Journal of Material Sciences & Engineering

Research Article

Open Access

Statistical Process Control Applied in the Chemical and Food Industry

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Abstract

Statistical process control (SPC) is a tool to improve the quality and productivity of processes. The objective of this research was to apply statistical control charts in chemical and food industrial processes and highlight their advantages in the control of processes. For the study, the control data of the processes of 4 industrial plants was used: rectified ethyl alcohol distillation plant, asparagus processing plant, soluble coffee production plant and light liquid fuel production plant. The deductive methodology was applied, based on the type of data: variable or attribute, constant or variable sampling, evaluation of the defective fraction, number of defects, variability of processes. With this, the statistical control chart suitable for the process was selected. The results showed that in the food industry the np and p charts can be used to evaluate the defective fraction and for the number of defects, as was the case in asparagus cans, u and c graphs are used. To control variables, the charts used were XmR, XbarR, Xbar Trend, Fixed limits and XbarS. It was concluded that the control charts in the chemical and food processes is not only applicable, but it allows predicting the behavior of the process and alerts when it tends to go out of control, thus allowing improving the quality.

Keywords: Statistical process control; Control chart; Variable; Attribute

Introduction

The application of statistical process control (SPC) was initially applied in the manufacturing, service and commercial industries, for example, in the automobile industry [1] and in the commercial industry [2]. The interest of applying this control system gave rise to studies such as that of Koretsky, in the USA, which developed Applied Chemical Process Statistics, in which it analyzed the variation of Processes applying the Statistical Control of Processes and Design of Experiments and introduced as an elective course the Statistics of Chemical Processes. On the other hand, Papazoglou [3] in Australia proposed the application of multivariable Statistical Control in chemical processes to monitor process performance and, fault detection and diagnosis. In Africa, Barreto-Villanueva [4] studied the integration of Statistical Process Control (SPC) with engineering process control (EPC). For validation, the proposed approach was applied to the data collected from an industrial batch alkyd polymerization reactor. Through this case study application, the company's process engineers can now use a valuable decision-making tool when the production process is affected by disturbances that affect product and process quality, productivity and the competitiveness.

This study is based on the importance of applying statistical control of industrial processes to assess their variability, predict the future of the process, to improve its quality. Its application will be a contribution to the industry through its strategy of quality improvement and competitiveness, and in the university academic sector it will be a contribution in the training of new process engineering professionals. This research will benefit the food industry in Peru, agribusiness and the chemical industry, without neglecting that it could be applied in any industrial process regardless of the sector, to make them more competitive.

The impact that occurs in the most competitive companies in the world that use Six Sigma as a tool in their quality management system will be the same as in the chemical and food industry in Peru. For the present study we had the data of Peruvian industries, and by ethics and confidentiality it was decided not to say their names. The industries are: rectified ethyl alcohol distillery, asparagus plant, soluble coffee processing plant, and light liquid fuel plant. Thanks to the work of the author as an industrial consultant, these industries could be committed to use their data.

Problematic Reality

Today, business competitiveness is the primary tool of large companies to be first in the market for goods and services. Medium and small businesses are not alien to it. The industrial sector, mainly the transformation companies such as chemical industries are increasingly concerned about being competitive and for this they have two basic tools that are quality and productivity. These can be molded to the needs of the market, but they depend on the quality of the industrial processes that are the ones that make the quality of the products, and the productivity that defines the cost.

In Peru there are few companies that handle their industrial transformation processes in the best way and this affects the quality of products that lose competitiveness compared to similar products that come from foreign companies that use better technologies and apply better tools for control of its processes. A tool with optimal results in the management of product quality is the Statistical Process Control (SPC), which in most cases has been applied only to the quality of the products, however, knowing that the quality of the products The product depends on the process, so it is obvious to think that the statistical process control system can be applied to industrial processes through the control of the variables and according to the characteristics of the products.

This is a problem that has motivated the present research of technological application type focused on the statistical control of industrial processes applied in Peruvian industries, especially in the chemical and food industry.

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Received July 08, 2019; **Accepted** July 30, 2019; **Published** August 05, 2019

Citation: Chero PPA (2019) Statistical Process Control Applied in the Chemical and Food Industry. J Material Sci Eng 8: 531.

