

Statistical Quality Control In The Production Of Pepsi Drinks

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Abstract—This study investigated if there is any significant difference in Brix level and gas volume in a 50cl Pepsi irrespective of different machines. The data collected was on the volume of sugar and CO₂ of the product for 30 consecutive days (30 samples) in the month of June, 2015, from 5 different machines in the Quality Assurance Department of 7UP company plant, Kaduna, Nigeria. The investigation was carried out using the Statistical Quality Control tool such as \bar{X} -Bar and R chart and Tabular Cusum to determine the statistical disposition of the process. The data was analyzed using Minitab-16. The findings showed that there was no significant difference for the sugar and CO₂ volume between the five machines used for the productions. However, one process mean and two process variations for the gas volume plotted outside the control limits but are within the tolerance or specification limits of the company's standard and thereby met customers' expectations. It was recommended that the Quality Control Manager should emphasize more on quality control techniques to enable the company know at all times when a product is running out of control.

Keywords—Brix, Carbon (iv)Oxide (CO₂), Quality Control, Production

INTRODUCTION

Manufacturing industries in a bid to attain their primary objectives which include survival, efficiency, and profitability must effectively control and make use of their resources for the production of quality goods that meet the standard and also satisfy the consumers of such product. When it comes to statistical approach to quality control, one definition of quality is conformance to the requirements and as such the application of statistical analysis in the production process is to ensure that the products of manufacturing industries meet their requirement in consistent and uniform manner (Cheng-Few *et al*, 2013).

The method of Statistical Quality Control (SQC) are not primarily directed at finding the reason for bad products and counting of number of such bad products but removing their causes by detecting such problems prior to bad production. The existence of deficiencies and defectives increases the running cost (such as: repairs, reworks, wastes, replacements, warranty and cost of detailed inspections) which possess expensive

manufacturing problem. These should not only be dictated and resolve at the earliest time, but prevented if possible. Quality Control (QC) has been with us for a long time when manufacturing began and competition accompanied manufacturing (Page, 1954).

Barring a monopoly, consumers would compare and choose the most attractive product. In modern times, we have regulatory bodies such as Food and Drugs Administration, Factory inspection and others aimed at assuring the quality of products sold to consumers. QC has thus had a long history. On the other hand, SQC is comparatively new. The science of statistics itself goes back only 2 to 3 centuries and its greatest development was in the 20th century. It was not until 1920's that statistical theory began to be applied effectively to quality control due to sampling theory. SQC was developed by Walter A. Shewhart of Bell Telephone USA in 1924 using the modern control charts. There were also contributions from H.F. Dodge and H.G. Romig who applied statistical theory to sampling inspection (Juran, 1997).

Statistical theory's effective application to quality control started in the 1920's with sampling theory. Statistical tools are used to control both the quantity and qualities of goods produced, evaluate new products before distribution, improve design tolerance and inspections, detect shift or change in process of conformance and also lead to improvement in productivity. Recently, it has been realized that society need not to be run based on trial and error, the development of statistics has shown that many aspects of progress depends on correction analysis of numerical information and its relationships to economics, business and industries. Statistics as a tool of all sciences is indispensable to research, intelligent judgment and decision making (Popper, 2002).

Objectives of the study

1. To measure the quality characteristics of the product and determine if the process is functioning as desired.
2. To determine the statistical control disposition of the process by exploring the application of Statistical Process Control methods especially the control charts (\bar{X} and \bar{R} charts in particular) and Tabular Cusum.

METHODOLOGY

This study is basically concerned with the periodic measurements of Brix and CO₂ levels Pepsi brand at

the 7UP Bottling Company Kaduna Plant in Kaduna State.

Method of Data Collection

The data for the analysis of this study was collected from the Quality Control Manager of the company which was primary data on hourly interval for the level of Brix and CO₂ content of 50cl Pepsi brand produced by the company. The data for the level of Brix and CO₂ contents were then extracted for analysis.

Secondary sources of data include past records of operational activities, number of service staffs, supervisors and managers, research papers aimed at proffering solution to the problems of quality and papers presented by some stakeholders on quality management.

