Internal inspection of the Lisama – El Centro gas pipeline using magnetic flux leakage technology in Santander, Colombia

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Abstract. The present work carried out the internal inspection of the pipeline that allows the natural gas transport from the “Compresora Lisama” to the gas plant “El Centro” in Santander, Colombia, establishing the current pipeline conditions and defining the actions that must be taken to maintain the safety of the process. The internal inspection was carried out using Magnetic Flux Leakage technology, which allowed identifying in a single run the different types of anomalies that may occur in the 8'' diameter steel pipeline during natural gas transport. The anomalies identified during the internal inspection inherent to natural gas transport through water bodies and unstable soils of variable height corresponded to thickness losses, dents, and programmed anomalies with estimated repair factor greater than 1. These anomalies were grouped into a total of 41 sections of the “Lisama–El Centro” gas pipeline that require replacement to guarantee the correct operation of the “Compresora Lisama” and the gas plant “El Centro”, preventing unscheduled plant shutdowns that may lead to shortages in communities and companies that require daily the natural gas.

1. Introduction
Over the last few decades, population growth has caused a great increase in the world energy requirements, which have been covered through the advancement of technologies designed to take advantage of different energy sources, especially fossil fuels [1]. A particular case is natural gas, which is a fossil fuel composed mostly of methane and has made it possible to supply around a fifth of the world energy demand over the last few years [2,3]. Natural gas industry has grown extensively because it is a fossil fuel that produces a low amount of CO₂ emissions, so it has less environmental impact than others currently used [4]. In addition to this, natural gas is one of the most versatile fuels in the market and it is used in a variety of applications such as: transportation (20%), power generation (31%), residential (26%) and industrial (23%) [5].

In the Colombian national scenario, natural gas is extracted with the crude oil from the producing fields to be compressed, dehydrated and sold in accordance with the quality standards that dominate the market [6, 7]. In the case of Lisama field, located in Santander, Colombia, natural gas is processed to increase its pressure at “Compresora Lisama (LIS)”, while dehydration and commercialization is carried out at the gas plant “El Centro (ELC)” [8, 9]. In this way, natural gas is transported between
these treatment plants through two pipelines, with diameter of 6” and 8’’, and length of about 52 km each.

Gas pipelines are highly susceptible to different types of damage during their operation such as: 1) dents, 2) thickness loss, 3) leaks, 4) fracture of the material and 5) corrosion by condensation of liquids inside the pipe, among others [9,10]. These damages can cause structural integrity loss of the gas pipelines, generating serious accidents and high economic losses for the petrochemical sector. Therefore, adequate and rigorous monitoring of the current internal and external conditions of the pipes in operation must be maintained [11,12].

For this reason, the present study carried out the internal inspection of the LIS–ELC pipeline (with diameter of 8’’ and length of 52 km) that connects the “Compresora Lisama” and the gas plant “El Centro” in the department of Santander, Colombia, using magnetic flux leakage (MFL) technology in order to establish the current pipeline conditions and define the actions that will be addressed to maintain the integrity of the pipeline and the safety of the process. The purpose of the study is to ensure that the natural gas transport through the national territory is carried out safely and efficiently through specialized monitoring of the gas pipelines integrity, thus preventing unscheduled plant shutdowns that may cause large economic losses for the hydrocarbons sector, or avoiding accidents that may affect the environment or the health of communities located within the influence area of the gas pipeline.

2. Experimental

The LIS–ELC pipeline, which allows to transport natural gas from the “Compresora Lisama” to the gas plant “El Centro” in Santander, Colombia, corresponds to a steel pipe with a nominal diameter of 8’’ and length of 51,493 km, designed to transport natural gas at a maximum pressure of 650 psi and room temperature through an irregular path where it has identified the presence of water bodies and unstable soils of variable height.

The internal inspection of the LIS–ELC pipeline was carried out using the ROSEN MFL–A/XT tool, which allows using the MFL technology to identify thickness losses and geometric anomalies in the pipeline [13]. This tool corresponded to an intelligent pig that was introduced in the LIS–ELC pipeline and moved by gas propulsion along the entire pipeline to simultaneously determine the sections where material losses and/or geometrical anomalies occur.

One of the greatest advantages of using this tool is that it analyzes each segment of the material by sweeping along the entire pipeline, unlike the discontinuous analyzes that are usually performed in the gas industry where only the sections highly susceptible to deterioration during the transport of natural gas are studied and it reduces the probability of a failure only through statistical projections [14,15].

