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Process Capability Analysis of Natural Gas Odorization ina Piped Gas Distribution Company

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ABSTRACT:*Natural gas is an energy source whose imminent growth prompts regulation to tighten ties with the security of consumer supply. Being an odorless product, a mixture of odorizing components is added to the gas so that it is detectable by the population. The following study examined the efficiency of this odorization process in a piped gas distribution company using process capability analysis. This, through indexes and quality tools, pointed to the lack of data normalization and non-compliance with specifications, proving the process is hardly capable and needs improvement.*
KEYWORDS–*Natural gas, odorant, odorization process, piped gas, process capability analysis*

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I. INTRODUCTION

Responsible for approximately 24% of the primary energy consumption in the world in 2015 [1], natural gas is a versatile, efficient, safe, abundant and clean energy source among the available fossil fuels [2]. According to the Brazilian association of piped gas distribution companies Abegás data, in 2010, natural gas held a 10.3% share in the Brazilian energy matrix. This number increased to 13.5% in 2014 according to the national energy balance from Ministry of Mines and Energy. These figures tend to reach to 15.5% in 2030, according to Abegás projection.

Although the economic situation determines the growth rate of the gas industry, in general, it is certainly considered essential and a fuel of the future [3]. Among its applications reside the use both in electric power generation and as feedstock in chemical, petrochemical, steel and fertilizer industries; as well as in combustion engines and the production of heat, steam and flames, reasons why it has been occupying more and more significant slices in Brazil's energy supply and several countries in the world [4].

The natural gas production chain is separated into exploration, production, processing, transportation and distribution; the latter two being basically differentiated in terms of gas volume involved and its operating pressure. Brito [5] states that when it comes to large volumes displaced at high pressure, transport is understood; while the movement within the cities until reaching the final customers, is distribution.

According to Brazilians' Law No. 9,478, of August 6, 1997, the distribution consists of the local services of piped gas commercialization to the end users, exploited exclusively by the States directly or through concession. The state-owned companies, called Local Distributing Companies (LDCs), hold the responsibility of these services provided by Article 25 of Brazilian's Federal Constitution of 1988 and have their area of action previously established in their concession agreement. They enable this energy source to be used in the most diverse segments: industrial, commercial, residential, vehicular and cogeneration.

Abegás, in its statistical survey of April 2017, pointed that in these segments there are more than 3 million consuming units of natural gas in Brazil. Approximately 98.7% of these units are from the residential segment, which indicates the reach extent of natural gas to the population in quantitative terms.Therefore, provide safetywhen delivering gas is a primary concern, since its presence in some circumstances may be difficult to the consumer and those living around the gas system determine [3].

Although it is lighter than air and rapidly dissipates in the atmosphere, natural gas is a flammable product and its exposure to sudden impacts, sparks or flames has already caused historical tragedies [6]. As a result, the use of odorants was decreed when the gas comes in contact with the population, so it can bequickly detectable by a person with normal smell [7], ensuring discernment in a distinctive and non-pleasurable way and aiming the recognition of leaks in the network [6].

The determination of odor sufficiency for such recognition is specified in standards and regulations, previously measured by human nose tests or olfactory systems instruments that enables a technician to smell and evaluate a gas sample [3]. In Brazil, it is regulated by the current standards NBR 15616, which involves the odorization, and NBR 15614, which involves the tests.

Despite the occurrence of odorization, several cases of odor weakening along the distribution network have been reported, especially in new pipelines. This shows that even though it is recognized as a safety issue, there are several problems still unresolved [8].Saadatmand, Foroughi et al. [8] in their research to identify the reasons why the odor dissipates in pipes, found that variables related to pressure, temperature, amount of rust, gas flow and odorant concentration significantly influence this phenomenon.

In view of the natural gas odorization process importance in relation to the safety of final consumers, the following paper sought to analyze the efficiency of this process, carried out by an injection system, in a piped natural gas distribution company. For such purpose, the study focused the odorant concentration variable, analyzed through historical data of measurements at specific points in the distribution network of the city where the company operates.

II. GAS ODORIZATION

Natural gas is a mixture of light hydrocarbons that, under normal conditions of temperature and pressure, remains in the gaseous state [4]. Typically, it contains small sulfur molecules such as hydrogen sulphate, carbonoxysulphide, carbon disulphide and other organic compounds such as sulphides, disulphides and mercaptans [9]. It is odorless, colorless and non-toxic; however, when inhaled in high concentrations may lead to asphyxia [4].

