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Analysis of Improving the Quality of Fatty Acid Methyl Ester (FAME) Products Against Acid Value (AV) Levels Using the Six Sigma and Kaizen Methods

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Abstract. PT XYZ is a palm oil derivative processing company that produces biodiesel / FAME (Fatty Acid Methyl Ester) products. However, there are several obstacles that still occur during the company's production process which causes the acid value (AV) level of FAME products to not meet specifications and there are 3% defective products. Therefore, this study aims to determine the improvement plan by applying kaizen to the Six Sigma improvement stage and reducing outspec products in the FAME production process. The results of the research conducted using the six sigma method show that the company has a DPMO value of 71,459 and a sigma value of 2.96 which is in the average position of the industry in Indonesia based on the results of data processing. While recommendations for improvement by implementing kaizen include training machine operators, making standard operating procedures (SOPs) for machine inspections on each shift, reducing the amount of strearin added to AV raw materials before pre-treatment, maintenance and machine calibration. This step are expected to overcome the main problems identified in the study.

Keywords: Quality, Quality Control, Biodiesel, Six Sigma, DMAIC, Kaizen

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1. Introduction

Biodiesel, which is made from vegetable oils such as palm oil, castor oil, soybean oil, etc., is produced through a transesterification process with methanol and ethanol reagents, which is an environmentally friendly way to reduce the use of fossil fuels [1]. SNI 7182:2015 is the national standard for biodiesel quality in Indonesia. This standard requires an acid value (AV) of 0.4%, a water/moisture concentration of 340 ppm, a monoglyceride concentration of 0.525%, a methyl ester concentration of 96.5%, and a contaminant/impurity concentration of 20 ppm [2]. So, good quality comes from good processes, in accordance with predetermined quality standards based on market needs [3].

PT. XYZ is a palm oil derivative processing company that produces biodiesel/FAME (Fatty Acid Methyl Ester) products. PT. XYZ has FAME quality standards that have been set by the company and customers. However, there are several problems that still occur during the company's production

process, which causes the acid value (AV) levels of FAME products to not comply with specifications and there are 3% of products that are defective. Product quality is very important to consider because it greatly affects customer satisfaction with the products produced. To face this challenge, manufacturers are now required to be able to produce products that meet and even exceed customer expectations [4]. Overcoming these problems by analyzing quality control using the kaizen and six sigma methods [5].

Where the Six Sigma Method is a method that finds the source of problems in production and reduces the level of product defects to reduce costs and streamline production time [6]. By going through the DMAIC stage approach (Define, Measure, Analyze, Improve and Control) [7]. Then, the kaizen method is used to find the right improvement recommendations for each work component so that the improvement goals achieved can be sustainable [8]. The Kaizen approach looks at the business from a broader perspective. The goal is to improve every aspect of the business, setting process standards, increasing efficiency, and constantly looking for ways to reduce waste. It is a system that is always focused on improvement, from the entry level to the highest [9]. Kaizen, meaning continuous improvement, is one of the important ways to gain an edge in production and is essential in today's competitive environment [10]. Kaizen is a principle of continuous improvement represented by the Japanese terms KAI and ZEN, which mean "change" and "getting better." [11]. According to [12] four tools can be used to implement kaizen, namely:

1. Kaizen checklist
   Used to find problems and point out opportunities and improvements.
2. The five-step Kaizen strategy
   The 5-S movement, which is another Japanese word that starts with the letter S, namely Seiri (Sorting), Seiton (Organizing), Seiso (Cleaning), Seiketsu (Stabilizing), and Shitsuke (Habituation).
3. Five W and One H:
   Who, What, Where, When, Why, and How are tools that are widely used as management tools in a variety of environments.
   environments
4. Five M's checklist
   In the kaizen approach, there are five main components involved in every process: people, machines, materials, techniques, and measurements. Within each process, any improvements can be made by reviewing the parts of the production process.

