Implementation of a Statistical Process Control System for a Selected Industrial Plant

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Abstract

In this paper, the process of implementation of statistical process control is being described with respect to the production line at the plant. In this way, main purpose of implementing the statistical process control is to analyze that how much performance of a process is contributing to maintaining the required level of quality. Control charts in the statistical control process are significant tools for analyzing the variability of product quality characteristics. Therefore, the charts are helpful for the management to determine that at which level the process needs to be changed. In addition to this, the control charts also help the management to estimate the process capability for the purpose of achieving the desired level of quality. For the purpose of analyzing the importance of using the statistical process control, a healthy water factory was selected. This factory has the processes of producing the healthy water in small size bottles. The main problem for which the SPC was used in the factory was that the quality characteristics in the plant were increased significantly and resulted in the low process capabilities hence leading to the low productivity at the plant. In this way, the work objectives were to decrease the variability in the quality characteristics of the production process and improve the quality characteristics at the points of control. In this respect, the three points of control have been selected for making the experiments. These three points includes the feed water in wells, the permeate water produced after the chemical treatment and the final water product after the filling operations. For this purpose, two significant quality characteristics were set as the purpose of making experiments. These quality characteristics were named as total dissolved solids and power of hydrogen. During the experiment, the one sample was taken as the point of control at the first points of control. For this, X and moving range charts (I-MR charts) have been established and revised and three samples was taken at the final product point of control. For this, X bar and R charts have been established and revised during the whole process. The Minitab software has been used for making the experiment. In addition to this, the process capabilities have been used and established at the low level of values such as Cp and Cpk. During the process, the factory workers have been questioned for the different circumstances. As a result, the corrective actions suggested by the staffs have been incorporated in the experimentation. Thus, new control charts were developed when the corrective actions were incorporated. Later on, new practices indices and values were incorporated and improvements were noted during the whole process. thus, the effectiveness of the statistical process control system and the feasibility could be concluded as the result of experiments.

Keywords
SQC, SPC, control charts for variables, XMR, X bar R charts, process capability, process capability index.

Acknowledgement

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1. Introduction

Statistical Process Control is a methodology for monitoring a process to identify special causes of variation and signal the need to take corrective action when appropriate. Statistical Process Control (SPC) has seven tools

- Pareto Diagram.
- Cause-Effect Diagram.
- Check Sheets.
- Process Flow Diagram.
- Scatter Diagram.
- Histogram.
- Control Charts [2]

The problem for which this work is seen as an effective solution is that the variability of the values of the quality characteristics of the plant's product is large that results in low process capabilities which, in turn, leads to lower productivity. The work objectives have been adopted to be eliminating the variability of the quality characteristics of the product and improving the process capabilities at selected points of control.

1.1 Literature Review

Control Charts are an outstanding technique for problem solving and the resulting quality improvement. Quality improvement occurs in two situations. When a control chart is first introduced, the process usually is unstable. As assignable causes for out-of-control conditions are identified and corrective action taken, the process becomes stable, with a resulting quality improvement. The second situation concerns the testing or evaluation of ideas. Control charts are excellent decision makers because the pattern of the plotted points will determine if the idea is a good one, poor one, or has no effect on the process. if the idea is a good one, the pattern of plotted points of the X bar chart will converge on the central line, X_0. In other words, the pattern will get closer perfection, which is the central line. For the *R* chart and the attribute charts, the pattern will tend to zero, which is perfection. These improvement patterns are illustrated in figure 1. If the idea is a poor one, an opposite pattern will occur. Where the pattern of plotted points does not change, then the idea has no effect on the process.