Once produced by the Natural Gas Processing Units (NGPU), it is drained to its consumer centers, where it will be distributed through a network of small diameter pipes and at low pressure [2]. For safety reasons, an odorant is added to the gas as a warning to consumers in case of leaks.Usually, this odorant is composed of mixtures of mercaptan, typically isopropylmercaptan, tert-butyl mercaptan or tetrahydrothiophene[9]. The addition of this mixture shouldn't modify the physical or chemical properties of the natural gas, only its odor [7].

The legal requirements for odorization are based on the fact that the smell of gas must be characteristic to avoid confusion with other odors in the environment and that its perception by human smell must occur before the gas concentration reaches a significant level, determine as a fifth of its lower explosive limit [10].The main task of this process is to ensure that all parts of the distribution system are complying with the operating conditions related to the required "odor warning levels" [7], which depends on the practices adopted by those responsible and must consider the characteristics of the network [11].

The requirements can be specified in standards and technical codes, however, it is the gas companies that define their odorization and monitoring procedures [10]. The odoration system must ensure the vaporization and homogenization of the injected odorant, and, in order to ensure the odorant concentration, the best relation between odorant injection rates and gas flow variations should be defined [11].Since it is an expensive product, the odorant addition must be kept at minimum; at the same time, those responsible for this process can't run the risk of subordination because of the safety issue [7]. Tukmakov, Mubarakshin et al. [12] indicates that the approximate density of 16 mg/m³ of odorant allows the human diagnosis of the natural gas presence in the air.

The gas odorization can be done by injection of odorant in both liquid or vapor state [11]. In the liquid state, the odorant is injected into the tubing with the aid of a dosing pump [12]. According to Parrott [3], the basic components of odoration systems are: injection pump, input controller, monitoring and verification system, alarm system and performance report. The basic flow chart process is presented in Fig. 1. The volume of each injection can be adjusted to increase or decrease the quantity of odorant at each launch, so the system can operate proportionally with the flowrate of the gas.

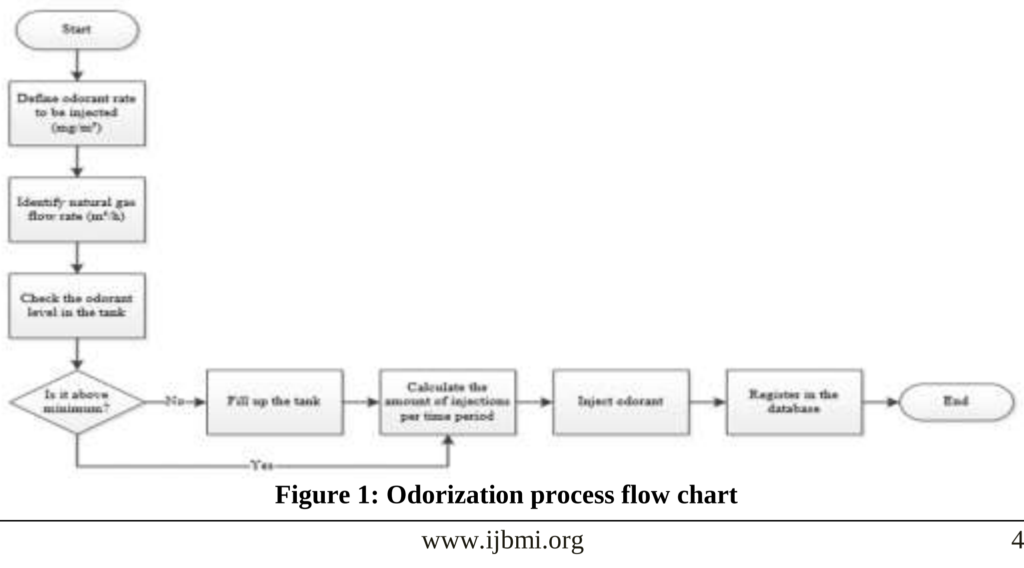


Figure 1: Odorization process flow chart

Source: Authors.

