Safety Engineering Series, ISSN 1805-3238 pp. 1 - 13, DOI 10.35182/tses-2023-0001

RISK ASSESSMENT IN GAS DISTRIBUTION NETWORK LEAKS USING THE PRELIMINARY RISK ANALYSIS AND EISENBERG VULNERABILITY METHOD

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Research article

Abstract: The natural gas distribution system is made up of an extensive network of pipelines and some equipment such as regulators, valves, filters, meters and converters that require maintenance to maintain operation and identify any gas leaks in advance. The risk analysis process is widely used in the gas industries to locate faults in operations and processes that could cause accidental release of chemicals, fire or explosion and to provide decisions to improve operational risk safety. It was concluded that for risk analysis (PRA) accidents occur due to lack of maintenance in the facilities and equipment set and the Eisenberg Vulnerability Method provided an assessment of the probability of damage to infrastructure and damage to the environment for 1%, 50% and 99% lethality.

Keywords: Risk Assessment, Natural Gas, Gas Distribution Networks, Probit Equation.

Introduction

Natural gas is the result of a process of degradation of organic matter in deep reservoirs underground and can only be removed through perforations, just as it is done with oil in the depths of the sea. Among fossil fuels, it generates the lowest carbon dioxide (CO_2) emission rate, contributing greatly to the reduction of the greenhouse effect thus generating less pollution in the atmosphere, moreover, it is odorless and colorless (Marques, 2017).

According to (Zimmermann, 2009; Araújo, 2014), it is necessary to make correct decisions in terms of prioritization and allocation of resources for monitoring and risk reduction, so it is necessary to sort according to their nature and relevance because all risk involves a possibility of gain or a chance of loss. Pipeline operators must have an understanding of the possible consequences of an accidental gas leak, to assist the risk management, and involvement, to develop an appropriate code of laws and standards for pipeline operations. But for this, it is necessary to have a deeper understanding of the characteristics of the pipeline and the environment around it (Junqueira, 2007).

The central theme of this research will be the identification of accident risks in gas distribution networks, using the Preliminary Hazard Analysis (PHA) technique. This technique is a widely disseminated tool in companies of various sectors as an instrument for assessing and controlling risks to health and safety at work and to the environment. Generally, the procedures related to prevention are centered on the formation of multidisciplinary teams, with the presence of professionals from various areas who jointly seek to establish consensus on the risks involved in each activity and recommend the adoption of measures that prevent the occurrence of unwanted situations. To this end, it was applied as a complementary method to the study, calculations of the Eisenberg Vulnerability estimates by the Probit equation method to measure the estimates of probability of damage of events exposed to a certain type of consequence and given the magnitude of an adverse effect such as: damage to humanity or death, collapse of infrastructure and damage to the environment. From the Eisenberg model it was possible to determine the overpressure peaks that correspond to the probability of occurrence of each effect (NSTB, 1997).

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This last method is presented through the Probit equations that correspond to the type of damage and the peak of overpressure relative to the probability of 1%, 50% and 99% of occurrence of the damage. These probability estimates serve to calculate the percentage of a population exposed to a certain type of consequence of a given magnitude of an adverse effect, represented by a linear function, related to values to be measured (Papadakis, 1999).

After this analysis it will be possible to identify and promote preventive actions in order to reduce existing risks, these factors contribute even more to the care regarding the prevention of accidents, especially in the unit of distribution networks under study. Thus, this research is justified, mainly by the need to evaluate the risks in the work environment and also by the social relevance of this study, which aims to verify the forms of accident prevention in the units of gas distribution networks (Mazzola, 1999).

Material and methods

Preliminary risk analysis

Dangerous events have been identified, these events are capable of giving rise to accidents in the analyzed events. Subsequently, the causes of each of these events and their consequences or effects were identified, which depend on the evolution of the accident after its occurrence. In addition, the qualitative evaluation of the frequency of occurrence and their consequences was analyzed, based on the previous establishment of each of these categories (Frequency and Severity) (Bjerketvedt, 1997).

