APPLICATION OF THE SIX-SIGMA CONCEPT TO TIME REDUCTION FOR RESIN RECIRCULATE RINSE IN DEMINERALIZED WATER PRODUCTION

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Abstract — In the Kraft recovery boilers plant, demineralized water is an important element in the heat exchanger process for the production of electricity and steam. Demineralized water exchanges ion with resins. The current problem of demineralized water qualification has high conductivity value in resin recirculation rinse. This makes the rinsing process take much longer compared with the standard and it decreases the production capacity of the demineralized water. In this paper using the Six Sigma method to reduce the duration of the recirculation rinse process. Cause and Effect Matrix and Failure Mode Effective Analysis (FMEA) were adopted to select the factors that affect the recirculation rinse time. The 2²¹ factorial design method was used to determine the potential preliminary root causes. After that a series of factorial design experiments was conducted to identify the factors that significantly impact the recirculation rinse period. Having done all that, the guidelines to setup the process parameters to effectively regulate the rinse period were established. The result showed that the process can reduce the recirculation rinse time from 150 minutes to 23 minutes. In addition, the production of the demineralized water increases to 10,780 cubic meters per month or 13% more than previously obtained.

Keywords— Demineralized water, Recirculation rinse, Six Sigma

I. INTRODUCTION

Demineralized water is used in the recovery boiler plant to process heat exchange for generate electricity and steam. When hard water is used and is completely evaporated, calcium and magnesium ions remain to foul water supply pipes, boilers, and heat exchangers. Therefore, the fouling slag forms quite thick and is hard to remove. It reduces the capability of the heat transfer system and also causes the cost to increase. The fouling slag can reduce the flow rate of the water in the pipe or even block the pipe. For as a reason, Demineralized water is used replacement and is a significant element in the production process [1-4]. If demineralized water is not enough to supply the demand of the recovery manufacturing boiler plant the outside procurement is needed to fulfill unsatisfied the demand. As a result, the cost of production of electricity and steam are rising. The current problem of demineralized water production is that when they are passing through the regeneration resin process the conductivity value is still high. This makes the rinsing process time much longer when compared with the standard and the production capacity of the demineralized water is decreased.

This research aims to shorten the time for the resin recirculation rinse in the production of demineralized water using the Six Sigma approach. In this paper, Six Sigma tools and concepts were adopted to improve water quality in an effort to reduce errors that occur in processes to a minimum by using statistical principles. Therefore, focusing on the customers need is the key issue for the process improvement as well as cost reduction. Six Sigma (6σ) levels mean a chance to waste that is 3.4 parts per million or referring to good product quality of 99.99966% [5]. The Six Sigma DMAIC procedure comprises five key steps namely; Define, Measurement, Analyze, Improve, and Control [6, 7]. This tool is used in this research to improve water quality, shorten time of the resin recirculation, and reduce costs in the production process.

II. DEFINE PHASE

In this case study, the production of demineralized water uses the concept of ion exchange with resins [8-10]. Cation and anion resins are used as a means to exchange cation and anion of hard water. This procedure is called the on-line process. When the resin performs poorly in ion exchange, the resin can be rejuvenated by using sulfuric acid and sodium hydroxide alkali. This procedure is called regeneration process. The resin has to be rinsed through water to clean acid and alkaline. This is called the rinse process. After that the resin is returned to the on-line process cycle again.

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The rinse process consists of three steps, i.e. slow rinse, fast rinse, and recirculate rinse. From the historical resin recirculation rinse time data (January 2014 - September 2015), it was found that the duration of the resin recirculation rinse became longer and longer as time passed. This results in the reduction of demineralized water production. Consequently, the electricity and steam costs are increased due to the need to purchase the demineralized water from outside vendors to meet the demands of production. The reason that the resin recirculation rinse takes a very long time is due to a high conductivity value of the water. As a result, the water in the system has to be circulated until its quality is acceptable. The criteria for accepting the demineralized water are conductivity less than 2 μS/cm and silica dioxide less than 20 ppb. This research aims at an improvement of the water quality and a decrease in resin recirculation rinse time.