Theoretical Framework

Theoretical basis

The theoretical basis focuses on the theoretical foundations of Statistical Process Control and on the unit operations of industrial processes. Statistics in the process industry seeks to implement the probabilistic and statistical procedures of analysis and interpretation of data from a set of elements called industrial statistics, which helps to make decisions in the control of industrial processes. This is how in the management and interpretation of data in industrial processes, we generally use the measures of central tendency, and for the decision making process management you can use the statistical tools for process control, especially, control charts. The statistical management of industrial process data obeys certain statistical methods.

Variability in industrial processes

No two products or services are exactly the same because the processes by which they are produced include many causes of variation, even when these processes are performed as planned [5]. The variation in quality, gives rise to an important task in quality control that consists in determining the range of natural random variation in the process. For example, the bottle of a soda called Cola Lux should contain an average of 16 ounces of liquid, but it is found that its volume when leaving the process varies between 15.8 and 16.2 ounces. If this is the case, the production process should be controlled to ensure that the filling volume remains within this range. If production were outside this range, such as bottles with an average content of 15.6 ounces, then it means that there is a problem in the process because the variation is greater than the natural random variation.

Types of variation

Shewhart [6] of Bell Telephone Laboratories developed the new variation management paradigm, basing his concept on the idea that a quality characteristic has one of two types of variation causes:

- **Common cause:** It is the natural variation that exists within any process therefore they are causes that are always part of the process and affect all those who work in it.
- **Special or assignable cause:** It is the variation that is due to something out of the ordinary. Normally it is not part of the process, or does not affect everyone, but they are attributable to specific circumstances. These types of causes are analyzed and corrected so that they do not happen again. It can be detected because it is not always active in the process [7].

The tolerance

In industrial processes there will always be variations in product characteristics, such as length, diameter, thickness, weight, volume, density, etc., due to the inherent variability that occurs in machines, tools, raw materials, and human operators The presence of an inevitable variation (disturbance), and the interchangeability results in specifying limits for the variation of any quality characteristic, which are the specifications required by the customer. This acceptable variation is called tolerance.

The tolerance in the quality of a product is specified by the customer. The estimation of the natural tolerance limits of a process is an important problem with many significant practical implications. If the values of the measurements in the data exceed the tolerance limits, an extremely high percentage of production will be out of the specifications, which will result in a high loss or reprocess rate [8].

Statistical control of processes

To know the type of cause of the variability, Shewhart [9] created the control graphs, which consist of three lines and points on a graph. The dots represent the measurements of a quality characteristic. The center line represents the average of the point values or the objective value that is evaluated. The other two lines represent the upper and lower control limits.

Types of control charts

Control charts are divided into: Charts for attribute control: p, np, c and u; and Charts for variable control: XmR, XbarR, ImR, XmR trend, XbarS, among others.

p chart: It is used to evaluate the defected fraction. Defective items can be counted and the sample size is not constant. The equations to build the charts are:

$$LC = \overline{p} = \frac{\sum P_I}{\sum n_i} \tag{1}$$

$$LSC = \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \tag{2}$$

$$LIC = \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \tag{3}$$

where, LC is Central Line, LSC is Upper Control Limit, LIC is Lower Control Limit, it is average of defective elements, and n is sample size.

np chart: It is used to evaluate the defective fraction when it is easy to count the number of defective elements and the sample size is always the same [10]. The equations to build the charts are:

$$LC = \overline{np} = \frac{\sum np_i}{\sum n_i} \tag{4}$$

$$LSC = \overline{np} + 3\sqrt{\frac{\overline{np}(1-n\overline{p})}{n}} \tag{5}$$

$$LIC = \overline{np} - 3\sqrt{\frac{\overline{np}(1-\overline{np})}{n}} \tag{6a}$$

where *np* is average of defective elements.

