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APPROACH TO THE DETERMINATION OF FAILURE RISK LEVEL INDEX ON THE EXAMPLE OF THE NATURAL GAS DISTRIBUTION SUBSYSTEM

The paper presents issues related to the failure risk analysis in the natural gas distribution subsystem (NGDS). In the operation analysis of the gas supply system, very crucial is safety assessment of its functioning, that is why the approach to determining risk in the NGDS by means of the risk level index of gas network failure has been proposed. The presented method can constitute the basis for a comprehensive failure risk management program and the process of making operational decisions.

Keywords: gas network functioning, gas network, risk, gas network failure

1. Introduction

The transport of natural gas by gas pipelines belongs to one of the safest types of transport of this fuel. However, also here, as everywhere, failures occur, which sometimes bring very serious consequences. The unsealing of the gas pipeline located in the ground is a particular threat, because due to the location of the failure, it is noticeable after a long time.

For economic and ecological reasons, natural gas is gaining more and more importance. The increased demand for this fuel causes the expansion of gas networks, which, in turn, increases the level of risk of undesirable events. Each undesirable event in the natural gas distribution subsystem causes disruptions in its supply and creates the risk of the explosion. For this reason, it is very reasonable to determine the level of risk associated with the occurrence of an undesirable event in the natural gas distribution subsystem. In this work, the natural gas distribution subsystem should be understood as a medium and low pressure network, while the high pressure network should be treated as a power source for the NGDS.

The most common causes of pipeline leaks are [2]:

- joints cracks,

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- mechanical damage, eg by an excavator bucket during construction works,
- unsealing of threaded connections,
- corrosion of gas pipelines,
- improper gas composition, which causes damage to the gas pipeline from the inside.

The procedure of defining the risk level of risk should take into account all aspects related to the construction of the gas pipeline starting from the project, the material from which the gas pipeline will be constructed by determining the probability of occurrence of the failure causes and its consequences, location of the gas pipeline and determination of the nuisance degree of failure for individual recipients [5-8, 11, 13-16].

In this work, based on the literature [12], a method of determining the level of risk in the natural gas distribution subsystem using the risk level index has been proposed. In order to properly determine the level of risk with implementation of this method, expert knowledge and experience gained in building and operating of NGDS are necessary.

2. Risk level index – assumptions

When dividing gas pipelines due to pressure, it should be remembered that the value of the working pressure, i.e. the pressure under which the gas is discharged under normal operating conditions, is taken into account, as presented in Table 1.

Medium pressure gas pipelines are supplied by high pressure gas pipelines, while low pressure gas pipelines are usually gas connections to buildings. The failure of medium-pressure gas pipelines results in greater losses as it disrupts the gas supply to the low-pressure network, disrupting the gas supply to a larger number of consumers. Failure of a low-pressure gas pipeline usually deprives (or disrupts the supply) of gas to a smaller number of consumers [1]. Of course, the type of failure should be taken into account. Sometimes the removal of low-pressure network failure forces the medium pressure network to close for a certain period of time, which deprives more gas consumers of access to the gas [17].

One of the key elements affecting the damage of the pipe is its location. Failure of the gas network as a result of an inadequate location may occur as a result of geological factors (eg. landslides, high level of groundwater in the pipeline) and urban planning.

Location the gas pipeline near traffic routes may contribute to damaging the gas pipeline from vehicle vibrations. The more urbanized the area is also the more likely to damage the gas pipeline during construction works. The location of the gas pipeline should be determined according to Regulation of the Minister of Economy of 26 April 2013 on technical conditions to be met by gas networks and their location. This Act divides the location of gas pipelines into [9]:

- first-class location - a land with buildings for collective housing and public utility buildings, single- or multi-family buildings, intensive wheeled traffic, developed underground infrastructure, such as water supply, sewage, heating, gas, energy and water supply networks telecommunications, and streets, roads and mining areas,

- location of the second class - single-family and prefabricated housing area, development with individual recreation buildings, and also necessary infrastructure for them,
- location of the third class - an undeveloped area and an area where only single-family, economic and livestock buildings as well as the necessary infrastructure can be located.

The gas pipeline material is another group of factors affecting the probability of a failure. Two types of materials are used on the gas pipeline, ie steel and polyethylene [2, 3]. It should be remembered that each type of material has different properties. The steel is characterized by high durability and stiffness. On the other hand, compared to polyethylene, it has a large mass compared to polyethylene, which makes it difficult to transport pipes to the site of the gas pipeline as well as the assembly itself. Steel is also susceptible to corrosion, especially electrochemical. The advantages of polyethylene as a material for gas pipelines are low weight and relatively high corrosion resistance. In turn, the defect of polyethylene is a low scratch resistance and greater susceptibility to cracking [10].

