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Study on the Implementation of Quality Control Charts in the Drinking Water Industry , A Case Study :Dajla Water Plant)

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Abstract. Statistical process control (SPC) is a set of methods and tools that use statistical techniques to monitor and control the quality of a process or a product. SPC can help to identify the sources of variation, reduce the variability, improve the process capability, detect out-of-control situations, and take corrective actions. This study aimed to implement SPC control charts in drinking water and to evaluate their effectiveness in improving the quality of drinking water. The study focused on one type of control chart: an x-bar chart. The study used data from a bottled Dajla water plant and applied the x-bar chart to one quality characteristic, the pH of water. The results showed that the pH of water was out of control and that several sources of variation affected the quality of water. The possible causes of variation were identified by examining the out-of-control points or patterns, and by investigating the production process and conditions. The improvement actions were suggested by eliminating or reducing the assignable causes of variation and adjusting or optimizing the production process and parameters. The limitations of this study are that it only used data from one production line and one company, and it only considered one quality characteristic.

Keywords: Statistical process control (SPC), control chart, Water quality, pH of water.

1.Introduction

Dajla factory is one of the most modern water plants of Assalwa for food industries and water purification, equipped with the latest packaging lines from the French company Sidel and the German company Krones. These lines place water in bottles of various sizes and in a 24-hour production in a half-litter container with a production capacity of 115,000 cans per hour, at a rate of 22,000 per hour for 330 ml containers and 18,000 per hour for litter and half-litter containers. The production of cups reaches 30,000 cups per hour. Dajla Water has a production quality to the highest standards. Dajla Water received the ISO 22 000 and ISO 9001 marks as confirmation of the level and quality of the service provided. The Dajla laboratory performs a total dissolved salts test and a pH test to ensure its pH and bait quality. This is every hour of production and the retention of reference samples for it, and we do not forget to check the taste, the grin, and the percentage of ozone gas in the water thus the Dajla plant sends several samples of raw and bottled water to international and local laboratories to verify the correctness of the analyses and the results obtained; which happen periodically [1].

Drinking water is one of the most essential and vital resources for human health and well-being. Drinking water quality is influenced by various factors, such as source water quality, treatment processes, distribution systems, storage conditions, and consumer practices. Drinking water quality can affect the aesthetic, chemical, microbiological, and radiological aspects of water, and thus pose potential risks to human health and consumer satisfaction.

Statistical process control (SPC) is a set of methods and tools that use statistical techniques to monitor and control the quality of a process or a product. SPC can help to identify the sources of variation, reduce the variability, improve the process capability, detect out-of-control situations, and take corrective actions. One of the main tools of SPC is control charts, which are graphical displays that show the variation of a quality characteristic over time and compare it with predefined control limits. Control charts can help to distinguish between the common causes and the assignable causes of variation, and signal when a process is in or out of control.

The aim of this study is to implement SPC: control charts in Dajla water for drinking and to evaluate their effectiveness in improving the quality of drinking water. The study will focus on one type of control chart: an x-bar chart. The study will use data from bottled water in the Dajla plant and apply the x-bar chart to one quality characteristic: the pH of water. pH is a measure of the acidity or alkalinity of water, and it can affect the taste, Odor, color, corrosion, scaling, disinfection, and microbial growth of water. The World Health Organization (WHO) recommends that the pH of drinking water should be between 6.5 and 8.5 [2].

The objectives of this study are:

- To collect data on pH of water from a bottled water plant.
- To construct an x-bar chart for pH of water using appropriate software.
- To analyses the x-bar chart and determine if the process is in or out of control.

- To identify the possible causes of variation and suggest improvement actions.

The structure of this paper is as follows:

- **Literature review:** This section will review the relevant literature on SPC: control charts and their applications in drinking water.
- **Methodology:** This section will describe the data collection methods, the software used for constructing control chart, and the criteria for interpreting control chart.
- **Results:** This section will present the x-bar chart for pH of water, and analyze its patterns and trends.
- **Discussion:** This section will discuss the findings from the x-bar chart, identify the sources of variation, and suggest improvement actions.
- **Conclusion:** This section will summarize the main points of this study, highlight its limitations and implications, and suggest directions for future research.