c Chart: It is used when a small number of defects can be counted in a large opportunity area, or in an article or product, and when the sample size is constant [10]. The equations to build the graphs are:

$$\mathrm{LC} = \overline{c} = \frac{\sum c_i}{n} \tag{6b}$$

$$\mathrm{LSC} = \overline{c} + 3\sqrt{\overline{c}} \tag{7}$$

$$\mathrm{LIC} = \overline{c} - 3\sqrt{\overline{c}} \tag{8}$$

where $\overline{c}$ is average of defective elements.

u chart: It is used when you can count the defects in an item or product, and the sample size varies [10]. The equations to build the graph are.

$$\mathrm{LC} = \overline{u} = \frac{\sum u_i}{\sum n_i} \tag{9}$$

$$\mathrm{LSC} = \overline{} \quad 3\sqrt{\frac{\overline{}}{}} \tag{10}$$

$$\text{LIC} = \bar{u} - 3\sqrt{\frac{\bar{u}}{n_i}} \quad (11)$$

where $\bar{u}$ is average of defective elements.

XmR/ImR chart (individual motion range chart): The XmR control chart tracks individual data elements and indicates observation with X as the average of the data, and mR indicates the range of motion [11]. The equations to build the charts are:

$$\text{LC} = \frac{\bar{X}_1 + \bar{X}_2 + \bar{X}_3 + \cdots + \bar{X}_n}{n} \quad (12)$$

$$\text{LSC} = \bar{\bar{X}} + A_3\bar{S} \quad (13)$$

$$\text{LIC} = \bar{\bar{X}} - A_3\bar{S} \quad (14)$$

For R Chart

$$\text{LC} = \bar{R} = X_{max} - X_{min} \quad (15)$$

$$\text{LSC} = D_4\bar{R} \quad (16)$$

$$\text{IC} = D_3\bar{R} \quad (17)$$

where, $\bar{R}$ is average range, $\bar{X}$ is average, and $\bar{\bar{X}}$ is the average of the averages, $X_{max}\ y\ X_{min}$ they are the maximum and minimum values of the sample. A2, A3, D3, D4 are constants of control graphs and are read in Table 1.

XbarR chart: The Xbar and R charts are used to monitor the average and variation of a process based on samples taken from the process at certain times (hours, shifts, days, weeks, etc.). The equations that are used are the same as the previous ones.

XbarS chart: The Mean (X) and Standard Deviation (S) chart is used to evaluate the stability of processes with variable data. This chart can help evaluate the cycle time for almost any process and is especially useful when you do this several times a day. Data collection could be expensive if it is continuous [12].

XmR trend graph: Graph that is applied to determine the trend of variable data.

Control charts for special case

Analysis of means (ANOM): It is used to analyze the differences between the means.

CUSUM chart: They are cumulative sum used to detect small changes in a process [12].

EWMA chart: It is used when you have a sample and you want to detect small changes in performance.

Fixed Limit chart: This chart is used to enter historical control limits or specification limits (for example, quality standard). It works just like any other control chart, except that it uses these control limits instead of calculated control limits.

Moving average control chart: This control chart is used for when there is only one sample and you want to evaluate the process changes using a simple moving average (that is, not the EWMA).

Pre-control chart: Used when you have less than 20 data points. The QI Macros for Excel has an easy-to-use pre-control chart template.

Pre Control chart template: A template to make a pre control is a quality assurance alternative. It can be built in Excel or use the Qi Macros template [13].

Materials and Methods

Bibliographic material and Qi Macros SPC Software for Excel, to analyze the data, select, build and interpret the control charts of variables and attributes applied in the processes. The deductive method

Sample size, n	Xbar chart constants		Constant for estimated sigma			Constants for chart S	
	A2	A3	d2	D3	D4	B3	B4
2	1.88	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.628	2.059	0	2.282	0	2.266
5	0.577	1.427	2.326	0	2.114	0	2.089
6	0.483	1.287	2.534	0	2.004	0.03	1.97
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.97	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0.266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.85	3.336	0.307	1.693	0.382	1.618
14	0.235	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.653	0.428	1.572
16	0.212	0.763	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.543
18	0.194	0.718	3.64	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.18	0.68	3.735	0.415	1.585	0.51	1.49
21	0.173	0.663	3.3778	0.425	1.575	0.523	1.477
22	0.17	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

Table 1: Control chart constants.

was applied, based on the type of data (attributes or variables); the algorithm of Figure 1 was used.