Data Analysis Techniques: X-bar and R charts

If the process mean and standard deviation, μ and σ are known, and it is reasonable to treat the measurements as samples from a normal population, we can assert with probability $1 - \alpha$ that the mean of a random sample of size n will fall between $\mu - Z_{\alpha/2}$ and $\mu + Z_{\alpha/2}$. These two limits on \bar{x} provide LCL and UCL respectively. In actual practice, μ and σ are usually unknown and we estimate their values from sample leading to a doubt on normality assumption. The $(1 - \alpha)100\%$ confidence level associated with the control limits is only approximate, therefore, in industrial practice the 3σ limits obtained by substituting 3 for $Z_{\alpha/2}$ is used.

With 3σ limits, there is high confidence that the process will not be declared out of control falsely. For long history of process of product control, μ and σ can be estimated from past data practically without error. Thus the center line of an \bar{x} chart will be μ and the upper and lower 3σ control limits will be $\mu \pm A\sigma$ where $A = \frac{3}{\sqrt{n}}$ and n should be a constant sample size for easy maintenance and interpretation of the chart, though this is not an absolute restriction (Tague, 2004 and Texlera, 2012).

In general, the control limits of \bar{x} chart are estimates of $\mu_{\bar{x}} \pm 3\sigma_{\bar{x}}$ which is given by $\bar{x} \pm 3\hat{\sigma}_{\bar{x}}$ where $\mu_{\bar{x}} = \mu$, $\hat{\sigma}_{\bar{x}}$ is an estimate of $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$. Also $3\frac{\sigma}{\sqrt{n}} \cong A_2\bar{R}$; thus the control limits can be rewritten into $\bar{x} \pm 3\frac{\sigma}{\sqrt{n}}$. d_2 is a factor to estimate σ from \bar{R} where $\hat{\sigma} = \frac{\bar{R}}{d_2}$ and d_2 is also a constant dependent on n . Substituting the estimate into the control limits, we obtain $\bar{x} \pm 3\frac{(\bar{R}/d_2)}{\sqrt{n}}$.

That is, $UCL_{\bar{x}} = \bar{x} + 3\frac{(\bar{R}/d_2)}{\sqrt{n}}$ and $LCL_{\bar{x}} = \bar{x} - 3\frac{(\bar{R}/d_2)}{\sqrt{n}}$

Therefore, \bar{x} -chart, plots successive subgroup means to monitor the behaviour of the average level of X .

The R chart tells us if the variance within each sample tends to be in control over time. The sample mean can be in control over time, yet the sample variance is getting worse and worse. The central (control) line CL, and the control limits of an R chart are based on the distribution of the range of samples of size n from a normal population. When σ is unknown, it is estimated from the past data obtained when the process is stable, and the 3σ control-chart values for R chart (with σ unknown) are as follows:

$$LCL = D_3\bar{R}; CL = \bar{R}; UCL = D_4\bar{R}$$

Where, D_3 = factor to determine LCL for R-chart, D_4 = factor to determine UCL for R-chart are all dependent on n . If μ_R and σ_R are respectively the mean and standard deviation of the range R of n observations sampled from a Normal distribution.

The formulae for UCL and LCL given as:

$UCL_R = \bar{R} + 3\hat{\sigma}_R = D_4\bar{R}$ and $LCL_R = \bar{R} - 3\hat{\sigma}_R = D_3\bar{R}$, follows when we estimate μ_R by the sample mean of the subgroup ranges, namely \bar{R} . Negative values of D_3 are not permitted as a sample range cannot be negative (Tague, 2004 and Texlera, 2012). Consequently, negative values are set to zero. Hence, R-chart, plots successive subgroup ranges to monitor the behavior of the variability of X .