1.1.Literature Review

SPC control charts are one of the most widely used tools for quality improvement in various industries and sectors. They were developed by Walter A. Shewhart in 1924 at Bell Laboratories as a method for monitoring variation in telephone transmission systems [3]. Shewhart proposed that variation in any process can be classified into two types: common causes and assignable causes. Common causes are inherent in the process and affect every output. Assignable causes are external or special factors that affect some outputs randomly or sporadically. Shewhart argued that a process is in control when only common causes are present, and out of control when assignable causes are present. He also suggested that a process should be left alone when it is in control, and investigated when it is out of control.

Shewhart introduced two types of control charts: variables control charts and attributes control charts. Variables control charts are used for continuous or measurable quality characteristics, such as length, weight or temperature. Attributes control charts are used for discrete or countable quality characteristics, such as defects or errors. Shewhart also defined three types of limits for each type of chart: upper control limit (UCL), lower control limit (LCL) and center line (CL). The UCL and LCL are calculated based on statistical formulas that reflect the natural variation of the process. The CL is usually equal to the mean or proportion of the quality characteristic. Shewhart's basic principle was that if a point falls outside the UCL or LCL, it indicates an out-of-control situation caused by an assignable cause. If all points fall within the UCL and LCL, it indicates an in-control situation caused by common causes.

Shewhart's original variables control charts were x-bar chart and R chart. An x-bar chart plots the sample mean (x-bar) of a quality characteristic against time or sample number. An R chart plots the sample range ® of a quality characteristic against time or sample number. The x-bar chart monitors the central tendency of the process, while the R chart monitors the dispersion of the process. Shewhart recommended that both charts should be used together to get a complete picture of the process variation. Later, other types of variables control charts were developed, such as s chart, which plots the sample standard deviation (s) of a quality characteristic against time or sample number. An s chart is similar to an R chart, but it is more sensitive to small changes in variability and more suitable for large sample sizes [4].

Control charts have been widely applied in various industries and sectors, including drinking water. Drinking water is one of the most essential and vital resources for human health and well-being. Drinking water quality is influenced by various factors, such as source water quality, treatment processes, distribution systems, storage conditions, and consumer practices. Drinking water quality can affect the aesthetic, chemical, microbiological, and radiological aspects of water, and thus pose potential risks to human health and consumer satisfaction.

Several studies have reported the use of control charts in drinking water for monitoring and improving the quality of water. For example, Elevli et al. [5] used x-bar charts and s charts to monitor and control the turbidity and pH of water in a drinking water treatment plant in Samsun, Turkey. They found that some processes were out of control due to various causes, such as raw water quality, filter backwashing, chemical dosing, etc. They suggested improvement actions, such as proper operation and maintenance of filters, proper adjustment of chemical doses, proper monitoring and recording of data, etc.

Another example is Al-Saleem et al. [6] who used x-bar charts and R charts to monitor and control the pH and residual chlorine of water in a drinking water distribution system in Riyadh, Saudi Arabia. They found that some processes were out of control due to various causes, such as chlorine decay, pipe corrosion, water age, etc. They suggested improvement actions, such as proper chlorination and booster stations, proper flushing and cleaning of pipes, proper sampling and analysis of data, etc.

these studies show that control charts can be useful tools for monitoring and improving the quality of drinking water. Control charts can help to identify the sources of variation, reduce the variability, improve the process capability, detect the out-of-control situations, and take corrective actions.

1.2.Methodology

The methodology of this study consists of four steps:

- data collection,
- software selection,
- control chart construction, and control chart interpretation.

2. Data Collection

Dajla water is extracted from the underground wells of after being treated and purified by sand filtering processes to remove impurities and material stuck in it. The two carbon-filtration phases follow to absorb any toxins, organic matter, or chlorine compounds it contained and the microfiltration phase through a 5-micron membrane. This water enters the advanced technology system that contains a carbon filter, then micrometer-sized filters (the most accurate measure for filtering operations) and starts from 10 to 5 microns to the most accurate 1-micron filter to remove any final impurities.