Control charts are identified for application in the processes of the chemical and food industry.

- If the data are attributes, there are two questions: Are the data countable? Is the sample size constant or does it vary?
- Defective fraction or the number of defects?
- If the data is variable, the question is: were the data collected in sub groups?
- If so: the sub group> 8 or ≤ 8?
- Does each sampling report several data from several elements or are they individual data?

The questions are asked and answered using the algorithm in Figure 1.

Results

The control of the temperature of the coffee powder at the exit of the dryer in one day of operation reported the following data (Table 2).

Assisted by algorithm, the graph selected for variable data is XmR, but to comply with the internal standard of 30°C to 35°C, the control chart is Fixed Limit and an R chart to assess process variability. To graph, the equations of the XmR and fixed-limit charts were used with the help of QiMacros software [11]. The upper and lower limits correspond to the limits of the internal standard (Upper control limit, 35°C, and Lower Control Limit, 30°C). For the variability of the process, an R chart was constructed, as shown in Figures 2 and 3.

Interpretation: The fixed limits chart shows permissible temperatures between 30 and 35°C, but wide variability is observed (points highlighted at 9.0 am, 5.0 pm, 6.0 pm, 5.0 am and 6.0 am) so much that exceeded the limits, what which indicates that the process is out of control. The R chart confirms the process variability in Figure 3, with

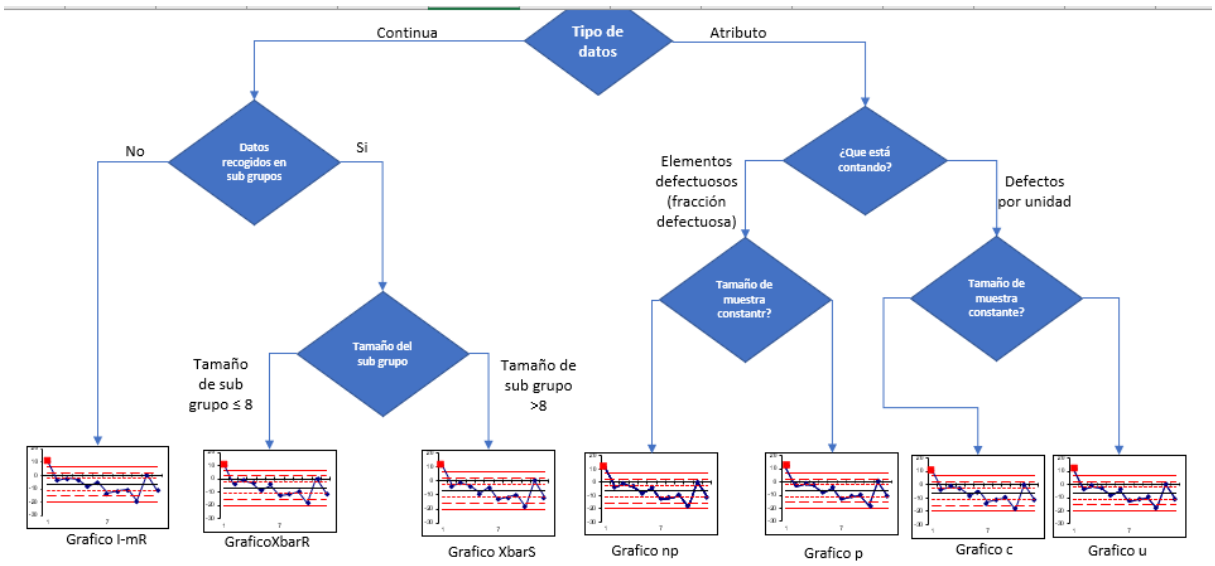

Figure 1: Algorithm to select the type of control chart.