Tabular or Algorithmic CUSUM

The desensitization of CUSUM chart to detect only shifts of desired magnitude is accomplished by setting a reference or allowable or slack value K that denote the size of shift one desires to detect. It is very common to choose K to be approximately one-half ($1/2$) of the size of shift to be detected. Thus, to detect process shift of magnitude (1σ), a reference value of $K = 0.5\sigma$ and decision interval $H = 4\sigma$ or 5σ are used. Then, instead of calculating the deviations $(\bar{x}_i - \mu_0)$ and the partial sum S_i , one forms a sequence of upper and lower deviations $U_i = \bar{x}_i - (\mu_0 + K)$ and $L_i = \bar{x}_i - (\mu_0 - K)$. Any resulting negative value reset to zero and U_i is always less than L_i . Sometimes, μ_0 is taken to be the target value for the quality characteristic X .

The tabular CUSUM works by accumulating the deviations from μ_0 that are above target with one statistic $CUSUM_U(i)$ and that are below target with another statistic $CUSUM_L(i)$; for $i = 1, 2, \dots, k$. These statistics (partial sums) are called one sided upper and lower CUSUM respectively (Montgomery, 2009). The process is initiated by setting $i = 0$. Thus, the calculations for the statistics are:

1. For upper CUSUM
 - i. $CUSUM_U(0) = 0$
 - ii. $CUSUM_U(i) = \max\{0, CUSUM_U(i-1) + U_i\}$
2. For lower CUSUM
 - i. $CUSUM_L(0) = 0$
 - ii. $CUSUM_L(i) = \max\{0, CUSUM_L(i-1) - L_i\}$

If a shift is expressed in σ units $\mu_1 = \mu_0 + \sigma\delta$, then K is one-half the magnitude of the shift or as $K = \frac{\sigma\delta}{2} = \frac{1}{2} |\mu_1 - \mu_0|$ where μ_1 is the out of control value of the mean to be detected (Montgomery, 2009).

RESULTS AND DISCUSSION

Results

Minitab-16 was employed for the computation of results and chart plotting in this study.

Measurements of Brix level of each 50cl Pepsi bottle from five different production sections (X_i) in degree Brix ($^{\circ}\text{Bx}$) on hourly interval:

Number of samples (subgroups) $k = 30$ and sample size $n = 5$

$$\bar{\bar{x}} = \frac{1}{k} \sum_{i=1}^k \bar{x}_i = \frac{1}{30} \sum_{i=1}^{30} \bar{x}_i = \frac{318.55}{30} = 10.618333$$

$$\bar{R} = \frac{1}{k} \sum_{i=1}^k R_i = \frac{1}{30} \sum_{i=1}^{30} R_i = \frac{9.25}{30} = 0.308333$$

Quality Process Charts for the Level of Brix (sugar content) in the Production of Pepsi

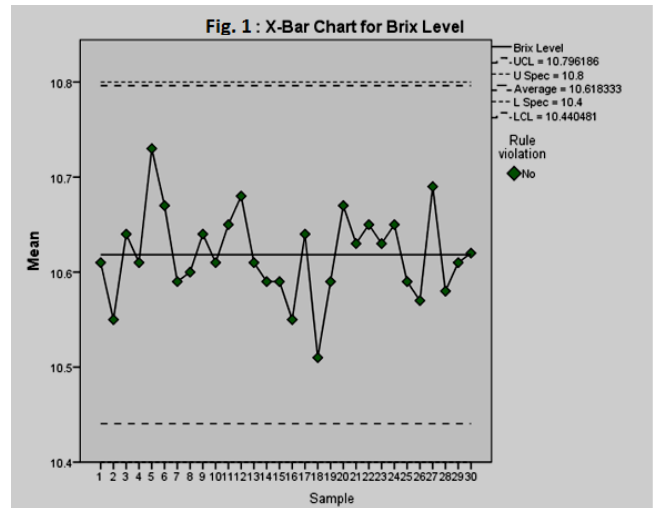
1. For \bar{X} -chart we have:

From the control chart constant table, $A_2 = A_2(n) = A_2(5) = 0.577$; $D_4 = D_4(n) = D_4(5) = 2.114$ and $D_3 = D_3(n) = D_3(5) = 0$

$$CL = \bar{\bar{x}} = 10.618333$$

$$UCL = \bar{\bar{x}} + A_2\bar{R} = 10.618333 + (0.577)(0.308333) = 10.79008$$

$$LCL = \bar{\bar{x}} - A_2\bar{R} = 10.618333 - (0.577)(0.308333) = 10.44659$$

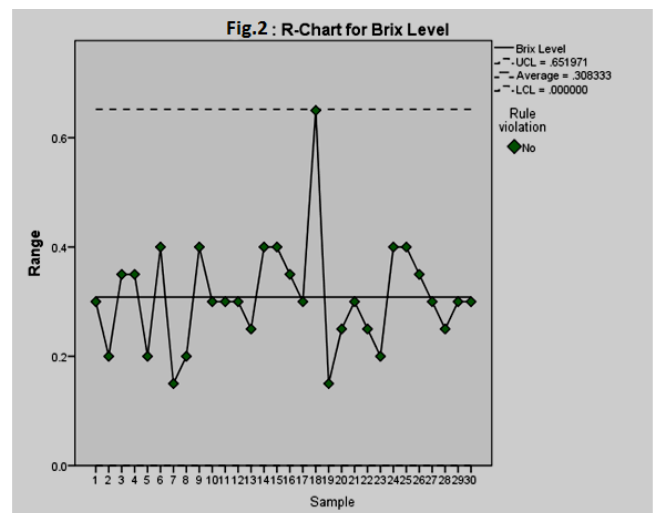


2. For R-chart, we have:

$$\bar{R} = CL = 0.308333$$

$$UCL = D_4\bar{R} = (2.114)(0.308333) = 0.651817$$

$$LCL = D_3\bar{R} = (0)(0.308333) = 0$$



From the control charts above, it could be observed that the process mean is in control for the Brix level of 50cl Pepsi production.

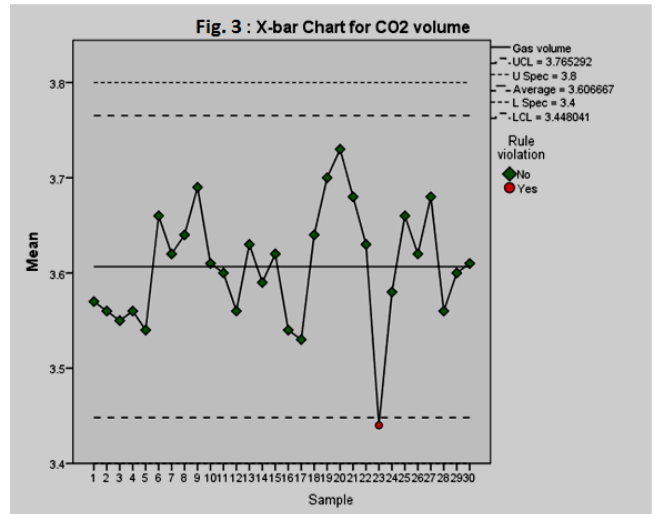
Tabular CUSUM for Brix Level

Table 1: Tabular Cusum Implementation for Brix Level

i	\bar{X}_i	U_i	$Cusum_U(i)$	N^+	L_i	$Cusum_L(i)$	N^-
1	10.61	-0.03123	0	0	0.014635	0	0
2	10.55	-0.09123	0	0	-0.04537	0.045365	1
3	10.64	-0.00123	0	0	0.044635	0.00073	2
4	10.61	-0.03123	0	0	0.014635	0	0
5	10.73	0.088765	0.088765	1	0.134635	0	0
6	10.67	0.028765	0.11753	2	0.074635	0	0
7	10.59	-0.05123	0.066296	3	-0.00537	0.005365	1
8	10.6	-0.04123	0.025061	4	0.004635	0.00073	2

