Sorbitol production optimization in B2B industry with six sigma approach

I I Pariasa, M A S Anam and A E Hardana

Department of Social Economic, Faculty of Agriculture, Universitas Brawijaya, Indonesia
E-mail: pariasa@ub.ac.id

Abstract. The purpose of this study is to examine quality control in the sorbitol industry using the six-sigma method to determine the causes of wasteful production costs and factors that influence them. This research collected 300 data with the details of 150 data in each phase, before and after the implementation of improvement action, and interviewed 12 employees in the sorbitol department. Six sigma approach consists of five phases: define tested by statistic descriptive, measure analyzed by process capability, analyze phase analyzed by fishbone diagram and action priority matrix, improve analyzed by process capability, and control phase tested by X Bar R chart. The results of this study are DPMO (Defect Per Million Opportunity) decreased from 994,497 to 543,058, sigma level increased from -1.04 to 1.39, standard deviation from 0.0072196 to 0.01, Pp (Process Performance) from 0.11 to 0.22, Ppk (Process Performance Index) from -0.85 to 0.09, average reducing sugar from 0.11 to 0.14, and the use of nickel from 298 to 221 Kg.

1. Introduction
Quality control is essential for companies to be able to produce the best products to win the market competition. Product quality is the product's ability to demonstrate its functions, including overall durability, reliability, accuracy, ease of operation, product repairs, and other product attributes so that quality control will spur companies to continue to improve their performance both for internal and internal purposes external [1]. Quality control is vital for the company as a tool to maintain quality and improve the level of product defects to zero defects by improving the production system [2]. Product quality is influenced by factors like human factors, machines, methods, raw materials, measurement, and the environment [3]. Quality control has urgent attention for B2B company because it integrates and produces intermediate products to be processed as the finish good by other companies. The quality control strategy in the B2B company is related to how it delivers value to the customers. The better the quality, the more satisfied the customer, and eventually, it can build a strong business foundation for the B2B company.

Therefore, quality research is essential for the company's development so that it is always of the best quality and reduces the increase in operational costs. This study examines the application of six sigma in the industry using the DMAIC (Define, Measure, Analyze, Improve, Control) flow. These stages will
explain the research object being studied, describe the factors that affect product quality, explain the alternative strategies implemented, analyze the process capability before and after the Six Sigma method, and analyze the sustainability of the project.

One of the industries that must strictly maintain quality control is the sweetener industry. The need for artificial sweeteners globally continues to increase and the emergence of new competitors and the strengthening of existing competitors’ competencies, so as B2B company integrated with the end producer or industry, a sweetener company should able to maintain the quality of its products. One of the artificial sweetener's products is sorbitol. Sorbitol is a sweetener made from agricultural products such as corn and cassava and has several advantages such as being safe for people with diabetes, does not cause reactions with dental plaque bacteria, cheap raw materials, and can be used as raw material for finished products ranging from food, candy, medicine, cosmetics, toothpaste, and others [4]. However, there are problems experienced by the sweetener industry, namely the increase in the cost of nickel as a catalyst in sorbitol making, especially in the hydrogenation process. Nickel helps to convert cellulose and cellobiose to be sorbitol to fasten the reaction in the hydrogenation process [5]. The necessary for nickel will increase if reducing sugar value from the sorbitol is out of the specification limit. Nickel is nonrenewable material, there will be a restriction for nickel export from Indonesia due to the urgency of remaining nickel existence [6]. So that the usage of nickel must be optimized well. Based on the descriptions that have been described, this research was conducted to improve the quality of reducing sugars to minimize the use of nickel catalysts.

2. Research Method

2.1 Sampling method

The sample used in this study was 150 sorbitol production data in August and October 2019. This number refers to the following formula:

\[ \text{Subgroup x daily data units} = 25 \times 6 = 150 \text{ batch} \]  

(1)

The need for a total sample of sorbitol production data is carried out based on the guidelines in Minitab 2018 required minimum subgroup is 25 multiply with the daily number of product data produced which is 6, resulting in a total data of 150 batch production data which is sufficient to explain the capability process in the phase before six sigma and 150 batch production after six sigma. Sampling was done using a simple random sampling technique. Meanwhile, for the fishbone diagram analysis, respondents were employees selected using a judgment sampling technique with the criteria that employees who are directly involved in the production of sorbitol.