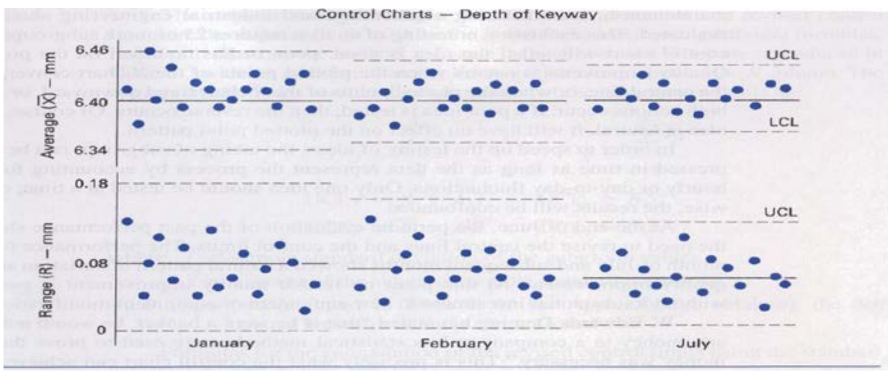

Figure 1. X bar and R charts, Showing Quality Improvement

While the control charts are excellent for problem solving by improving the quality, they have limitations when used to monitor or maintain a process. The pre-control technique is much better at monitoring. Improvement patterns are illustrated in figure 1. If the idea is a poor one, an opposite pattern will occur. Where the pattern of plotted points does not change, then the idea has no effect on the process [2].

1.2 Capability Index

The capability index does not measure process performance in terms of the nominal or target value. This measure is accomplished by C_{pk},.

$$C_{pk} = \frac{Min\{(USL - \overline{X}) \, or \, (\overline{X} - LSL)\}}{3\sigma}$$

1.3 Chart for Individual values

It is used when only one measurement is taken on quality characteristic. This may be due to the fact that it is too expensive, time consuming, destructive, or very few items to inspect.

1.4 Points of Control and Quality Characteristics

Three points were selected to establish the control charts at. Those are: (1) the source water, samples are able drawn directly from the well, (2) the permeate water, after the chemical treatment, and (3) the Final Product, just before the filling operation. Two characteristics were seen as the most important quality characteristics; the power of hydrogen (pH) and the total dissolved solids (TDS). Here in Table 1 the limits that had been specified by the Saudi Standards, Metrology and Quality Organization (SASO) for these two characteristics and the values targeted by the selected plant in the final product are presented.

Table 1. Specification Limits and Target Values of Water Quality Characteristics

	pH	TDS
Lower Specification Limit, LSL	6.5	100
Target Value	7.5	150
Upper Specification Limit, USL	8.5	500

In table 1, we got these limitations for PH and TDS from SASO. So as a factory policy and strategic for continue producing is that to be inside these limitations between 6.5 and 8.5 for PH and between 100 and 500 for TDS which is accepted as a safe produced, but they ambitious to be in target which is 7.5 for PH and 150 for TDS. the variations are natural things at any production process, but we can reduce it by different ways; one of them is SPC.

2. Methodology

2.1 Research Design

The methodology followed to finish this work was to record the data on the quality characteristics, establish the control charts, and determine the values of the process capability indices; all are for the processes before introducing any improvements. After that, results are analyzed, discussed with the plant's staff, and improvements are suggested then put in experimentation. Finally, all measurements are repeated but for the processes after improvements and effectiveness of solutions are evaluated.

2.3 Sample Size

It is necessary to collect a minimum of 25 subgroups of data. A few numbers of subgroup would not provide a sufficient amount of the accurate computation of the central and control limits, and the largest number of subgroups would delay the introduction of the control chart [3]. The sample size was 25 samples selected each period randomly across the period 2015 from Jan to Jul based on the factory data base and from Jan to March. As shown on the distribution in tables below.

2.4 Data Analysis

The data was edited for accuracy, trail and revise. In the first trial, sample size estimation was taken direct from data base without analysis. Then the revise trial was happened for all points that was selected to get the accuracy for the results. The data was then analyzed using descriptive statistics to generate frequencies.

2.5 Place of application

The organization that was selected to be place of system design in Jazan, Saudi Arabia. It produces healthy water in: 1-330ml. and 2-600ml.of water bottles. The factory work on water product are extracted from underground wells, treatment it and are subject to careful quality tests with the most modern machinery located in the Middle East.