9	10.64	-0.00123	0.023826	5	0.044635	0	0
10	10.61	-0.03123	0	0	0.014635	0	0
11	10.65	0.008765	0.008765	1	0.054635	0	0
12	10.68	0.038765	0.04753	2	0.084635	0	0
13	10.61	-0.03123	0.016296	3	0.014635	0	0
14	10.59	-0.05123	0	0	-0.00537	0.005365	1
15	10.59	-0.05123	0	0	-0.00537	0.01073	2
16	10.55	-0.09123	0	0	-0.04537	0.056096	3
17	10.64	-0.00123	0	0	0.044635	0.011461	4
18	10.51	-0.13123	0	0	-0.08537	0.096826	5
19	10.59	-0.05123	0	0	-0.00537	0.102191	6
20	10.67	0.028765	0.028765	1	0.074635	0.027556	7
21	10.63	-0.01123	0.01753	2	0.034635	0	0
22	10.65	0.008765	0.026296	3	0.054635	0	0
23	10.63	-0.01123	0.015061	4	0.034635	0	0
24	10.65	0.008765	0.023826	5	0.054635	0	0
25	10.59	-0.05123	0	0	-0.00537	0.005365	1
26	10.57	-0.07123	0	0	-0.02537	0.03073	2
27	10.69	0.048765	0.048765	1	0.094635	0	0
28	10.58	-0.06123	0	0	-0.01537	0.015365	1
29	10.61	-0.03123	0	0	0.014635	0.00073	2
30	10.62	-0.02123	0	0	0.024635	0	0

$$LCL = \bar{\bar{x}} - A_2\bar{R} = 3.606667 - (0.577)(0.275) = 3.447992$$



2. For R-chart, we have:

$$\bar{R} = CL = 0.275$$

$$UCL = D_4\bar{R} = (2.114)(0.275) = 0.5896$$

$$LCL = D_3\bar{R} = (0)(0.275) = 0$$

Decision Interval $H = h\sigma = 5\sigma = 5(0.0459) = 0.2295$.

Conclusion: the process will be said to be out of control if any upper or lower cusum is greater than the decision interval H. From the table above, it could be observed that no value exceeds the H. Hence, the process is in control and no shift occurred.

Measurements of CO₂ of each 50cl Pepsi bottle from five different production sections (X_i) in volume (vol.) on hourly interval:

$$\bar{\bar{x}} = \frac{1}{k} \sum_{i=1}^k \bar{x}_i = \frac{1}{30} \sum_{i=1}^{30} \bar{x}_i = \frac{108.2}{30} = 3.606667$$

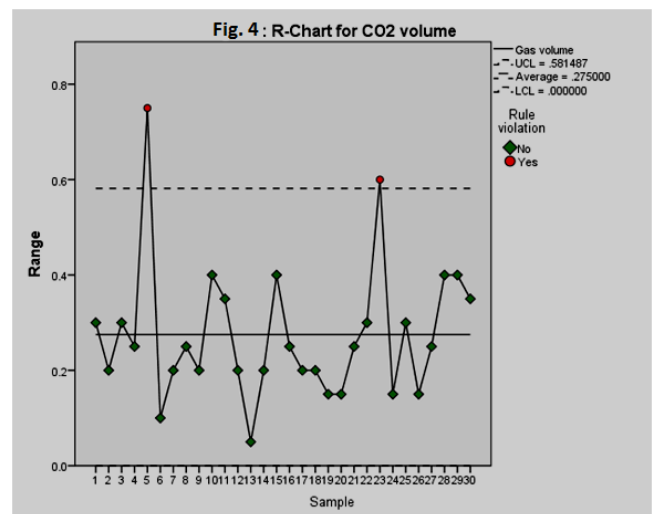
$$\bar{R} = \frac{1}{k} \sum_{i=1}^k R_i = \frac{1}{30} \sum_{i=1}^{30} R_i = \frac{8.25}{30} = 0.275$$