2. Methods

This research uses data such as laboratory testing results and FAME product defect data to reduce the value of defective products and provide improvement recommendations for PT. XYZ. DMAIC and Kaizen methods are used. Researchers collected data samples from 01 October to 01 November 2023. Then this data was processed and analyzed using various DMAIC tools, including X and R maps, process capability, and fishbone diagrams[13]. In addition, the kaizen implementation tool M Checklist was also used [14]. Then the results are processed using the following stages:

A. Define (identify the problem)
   At the Definition stage, observations and interviews with the head of production are carried out to determine Critical to Quality (CTQ). Which is a quality characteristic of the product produced and to determine the specification limit of a product in accordance with customer desires [15].
B. Measure (measurement)
   In this step, process capability analysis is carried out by calculating the Defect Per Million Opportunities (DPMO) value to get the results of the sigma value calculation [16].
C. Analyze (analysis)
   In the analysis stage, a fishbone diagram is used to analyze the causes of the increase in FAME Acid Value (AV) levels. To do this, the fishbone diagram is divided into human, material, machine and method elements [17]. This analysis stage uses the findings from the interview with the production manager to produce the fishbone diagram results. The results of the analysis

stage will be used to make recommendations for improvement at the improvement stage.

D. Improve (repair)
After identifying the root cause of the quality problem, the fourth step of the Six Sigma approach is improvement. The improvement is by implementing kaizen using kaizen method M checklist [18]

E. Control
The final analysis process of Six Sigma is control, which emphasizes the documentation and dissemination of the actions that have been taken [19]

3. Results and Discussion

Data collection

The following is the data of FAME production defect products on 01 October – 01 November 2023

Table 1. FAME production defect products on 01 October – 01 November 2023

No	Date	Production (Ton)	Defect type Acid Value (Ton)	Defect products (%)
1	01 October – 01 November 2023	48.000	1.440	3

Table 1 shows that the total production is 48,000 tons, with defective products of 1,440 tons or about 3%.

The following are the results of quality measurements of Fatty Acid Methyl Ester (FAME) AV (Acid Value) levels carried out in the PT. XYZ laboratory on October 1 to November 1, 2023 used for this study. shown in table 2.

Table 2. Test Results for FAME Acid Value (AV) levels

Date	Acid Value (AV) levels		
01-Okt-23	0,129	0,191	0,187
02-Okt-23	0,217	0,196	0,125
03-Okt-23	0,178	0,155	0,151
04-Okt-23	0,199	0,106	0,204
05-Okt-23	0,222	0,188	0,135
06-Okt-23	0,143	0,161	0,130
07-Okt-23	0,201	0,210	0,231
08-Okt-23	0,198	0,259	0,210
09-Okt-23	0,177	0,213	0,189
10-Okt-23	0,180	0,143	0,124
11-Okt-23	0,164	0,222	0,207
12-Okt-23	0,200	0,165	0,156
13-Okt-23	0,142	0,152	0,163
14-Okt-23	0,280	0,258	0,242
15-Okt-23	0,210	0,143	0,160
16-Okt-23	0,132	0,123	0,142
17-Okt-23	0,211	0,221	0,190
18-Okt-23	0,132	0,146	0,190
19-Okt-23	0,178	0,193	0,278
20-Okt-23	0,267	0,221	0,175
21-Okt-23	0,259	0,211	0,193
22-Okt-23	0,293	0,268	0,220
23-Okt-23	0,190	0,156	0,172
24-Okt-23	0,190	0,134	0,145
25-Okt-23	0,170	0,145	0,153
26-Okt-23	0,123	0,134	0,164
27-Okt-23	0,135	0,152	0,190
28-Okt-23	0,298	0,279	0,200
29-Okt-23	0,135	0,123	0,150
30-Okt-23	0,150	0,142	0,167
31-Okt-23	0,153	0,153	0,124
01-Nov-23	0,163	0,191	0,145

Table 2 shows the results of the FAME Acid Value (AV) test conducted by the laboratory of PT XYZ.

Data processing

A. Define stages

At this stage, the first step taken is to determine the project to be implemented based on a predetermined priority scale. After that, the next step is to establish an action plan. After that determine Critical to Quality (CTQ). In this research, the factor or driver that consumers want is the level of AV (Acid Value) which produces product quality standards in the table 3.

Table 3. CTQ (Critical To Quality) FAME Products

CTQ (Critical to Quality)	Type of Content	Specification	Description
CTQ -1	Acid Value (AV)	AV <0,25%	One of the main factors influencing FAME quality is acid content. High acid levels can cause the resulting biodiesel to become corrosive or damage fuel injectors, damage fuel pumps and diesel engines.

Table 3 shows that the company set a CTQ for the Acid Value (AV) level of FAME products at <0.25%.

B. Measure Stages

At this stage, the Defect Per Million Opportunities (DPMO) value is calculated to obtain the sigma value calculation results. At PT. XYZ, this research will evaluate the performance of the Fatty Acid Methyl Ester (FAME) production process using Maps $\bar{X}$ and R, then value the process capability for each quality characteristic or Critical to Quality (CTQ).