However, since the mixtures of compounds are added at very low concentrations, it may complicate the monitoring process [13], that should occur through sampling analysis at primary and secondary points in the distribution network, meeting the requirements of ISO 10715 [11].

III. RESEARCH METHODOLOGY

This research has a quantitative descriptive character, since it establishes and evaluates the relation among variables of a given phenomenon without manipulating them, that is, analyzes them according to their spontaneous manifestations in existing facts, situations and conditions [14].

The evaluation was made using the odorant concentration data that a natural gas distribution company monthly sends to its regulatory agency, responsible for supervising the public services of its state of performance. Such information was previously collected by the concessionaire itself through its operational procedures, being characterized as secondary data.

The tests were performed once a month by a trained technician equipped with a portable analyzer instrument, which ascertains the present quantity of odorant in mg per cubic meter of natural gas at six predetermined points in the distribution network. Theodoration rate used by the company is 16 mg/m³ and the measurements taken at these points must lie within the specification range proposed by the regulatory agency, which is at least 5 and at most 20 mg/m³ of odorant. Because of that, the process capability analysis was selected, since it can determinethe level of assertiveness within a range of tolerances, using quality tools such as histograms and control charts [15].

The control chartis responsible to indicate if a process is under statistical control, that is if the sampling points are arranged within the control limits [16]. If it is out of control, an investigation is necessary to find the causes and propose corrective actions to eliminate them.Due to the data characteristic, the appropriate control charts are those of the individual values (Chart I) and mobile range (Chart MR), since the few measurements can't be grouped due to the reference of that particular point and low frequency occurrence.Data analysis was performed using Minitab software and all the Special Cause Tests available for control charts were used.

In addition to the histograms and control charts, the potential indexes within the capability were calculated based on the specifications and estimates of the standard deviation, allowing the verification of process dispersion with the Cp index, its displacement with the Cpk index and the average number of parts above and below specification limits in parts per million with PPM index[15].According to Amar [15], the comparison of theCp and Cpkindexes can be interpreted as indicated in Table I.

Table I: Cp and Cpk comparison

Cp< 1	Incapable process
Cpk< 1	Need of process improvements
Cpk = Cp	Centered process

Source: Adapted from Amar (2013).

IV. RESULTS

The distance from the measurement pointsto the Odorization Unit (OU), where the odorant is mixed with the gas, was evaluated and displayed in Table II. It refers to the extent in meters of pipe that the odorous gas travels until it is measured by the equipment.

Table II: Distance between the OU and the measurement points

Point	OU Distance (m)
1	20,584
2	25,153
3	28,853
4	24,874
5	26,683
6	20,000

Source: Authors.

Once all data were available, it's validity was checked and outliers were identified and removed from the calculations of the points 1, 4 and 5. These data presented superodoration, and the company pointed out the change of odoranttypeas the cause, and not the process capability.

The validated data were manipulated in the Minitab software and the results of each point can be observed in Table III. First of all, the histograms point to high variability in the process itself, since all measured points have in common the wide dispersion outside the lower (LIE) and upper (LSE) limits of specifications and the tendency of concentration of the majority of the data near the LIE. Also, they are not symmetrical and have isolated peaks around the lower limits, proving the lack of odorant at those points.

Then, both Individual and Mobile Range Charts presented significant differences between measurements, exiguity ofdata position around the average points, growth and decay trends, consecutive items below the centerline and outside the control line at points 1, 3 and 4. All of these characteristics express that the odorization process is not under control and needs improvements.