The term corrosion is defined as the phenomenon of destruction of materials under the influence of the surrounding environment (atmosphere, precipitation, waters) as well as technological factors released into the atmosphere as a result of human activity. They are sulfur oxides, nitrogen, carbon dioxide, dust, etc. and all kinds of chemicals. Most often, we refer to the phenomenon of corrosion to metals and their alloys, however, it also applies to non-metallic materials, such as those used for the construction of polyethylene gas pipelines [18].

In the case of NGDS, the probability of a failure due to corrosion mainly concerns gas pipelines made of steel, which spreads in the walls of a gas pipe causing a gas leak, which ultimately poses a threat to the health or life of its surroundings and the interruption of gas supplies. The type of corrosion, the rate of its operation and the method of protection against it depends mainly on the gaseous material and its location. The vast majority of gas lines is in the ground. In this case, gas pipelines should consider the following corrosion causes:

- factors from the ground in which the gas-stream is located,
- factors from the improper composition of the transposed gas,
- atmospheric factors (e.g. derived from compounds that got into the ground together with rainfall).

Corrosion should be taken into account when determining the rank of the location of the gas pipeline.

The risk level of the natural gas distribution subsystem should be estimated starting from the division of subsystem elements into groups of factors of the same type. This division is presented in Table 1.

Table 1. Groups and factors connected with functioning of the natural gas distribution subsystem
Tabela 1. Grupy i czynniki związane z funkcjonowaniem podsystemu dystrybucji gazu ziemnego

Group of elements of the natural gas distribution subsystem	Factors of a given gas distribution subsystem group
Type of gas network	Medium-high pressure network 0,5÷1,6 MPa
	Medium pressure network 10 kPa÷0,5 MPa
	Low pressure network ≤ 10 kPa
Location class of the gas pipeline	First class of location
	Second class of location
	Third class of location
Geological conditions	Landslides
	High soil moisture
	Quicksand
Material of the gas pipeline	Steel
	Polyethylene
Working time of the gas pipeline	≤ 10 years
	11÷30 years
	> 30 years

The next step in evaluating the risk level is assigning ranks to individual groups and weights to their factors. Individual ranks and weights are presented in Tables 2 and 3.

Table 2. Division of ranks for NGDS groups, developed on the basis of [12]
Tabela 2. Podział rang dla grup PsDGZ, opracowano na podstawie [12]

Ranks for groups of elements of the gas distribution subsystem R_{gi}	Rank
1	irrelevant
2	not important
3	moderately important
4	important
5	very important

Table 3. Value of weights for factors for NGDS, developed on the basis of [12]
Tabela 3. Wartość wag dla czynników PsDGZ, opracowano na podstawie [12]

Weight value for individual factors W_{ei}	Weight
1	low
2	medium
3	high
4	very high

In Table 4 the assumed risk levels are proposed.

Table 4. Risk levels

Tabela 4. Poziomy ryzyka

IPR	< 40	40÷70	71÷100	>100
Risk levels	insignificant	tolerable	controlled	unacceptable

The obtained value of IPR through performed analysis helps to make decisions concerning the operation or modernization of the system. In case of obtaining insignificant risk, no further action is required and is operated in proper and reliable way. In case of obtaining tolerable risk the system preventive action is not needed. Controlled risk means, that the system is allowed to operate but under the condition that modernization or repair will be undertaken. If unacceptable level occurs immediate action should be taken as to reduce *IPR* [11, 12, 14].

3. Risk level index - methodology

Estimating the level of risk according to the presented method consists in assigning the rank of the gas network to the group and then to the given factor of a given weight group. Then, the risk level index should be calculated from the dependence 1 [12]:

$$IPR = \sum_{i=1}^{n} R_{gi} \cdot W_{ei} \tag{1}$$

where:

IPR - risk level index,

R_{gi} - assigned to the rank of the *i*-th group of elements of the natural gas distribution subsystem,

W_{ei} - value of the weight of the *i*-th factor of a given group of elements of the natural gas distribution subsystem,

n - number of considered groups of factors when estimating the risk level index.