2.6 Data Collection

Data is collected from factory's data base within two different periods through 2015 and 2016. the first one was before improvement and the second one was after corrective action as shown in tables below. The quality characteristics of the final product, PH and TDS, in the third point control (before the filling operation) are measured on three pieces every hour. Tables 2 and 3 are the available data over the period from 01/ 01/ 2015 to 7/ 01/ 2015, where the subgroup size is 3 pieces. X bar and R trial charts have been first constructed to discard the out-of-control points. Revised charts are, then presented. This work is illustrated in the corresponding figures shown below.

Table 3. Measurements of the TDS for the Final Water (Before Improvement)

S N	Date	Time	X1	X2	X3	Average	Range
1	01/01/15	19:18	147.288	147.6224	148.3672	147.7592	1.0792
2		20:21	150.2064	149.8112	148.3976	149.4717333	1.8088
3		21:23	147.5008	146.6192	146.072	146.7306667	1.4288
4		22:21	145.084	145.9352	148.8688	146.6293333	3.7848
5		23:19	147.7896	146.984	146.0872	146.9536	1.7024
6	02/01/15	01:49	148.2152	146.1632	147.1968	147.1917333	2.052
7		03:20	147.136	147.4856	146.832	147.1512	0.6536
8		07:23	145.8592	146.7712	145.9656	146.1986667	0.912
9		10:25	146.984	147.9416	150.1912	148.3722667	3.2072
10		13:25	147.4856	149.416	146.832	147.9112	2.584
11		16:25	146.756	147.0296	148.1544	147.3133333	1.3984
12		20:44	146.4824	145.7528	148.8992	147.0448	3.1464
13		23:32	146.3608	146.6496	148.5344	147.1816	2.1736
14	06/01/15	08:45	147.4096	145.3576	148.808	147.1917333	3.4504
15		09:11	147.592	148.96	148.656	148.4026667	1.368
16		12:32	149.264	146.6496	148.352	148.0885333	2.6144
17		16:47	150.0392	147.592	150.5864	149.4058667	2.9944
18		20:17	145.312	148.2	149.264	147.592	3.952
19		23:50	149.872	148.2608	147.06	148.3976	2.812
20	07/01/15	03:52	146.5584	148.048	147.6224	147.4096	1.4896
21		05:18	147.8504	150.9208	151.3312	150.0341333	3.4808
22		08:25	150.0088	148.8688	149.72	149.5325333	1.14
23		10:47	147.6984	146.7712	147.2728	147.2474667	0.9272
24		13:27	146.5584	145.8288	146.3152	146.2341333	0.7296
25		16:42	149.112	150.7384	148.6104	149.4869333	2.128

Table 2. Measurements of the pH for the Final Water (Before Improvement)

S N	Date	Time	X1	X2	X3	Average	Range
1	01/01/15	19:18	6.36	6.38	6.32	6.353333	0.06
2		20:21	6.36	6.3	6.28	6.313333	0.08
3		21:23	6.35	6.29	6.33	6.323333	0.06
4		22:21	6.2	6.33	6.36	6.296667	0.16
5		23:19	6.4	6.39	6.16	6.316667	0.24
6	02/01/15	01:49	6.05	6.1	6.37	6.173333	0.32
7		03:20	6.39	6.36	6.29	6.346667	0.10
8		07:23	6.37	6.39	6.29	6.35	0.10
9		10:25	6.3	6.33	6.49	6.373333	0.19
10		14:25	6.48	6.47	6.38	6.443333	0.10
11		18:25	6.48	6.31	6.11	6.3	0.37
12		21:44	5.89	6.12	6.34	6.116667	0.45
13	06/01/15	08:32	6.19	6.22	6.58	6.33	0.39
14		10:45	6.29	6.31	6.62	6.406667	0.33
15		12:11	6.28	6.31	6.65	6.413333	0.37
16		15:32	6.36	6.33	6.6	6.43	0.27
17		18:47	6.29	6.32	6.51	6.373333	0.22
18		22:17	6.3	6.39	6.51	6.4	0.21
19	07/01/15	01:50	6.39	6.42	6.42	6.41	0.03
20		03:52	6.39	6.45	6.28	6.373333	0.17
21		05:18	6.26	6.43	6.61	6.433333	0.35
22		06:25	6.33	6.35	6.34	6.34	0.02
23		07:47	6.47	6.51	6.45	6.476667	0.06
24		08:27	6.46	6.46	6.52	6.48	0.06
25		10:42	6.13	6.29	6.53	6.316667	0.40