2.2 Research stages

This research consists of five stages. The first is Define, using descriptive statistics and the SIPOC diagram. The second is Measure, using process capability. The third is Analyze, using a fishbone diagram and action priority matrix. The fourth is Improve, using process capability, and the last is Analyze, using control X bar R chart.

3. Results and Discussion

3.1 Current conditions of sorbitol indicator
Table 1. Sorbitol quality variable indicators.

| Indicator                        | Ideal     | Actual   |
|----------------------------------|-----------|----------|
| RS                               | 0.13-0.15 | 0.11     |
| Ph                               | 4.5-7     | 4.51     |
| Brix (°Bx)                       | 40-57     | 53.33    |
| EC (electrical conductivity) (μs/cm) | Max. 300  | 13.61    |

The indicators for the characteristics of sorbitol in the autoclave hydrogenation process are presented in Table 1. Four indicators can affect the quality of sorbitol, including reducing sugar, pH, Brix, and electrical conductivity. Based on the table, the sorbitol indicator that does not match the ideal limit is reducing sugar. Reducing sugar (RS) is a substance that contains or forms aldehydes or ketones, which can affect the level of caramelization, color, dry texture, and taste of the product in the Maillard's reaction making bread [7]. Outlier data in reducing sugar level also affects more nickel consumption, which contributes most to the production budget of sorbitol so that this condition can exceed the company budget. In the table, because the results of the indicators that do not meet the ideal level are reducing sugars, future research will focus on improving the quality of reducing sugars.

3.2 Six sigma implementation
There are five stages in Six Sigma, namely Define, Measure, Analyze, Improve, Control stages.

3.2.1 Define
Define phase aims to identify and define problems. This phase uses descriptive statistical methods to measure variables that are indicators of sorbitol and uses a SIPOC diagram to see the process flow in detail for the object to be studied [3].

Figure 1. Results of descriptive statistics for reducing sugars.

This diagram shows that the supplier comprises of a series of processes that occur before the hydrogenation process, then the input consists of dextrose, steam, H2, electricity, nickel, and schedule (reaction plan). The primary process is called a hydrogenation process that occurs in an autoclave. In this process, the addition of nickel occurs. There is an output in the form of a sorbitol product with several product characteristics such as aroma, reducing sugar value (%) obtained by knowing the Brix, electric conductivity, and pH values. Furthermore, the customer is the next process that will be gone through, such as refining, evaporation, and storing in the warehouse by cooperating with customers or the next department,
such as quality control, filling, production planning, and inventory control (PPIC), warehouse, and delivery. Through the SIPOC diagram, the team understands the project flow in detail and clearly.

![Figure 2. SIPOC diagram.](image)

**Table 2. Process capability results in the measure phase.**

| Criteria                      | Ideal | Actual |
|-------------------------------|-------|--------|
| Pp (Process Performance)      | 1.33  | 0.11   |
| Ppk (Process Performance Index)| 1     | -0.85  |

### 3.2.2 Measure
In the measure phase, data is calculated on reducing sugar to determine the actual quality conditions. Through the process capability carried out with Minitab 2018, the results were produced and presented in Table 2. The DPMO level indicates the defect rate of the products per one million. Based on the table, the DPMO is so poor because the number indicates that there are 994,497 defective products from one million productions. Sigma level also shallow that far from the ideal number, namely -1.04. Standard deviation is within the ideal range that indicates there are no many variants of data. Process Performance has a shallow level under 1, which indicates the process is not good because its quality is out of specification. Process Performance is under 0 level, which indicates the usual process is not good because the process is out of the specification limit.

**Table 2.** Process capability results in the measure phase.

### 3.2.3 Analyze
The third stage is the Analyze phase, which is the phase to analyze the factors that cause an indicator to have a poor quality of reducing sugar so that it will be analyzed by using a fishbone diagram with 6 M factors (man, machine, method, material, measure, mother nature) which affect reducing sugar quality (Figure 3).
Project execution has a limited time, so only the highest priority issues are executed. The determination of these problems' priority is analyzed using an action priority matrix, based on the results of the analysis and the classification of problems based on the level of project implementation effort and their impact.

The problem that is prioritized to be executed is a problem that belongs to the category of quick wins because it requires an effort that is easy to implement and has a significant impact. The second priority is a problem that is classified as a significant project category because it requires a complicated business but has a tremendous impact. The third priority is the fill-in category, which is an action that is easy to implement but has little impact. The last priority is thankless tasks with strenuous effort and little impact. The following are the factors that fall into the quick wins category, including incomplete operator tools, differences in how to calculate the RS value between the lab and the plant due to different tools, differences in operator abilities, operators forgetting to check samples, and there is no standard in nickel dumping. Only factors that are classified as quick wins will be fixed in the improvement phase (Figure 4).