The following data has been selected for the calculation example:

- type of gas pipeline depending on the pressure - medium-pressure gas pipeline,
- material of the gas pipeline - polyethylene,
- location of the gas pipeline - a gas pipeline located near a road with fairly intensive vehicular traffic, one-family and multi-family area - based on data, the first class of location was assumed,
- geological conditions - the area where the so-called quicksand.

The fragment of the gas pipeline shown in Figure 1 has been analyzed.

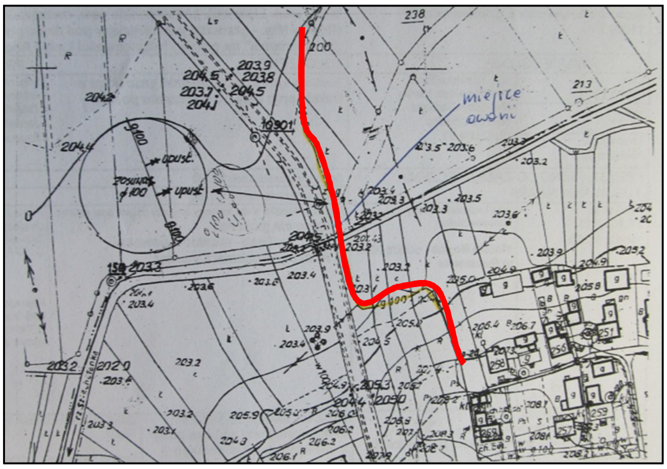

Fig. 1. The fragment of the gas pipeline (marked in red) subjected to analysis, developed on the basis of [5]

Rys 1. Fragment gazociągu (zaznaczono na czerwono) poddanego analizie, opracowano na podstawie [5]

To presented in Table 1 groups of elements of the natural gas distribution subsystem and their factors on the basis of Table 2 and 3 were assigned rank and weight, which are presented in Table 5.

Table 5. Characteristics of the analyzed gas network

Tabela 5. Charakterystyka analizowanej sieci gazowej

Group of elements of the natural gas distribution subsystem	Rank for a given group R_{gi}	Factors of a given group of the natural gas distribution subsystem	Weigh factor W_{ei}	R_{gi} W_{ei}
Type of gas network	4	medium pressure network	2	8
Gas pipeline location class	3	first location class	4	12
Geological conditions	5	dustbox	4	20
Material of the gas pipeline	4	polyethylene	3	8
Work time of the gas pipeline	3	11÷30 years	3	9
IPR				57

According to the adopted risk levels in tab. 4, for the IPR value = 57 the level of risk is at the tolerated level. The estimation of the level of risk posed by the IPR must be "supported" by expert knowledge on the construction and design of gas pipelines as well as the management of gas networks.

4. Conclusion

Currently, due to the increasing residential areas, the length of gas networks is growing, and the probability of their failure is constantly growing. Therefore, it is justified to develop new research methods that will allow to determine the level of risk on a given section of the gas network. Such studies supported by experience and expert knowledge to develop more effective methods of control and protection of gas networks against failure. It gives the opportunity to combine experience of professionals in a given field, which allows taking into account all the most important factors affecting the risk values associated with damage to the gas network. The proposed method is an alternative to other methods of assessing and managing the failure of the water-pipe network, and its application is justified in the case of subjective assessments of risk parameters.

The method belongs to the group of expert methods and can also be an element of the decision-making process regarding modernization plans of gas network.

Companies, to which belong operational supervision over gas network, should be able to estimate the risk, inform users about its size, take appropriate actions to minimize it and initiate actions that must be taken in the face of the risk. Risk analysis can also be useful for planing prevention activities related to preventing damage, as well as developing emergy and rescue scenarios.

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PODEJŚCIE DO OKREŚLENIA INDEKSU POZIOMU RYZYKA AWARII NA PRZYKŁADZIE PODSYSTEMU DYSTRYBUCJI GAZU ZIEMNEGO

Streszczenie

W pracy przedstawiono zagadnienia związane z analizą ryzyka awarii w podsystemie dystrybucji gazu ziemnego (PDGZ). W analizie eksploatacji systemu zaopatrzenia w gaz ważna jest ocena bezpieczeństwa jego funkcjonowania, dlatego też zaproponowano podejście do określania ryzyka w PDGZ za pomocą indeksu poziomu ryzyka awarii uszkodzenia sieci gazowej. Przedstawiona metoda może stanowić podstawę kompleksowego programu zarządzania ryzykiem awarii oraz procesu podejmowania decyzji eksploatacyjnych.

Słowa kluczowe: funkcjonowanie sieci gazowej, sieć gazowa, ryzyko, awaria sieci gazowej

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