In table 2 which presents that data for Measurements of the pH for the Final Water at production line is before improvement. For 25 subgroups**" it is necessary to collect a minimum of 25 subgroups of data a few number of subgroup would not provide a sufficient amount of the accurate computation of the central and control limits, and a larger number of subgroups would delay the introduction of the control chart "[3]**. three sample are taken at one time in morning, after noon, evening and midnight too. These data are taken randomly from data base in factory through period from Jan to Jul. it is shown that some of the data is not in SASO limitation.
In table 3 which presents that data for Measurements of the TDS for the Final Water is before improvement at production line. For 25 subgroups as well. three sample are taken at one time in morning, after noon, evening and midnight too. We can notice that the time is the same as in PH because they take money different type of quality characteristics at the same time and collecting data and inter it to the system. Also These data are taken randomly from data base in factory through period from Jan to Jul too. it is very clear in average of subgroup a lot of rustles are near to target 150 nut it shifts to one side more than other" it is not natural for seven or more consecutive points to be above or below the center line" [3] that is shown in the figure 3 below.

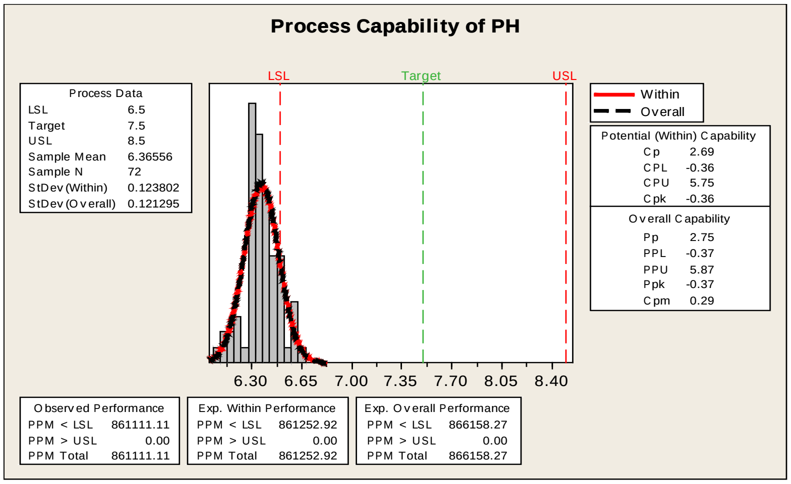

Figure 3. Process Capability of pH of the Final Product (Before improvement)

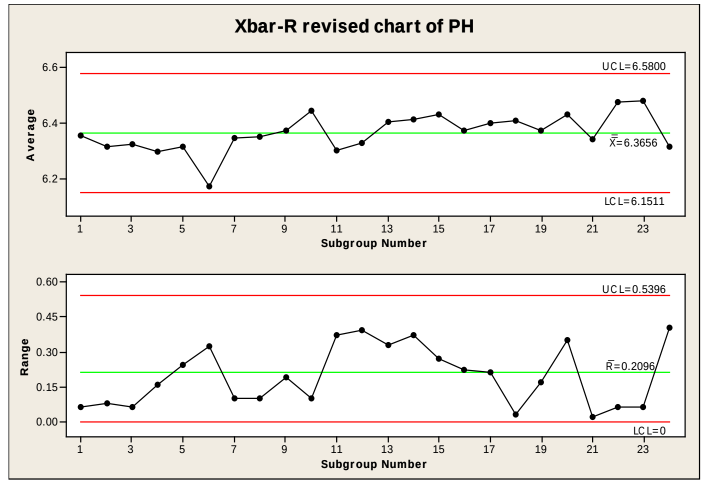

Figure 2. X bar and R Revised Charts of the pH of the Final Product (Before Improvement)