1. Maps $\bar{X}$ and R

   Maps $\bar{X}$ and R control charts are used to illustrate the differences that occur in the production process [20]. Next, data processing is carried out using Minitab to calculate the CL center limit, UCL lower limit, and LCL lower limit values which are displayed in the graph. The following image 1 shows a maps of $\bar{X}$ and R Acid Concentration (AV)/Amount of Acid.

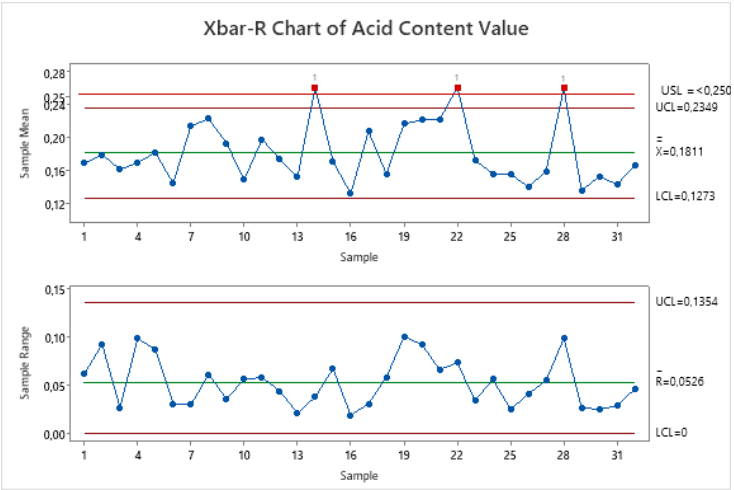

Figure 1. Map of $\bar{X}$ and R AV levels

As shown in Figure 1. On the $\bar{X}$ map, the CL value is 0.181, the UCL value is 0.235, and the LCL value is 0.127, data numbers 14, 22, and 28 on the $\bar{X}$ map are (outside the control limits). while on the R map, the CL value is 0.052, the UCL value is 0.135, and the LCL value is 0. Thus, all data on the R map are within (inside the control limits).

2. Processability Acid Content Value (AV)
   To improve process quality, the process capability index is used to measure the performance relationship between the actual process and the expected specification limits..

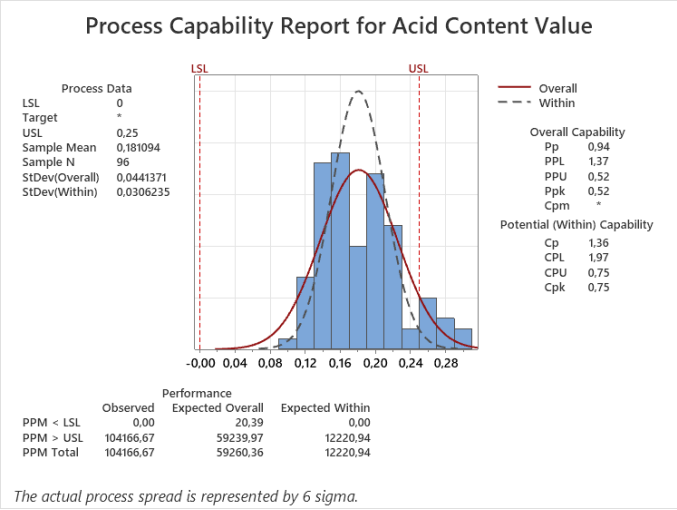

Figure 2. Process Capability AV Level

As shown in Figure 2. The results show Cp of 0,60, CPL of 0,90, CPU of 0.29, and Cpk of 0.29. Since this study is a short-term study, the goal is to find out the actual capability of the production process based on the quality of the products produced. If the Cpk value is <1, then the production process may fail to produce products that do not conform to specifications [1].

3. Sigma Value Measurement

   a. DPMO value
      - Part Per Million Defect (PPM) Overall Performance

Total DPMO
= PPM Overall + PPM Within (1)
= 59.239 + 12.220
= 71.459

The DPMO value is 71.459, and when converted to the Sigma Table, the sigma value is 2,96. The company is at the industry average position in Indonesia with this sigma value.

C. Analyze stages

Analysis of causal factors affecting low FAME quality levels using fishbone diagram. The following fishbone diagram shows the variation of acid content value (AV).

