INCIDENTS IN NATURAL GAS TRANSPORT

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ABSTRACT. Attempting to reduce greenhouse gas emissions makes natural gas highly preferred fuel, as evidenced by statistics. Safety and efficient fuel transportation to distribution networks have been posing more and more challenges to facilities and people. Statistical analysis of gas pipeline incidents in production and transportation is presented. This shows different types and frequency of incidents. Quantitative analysis of the main reasons for emergency leakage from transmission pipelines is made. Event trees are mapped showing likelihood of various emergency scenarios leading to fire, jet fire, vapor cloud explosion, and non-ignition dispersion. There is a need for a national regulation of different standards for emergency planning that are not yet in place in our country.

Keywords: natural gas, transport, incidents

ИНЦИДЕНТИ ПРИ ПРЕНОСА НА ПРИРОДЕН ГАЗ

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РЕЗЮМЕ. Стремежът към намаляване на вредните емисии в околната среда прави природния газ изключително предпочитано гориво, което се доказва от статистиката на добива. Предизвикателствата пред съоръженията и човека стават все по-големи в усилията им да транспортират безопасно и по най-ефективен начин горивото до разпределителните мрежи. Направен е статистически анализ на данни свързани с добива , транспорта, вида и честотата на инцидентите при тръбен пренос на природен газ. Характеризирани са количествено основните причини за аварийно изтичане от преносни газопроводи. Построени са дървета на събитията, показващи вероятността за реализиране на различни аварийни сценарии, водещи до пожар, факелно горене , експлозия на облак от пари и дисперсия без запалване. Обоснована е необходимостта от национален регламент на различни норми за аварийно планиране, каквито в страната не съществуват.

Ключови думи: природен газ, транспорт, инциденти

Introduction

Natural gas is driving a number of economies around the world, because it is compliant with modern environmental standards. The increased demand has led to the development of gas transmission networks to satisfy the markets. The more the transmission network evolves, the closer they are to settlements and sites. Such gas installations hide potential risks of a larger accident or ecological disaster. To avoid any incidents, it is necessary to thoroughly study documented cases of uncontrolled leakage of natural gas and to analyze the applied prevention methods. For this purpose, a statistical analysis of the frequency of the incidents was made, which allows quantifying the main causes of emergency leakage. This data would allow us to describe possible scenarios of development in case of potential accidents. The survey is centered on the gas transmission network in the European Union. It would serve to assess the risk of future projects in real gas distribution facilities.

Trends in natural gas extraction

The methods of exploration, extraction, storage and transport of natural gas have changed in recent years thanks to technological advances. Initially, the search was carried out by examining folded structures with traces of hydrocarbon accumulation. Given the location of the deposits, this is a long and difficult process. As consumption increases, there is a growing need for more efficient ways to detect raw material. The main purpose of the prospecting is to obtain a detailed picture of the depth and volume of the field before the start of the actual extraction process. In the past the preferred fields were the ones of small depth, great potential and easy access. Nowadays these preferred natural gas sources are exhausted. This fact forces geologists to look for non-standard and innovative methods for discovering new natural gas deposits. The most commonly exploited are the conventional ones, which are located in the so-called "traps". They are accompanied by the presence of oil and water. With the help of new and innovative technologies in recent years, more and more unconventional fields are being discovered and developed. The raw material is placed in coal or shale layers beneath the surface. In the shale deposits most of the natural gas has already migrated from the rock. Due to the considerable geological differences between the conventional and unconventional fields different technologies for their extraction and processing have been developed (Павлова, Костова, 2012).

As more and more fields are being developed natural gas has become an extremely attractive product. It is expected that the share of natural gas in the global energy market will reach 40% by 2020. This is due to increased electricity consumption and the replacement of liquid fuels in transportation. (Николов, Бояджиев, 2011). Figure 1 shows the growth of natural gas production over the last quarter of a century. Statistics show that more than one third of the world's yield is shared almost equally between the USA and Russia.