It is shown in Figure.2 that there are variations in process more appear in R chart at points 12,18,21, and 25 which are reflected discuss that production is not stable or under control. The reasons for variations as we figure out these data are taken at time like after noon or in mooring also error data was interring to the system. In figure 3, process capability which shows more clearly for distribution for the data for PH that can tell there is a problem in production because the distribution was shifted outside of the limitation. And more discuss and results with explain at Results and Discussion

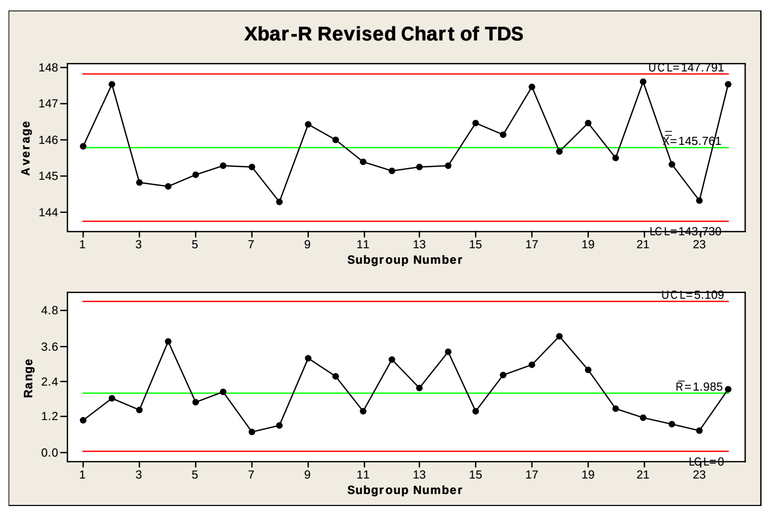

Figure 4. X bar-R Revised Charts of the TDS of the Final Water (Before Improvement)

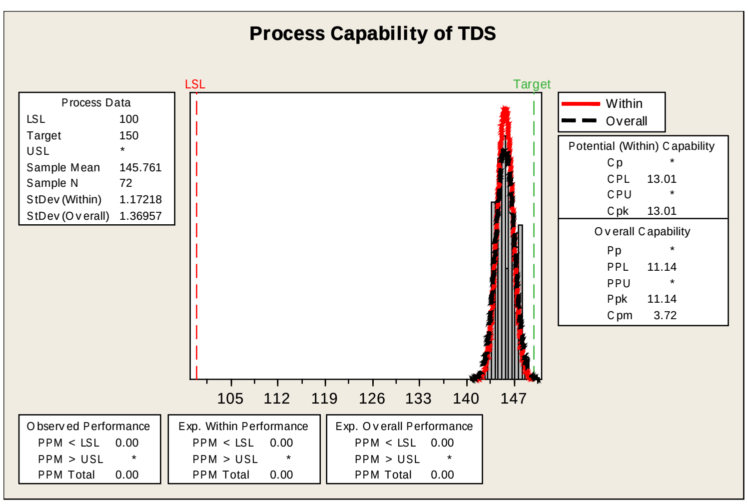

Figure 5. Process Capability of TDS of the Final Product (before improvement)

At TDS there are variations as well at the first data that taken with revised. It is not much but still effect the production process because the average is near to 150 that we got in calculation. However, there are some points shifted to up area points 15,16,17, 19,21and 22 so that mean there is a problem as well in process and that appears in R chart. In Figure 5, the distributions are shifted to lower line. And more discuss and results with explain at Results and Discussion

3. Corrective Actions

The results of the presented-before charts have been discussed with the plant's staff. They explained the results and defended the cases of out of control. However, they were asked for (1) adopting the doses and frequency of treatments, (2) making update calibration for their devices of measurements, and (3) conducting "quality circles" to discuss in deep the trends of the measures. After implementing the solutions, the following results have been obtained.

4. System Development

The corrective actions that were suggested and just presented in data collection section are put in implementation starting from first of March 2016. Results were taken and analyzes in the same manner as presented in the same chapter.

The quality characteristics of the final product, Ph and TDS, in the third point control (before the filling operation) are measured on three pieces every hour. Tables 4 and 5 are the available data over the period from 1/ 4/ 2016 to 04/ 20/ 2016, where the subgroup size is 3 pieces. X bar and R trial charts have been first constructed to discard the out-of-control points. Revised charts are, then presented. This work is illustrated in the corresponding figures below.