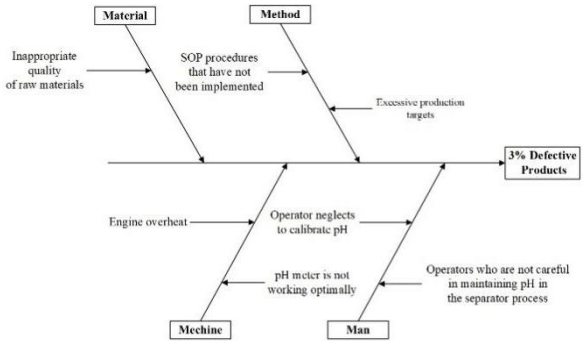

Figure 3. Fishbone Diagram of AV Levels

Based on Figure 3. The varying AV levels are caused by 4 (four) factors. The following is an explanation of the fishbone diagram of Acid Value (AV) levels :

Table 4. Explanation of AV Levels Fishbone Diagram

Category	Problems	Description
Man	Operators who are not careful in maintaining pH in the separator process	pH is one of the processes that can cause high AV levels in FAME. pH that is not in accordance with procedures can occur because the operator does not monitor properly.
	Operator negligence in Performing pH calibration	Due to fatigue, the operator fails to calibrate the pH meter. can cause the pH meter value does not match the pH of the field.
Method	SOP procedures that have not been implemented	The absence of standard operating procedures (SOPs) led to incomplete machine inspections, which resulted in some elements not being evaluated.
	Targeted production excess	One of the factors affecting the quality of FAME produced is excessive production targets. Excessive production targets cause the production process to be accelerated than usual, resulting in a decrease in FAME quality.
Material	Inappropriate quality of raw materials	The main factor affecting the quality of the FAME produced is the raw material. mixing RBDPO with Stearin this causes the AV value of the raw material to not match.
Machine	Engine overheat	Engine overheat occurs when the engine is used continuously. This reduces the performance of the engine significantly and may even cause the engine to become unusable.
	pH meter is not working optimally	The pH meter is not working properly because there is no pH inspection or calibration.

Table 4 shows the explanation of the fishbone diagram of AV levels caused by four defect-causing factors: man, machine, material, and method.

D. Improve Stages

At the improvement stage, the kaizen implementation tool used is the Five-M Checklist

Table 5. Five M checklists

Factor	Problems	Description
Man	- Operators who are not careful in maintaining pH in the separator process - Operator negligence in Performing pH calibration	- Strictly and gradually supervise the separator process - Provide training to separator machine operators on machine mechanisms and process procedures - Appoint an operator to be responsible for calibration in each shift
Method	- SOP procedures that have not been implemented - Targeted production excess	- Thorough machine inspections and regular scheduling of each shift - Reducing the production target so that the FAME production produced is in accordance with specifications
Material	- Inappropriate quality of raw materials	- Reduce the amount of strearin mixed so that the AV before the pre-treatment process meets the standard.
Machine	- Engine overheat - pH meter is not working optimally	- Perform routine maintenance of separator machines - Perform pH meter calibration every shift

Table 5 above shows suggestions that can help reduce production failures in FAME products by applying the Kaizen method

E. Control Stage

This control stage emphasizes the documentation and dissemination of actions that have been proposed for the improvement process :

a. Provide training to separator machine operators on machine mechanisms and process procedures
b. Making SOPs regarding routine machine inspections on each shift and Reducing the production target so that the FAME production produced is in accordance with specifications
c. Reduce the amount of strearin mixed in the raw materials so that the AV before the pre-treatment process meets the standard.
d. Perform routine maintenance of the separator machine and calibrate the pH meter every shift.

In addition, the company should have a strong internal audit team to ensure continuous improvement and up-to-date update documents for long-term success.

4. Conclusion

According to the above research, there are several factors that affect the quality of FAME products that do not meet specifications, such as human resource management, raw material handling, and production machine maintenance, which cause acid levels to increase during the production process. Based on data analysis and processing using the six sigma method, the company has a DPMO value of 71.459 and a sigma value of 2.96, which indicates that the company is in the average position of the

industry in Indonesia. Furthermore, suggestions for improvement are based on kaizen implementation tools : include training machine operators, making standard operating procedures (SOPs) for machine inspections on each shift, reducing the amount of strearin added to AV raw materials before pre-treatment, maintenance and machine calibration. However, for validation and deeper understanding, further research is needed with a wider dataset and longer research period.

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