III. MEASURE PHASE

This phase involves two main steps, i.e. measurement system analysis and problem identification analysis.

A. Measurement System Analysis

The automatic measuring instruments are tested to assess their precision and accuracy. It is noticeable that all measuring instruments used in laboratories have been certified by a third party. As a result, we can conclude that all measuring instruments are acceptable and ready to use. Analyze accuracy and precision of the measuring system of Silica dioxide (SiO₂) [11]. Three staff members analysed silica dioxide in the water. Ten samples with two replicates were conducted in this experiment. The results are shown in Table I.

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Components</th>
<th>Contribution rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.1312</td>
<td>0.19%</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.1312</td>
<td>0.19%</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.0000</td>
<td>0.00%</td>
</tr>
<tr>
<td>Operator</td>
<td>0.0000</td>
<td>0.00%</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>65.5089</td>
<td>99.81%</td>
</tr>
<tr>
<td>Total Variation</td>
<td>69.6398</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Table 1 shows that the part-to-part variability is 99.81 and total gage R&R variability is 0.19 from which it can be concluded that this system of measurement accuracy and variation is acceptable.

B. Problem Identification Analysis

Brainstorming by a knowledgeable team who specializes in the production process of demineralized water was conducted. They articulated the relevant factors that can affect resin recirculation rinse time. The cause and effect diagram with 5M1E is applied to this process. It was revealed that the numbers of tentative causes is 28. These factors are then used to analyze the relationship between cause and effect using the cause and effect matrix. By scoring these relationships (i.e. 0, 1, 3 and 9), the factors with significant impacts on the problem are selected through Pareto analysis (Fig. 1).
The result shows that nine factors have a high score. These factors are further screened by using Failure Mode and Effects Analysis (FMEA). Five factors with high ratings were selected for the experiments in the next phase (Fig. 2), which is 82% of the total score.

IV. ANALYSIS ROOT CAUSE OF PROBLEM

From the Pareto chart, five factors are selected including the anion resins, the flow rate of slow rinse in the anion and cation exchanger, the amount of slow rinse water in the anion and cation exchanger. The $2^{4-1}$ fractional factorial design [12] with 5 factors and 2 levels of each factor were adopted (Table II). The levels of each factor are mainly chosen from the minimum and maximum adjustable values of the instruments used in the plant. All 16 trials were conducted within a completely randomized experiment. The response variable in this study was the duration of the resin recirculation rinse.

<table>
<thead>
<tr>
<th>No.</th>
<th>Factors</th>
<th>Units</th>
<th>Symbols</th>
<th>Levels of factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anion resin</td>
<td>-</td>
<td>A</td>
<td>Low (-1) High (1)</td>
</tr>
<tr>
<td>2</td>
<td>Flow rate of slow rinse in the anion exchanger</td>
<td>litres/minute</td>
<td>B</td>
<td>0.01 0.10</td>
</tr>
<tr>
<td>3</td>
<td>Amount of slow rinse water in the anion exchanger</td>
<td>litres</td>
<td>C</td>
<td>2 6</td>
</tr>
<tr>
<td>4</td>
<td>Amount of slow rinse water in the cation exchanger</td>
<td>litres</td>
<td>D</td>
<td>2 6</td>
</tr>
<tr>
<td>5</td>
<td>Flow rate of slow rinse in the cation exchanger</td>
<td>litres/minute</td>
<td>E</td>
<td>0.05 0.30</td>
</tr>
</tbody>
</table>

The experimental data were analyzed by using the Minitab software and its results are shown in Fig. 3. The test statistic results [13] show that the main effects A, B and E have a P-value less than 0.05 (significant level $\alpha$), whereas factors C and D are not significant. Therefore, it can be concluded that the main effects A, B, and E (i.e. anion resin, the flow rate of slow rinse in the anion and cation exchanger) are significant at 95% confident interval. In addition, two-way interactions of AB, AE and BE are also significant. As a result, anionic resin, the flow rate of slow rinse in the anion, and cation exchanger need further investigation to find their appropriate level settings.