Table 5: Measurements of the TDS for the Final Water (After Improvement)

S N	Date	Time	X1	X2	X3	Averages	Ranges
1	01/04/12	19:18	150.195	150.536	151.2955	150.6755	0.7595
2		20:21	153.171	152.768	151.3265	152.4218333	1.4415
3		21:23	150.412	149.513	148.955	149.6266667	0.671667
4		22:21	147.9475	148.8155	151.807	149.5233333	2.9915
5		23:19	150.7065	149.885	148.9705	149.854	0.9145
6	02/04/12	03:49	152.5355	151.218	150.257	151.3368333	1.079833
7		05:20	150.66	151.3265	150.35	150.7788333	0.9765
8		07:23	148.738	149.668	148.8465	149.0841667	0.8215
9		10:25	149.885	150.8615	153.1555	151.3006667	2.294
10		13:25	150.3965	152.365	149.73	150.8305	2.635
11		18:25	149.6525	149.9315	151.0785	150.2208333	1.147
12		20:44	149.3735	148.6295	151.838	149.947	3.2085
13		23:32	149.2495	149.544	151.466	150.0865	1.922
14	06/04/12	01:45	149.854	148.8465	150.0865	149.5956667	1.24
15		04:11	150.505	151.9	151.59	151.3316667	0.568333
16		07:32	152.21	151.094	151.59	151.6313333	0.537333
17		10:47	153.0005	150.505	153.5585	152.3546667	3.0535
18		13:17	148.18	151.125	152.21	150.505	1.705
19		16:50	152.83	151.187	149.9625	151.3265	1.364
20		19:52	149.451	150.97	150.536	150.319	0.651
21		22:18	150.7685	153.8995	153.233	152.6336667	1.265833
22	07/04/12	06:33	152.9695	154.907	152.675	153.5171667	2.232
23		07:47	150.6135	149.668	150.1795	150.1536667	0.5115
24		09:27	149.451	148.707	149.203	149.1203333	0.496
25		11:42	152.055	153.7135	151.5435	152.4373333	2.17

Table 4. The values of PH of the Final Product (After Improvement)

S N	Date	Time	X1	X2	X3	Average	Range
1	01/04/16	19:18	7.16	7.18	7.12	7.153333	0.06
2		20:21	7.16	7.1	7.08	7.113333	0.033333
3		21:23	7.15	7.09	7.13	7.123333	0.04
4		22:21	7	7.13	7.16	7.096667	0.063333
5		23:19	7.2	7.19	6.96	7.116667	0.23
6	02/04/16	01:49	7	6.99	7.17	7.053333	0.18
7		03:20	7.19	7.16	7.09	7.146667	0.07
8		06:23	7.17	7.19	7.09	7.15	0.1
9		10:25	7.1	7.13	7.29	7.173333	0.16
10		13:25	7.28	7.27	7.18	7.243333	0.09
11		16:25	7.28	7.11	6.91	7.1	0.2
12		19:44	6.69	6.92	7.14	6.916667	0.223333
13		22:32	6.99	7.02	7.2	7.07	0.18
14	06/04/16	01:45	7.09	7.11	7.42	7.206667	0.31
15		04:11	7.08	7.11	7.45	7.213333	0.34
16		08:32	7.16	7.13	7.4	7.23	0.27
17		12:47	7.09	7.12	7.1	7.103333	0.02
18		16:17	7.1	7.19	7.17	7.153333	0.036667
19		18:50	7.19	7.22	7.22	7.21	0.01
20		23:52	7.19	7.25	7.08	7.173333	0.17
21	07/04/16	01:18	7.06	7.23	7.41	7.233333	0.18
22		03:25	7.13	7.19	7.19	7.17	0.02
23		05:47	7.27	7.13	7.2	7.2	0.07
24		07:27	7.26	7.26	7.32	7.28	0.06
25		08:42	6.93	7.09	7.33	7.116667	0.24

Table 4 shows that the values of PH of the Final Product is after Improvement. It has 25 subgroups which is taken through different periods of time. the change in system process illustrates the corrective action was happen lately before taking these data from the line. When we take a look to the average it is appear that all data seem near to the target exception a few points like 2,4, 5, 7,12, 25. Table 5 shows the Measurements of the TDS for the final water after improvement. All data seem as near to the factory target 150. And that are reflected the improvement thought this period. It is easier to read these data from the figures below. It is given us more accuracy.