Thus, each scenario of an accident is classified into a frequency category. This frequency category provides a qualitative indication of the expected frequency for the occurrence of each identified scenario, as shown in Table 1. This frequency assessment can be determined by the experience of the team members, or by an accident database (Sousa and Jerónimo, 2014).

For the severity categories, each accident scenario is classified according to Table 2. The severity category provides a qualitative indication of the degree of severity of the consequences of each of the identified scenarios (Sousa and Jerónimo, 2014).

The application of the as low as reasonably practicable (ALARP) principle consists of defining two levels of risk. The first consists of an absolute level of risk "not permissible", which cannot be exceeded, regardless of the cost of containment measures, according to (De Cicco and Fantazzini, 2015).

The second is a level of risk that is considered insignificant and therefore does not require mitigating measures other than existing measures. The table 3 shows the Risk Matrix, resulting from the combination of the Frequency and Severity categories (Brito, 2007).

Table 1 Frequency categories of PHA scenarios

Category	**Denomination**	**Description**
A	Extremely remote	Extremely unlikely to occur during the life of the installation
B	Remote	Should not occur during the life of the installation
C	Improbable	Unlikely to occur during the lifetime of the installation
D	Probable	Expected to occur at least once during the life of the installation

Table 2 Severity categories of PRA scenarios

Category	**Denomination**	**Description**
I	Despicable	No injuries or deaths occur The most that can happen are cases of minor first aid
II	Marginal	Minor injuries
III	Criticism	Moderate-severity lesions with a likelihood of death Requires immediate corrective action
IV	Catastrophic	Causes death or serious injury in several people

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Table 3 Risk Matrix

		Severity			
		I (Despicable)	II (Marginal)	III (Criticism)	IV (Catastrophic)
Frequency	A (Extremely Remote)	MR	HR	VHR	VHR
	B (Remote)	LR	MR	HR	VHR
	C (Improbable)	VLR	LR	MR	HR
	D (Probable)	VLR	VLR	LR	MR

VHR	Very High Risk
HR	High Risk
MR	Medium Risk
LR	Low Risk
VLR	Very Low Risk

Eisenberg vulnerability model

Several effects resulting from a gas cloud explosion have been studied for many years and can be classified for studies of estimates of the consequences of toxic exposures, thermal radiation to fire and explosion overpressures. Probit equations corresponding to the type of damage and the peak of overpressure relative to the probability of 1%, 50% and 99% of damage occurrence are presented (AIChE, 2000).

The effects caused by the passage of a shock wave can be estimated by Eisenberg's vulnerability model, a method that makes use of the Probit equations for probability estimates that are used to calculate the percentage of a population exposed to a certain type of consequence of a given magnitude of an adverse effect. In mathematical terms, Probit is the development of probabilities represented through a linear function related to values to measure, for example human damage, damage to infrastructure and damage to the environment (Brito and Almeida, 2008).

The Probit equation can be written as below proposed by (CCPS, 2014):

$$Y = K_1 + K_2 \cdot lnV \qquad (1)$$

Where:

Y is Probit, which is related to the percentage of the population subject to the consequence. k_1 and k_2 are constants that are determined from historical data and V is the magnitude of the effect.

$$Po = V = \left(\frac{t \cdot I^{\frac{4}{3}}}{10^4} \right) \qquad (2)$$

Where:

Po is the peak of highest pressure ($N.m^{-2}$). I is the radiation intensity ($W.m^{-2}$) and t is the exposure time (s).

Table below shows the Probit equations collected from the literature for this study and, next to each one, the respective damage in which it will be used. With the level of overpressure, the value of the Probit variable is found and with it the probability of occurrence of the damage (CCPS, 2014).

Table 4 Probit equations with their respective uses

Probit Equations	**Effects**
$y = -15{,}6 + 1{,}93 ln(Po)$	Infrastructure collapse
$y = -77{,}1 + 6{,}91 ln(Po)$	Damage to humanity (Death)
$y = -12{,}6 + 1{,}524 ln(Po)$	Damage to the environment

As can be seen in the Table 4, each type of damage has an equation with different parameters; these were determined through observations made of accidents that have occurred throughout history.