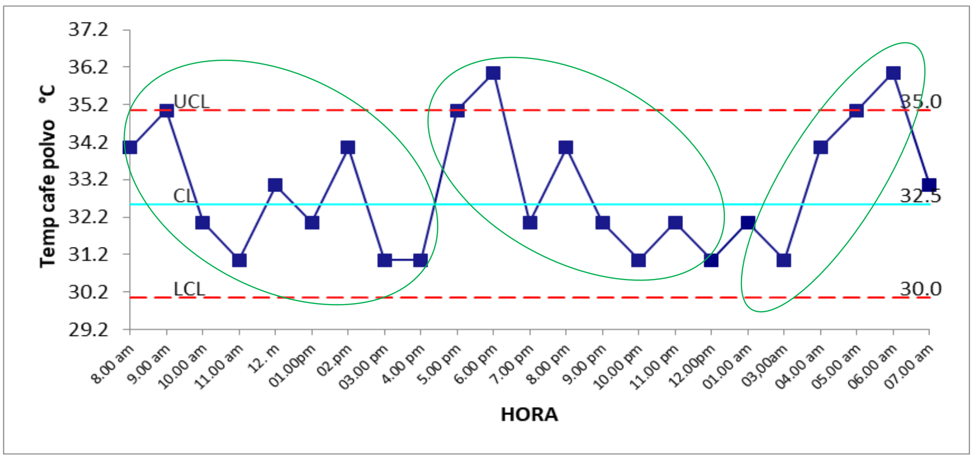

Figure 2: Fixed limit control chart for coffee powder temperature.

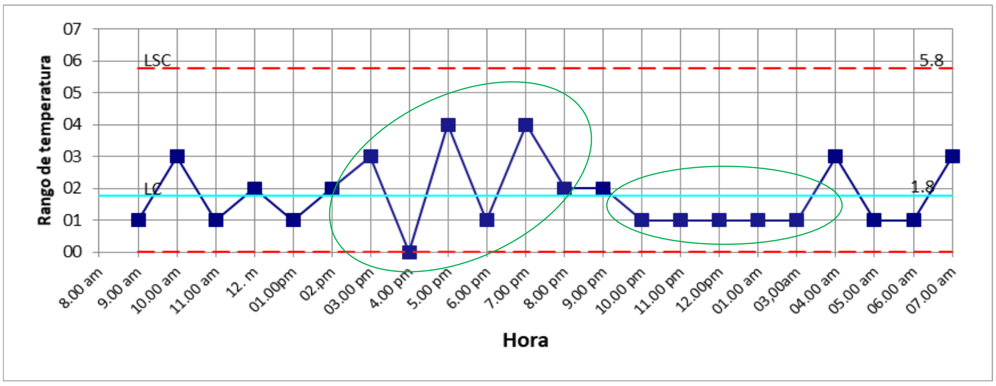

Figure 3: mR Chart for the temperature of coffee powder in the dryer discharge.

Hour	T, °C	Hour	T, °C	Hour	T, °C
8.0am	34	4.0pm	31	12.0pm	31
9.0am	35	5.0pm	35	1.0pm	32
10.0am	32	6.0pm	36	3.0 am	31
11.0am	31	7.0pm	32	4.0am	34
12.0m	33	8.0pm	34	5.0am	35
1.0pm	32	9.0pm	32	6.0am	36
2.0pm	34	10.0pm	31	7.0am	33
3.0pm	31	11.0pm	32		

Table 2: Coffee powder temperature at the dryer outlet (°C).

Hour	% salt	Hour	% salt	Hour	% salt
8:0am	2.15	4:0am	2.12	12:0 m	2.09
9:0am	2.2	5:0am	2.08	1:0pm	2.09
10am	2.12	6.0am	2.09	2.0pm	2.09
11am	2.14	7.0am	2.21	3-0pm	2.08
12pm	2.16	8.0pm	2.11	4.0pm	2.08
1:0pm	2.25	9.0pm	2.11	5.0pm	2.07
2:0pm	2.01	10.0pm	2.10	6:0pm	2.07
3:0pm	2.1	11.0pm	2.10	7:0pm	2.07

Table 3: Percentage of salt in asparagus governing liquid.

wide ranges between 3.0 pm and 8.0 pm while between 10.0 pm and 3.0 am the ranges are almost zero. The supervisor of the next shift, determined that the cause of the variability was due to mechanical problems that affected the air flow (assignable cause), and corrected the problem. This improved product quality.