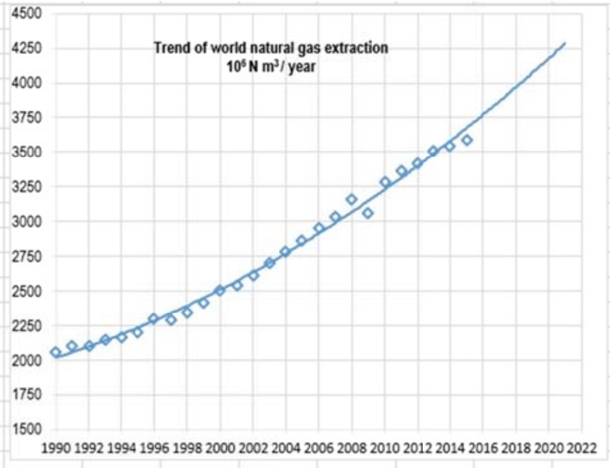

Fig. 1. Global natural gas extraction

Natural gas transport

Due to objective (engineering) and subjective (geopolitical) reasons, transport is perhaps the most difficult part of the gas market. Innovative methods such as Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Natural Gas Hydrates (NGH), and others are alternatives to pipeline transport. According to sociological studies, CNG technology is beneficial in small fields and at small distances. For larger distances and fields it is economically advantageous to apply LNG technology or a pipeline transport.

When it is necessary to cross water basins of considerable depth and length, LNG transport in vessels is overpaying the pipeline method. But the LNG technology has significant limitations from economic point of view. The construction of a re-gasification terminal is economically justified with natural gas consumption greater than 12.106 m^3/ day (Николов, Бояджиев, 2011).

Despite the scientific and industrial advances in natural gas transportation methods, the pipeline remains the main and most preferred one. Different types of gas pipelines are differentiated depending on their purpose. In the primary yield prior to purification and obtaining the final product, the gas together with the desired and undesirable substances are transported to processing plants through small diameter pipelines. After processing the raw product to the desired state the product is distributed via a gas transmission pipeline system. This way the gas reaches the global distribution network.

The aim of this report is to provide more information on the transmission gas pipelines. They operate under high pressure and they are controlled by different compressor stations depending on the length of the pipeline and its capacity. Feed stations that lower the working pressure of the main gas pipeline are the ones that manage the gas distribution network in urban and industrial areas.

Accidents in gas pipeline transport

Highway pipelines are facilities of fundamental importance for the security of energy supply. Any failure in them causes delays, reductions or suspensions of deliveries. This results in inconveniences and/or losses to the end user. This conclusion is based on studies and reports conducted by European Gas Pipeline Incident Data Group (10th Report of the European Gas Pipeline Incident Data Group 2018, 9th Report of the European Gas Pipeline Incident Data Group 2015, 8th Report of the European Gas Pipeline Incident Data Group 2011). These reports have collected data from 17 gas distributors and from stations across 142,794 km of gas pipelines.

The frequency of accidents on transmission pipelines is calculated as the number of incidents over a given period of time is divided by the total length of functioning gas pipelines in the same period as presented in Table. 1. An accident is any uncontrolled (unmanageable) leakage of natural gas from a steel pipeline which is on shore.

Table 1.
Frequency of accidents

Period	Number of years	Number of incidents [N]	Exposition [km.yr]	Frequency [N/1000 km.yr]	95% LL	95% UL
1970-2007	38	1173	3150000	0.372	0.351	0.394
1970-2010	41	1249	3550000	0.351	0.333	0.372
1970-2013	44	1309	3980000	0.329	0.311	0.347
1970-2016	47	1366	4410000	0.310	0.294	0.327
1977-2016	40	1143	4120000	0.278	0.262	0.294
1987-2016	30	723	3440000	0.210	0.195	0.226
1997-2016	20	418	2530000	0.165	0.150	0.182
2007-2016	10	208	1390000	0.150	0.130	0.172
2012-2016	5	97	720000	0.136	0.110	0.165

The statistical data from the EGIG reports show that by increasing the diameter and thickness of the tube wall the number of incidents decreases. This information is a basis for starting an average frequency of 95% above the upper limit confidence interval.

$$F = 0.275\ events/(km - year) \quad (1)$$

The occurrence of an emergency event is a consequence of many factors which may subsequently be established or not. The reasons for uncontrolled leakage of natural gas are classified by EGIG statistics as:

- External impact from activities carried out by "third parties" near the pipeline leading to external damage to the pipe, including: agricultural activities, construction, road construction, etc .;
- Construction defects and material defects, including tearing, installation errors, poor welding, etc.
- Corrosion - external and internal, galvanic, cracks;
- Earth moving - landslides, earthquakes, breakdowns, floods and mining activities;
- Operator error during hot tap made;
- Other and unknown - project error, lightning, maintenance, and other uncertain.