Calculations of the probabilities of consequences

Several uncertainties are present in the estimation of scenarios and danger zones, such uncertainties are not desirable for the model, because it becomes impossible to determine deterministically what multidimensional consequences may occur due to an accidental leakage of natural gas (Henselwood and Phillips, 2006).

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According to (Brito and Almeida, 2008), it can be considered, in the context of accidents in gas distribution networks that the human, structural and environmental consequences have negligible correlation with each other, due to the fact that the danger rays are a few tens of meters, and the combination of these dimensions of consequences occurs randomly and independently according to the specific characteristics of each stretch, so that probabilities can be estimated independently.

From equation 3 it is possible to determine the peak of overpressure for any probability of occurrence of damage in previously mentioned scenarios, from 1%, 50% and 99%, (CCPS, 2014):

$$Po(y1) = e^{\left(-\frac{y1+k1}{k2}\right)} \tag{3}$$

Studies of effects of a gas explosion to cause harm to mankind such as death, collapse of a masonry structure and damage to the environment are represented by the equations below.

Equation 4 represents the Probit Equation, for humanity damage or death:

$$Po(y1) = e^{\left(-\frac{y1+77.1}{6.91}\right)} \tag{4}$$

Equation 5 represents the Probit Equation for infrastructure collapses:

$$Po(y2) = e^{\left(-\frac{y1+15.6}{1.93}\right)} \tag{5}$$

Equation 6 represents the Probit Equation for damage to the environment:

$$Po(y3) = e^{\left(-\frac{y1+12.6}{1.524}\right)} \tag{6}$$

Probit equations corresponding to the type of damage and the peak of overpressure relative to probability in percentage terms of occurrence of the damage were presented, which are now represented in the table 5.

The vulnerability of the consequences originated by these phenomena are determined by the application of Probit-type methodologies, resulting in the estimation of the probability of occurrence of a given damage, or percentage of affected factors, due to the radiation doses received and exposure times, according to the (TNO, 2004).

Case study

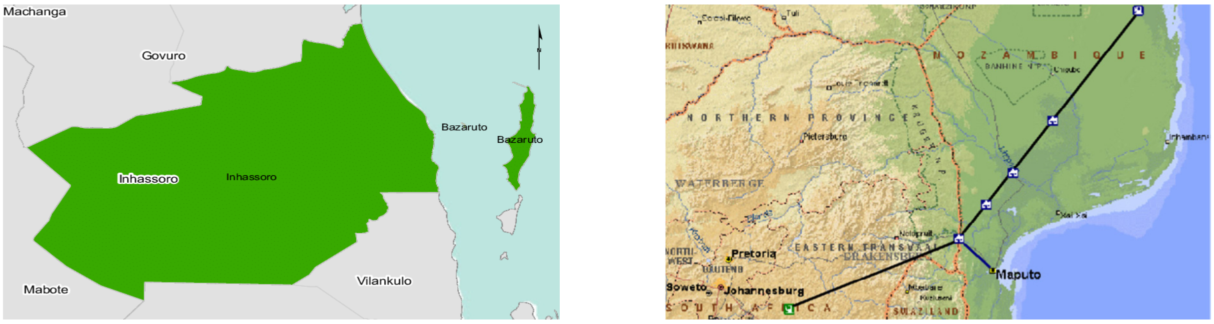
The project under study is gas energy, at the Temane Thermal Power Plant, which is located in the Temane area, in the Inhassoro district, Inhambane province, in southern Mozambique (MAE, 2014).

It has geographical boundaries, to the north with the district of Govuro, to the east with the Indian Ocean, to the south with the districts of Vilankulo, Massinga, Funhalouro and the west with the district of Mabote. The district of Inhassoro has an area of 4,746 km² and a population of 48,537, according to the preliminary results of the 2007 Census, resulting in a population density of 10.2 inhabitants/km². The population registered in 2007 represents an increase of 11.8% compared to the 43,406 inhabitants recorded in the 1997 Census (MAE, 2014).

The Inhassoro District has two islands that are part of the Bazaruto Archipelago National Park, the island of Santa Carolina and Bazaruto Island. These islands are approximately 30 to 35 km away from Inhassoro, especially the Santa Carolina Integral Reserve, which is considered a take zone (MAE, 2014).