Quality Process Charts for the Gas Volume (CO₂) in the Production of Pepsi

1. For \bar{X} -chart, we have:

$$CL = \bar{\bar{x}} = 3.606667$$

$$UCL = \bar{\bar{x}} + A_2\bar{R} = 3.606667 + (0.577)(0.275) = 3.765342$$



Tabular CUSUM for Gas Volume

Table 2: Tabular Cusum implementation for CO₂ volume

i	\bar{X}_i	U_i	$Cusum_U(i)N^+$	L_i	$Cusum_L(i)N^-$	
1	3.57	-0.06722	0	0	-0.00618	0.006178
2	3.56	-0.07722	0	0	-0.01618	0.022355
3	3.55	-0.08722	0	0	-0.02618	0.048533
4	3.56	-0.07722	0	0	-0.01618	0.064711
5	3.54	-0.09722	0	0	-0.03618	0.100889
6	3.66	0.022778	0.022778	1	0.083822	0.017066

7	3.62	-0.01722	0.005555	2	0.043822	0	0
8	3.64	0.002778	0.008333	3	0.063822	0	0
9	3.69	0.052778	0.061111	4	0.113822	0	0
10	3.61	-0.02722	0.033889	5	0.033822	0	0
11	3.6	-0.03722	0	0	0.023822	0	0
12	3.56	-0.07722	0	0	-0.01618	0.016178	1
13	3.63	-0.00722	0	0	0.053822	0	0
14	3.59	-0.04722	0	0	0.013822	0	0
15	3.62	-0.01722	0	0	0.043822	0	0
16	3.54	-0.09722	0	0	-0.03618	0.036178	1
17	3.53	-0.10722	0	0	-0.04618	0.082355	2
18	3.64	0.002778	0.002778	1	0.063822	0.018533	3
19	3.7	0.062778	0.065555	2	0.123822	0	0
20	3.73	0.092778	0.158333	3	0.153822	0	0
21	3.68	0.042778	0.201111	4	0.103822	0	0
22	3.63	-0.00722	0.193889	5	0.053822	0	0
23	3.44	-0.19722	0	0	-0.13618	0.136178	1
24	3.58	-0.05722	0	0	0.003822	0.132355	2
25	3.66	0.022778	0.022778	1	0.083822	0.048533	3
26	3.62	-0.01722	0.005555	2	0.043822	0.004711	4
27	3.68	0.042778	0.048333	3	0.103822	0	0
28	3.56	-0.07722	0	0	-0.01618	0.016178	1
29	3.6	-0.03722	0	0	0.023822	0	0
30	3.61	-0.02722	0	0	0.033822	0	0

Decision interval $H = h\sigma = 5\sigma = 5(0.061044548) = 0.30522$

Conclusion: From the Tabular cusum for CO₂ volume above, the process will be said to be out of control if any upper or lower cusum is greater than the decision interval H. From the table above, it could be observed that no value exceeds the H. Hence, the process is in control and no significant shift occurred.

Discussion

In the course of this study, statistical quality control was carried out by the use of X-bar and R charts and Tabular Cusum. The process variation and process mean in the Brix level for all the sample was in control, but for the gas volume, the process mean was out of control as one point (sample 23) plotted out of the control limits and the process variation plotted out of the control limits at sample 5 and 23 which was in line with the findings of (Amasaka, 1993) on Statistical Quality Development and Effect at Toyota.

CONCLUSION AND RECOMMENDATIONS

Conclusion

In view of the results obtained in this study, there is no difference in taste considering the brix level. Also the gas volume process is out of control as 2 samples

out of 30 samples process variations plotted outside control limits but they were still within the tolerance or specification limits set-up as standard by the company to meet the customer's expectations. Also, after the removal of the two samples, the process falls in total statistical control.

After due consideration, the use of statistical quality control has enhanced improvement in the industrial sector by enabling the products to conform to specification irrespective of different sections.

Recommendations

The following recommendations were made in this study:

1. The management should ensure that the equipments used in the carbonation of drinks are in a standardized state for effective, quantitative and qualitative production.
2. The Quality Control Manager should emphasize more on quality control techniques to help him know at all times when a product is running out of control, to avoid sending defective product to the market. (eg. Product with poor taste due to wrong brix level or bad freshness due to wrong CO₂ volume from standard.)

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