3. Results and discussion

The natural gas transported from the “Compresora Lisama” to the gas plant “El Centro” through the LIS–ELC pipeline corresponds to a sweet wet gas, as shown in the gas chromatography analysis of Table 1, with a large amount of higher order hydrocarbons and no hydrogen sulfide (H₂S).

| Compound | Content (%) | Compound | Content (%) |
|----------|-------------|----------|-------------|
| C₁       | 77.736      | i-C₃     | 0.597       |
| C₂       | 9.489       | n-C₃     | 0.579       |
| C₃       | 5.351       | C₅+      | 0.118       |
| i-C₄     | 0.841       | N₂       | 2.365       |
| n-C₅     | 1.495       | CO₂      | 1.428       |

Figure 1 presents the envelope of the Lisama field gas where it is observed that, in the range of pressure and temperature conditions at which the LIS–ELC pipeline operates, occurs the condensation of hydrocarbons that accumulate inside the pipeline causing clogging and erosive damage to the material, which generates pressure drops close to 15% affecting the efficiency of natural gas transport.
Additionally, the presence of water bodies in the route of the gas pipeline aggravates this situation because they cause a decrease in temperature, which favors the formation of condensed liquids.

![Figure 1](image)

**Figure 1.** Envelope of natural gas transported by LIS–ELC pipeline.

The internal inspection carried out with the ROSEN MFL–A/XT tool allowed to identify in the same run the thickness losses and geometric anomalies in the LIS–ELC pipeline. Thus, the analysis identified 9 critical points where the loss of thickness is greater than 80%, as shown in Table 2, which is associated with external corrosion phenomena caused mainly by environmental factors, since the LIS–ELC pipeline crosses several water bodies and presents sections buried in soils of highly heterogeneous composition. In this way, the internal inspection identified specific areas where the pipeline thickness has been significantly reduced and have become potential sources of natural gas leaks, which would lead to great economic losses for the sector due to the fluid loss and the environmental impact, making necessary the execution of an unscheduled plant shutdown of the natural gas transportation system that would affect the operations at “Compresora Lisama” and the gas plant “El Centro” [16].

| Distance in pipeline (m) | Latitude          | Longitude          | Thickness loss (%) |
|-------------------------|-------------------|--------------------|--------------------|
| 9836                    | N 07° 01’ 25.626’’ | W 73° 33’ 33.498’’ | 88 %               |
| 12971                   | N 06° 59’ 51.654’’ | W 73° 33’ 34.523’’ | 95 %               |
| 15818                   | N 06° 58’ 27.005’’ | W 73° 33’ 41.395’’ | 95 %               |
| 18540                   | N 06° 57’ 03.722’’ | W 73° 33’ 59.645’’ | 81 %               |
| 19585                   | N 06° 56’ 39.437’’ | W 73° 34’ 21.179’’ | 85 %               |
| 28206                   | N 06° 53’ 43.480’’ | W 73° 36’ 47.448’’ | 84 %               |
| 35306                   | N 06° 54’ 45.851’’ | W 73° 39’ 44.470’’ | 95 %               |
| 35631                   | N 06° 54’ 36.388’’ | W 73° 39’ 47.992’’ | 95 %               |
| 40942                   | N 06° 54’ 31.125’’ | W 73° 42’ 18.624’’ | 88 %               |

Four critical points were also identified where the LIS–ELC pipeline presented dents with a difference greater than 5% between the nominal diameter of the pipe and the minimum diameter measured by the ROSEN MFL–A/XT tool, which are presented in Table 3. The presence of this type of anomalies in the pipeline reduces the effective area for natural gas transport and can modify the flow regime, alter the fluid conduction capacity and generate damages to the pipe by erosion or condensation of corrosive liquids [17,18].

Finally, the internal inspection carried out identified the existence of 62 points called programmed anomalies, where the value of the estimated repair factor (ERF) is greater than 1 calculated by Equation (1) from the maximum allowable operating pressure (MAOP) and the theoretical defect failure pressure (TDFP). Thus, according to the results of the present analysis and the indications of
the ASME B31.G code [19], it was recommended the replacement of the pipe sections of the LIS–ELC pipeline associated with the identified programmed anomalies.

Table 3. Anomalies identified with diameter difference greater than 5%.

| Distance in pipeline (m) | Latitude          | Longitude          | Diameter difference (%) |
|--------------------------|-------------------|--------------------|-------------------------|
| 3403.017                 | N 07° 04' 36.404'' W 73° 33' 11.866'' | 6.3 %              |
| 27821.613                | N 06° 53' 44.135'' W 73° 36' 36.152'' | 5.1 %              |
| 29850.952                | N 06° 54' 17.132'' W 73° 37' 23.188'' | 5.5 %              |
| 34309.410                | N 06° 54' 51.957'' W 73° 39' 18.529'' | 7.4 %              |

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ERF = \frac{MAOP}{TDFP}
\] (1)