Table 5 Relationship between Probit variable and probability

%	0	1	2	3	4	5	6	7	8	9
0	---	2.67	2.95	3.12	3.25	3.36	3.34	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09



(a) (b)

Figure 1 (a) Geographic location of the study area; (b) Location of the Study Branch at the Mozambican Territory Level

The Pande and Temane project has a steel pipeline with an extension of 865 km and 26" in diameter connecting (Temane to South Africa). The study will be directed to the Mozambican territory, where it has a central gas processing facility with system capacity: 120 Mil GJ/year with an extension of 531 km on the Mozambican side (INP, 2005).

The gas distributed by this extension is being used as fuel by Mozambique Aluminum-(MOZAL) and as a primary energy source for the production of electricity and for domestic consumption for the districts of Vilankulo, the Village of Inhassoro and the Bazaruto Archipelago, this in the province of Inhambane. And later, it will be used by the Maputo Iron and Steel Project and the power plants that supply power to the cities of Maputo, Matola and Chokwe (MIREME, 2014).

Results

Presentation of the results of the preliminary risk assessment in gas distribution networks leaks

At this stage, results will be presented using risk assessment methods depending on the identification of the hazards associated with leaks in gas distribution networks. During the case study, descriptions of the initial stages of the procedure for the execution of the (PRA) will be made, which are fundamental: Identification of causes, classification of frequency and severity to achieve risk classification and propose mitigation measures for leaks in gas distribution networks.

For the elaboration of the (PRA) matrix, all hazardous events whose failures originate in the installation under analysis were focused, contemplating both the intrinsic failures of equipment, instruments and materials, as well as human errors. However, the definition of the system and its components that fail can compromise function, safety, ergonomics, as well as those that have the highest failure rate, knowing now that the system is the gas distribution network and its components are valves, filters, regulators, and pipes.

The procedure for data collection and the preparation of the preliminary risk analysis was based on a focus group through interaction with employees of the operation area of a gas distribution refinery. Structured and semi-structured questions were elaborated in the form of a questionnaire, in order to obtain information on the theme under study where the subjects were asked to answer questions such as: What are the possible failure modes for each item? What rating does each failure mode give in relation to severity indices, frequency and how would it be classified? To obtain the improvement actions, the topics addressed were: "What are the possible improvements aimed at reducing the risks found in each item? The questionnaire and the survey of the answers can be seen in the annex to this document.

In the preliminary risk analysis, the hazards, causes and effects or consequences and the corresponding severity categories were identified, as well as the observations and recommendations relevant to the identified hazards, and the results should be presented in a standardized spreadsheet as can be observed below:

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Table 6 Preliminary Risk Analysis for GAS Distribution Network

Preliminary Risk Analysis							
Area:			**Subsystems:**			**Date:**	
Hazard	**Cause**	**Detention Mode**	**Effects/ Consequences**	**Frequency**	**Severity**	**Classification**	**Recommendation**
Small Leak	Intrinsic failure of the safety valve	Odor Sensors Pressure drop on the network with the information in the control room	Flammable cloud dispersion with possibility of fire Explosion in case of contact of the gas with an ignition source	**A**	**I**	**MR**	Periodic monitoring of the system
Medium leakage	Failure in material quality inspection (pipes, valves, filters and regulators) Opening the fuse plug	Odor Visual Sound Sensors	Flammable cloud dispersion with possibility of fire Explosion in case of contact of the gas with an ignition source	**C**	**III**	**MR**	Maintain quality standard of the materials to be purchased for their use Review emergency procedures
Large Leak	Metallurgical failure Large corrosions Disruption of distribution channels	Odor Visual Sound Sensors	Flammable cloud dispersion with possibility of fire Explosion in case natural gas contact with an ignition source	**C**	**IV**	**HR**	Reevaluate tests for determining structural modes
Catastrophic disruption	Domino effect occurrence	Visual Sound Sensors	Possibility of fire and explosion in case of immediate ignition at the beginning of the leak	**C**	**IV**	**HR**	Review operational procedures
Gas leak in the valve	Improper installation Defective valve Corrosion	Odor Sensors	Fire or explosion in case of immediate ignition at the beginning of the leak Atmospheric dispersion of flammable gas	**B**	**II**	**MR**	Change the Valve Management of coating projects, cathode protection, maintenance and inspection plan) Damage Prevention Plan Patrolling the entire route of the network Monitoring of valve operating parameters (temperature, pressure and flow) in order to reduce the time to identify larger leaks City gate in fenced area, with access control (gate closed access) and risk signaling