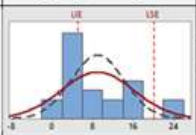
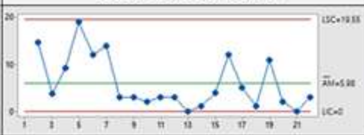
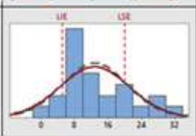
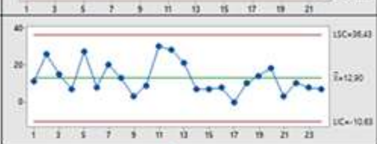
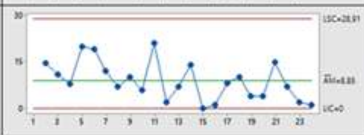
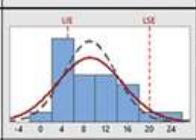
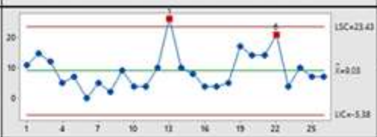
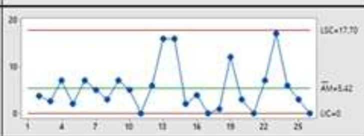
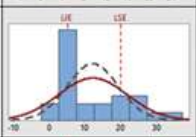
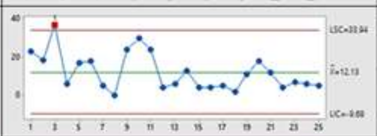
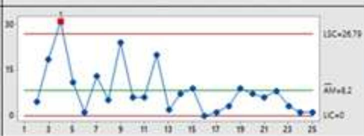
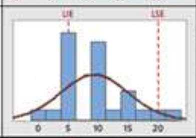
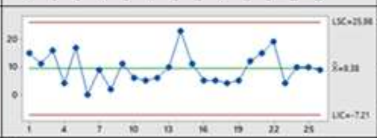
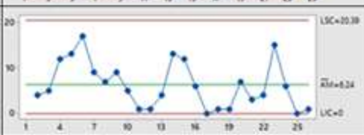
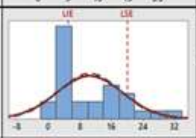
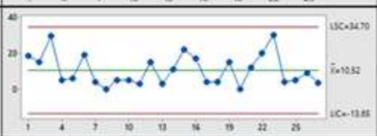
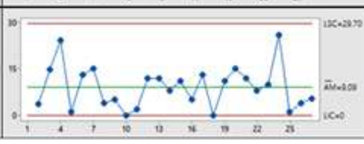
The Special Cause Tests of the charts indicated that three points have failed when tested:

a) Point 1: In Chart I, one of the measures had more than three standard deviations of the centerline and nine points occurred on the same side of the line. This demonstrate that Point 1 has a tendency of measures being smaller than the average.
b) Point 3: In Chart I, one of the measures had more than three standard deviations of the centerline and four of five measures had more than one standard deviation on one side of the centerline. This evidence that various measures are distant from the average in Point 3.
c) Point 4: In both Chart I and Chart AM, one of the measures had more than three deviations from the centerline. This indicate that one measure at Point 4 is too far from the average.

As for the capacitance indexes, it was noted in all six points that the values of Cp and Cpk are less than 1, confirming the incapability of the process and the need of revision aiming the enhancement of the odorization. In addition, the values of Cpk are smaller than those of Cp, although the proximity in points 2 and 4, demonstrating that the process is not centered.

Finally, PPM was lower in point 3, 211,844.83, the farthest from the OU; and higher in point 6, 366,382.77, the closest one. This fact didn't lead to theconclusion that the distance is directly related, but exposed that it may have an effect on the final result, needing further studies to prove.

Table III: Process capability analysis results

Points	Capacity Histograms	Individual Chart (I)	Mobile Range Chart (MR)	Cp	Cpk	PPM
1				0,47	0,25	243.396,80
2				0,32	0,30	339.557,82
3				0,52	0,28	211.844,83
4				0,34	0,33	302.841,99
5				0,45	0,26	241.500,71
6				0,31	0,23	366.382,77

Source: Authors.

V. CONCLUSION

Analyzing the results from the tools used, it's possible to affirm that the company's odorization process has low capability, due to the fact that the histograms indicate non-compliance with the specifications, and the control charts indicate that the process is partially under control - because it contains points outside the specifications and presents lack of data normality.

About the indexes, the values of Cp and Cpk reported on the process performance in its specification limits, demonstrating that it is hardly capable, not centralized and needs improvement. Comparing the higher and lower PPM numbers with thepoints distancefrom the OU, it was not possible to verify that these were directly related. Therefore,the need to adapt to follow the current standards and provide greater safety to final consumers,it’s recommended that future studies establish the causes that affect the odorization process and draw up a plan of action so it can become fully capable.

Still, since the data are secondary, one can’t state the accuracy which they were collected and their level of uncertainty.So checks on measuring instrument calibration, standardization of the measurement process, training of the responsible technician, possible changes in the odoration system and the odorant mixture are suitable for a more affirmative analysis.

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