After these processes, water is transferred to the sterilization stage by ultraviolet radiation and then sterilized by ozone to remove bacteria, microparticles, and microbes. This water is then transported to fill in the production line. The process of making the Dajla bottles from plastic sheeting starts with a moving rug until they reach the inflator, and the cans heat up to 120°C to enter the inflation template and take the shape and size required to guarantee their quality. Then, they seal their covers securely to enter a laser sensor to exclude non-standard and format packs, navigate the label phase, print the date of validity and production laser, and seal the storage and transport stage, as every 12 packs of a half-litter capacity are collected. Every six packs are collected for a litter and a half capacity. Then, an adhesive loading strap is placed to carry the packages. The quality characteristic that is monitored in this production line is pH of water.

3.Software Selection

The software used for constructing the x-bar chart for pH of water is Minitab 19, which is a statistical software that provides various tools for data analysis and quality improvement. Minitab 19 has a built-in function for creating control charts, which allows the user to select the type of chart, the data set, the subgroup size, the control limits method, and the display options. Minitab 19 also provides various features for analyzing and interpreting control charts, such as tests for special causes, run chart rules, capability analysis, etc.

3.1. Control Chart Construction

The x-bar chart for pH of water was constructed using the following steps:

- The data on pH of water were collected from the bottling step of the production line. The data were recorded in a spreadsheet file, with each row representing a sample of 4 bottles and each column representing a bottle. The data were collected for 24 consecutive days, with one sample per day. The total number of samples was 24 and the total number of observations was 96.
- The spreadsheet file was imported into Minitab 19, and the data were arranged in a worksheet with one column for pH and one column for sample number.

- The x-bar chart function was selected from the Stat menu, under Control Charts and Variables Charts for Subgroups. The pH column was selected as the variable and the sample number column was selected as the subgroup.
- The x-bar chart options were set as follows: the subgroup size was 4, the control limits method was based on overall standard deviation, the confidence level was 95%, and the tests for special causes were enabled.
- The x-bar chart was displayed in a separate window, showing the x-bar values, the UCL, the LCL, and the CL. The x-bar chart also showed any points or patterns that violated the tests for special causes or the run chart rules.

3.2.Control Chart Interpretation

The x-bar chart for pH of water was interpreted using the following criteria:

- The process is in control if all points fall within the UCL and LCL, and no points or patterns violate the tests for special causes or the run chart rules.
- The process is out of control if any point falls outside the UCL or LCL, or any point or pattern violates the tests for special causes or the run chart rules.
- The possible causes of variation are identified by examining the out-of-control points or patterns, and by investigating the production process and conditions.
- The improvement actions are suggested by eliminating or reducing the assignable causes of variation, and by adjusting or optimizing the production process and parameters.

4.Results

The x-bar chart for pH of water is shown in Figure 2. The x-bar values range from 6.91 to 7.07 with a mean of 7.01. The UCL is 7.1211, the LCL is 6.9022, and the CL is 7.0177.

The x-bar chart shows that there are three out-of-control points: point 2 (7.17), point 3 (7.18), and point 16 (7.13). These points fall outside the UCL, indicating that they are caused by assignable causes of variation. The x-bar chart also shows that there are two patterns that violate the tests for special causes: a run of six points above the CL, and a run of Fourteen points below the CL. These patterns indicate that there are systematic shifts in the mean of the process.