In the asparagus processing plant, the brine content in the government liquid was evaluated. In a day of operations the data control is carried out every hour, and in Table 3 the control results are shown that are subjected to a statistical control with control charts. The data is as follows:

Due to the type of variables available, an XmR chart was selected and because of the suspicion of a drop in the values at the end of the shift, an XmR Trend chart was prepared, as shown in Figures 4-6.

Interpretation: X Chart shows process instability between 12.0 pm and 7.0 pm which is then normalized and the data is at the average limit, with a minimum variability that is unusual between 8.0 pm and 5.0 am. On two occasions, the % brine in the government liquid is above the upper limit and the same applies to the ranges between the data as shown in Figure 5. The attributable cause as determined by the shift supervisor was that the operators of the shift first and second shifts are new workers who were not trained, while the third shift operator has more than 5 years in the position. In the trend chart (XbarR trend) of Figure 6 you can see that the salt concentration the liquid of government. The chart shows the adjustment of the line to the trend that should be >0.80, here it is smaller and indicates a downward trend. Ryx is the linear correlation coefficient, and 0.473 is a very low correlation supported by the variability in the data. The slope is slightly negative that confirms the trend. The standard deviation is minimal given the latest data and the probability that it is less than Ryx indicates and reaffirms that there is no significant correlation between the data, therefore, the control data tends towards the lower control limit and is an alert for review the process and input preparation of the saline solution.

Discussion

In the statistical control charts that were applied to asparagus, rectified ethyl alcohol, and light fuel processes, it is demonstrated that the process performance can be improved by correcting the causes of defects or disturbances that affect quality, very similar to results of Papazoglou [3], who monitored the process performance and the detection and diagnosis of failures by monitoring the performance of the polymerization process.

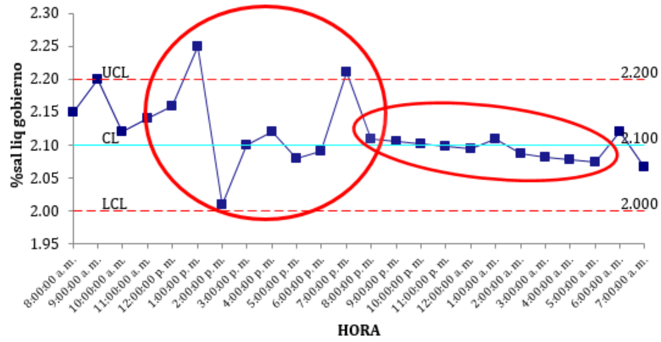

Figure 4: X Chart to control % salt in government liquid in asparagus can. Source: Prepared by author with QiMacros.

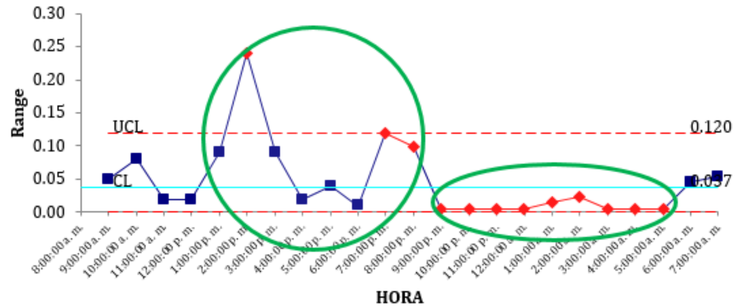

Figure 5: mR Chart for to control the stability of the government liquid preparation process.

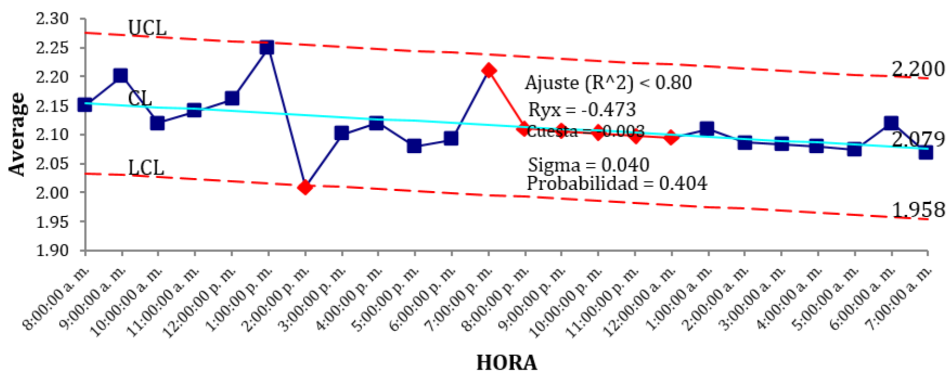

Figure 6: Trend XmR chart to identify trend of the % salt data in the government liquid preparation process.