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Preliminary Risk Analysis							
Area:			**Subsystems:**			**Date:**	
Hazard	**Cause**	**Detention Mode**	**Effects/ Consequences**	**Frequency**	**Severity**	**Classification**	**Recommendation**
Gas leak in valve fuse plug	Damaged plug	Odor Sensors	Fire or explosion in case of immediate ignition at the beginning of the leak	**B**	**IV**	**VHR**	Change the valve or fix the plug City gate in fenced area, with access control (gate closed access) and risk signaling
Gas leak in the pipe	Damaged pipe Thermal weakening (by exposure to excessive thermal radiation) or mechanical material Excessive pressure increase in the pipe (by increasing temperature in case of prolonged system failure without drainage of the line) Weakening of welding or thread sewing	Odor Sensors	Fire and fire jet, in case of immediate ignition Atmospheric dispersion of flammable gas	**C**	**IV**	**HR**	Change the pipe Management of coating projects, cathode protection, maintenance plan and inspectio Damage Prevention Plan Provision of registration and monitoring of works Patrolling the entire route of the network Specification of materials, qualification of suppliers Monitoring of the operational parameters of the duct resulting in the reduction of the time to identify larger leaks
Disruption of the gas transport pipe	Third-party action/ interference Corrosion Material failure Incorrect construction Geotechnical movements Weather Mechanical impacts Thermal weakening (by exposure to excessive thermal radiation) or mechanical material Excessive pressure increase in the pipe (by increasing temperature in case of prolonged system failure without drainage of the line)	Odor Sensors Visual	Fire or explosion in case immediate ignition in the beginning of the leak	**C**	**IV**	**HR**	Change the pipe Management of coating projects, cathode protection, maintenance plan and inspection) Damage Prevention Plan Provision of registration and monitoring of works Network patrol Specification of materials, qualification of suppliers Monitoring of the operational parameters of the duct resulting in a reduction in the time to identify larger ruptures

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Preliminary Risk Analysis							
Area:			**Subsystems:**			**Date:**	
Hazard	**Cause**	**Detention Mode**	**Effects/ Consequences**	**Frequency**	**Severity**	**Classification**	**Recommendation**
Gas leakage through the filters	Inadequate installations Filter damaged or in trouble Clogging of filters	Odor Sensors	Fire and Fire Jet, in case of immediate ignition in the start of the leak Atmospheric dispersion of flammable gas	**D**	**II**	**VLR**	Change of filters and auxiliary components Coating design management, maintenance plan and inspection Damage Prevention Plan Acceptance tests
Clogging of filters by impurities	Inadequate facilities Accumulation of impurities dragged from production wells and during transport by the distribution pipe	Odor Sensors Visual	Formation of hydrides and acids, both of which will attack the pipe causing corrosion in them Reduction of gas flow during its circulation	**A**	**IV**	**VHR**	Immediate filter change Clogging management (design, coating, filter protection, maintenance plan and inspection Damage Prevention Plan
Gas leak in regulators due to increased pressure	Defect in regulator Disruption of the regulator due to increased pressure of released gas Third-party action/ interference Corrosion Material failure	Odor Sensors Pressure drop in the distribution network with information checked in the control room	Fire and fire jet, in case of immediate ignition Atmospheric dispersion of flammable gas	**C**	**II**	**LR**	Immediate exchange of regulators Specification of materials, qualification of suppliers Anti-corrosion management (design, coating, cathodic protection, maintenance and inspection plan) Monitoring of the operational parameters of the regulator (temperature, flow and pressure)

Presentation of the results of Eisenberg vulnerability estimates

For the validation of the collected data, it was necessary to present calculations of Eisenberg's Vulnerability estimates by the Probit equation method to measure the estimates of probability of damage of events exposed to a certain type of consequence and a given magnitude of an adverse effect such as: damage to humanity or death, infrastructure and damage to the environment. From the Eisenberg model it was also possible to determine the overpressure peaks that correspond to the probability of occurrence of each effect.