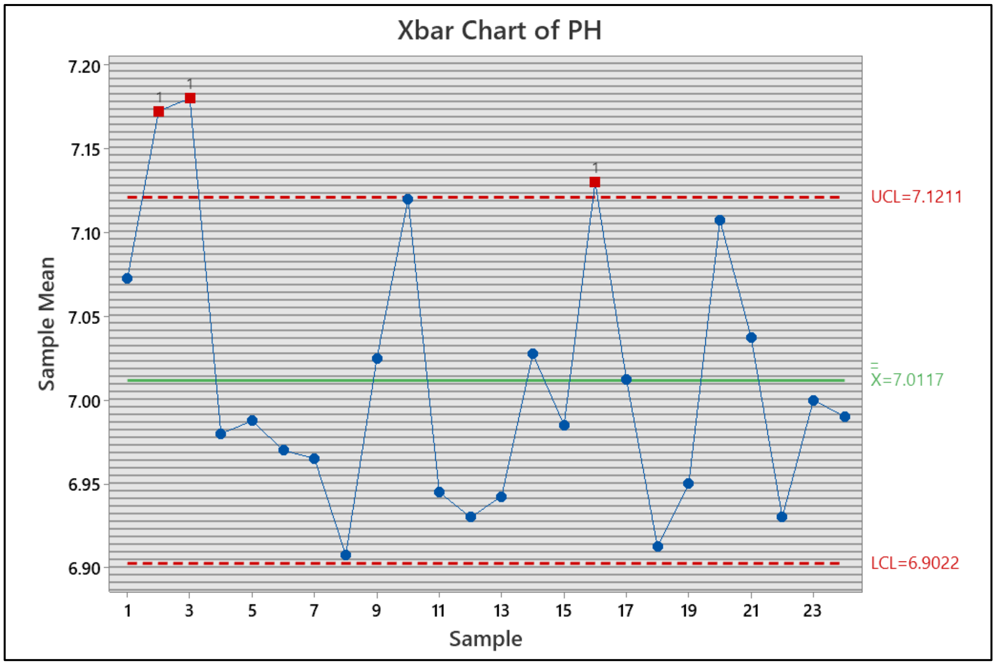

Fig. 1. X-bar chart for pH of water.

5.Discussion

The results from the x-bar chart indicate that the process of pH of water is out of control, and that there are several sources of variation that affect the quality of water. The possible causes of variation are discussed below:

point 2 (7.17) and point 3 (7.18), are above the UCL, indicating that the pH of water is too high on that day. This could be caused by a malfunction in the post-treatment step, where the water is disinfected by ultraviolet light and ozonation. If the ultraviolet light is too weak or the ozonation is too strong, it could increase the pH of water by producing excess hydroxyl radicals [7]. An improvement action could be to check and adjust the ultraviolet light intensity and the ozonation dose, and to monitor and record the pH of water after the post-treatment step.

point 16 (7.13) is above the UCL, indicating that the pH of water is too high on that day. This could be caused by a human error in the bottling step, where the water is filled into plastic bottles by a filling machine. If the filling machine is not calibrated or operated properly, it could overfill or underfill the bottles, resulting in different volumes and pressures of water. If the water has a high volume or pressure, it could release carbon dioxide gas from the dissolved carbonates, which could increase the pH of water [8]. An improvement action could be to calibrate and operate the filling machine correctly, and to measure and record the volume and pressure of water in each bottle.

A run of six points above the CL indicates that there is a positive shift in the mean of the process during that period. This could be caused by a seasonal change in the source water quality, where the groundwater is influenced. If the groundwater has a high amount of dissolved oxygen or organic matter, it could increase the pH of water by consuming carbon dioxide gas or producing bicarbonates [9]. An improvement action could be to adjust the treatment processes according to the seasonal variations of source water quality, and to monitor and record the pH of water before and after each treatment step.

A run of fourteen points below the CL indicates that there is a negative shift in the mean of the process during that period. This could be caused by a change in the storage conditions, where the bottled water is exposed to light or heat. If the bottled water is exposed to light or heat, it could degrade the plastic material of the bottles, which could leach chemicals or microorganisms into the water. If the water has a high amount of chemicals or microorganisms, it could decrease the pH of water by producing acids or consuming hydroxyl radicals [11]. An improvement action could be to store the bottled water in a dark and cool place, and to check and replace the damaged or expired bottles.

6.Conclusion

This study aimed to implement SPC control charts in drinking water, and to evaluate their effectiveness in improving the quality of drinking water. The study focused on one type of control chart: x-bar chart. The study used data from a bottled water plant, and applied the x-bar chart to one quality characteristic, pH of water.

The results showed that the process of pH of water was out of control, and that there were several sources of variation that affected the quality of water. The possible causes of variation were identified by examining the out-of-control points or patterns, and by investigating the production process and conditions. The improvement actions were suggested by eliminating or reducing the assignable causes of variation, and by adjusting or optimizing the production process and parameters. The limitations of this study are that it only used data from one production line and one company, and it only considered one quality characteristic. The implications of this study are that it can provide a guideline for other bottled water manufacturers to implement SPC control charts in their production processes, and it can contribute to the literature on quality control in drinking water.

The directions for future research are to collect data from more production lines and companies, and to consider more quality characteristics. Moreover, other types of control charts, such as R chart or s chart, can be used to compare their performance with x-bar chart. Furthermore, other methods of SPC, such as process capability analysis or acceptance sampling, can be integrated with control charts to enhance the quality improvement.

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