In summary, the internal inspection carried out on the LIS–ELC pipeline with the ROSEN MFL–A/XT tool allowed the identification of: 9 critical points with thickness loss greater than 80%; 4 critical points with diameter difference greater than 5%; and 62 programmed anomalies with an ERF value greater than 1. In some cases, it was possible to group two or more points due to their geographical location, in such a way that the cost/benefit ratio was lower for the replacement of a single section of greater length compared to the replacement of two independent sections of shorter length. Thus, the results of the internal inspection indicated that it is necessary to replace 41 sections of the LIS–ELC pipeline with different lengths (in meters), located as shown in Figure 2.
4. Conclusions

Internal inspection of the LIS–ELC pipeline, which transports natural gas from the “Compresora Lisama” to the gas plant “El Centro” in Santander, Colombia, was carried out using the MFL technology and allowed the identification of different types of anomalies which can compromise the structural integrity of the 8” diameter pipe and the safety in the natural gas transport between the two facilities. The anomalies identified are inherent to the natural gas transport process due to the presence of liquids inside the pipeline, since the current conditions of pressure, temperature and composition of the processed gas lead to the condensation and accumulation of liquid hydrocarbons inside the gas pipeline. The different types of anomalies identified corresponded to: thickness losses, associated with external corrosion phenomena; dents, with significant variation of the nominal diameter of the pipe; and points where the calculated value for ERF is greater than 1. Thus, the present investigation recommends the replacement of 41 sections of pipeline in the LIS–ELC pipeline in order to ensure that natural gas transportation is carried out safely and efficiently, avoiding leaks and unscheduled plant shutdowns that can cause high economic losses for the company and the national industry.

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References

[1] International Energy Agency (IEA) 2018 Headline global energy data (Paris: The Organization for Economic Cooperation and Development)
[2] Reinking A 2014 Gas natural (Mexico: Universidad Nacional Autónoma de México) p 47
[3] British Petroleum 2009 BP Statistical review of world energy (London: British Petroleum) p 45
[4] European Gas Advocacy Forum 2011 The future role of natural gas (Oslo: Xynteo) p 27
[5] Department of Energy 2017 Transforming the nation’s electricity system: The second installment of the quadrennial energy review (Washington D.C.: Department of Energy) p 494
[6] Guerrero F and Llano F 2003 Caso de estudio: Gas natural en Colombia – gas e.s.p. Estudios Gerenciales 87 115
[7] Santos N, Pérez J C and Carbaceas M 2017 Establecimiento de un valor adicional de punto de rocio de hidrocarburo para la zona cálida de Colombia Rev. Fuentes: El Reventón Energético 15 59
[8] Rivera J A and Rodríguez E 2011 Adecuación de la planta de gas del campo Abanico (Bucaramanga: Universidad Industrial de Santander) p 98
[9] Barrios I J and Siza R A 2017 Evaluación técnica y económica para actualizar y/o seleccionar el proceso de recuperación de LGN más apropiado para la planta de gas del Centro, Barrancabermeja (Bucaramanga: Universidad Industrial de Santander) p 86
[10] Mansoori H, et al. 2017 Pitting corrosion failure analysis of a wet gas pipeline Eng. Fail. Anal 82 16
[11] Intergovernmental Panel on Climate Change 2014 Cambio climático 2014: informe de síntesis ed R Pachauri and L Meyer (Geneva: Intergovernmental Panel on Climate Change) p 157
[12] Hausamann D, Zirnig W, Schreier G and Strobl P 2005 Monitoring of gas pipelines – a civil UAV application Aircr. Eng. Aerosp. Tec. 77 352
[13] Ege Y and Coramik M 2018 A new measurement system using magnetic flux leakage method in pipeline inspection Measurement 123 163
[14] Usarek Z and Warnke K 2017 Inspection of gas pipelines using magnetic flux leakage technology Adv. Mater. Sci. 17 37
[15] Shi Y, Zhang C, Li R, Cai M and Jia G 2015 Theory and application of magnetic flux leakage pipeline detection Sensors 15 31036
[16] Majid Z A, Mohsin R, Yaacob Z and Hassan Z 2010 Failure analysis of natural gas pipes Eng. Fail. Anal. 17(4) 818
[17] Shabani H, et al. 2018 Failure analysis of a natural gas pipeline Eng. Fail. Anal. 84 167
[18] Massa J C and Giudici A J 2010 Daño por efectos de oxidación en gasoductos Rev. Int. de Desastres Naturales, Accidentes e Infraestructura Civil 10 119
[19] American Society of Mechanical Engineers (ASME) 2012 Manual for determining the remaining strength of corroded pipelines, B31G (New York: American Society of Mechanical Engineers)