V. IMPROVEMENT PHASE

In this phase, more levels of the significant factors derived from the previous experiment are tested to find their appropriate levels that can shorten the duration of resin recirculation to a minimum. All 3 factors, i.e. two levels of the anion resin (A), three levels of the flow rate of slow rinse in the cation exchanger (B), and three levels of the flow rate of slow rinse in the anion exchanger (C) are experimented with 2 replicates (Table III).
TABLE III. FACTORS AND LEVEL OF FACTORS IN FACTORIAL EXPERIMENTAL DESIGN

<table>
<thead>
<tr>
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<td>Low (-1) Medium (0) High (1)</td>
</tr>
<tr>
<td>2</td>
<td>Flow rate of slow rinse in the cation exchanger</td>
<td>litres/minute</td>
<td>B</td>
<td>0.05 0.15 0.30</td>
</tr>
<tr>
<td>3</td>
<td>Flow rate of slow rinse in the anion exchanger</td>
<td>litres/minute</td>
<td>C</td>
<td>0.01 0.05 0.10</td>
</tr>
</tbody>
</table>

Fig. 4 shows the statistical analysis that the main effects, two-way interactions and three-way interactions have a P-value less than 0.05 (significant level, $\alpha$). Therefore, it can be concluded that the main effects, two-way interactions and three-way interactions affect the resin recirculation rinse time significantly at 95% confident interval. Since the interaction effects are significant, the interaction effect plots are used as a mean to select the proper settings for the factors (Fig. 5). It is found that the level of each factor that can minimize the resin recirculation rinse time is selected as follows: a new anion resin, flow rate of slow rinse Cation at 0.15 litres per minute, and the flow rate of slow rinse Anion at 0.10 litres per minute. This selection is also based on the practicality adjustment of the factors.

VI. CONTROL PHASE

All levels of the three significant factors are implemented in the production process and the data relating to the period of resin recirculation rinse time are collected for 30 days. It was found that the average period of resin recirculation rinse time is reduced substantially to 23 minutes (Fig. 6), whereas the average data previously obtained before improvement was 150 minutes. As a result, the production of demineralized water was increased to 10,780 cubic meters per month or 13% more than previously obtained. To maintain the quality of demineralized water production after the improvement process, the work instruction for operational control in demineralized water production is in written form. In addition, the concerned staff members are trained to recognize and understand the importance of controlling these parameters to ensure that the performance improvements are maintained.

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VII. CONCLUSIONS

The Six Sigma approach was applied to improve the production of demineralized water. Quality tools and statistical analysis played a significant role in shortening the process of resin recirculation rinse time in demineralized water production. The DMAIC steps incorporating the $2^{k-1}$ fractional factorial design were employed to find the root causes of the problem and suggest how to set the relevant process parameters. The result indicated clearly that a new set of process parameters increased the in-plant production capacity of demineralized water, which in turn lowered the cost of outside procurement.

REFERENCES


BIOGRAPHY

Thidarat Thanyarak graduated in 2010 from Chulalongkorn University, with a B.Sci. degree in chemistry. Currently, she is studying her second year of the Master Program in industrial engineering at Chulalongkorn University. Thidarat worked as a researcher with over 5 years of progressive and hands-on experience in demineralized water production and recovery boiler system. As part of her role, she was involved in an exhaustive program to implement Six Sigma throughout the company.

Parames Chutima is a professor in industrial engineering at Chulalongkorn University. He obtained his B.Eng. degree in electrical engineering from Chulalongkorn University, and a M.Eng. degree in industrial engineering and management from Asian Institute of Technology, and a Ph.D. degree in manufacturing engineering and operations management from the University of Nottingham. His area of research includes lean, VE and Six-Sigma implementations in industry. Parames is now serving as the director of Regional Centre of Manufacturing Systems Engineering, Faculty of Engineering, Chulalongkorn University. He has published several papers for leading international conferences and journals.