Another important aspect to highlight in this study is the advantage that control charts allow to monitor the variability of the process and correct it at the moment, which reduces the downtime in the process, reduces waste, and improves quality of the product. This was also confirmed by Ali, in London, in the application of quality control techniques to ensure the quality of the designed and manufactured parts, which were carried out in the Engineering and Manufacturing area of the Department of Technical Services of a recognized Factory, using the Statistical Process Control charts according to its study called Statistical Process Control for Total Quality based on the routine practice of a technique.

An advantage of this study is that you can improve profitability in industries; however, companies hardly grant facilities and less data. As it could be seen, with the control charts the correction can be made as soon as the charts indicate that the process is deviating and close to getting out of control and with greater precision when it is a trend chart that forecasts what can happen In the near future. It should be noted that Madanhirea et al. in South Africa [14], focused on improving quality and profitability, and demonstrated that the SPC had a clear advantage over quality methods, such as inspection of the final product, as described in his research study, Application of Statistical Process Control (SPC) in Manufacturing Industry in a Developing Country.

It is important to note that at the national level no studies have been carried out in this regard, which is a major reason to promote its application in the agribusiness, chemical and food industry that have a greater presence in our country [15-20].

Conclusions

To apply the statistical process control charts, control data from:

- Rectified ethanol distillation plant,
- Asparagus processing plant,

- Soluble coffee production plant,
- Light liquid fuel plant.

From the data mining of the processes of the mentioned process plants, data of variables and attributes to which the statistical process control was applied was taken for convenience. The variables were: % of fermentation ethanol, °G.L. of rectified ethyl alcohol, cooling temperature of light liquid fuel, % of salt in asparagus governing liquid. In addition to these controls, the number of defects in the closure of asparagus cans, temperature of dry coffee powder, °Brix of coffee extract, and water temperature for coffee extractors were also evaluated. The charts used for process control were:

- Coffee powder temperature: XmR
- Water temperature to the extractor: XmR
- ° Brix of coffee extract: XmR, XmR Trend
- % ethanol in fermenter: XbarR
- ° GL distilled ethyl alcohol: XbarR, XbarS
- Defective asparagus cans: np, c
- % government liquid salt: ImR, XmR Trend.
- The application of statistical control charts gave the following results:
- The control of the Brix in the coffee extract, and the temperature of the light liquid fuel were under control, while the rest of the processes were out of control.
- Assignable causes were found for certain disturbances that caused the process to get out of control, as are the case of untrained operators who prepared the government liquid with a very variable % salt.
- In the coffee extraction process, a trend in data was identified towards the lower limit, which was an alert that the process would soon go out of control, and was corrected in time. Another was the temperature of the light liquid fuel with a tendency to increase the temperature that would make the process out of control.
- Some processes had high variation of their data due to assignable causes that were identified in a timely manner, such as the °Brix of the coffee extract, the °G.L in rectified ethanol, % of salt in asparagus governing liquid.
- The % of salt in government liquid showed noticeable changes of the data in each work shift, which coincided precisely with the changes of the process operator in each shift, in which the assignable cause was the lack of training to handle the process.
- The application of the statistical control of the processes allowed detecting when the process does not do what it is used to do, when the results have a tendency to go outside the permissible limits and identify when there are assignable causes that affect the process and make it go out of control.

Acknowledgements

A special thanks to my friends and former co-workers in the beer industry, asparagus processor, rectified ethyl alcohol distillery, soluble coffee processor and light liquid fuel processing industry. Thanks to your input, this investigation was possible.

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