The peak of overpressure was determined from the equations presented in Table 4 using as Probit variable the value corresponding to the probability of 1%, 50% and 99% for the effects related to damage to humanity or death, collapse of infrastructure and damage to the environment. The results were supported by a comparison between the result of the general objective of the article, in relation to that found in the bibliography, in order to obtain reliable information, avoiding harming the research result.

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Application of the calculation of overpressure necessary to have 1% probability of damage to humanity or death (Equation 4):

Data

$K_1 = -77.1$

$K_2 = 6.91$

$(Y = 2.67 \text{ table } 5)$

Formula

$$Po(1\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(1\%) = e\left(-\frac{2.67+77.1}{6.91}\right)$$

$$Po(1\%) = 1{,}0317.10^5 \text{ Pa}$$

Application of the calculation of overpressure necessary to have a 1% probability of infrastructure collapses (Equation 5):

Data

$K_1 = -15.6$

$K_2 = 1.93$

$(Y = 2.67 \text{ table } 5)$

Formula

$$Po(1\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(1\%) = e\left(-\frac{2.67+15.6}{1.93}\right)$$

$$Po(1\%) = 1{,}2917.10^4 \text{ Pa}$$

Application of the calculation of overpressure necessary to have 1% probability of damage to the environment (Equation 6):

Data

$K_1 = 12.6$

$K_2 = 1.524$

$(Y = 2.67 \text{ table } 5)$

Formula

$$Po(1\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(1\%) = e\left(-\frac{2.67+12.6}{1.524}\right)$$

$$Po(1\%) = 2{,}2464.10^4 \text{ Pa}$$

Application of the calculation of overpressure necessary to have 50% probability of damage to humanity or death (Equation 4):

Data

$= -77.1$

6.91

$(\quad 5.00 \text{ table } 5)$

Formula

$$Po(50\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(50\%) = e\left(-\frac{5.00+77.1}{6.91}\right)$$

$$Po(50\%) = 1{,}44542.10^5 \text{ Pa}$$

Application of the calculation of overpressure necessary to have a 50% probability of infrastructure collapses (Equation 5):

Data

$K_1 = -15.6$

$K_2 = 1.93$

$(Y = 5.00 \text{ table } 5)$

Formula

$$Po(50\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(50\%) = e\left(-\frac{5.00+15.6}{1.93}\right)$$

$$Po(50\%) = 4{,}3199.10^4 \text{ Pa}$$

Application of the calculation of overpressure necessary to have 50% probability of damage to the environment (Equation 6):

Data

$K_1 = -12.6$

$K_2 = 1.524$

$(Y = 5.00 \text{ table } 5)$

Formula

$$Po(50\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$$

Resolution

$$Po(50\%) = e\left(-\frac{5.00+12.6}{1.524}\right)$$

$$Po(50\%) = 1{,}03627.10^5 \text{ Pa}$$

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Application of the calculation of overpressure in necessary to have 99% probability of damage to humanity or death (Equation 4):

Data	**Formula**
$K_1 = -77.1$ $K_2 = 6.91$ $(Y = 7.33 \text{ table } 5)$	$Po(99\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$

Resolution

$$Po(99\%) = e\left(-\frac{7.33+77.1}{6.91}\right)$$
$$Po(99\%) = 2,02505.10^5 \text{ Pa}$$

Application of the calculation of overpressure necessary to have a 99% probability of infrastructure collapses (Equation 5):

Data	**Formula**
$K_1 = -15.6$ $K_2 = 1.93$ $(Y = 7.33 \text{ table } 5)$	$Po(99\%) \quad e^{\left(\ \frac{y1\ \ k1}{}\right)}$