Figure 2 presents the distribution of incidents occurrence according to the registration periods.

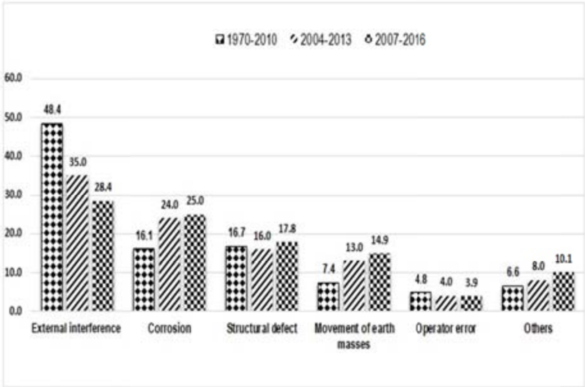

Fig.2. Percentage distribution of incidents for reasons

The accidents caused by gas leakage can damage the gas pipeline to varying degrees, which requires a fault classification. According to the latest 10th EGIG report from 2018 they are directly related to the size of the facility. Depending on the size of the hole, we distinguish three types of uncontrolled leaks through:

- Pinhole – a hole less than 2 cm in diameter;
- Hole – a hole greater than 2 cm in diameter and less than or equal to the diameter of the pipe;
- Rupture - the diameter of the hole is larger than the diameter of the pipe.

Table 2.
Frequency [F] of accidents for reasons

F per 1000km/year			
Reason	Hole size		
	Pinhole	Hole	Rupture
External impact	0.0169	0.0197	0.0060
Corosion	0.0360	0.0014	0.0000
Construction defects	0.0227	0.0016	0.0024
Operator error	0.0043	0.0014	0.0000
Earth moving	0.0069	0.0085	0.0069
Others	0.0126	0.0016	0.0009

Modeling of emergency events

For the purpose of this study, a probability of random events are modeled. Such events can occur everywhere. For example, in the case of failure of a technical device the data presented in the incident reports using Basis theorem [2], it is possible to calculate the conditional probability of realization of each scenario, to construct events trees and to determine the relative frequency of the accident scenarios to the final consequences (losses).

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}, \qquad (2)$$

The listed variables are as follows:

P (A) - probability of event occurrence A

P (A|B) – probability of occurrence of the event A given that event B has occurred;

P (B|A) – probability of occurrence of B assuming A has occurred;

P (B)–probability of event occurrence B.

When talking about an emergency event, we are referring to an uncontrolled leakage of natural gas. There are three different types of pipeline structure problems: breakthrough, hole or rupture. The distribution of frequencies between these three types in gas pipeline is shown in Figure3.

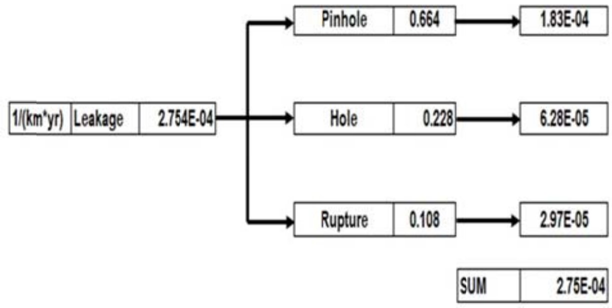

Fig.3. Event tree

Applying the model shown in combination with statistics from EGIG reports allows us to build event trees for each type of uncontrolled leakage (breakthrough, hole, rupture) of natural gas, depending on the cause of occurrence. Figures 4, 5 and 6 show contingency probabilities for accidents.