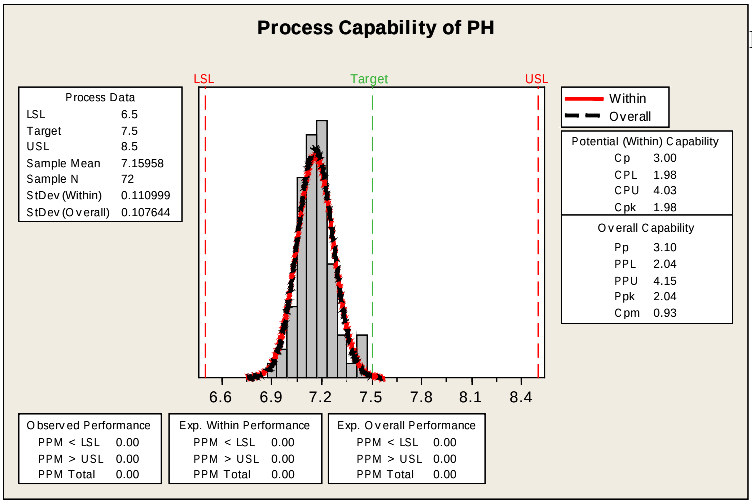

Figure 7. Process Capability of the PH of the Final Product (After Improvement)

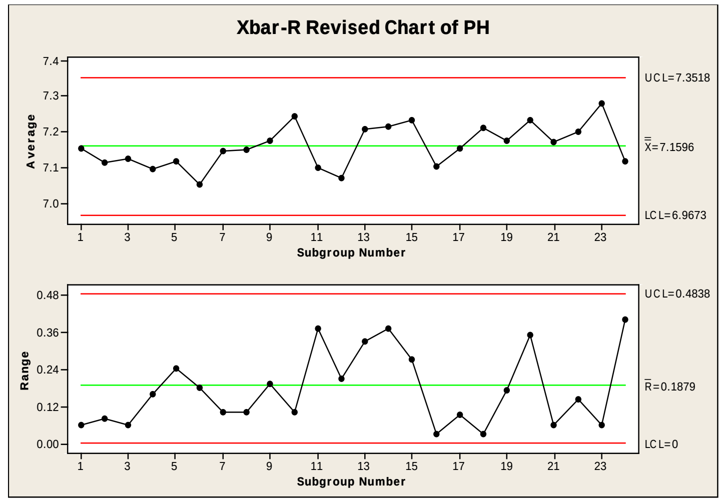

Figure 6. X bar-R Revised Chart of Ph of the Final Product (After Improvement)

It really appears that the improvements in production and stable process, with less variations through the period of processing. In addition, the target is shifted or go near to target with is 7.5 at Ph. That is reflect improvements with good evidence with different distribution to the better way.

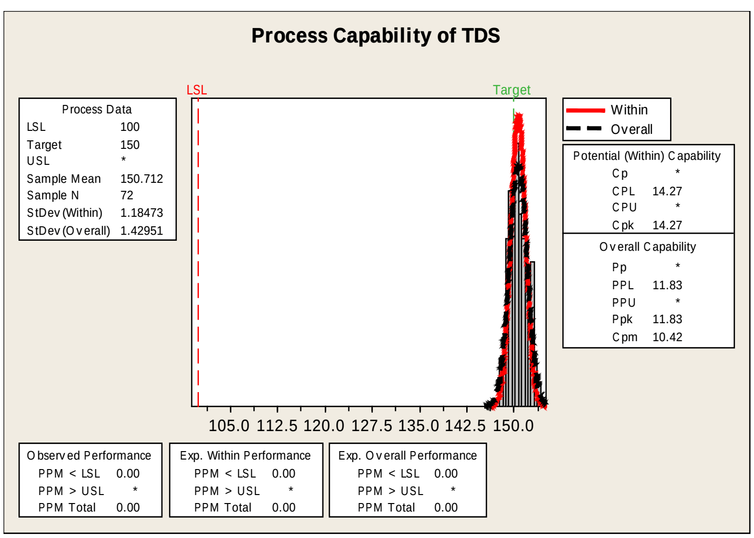

Figure 9. Process Capability of the TDS of the Final Product (After Improvement)