Resolution

$$Po(99\%) = e\left(-\frac{7.33+15.6}{1.93}\right)$$
$$Po(99\%) = 1,44470.10^5 \text{ Pa}$$

Application of the calculation of overpressure necessary to have 99% probability of damage to the environment (Equation 6):

Data	**Formula**
$K_1 = -12.6$ $K_2 = 1.524$ $(Y = 7.33 \text{ table } 5)$	$Po(99\%) = e^{\left(-\frac{y1+k1}{k2}\right)}$

Resolution

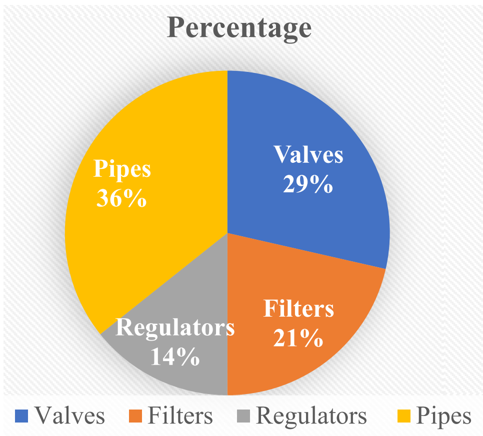
$$Po(99\%) = e\left(-\frac{7.33+12.6}{1.524}\right)$$
$$Po(99\%) = 4,78029.10^5 \text{ Pa}$$

Discussion

Preliminary risk analysis associated with leakage in gas distribution network

After studies carried out throughout the research, by carrying out the preliminary risk analysis in accordance with the literature consulted on the detection of natural gas leakage, which addresses what are the equipment that make up the gas distribution system as a way to guarantee the safe distribution of the even approached by (Marques, 2017), it was found that the gas distribution process is composed of components such as Valves, Filters, Regulators and Pipes, being part of it, since gas distribution systems are considered the main critical causes for the occurrence of leaks in the distribution network. The critical causes were only possible to identify taking into account the exact and concise description of the function of each component provided by the questionnaire prepared for a group of experts in the area the so-called focus group. The functions are very important, as they are a great reference for identifying the dangers present in an installation, which can be caused by undesirable events.

The Graph 1 shows the main cause of leaks in gas distribution networks, taking into account the preliminary risk analysis carried out throughout the research, showing that pipes are responsible for leaks.



Graph 1 Percentage of critical causes of leaks in gas distribution networks

According to (Corteletti, 2008), This is due to its exposure and sensitivity along the path that comes into contact with third parties by excavations for

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the installation of rainwater networks, drainage networks of sewers on the track, electrical installation networks, renovations or maintenance, mining, design error and welding errors, lamination, inflexible points are seen as reasons for their occurrence, and one also sees allies extreme factors outside human control such as tropical storms, cyclones, tsunamis, falling trees, soil movement or erosion, floods.

(EGIG, 2018) supporting Laws 13.303/2016 and 8.666/1993 mentions that to avoid operational, mechanical and third-party failures, it is necessary to hire specialized and legalized companies to carry out the activity providing data in forms of drawings of the tracks to be built and the type of material that will be adopted in the project, from the process of capturing gas in reservoirs to the distribution channels according to the purpose of the product.

That way, the companies in turn should evaluate alternative routes for gas distribution, which environmental areas and population centers can be crossed; and what other infrastructure systems are along the route.

Calculation of Eisenberg vulnerability probabilities using the Probit equation

By estimating Eisenberg Vulnerability model and Probit equation, the probability of 1% of damage occurred, it was found that the shock wave of an explosion from a gas leak had a greater impact on the scenario of damage to the environment, where the impact value was approximately *2.2464.10⁴ Pa*. According to (TNO, 2005), the peak of overpressure at these levels offers a higher risk of damage verified at the level of proximity and contact with the environment, providing burns to vegetation, animal deaths and even reached the point of emission of air pollution. And for other scenarios, such as damage to humanity and the collapse of infrastructure due to factors such as reaction time and mobility to reduce the risk doesn't come to be affected to the point of causing risk along the gas distribution network.

