from the fermentative processes;
- Scaling occurring due to the lack of routine cleaning of the plates in the heat exchangers.

The multifunctional team was challenged to critically evaluate the effectiveness of the FMEA. Team members found the use of severity (S), probability of occurrence (O), and detection (D) scores to determine the Risk Priority Number (RPN) subjective. They mentioned that even with defined rules, it was still challenging to classify, as the range from 1 to 10 was considered too broad. For this reason, the FMEA was associated with the Fault Tree Analysis (FTA) method.

The first fault tree constructed was for the failure classified as “Adjustment of temperature below the lower specification limit”. Four causes were obtained for the evaluated failure mode:

- Interlocking due to temperature was removed (bypassed), and temperature adjustments were made manually by the operation.
- There was no cleaning frequency of the plates in the heat exchangers.
- It was found that the number of plates in the second heat exchanger was lower than necessary to reduce the temperature to the limits required for the adsorption process of impurities by charcoal columns.
- The cooling water quality of the heat exchangers was outside the standards, leading to scaling.

For the second fault tree, five root causes were found for the problem:

Lack of renewal of the microbial culture.

- It was observed that the supplementation of the fermenter with the necessary nutrient was in an amount higher than recommended. It is known from the literature that an excess of nutrients in fermentative processes increases the viscosity of the fermented must.
- It was observed that when the company used sugar from a specific supplier in fermentation, bacteria underwent stress, and this was reflected in the productivity curve.
- An operational error was observed regarding the interpretation of the productivity curve, where the end of fermentation was being declared late.
- It was observed that the heating of the fermenters had a lot of oscillation due to fluctuations in steam demand.

After the analysis through the fault tree, several opportunities for improvement in the process were identified. Before the action plan was created by the team, a GUT (Gravity, Urgency, Tendency) matrix was developed. In this matrix, the criteria used for gravity, urgency, and tendency followed the parameters described in Table 1.

Table 1 Scoring Criteria for the GUT Matrix

Punctuation	Gravity (G)	Urgency (U)	Tendency (T)
1	No gravity	No urgency	No tendency to worsen
2	Slight gravity	Slight urgency	Worsens in the long term
3	Serious	Urgent	Worsens in the medium term
4	Very serious	Very urgent	Worsens in the short term
5	Extremely serious	Extremely urgent	Rapidly worsens

In this way, the identified causes were entered into this table and classified based on the scoring criteria defined for the GUT Matrix. The obtained values were multiplied together, and the result of these products was used as the prioritization criterion. That is, the priority for implementing actions was defined from the highest score to the lowest. Table 2 shows the result of this prioritization criterion.

Table 2 GUT Matrix Resulting From the Classification of the Root Causes Obtained

Root Cause	G	U	T	Product
Temperature interlock withdrawal (bypass)	3	4	3	36
Lack of cleaning frequency for the heat exchanger plates	4	4	3	48
Error in the design of the 2nd heat exchanger regarding the number of plates	3	3	3	27
Cooling water quality outside the standards	5	4	4	80
Lack of renewal of microbial culture	2	2	2	8
High potassium supplementation rate for the fermenter	3	3	2	18
Supplier sugar X generating stress in fermentative bacteria	3	2	2	12
Operational error in interpreting the productivity curve	3	4	3	36
Fluctuation in steam demand for fermenter heating	5	5	4	100

Based on the result of the product of the root cause scores, actions were created for the action plan. In this plan, the company chose to use the 5W1H. The actions were prioritized based on the positive response to one of the two questions listed below:

a) Does this action eliminate the mapped root cause?

b) Does this action prevent the recurrence of the mapped root cause?

Monthly, the cross-functional team began to meet to review the actions and check their progress. The process engineer from the plant was responsible for carrying out this task and assessing the effectiveness of the actions as they were implemented.

4. Conclusion

In general, the application of MASP as a guiding methodology for the work proved to be effective in solving the problem. Through the application of the Pareto Chart, the company was able to identify that the failure mode limiting the increase in production flow was the high reaction temperature, as over 80% of the 8 failures reported by the operator were related to it. Based on this analysis, the use of brainstorming involving the operations team revealed the failure modes causing the high reaction temperature. The Ishikawa diagram helped organize the obtained ideas and served as an excellent guiding tool for applying FMEA to the heat exchangers.

The use of FMEA was important because it provided a better understanding of failure modes related to the heat exchangers in the context of the production process. It also allowed for the prioritization of actions based on its methodological foundation. The use of fault trees was crucial in obtaining the nine root causes of the problem.

The GUT matrix was an excellent tool for prioritizing actions to be taken in eliminating or mitigating the root causes of the problem. Analyzing the actions regarding the elimination or prevention of the identified causes was an excellent guide for obtaining effective solutions. The 5W1H tool proved to be diligent in organizing the actions to be implemented.

Finally, it was observed that the chosen actions were effective, reducing losses from the "high reaction temperature" failure mode by approximately 95% (about 95 tons of production). Therefore, it can be affirmed that MASP proved to be an effective methodology for solving the problem presented by the company.

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