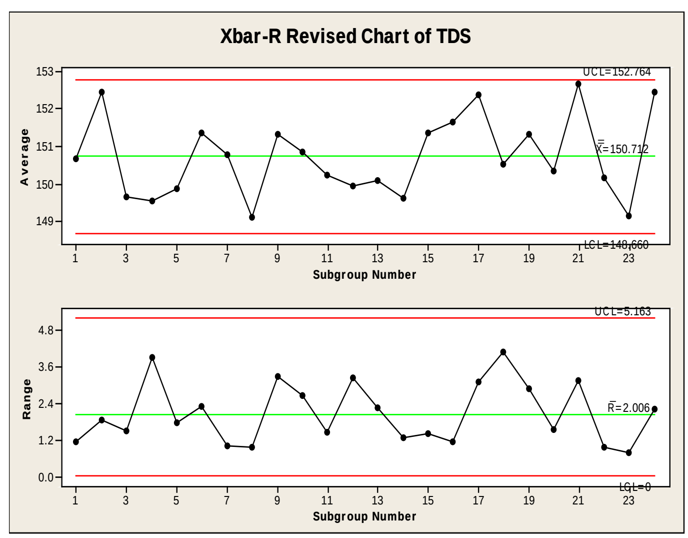

Figure 8. X bar-R Revised Chart of the TDS of the Final Product (After Improvement)

At TDS we got a good and satisfaction results, because the variations are very close to the central line with is appear clearly at the process capability. Which is reflect improvements on production processes. And there is more explanation and discussion at the results and discussion

5. Results and Discussion

Tables 6 and 7 summarize the results obtained from the revised control charts that had been established for the pH and TDS, respectively, for the final product before and after improvement.

Table 6. Parameters of the Ph of the Final Product Before and After Improvement

Parameters	Period of Measurement w.r.t. the SPC-System Development	
	Before	After
UCL_X	6.5800	7.3518
X Bar	6.3656	7.1596
LCL_X	6.1511	6.9673
CP	2.69	3.00
C_{PK}	-0.36	1.98
UCL_R	0.5396	0.4838
R Bar	0.2096	0.1879

Table 7: Parameters of the TDS of the Final Product Before and After Improvement

Parameters	Period of Measurement w.r.t. the SPC-System Development	
	Before	After
UCL_X	147.791	152.764
X Double Bar	145.761	150.712
LCL_X	143.730	148.660
C_{PK}	13.01	14.27
UCL_R	5.109	5.163
R Bar	1.985	2.006

From these two tables, it is clear that:

a) The variability in the two quality characteristics has been decreased. This is read in terms of the differences between the control limits of the X bar charts and the value of the central lines and upper control limits of the R charts.
b) As a result of a), the process capability indices have been increased.
c) The central lines of the X bar charts of both the Ph and TDS approach to the target values that are 7.5 and 150, respectively.

6.Conclusion

After implementing the SPC system and according to the results obtained and just discussed here above, it is concluded that the developed SPC system has proved effectiveness in reducing the variability in the quality characteristics through over the production process. In the other hand, the SPC system has proved high effectiveness in centering the processes (making the averages of the measurements of the quality characteristics so close to their target values) As a result of, the process capability indices have been significantly increased. Also, the increase in the process capability index C_{pk}, in particular, was behind the decrease in the percent nonconforming bottles. In addition, the regular analyses of the control charts, by the plant, were behind activating the maintenance activities, increasing the frequency of treatments, and adopting new doses of treatments. The belief that "being within the specifications" is a satisfactory objective has been changed to "being in control". Awareness with quality concepts and importance, within the plant, is increasing from day to day.

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