Therefore, for the results obtained by estimating Eisenberg's Vulnerability model and Probit equation, the probability of 50% of damage occurrence, it was noted that for the collapse in infrastructures had a shock wave explosion impact level around $4.3199.10^4$ *Pa*. Value that according to (TNO, 2005; Henselwood Phillips, 2006), mention in being in the values of higher risks, this due to the impact that reaches to affect high financial losses from damage to properties of the distribution network itself, losses of third-party properties, payment of compensation.

Based on the results obtained for the 99% probability of damage occurring by estimating Eisenberg's vulnerability model and the Probit equation, it can be concluded that the most impact shock wave was linked to the scenario of damage in the environment and a slight effect was verified for the scenario of damage to humanity or death, with values around $4.78029.10^5$ *Pa* and $2.02505.10^5$ *Pa* respectively. (TNO, 2004; Brito and Almeida, 2008) argue that shock waves for gas explosions at these levels pose risks to the environment and humanity. Overpressure spikes can cause damage due to emitted thermal radiation, a factor that reports a fatality in terms of large-scale vegetation burn, animal death and pollution, first and second degree burn checks, tympanum ruptures, and even can cause immediate death.

Conclusion

This chapter presents the results of the Preliminary Risk Analysis and the effects of gas cloud explosions based on Eisenberg's vulnerability method in a gas distribution network, as well as recommendations.

The main objective of this work was to use risk analysis techniques to estimate the explosion levels of where shock in case of a possible natural gas leak for the Pande and Temane steel gas distribution network with an extension of 865 km and 26" in diameter connecting (Temane to South Africa), specifically directed to Mozambican territory with an extension of 531 km. The gas distributed by this extension is being used as fuel by Mozambique Aluminum (MOZAL) and as a primary energy source for electricity production and internal consumption, in order to assess whether throughout the installed network offers risks in the facilities in order to be likely to collapse infrastructure, damage to humanity and damage to the environment.

After identifying the risk and analyzing the effects of this risk, the results of this work showed, most accidents in gas distribution networks, occur due to lack of maintenance in installations and the set of equipment that cause gas leaks in the valve fuse plug, gas leaks by filters, clogging of filters by impurities, gas leakage by regulators due to increased pressure and catastrophic pipe disruption, failure in the preparation of risk analysis, lack of information, either due to lack of interest of the employee, or lack of training, adequate supervision in relation to the equipment installed in its network and also regarding bottling, handling, transportation and storage of gas.

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And through mathematical calculations and with the aid of Eisenberg's vulnerability model and the Probit equation, it was determined that by the probability of 1% of damage the occurrence of damage from an explosion of a leak in the gas distribution network had greater impact on the scenario of damage to the environment, where the impact value was approximately $2.2464.10^4$ *Pa*. For the probability of 50% of damage occurrence, it was noted that for the collapse in infrastructure had shock wave explosion impact level around $4.3199.10^4$ *Pa* and finally for the probability of 99% of damage occurrence it can be concluded that the shock wave of greater impact was linked to the scenario of damage in the environment and a slight effect was verified for the scenario of humanity with values around $4.78029.10^5$ Pa and $2.02505.10^5$ *Pa* respectively.

Recommendations

It proposes that more modern constructions of facilities should be designed in order to optimize the control conditions of the process unit and also with regard to the safety of the workers who remain there. It is necessary to have a maintenance plan, being attentive to the fulfillment of maintenance deadlines, it is also important for the safety of users, that the installation of the gas distribution network has evaluation of a professional and gas arrest equipment and automatic alarms in sufficient quantity, because the gas leak can be silent and extremely dangerous.

For the purposes of the safety criteria in the installation and operation of the storage bases up to the gas distribution networks, it should be established that any installation involving handling, handling and storage must have intrinsic safety measures provided for already in the design phase of the plant or equipment. Some of these main measures are the installations of diameter pipes suitable for the working pressure, the locations of large capacity installations and too many branches in areas adequately detached from urban conglomerates, shopping centers and the use of specific electrical equipment and installations for areas subject to the formation of explosive air and gas mixtures.

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