**Figure 3.** Fishbone diagram analysis on reducing sugar.

3.2.4 Improve

The next phase is the Improve phase, which implements the recommended improvement activities based on quick wins and evaluation of the process's capability to reduce the sugar quality (Table 3). Therefore, the improvement activities were conducted with the following details:
1. Conduct refresh training for the operator.
2. Complete the tools for the operator.
3. Create a one-point lesson.
4. Revise the work instruction.
5. Calibrate the nickel glass.

Table 3. Process capability results in the improve phase.

| Indicator                        | Ideal   | Result  |
|----------------------------------|---------|---------|
| RS                               | 0.13-0.15 | 0.14   |
| pH                               | 4.5-7   | 6.07   |
| Brix (“°Bx”)                     | 40-57   | 52.87  |
| EC (electrical conductivity) (μS/cm) | Max. 300 | 17.23  |
| DPMO                             | 3.4     | 543,058 |
| Sigma                            | 6       | 1.39   |
| Standard deviation               | <1      | 0.01   |
| Pp (Process Performance)         | >1.33   | 0.22   |
| Ppk (Process Performance Index)  | >1      | 0.09   |

After finishing all those activities, the 150 data of post six sigma implementation need to be researched to understand the progress level. After getting the result of analysis after six sigma implementations, it can be compared with the result from the pre-six-sigma implementation's result. As a result of this, the comparison of process capability from pre and post six sigma implementation.

Figure 5. Minitab analysis pre and post-implementation of six sigma.
Table 4. Evaluation of six sigma implementation.

| Criteria                        | Ideal       | Before    | After     |
|---------------------------------|-------------|-----------|-----------|
| RS                              | 0.13-0.15   | 0.11      | 0.14      |
| pH                              | 4.5-7       | 4.51      | 6.07      |
| Brix (°Bx)                      | 40-57       | 53.33     | 52.87     |
| EC (electrical conductivity)    | Max. 300    | 13.61     | 17.23     |
| (μs/cm)                         |             |           |           |
| DPMO (Defect per million        | 3.4         | 994,497   | 543,058   |
| opportunity)                    |             |           |           |
| Sigma level                     | 6           | -1.04     | 1.39      |
| Standard deviation              | <1          | 0.0072196 | 0.01      |
| Pp (Process Performance)        | >1,33       | 0.11      | 0.22      |
| Index                           | >1          | -0.85     | 0.09      |
| Nickel usage (Kg) (N=150 batch) | 180         | 298 Kg    | 221 Kg    |

Figure 6. Control phase analysis with minitab.

Based on the Figure 5 and Table 4, reducing sugar values increases from 0.11 to 0.14, pH increases from 4.51 to 6.07, Brix decreases from 53.33 to 52.87, and EC still stable namely from 13.61 to 17.23 and there is a decrease in value DPMO from before the implementation and after six sigma, namely 994,497 to 543,058, the sigma level from -1.04 to 1.39 this value has increased but needs to be improved again. Standard deviation is 0.0072196 to 0.01, Pp (Process Performance) from 0.11 to 0.22, Ppk (Process Performance Index) from -0.85 to 0.09, average RS from 0.11 to 0.14. Nickel use from 298 to 221.
3.2.5 Control

The last phase is control. The purpose of this phase is to determine whether the existing development can be stable for the next process. The picture above shows that the entire process is still unstable, with 12% out of control subgroups existed. X bar and R Charts also show that there three points of outliers, which means although the process was improved but still not stable for long-term implementation.

4. Conclusions

The research successfully minimizes the use of nickel catalysts by improving the quality of reducing sugars. The study suggested many factors influencing the quality of reducing sugar based on 6M, and only a few corrective actions were included in the "quick wins" category based on the Action Priority Matrix such as incomplete operator tools, differences in how to calculate the RS value between the lab and the plant due to different tools, differences in operator abilities, operators forgetting to check samples, and there is no standard in nickel dumping. The findings suggest some strategies for improvement such as conducting refresh training for the operator, complete the tools for the operator, create a one-point lesson, revise the work instruction, and calibrate the nickel glass.

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