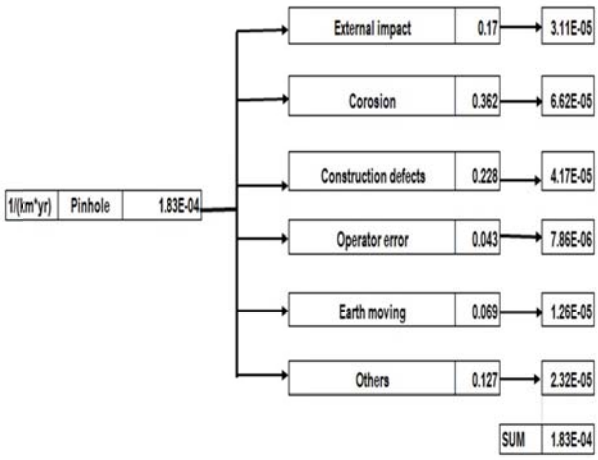

Fig. 4. Events tree – Pinhole

Any development (scenario) of the emergency leakage leads to a different, eventually extreme emergency event - different forms of combustion or dispersion.

- EX - Explosion. Rapid combustion (deflagration or detonation). Very often after the explosion the gas continues to jet fire (JF);
- • JF – jet fire (Jet Fire). It is combustion in the gas stream, limited by the range of gas ignition, i.e. by mixing it with the air that the jet ejects upon its leakage from the pipeline breakdown;
- FF - deflagration burn (Flash Fire) in an unlimited gas cloud, which creates a limited overpressure for a short time. It occurs in an environment where combustible gas and air form a combustible gas-air mixture. The flame front moves rapidly into the combustible mixture and accelerates but does not reach the speed of the sound. This is deflagration burning at a speed of several tens of meters. Compared to the explosion, combustion is so slow that the combustion gas expands prior to the ignition and can not form an open airborne wave with energy sufficient to cause damage;
- VCE - Vapor Cloud Explosion;
- Dispersion (DISPERSION) or distribution of gas without ignition.

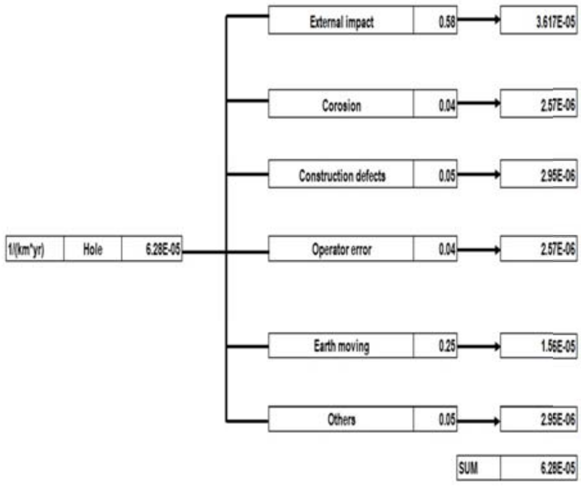

Fig.5 Events tree–Hole.

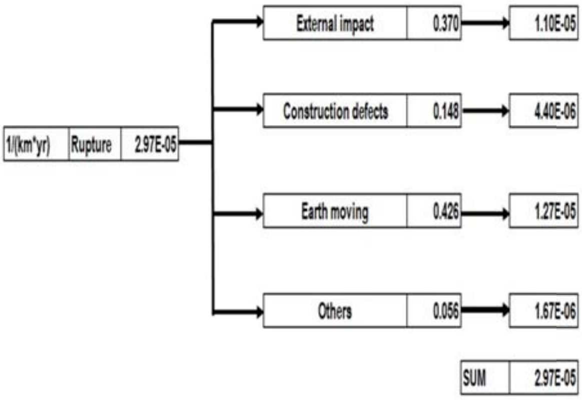

Fig.6 Events tree – Rupture.

The accident statistics, which have occurred or have not occurred, allows us to calculate the probability of occurrence of an adverse event (Fig. 7). A summary of the development of scenarios in the event tree (Fig. 7) for adverse events is given in Table 3. The frequencies in the table that are assumed to be probabilities and are used in the risk assessment are provided.

Table.3.
Frequency violations by size (scale)

Violation / Size	Rupture	Hole	Pinhole	SUM
For violation	2.97E-05	6.28E-05	1.83E-04	2.75E-04
Dispersion	5.09E-06	3.22E-05	1.22E-04	1.59E-04
Ignition	2.47E-05	3.06E-05	6.06E-05	1.16E-04
Immediately	4.28E-06	1.38E-06	8.23E-06	1.39E-05
Delayed	2.04E-05	2.92E-05	5.24E-05	1.02E-04
Explosion	3.73E-06	1.66E-07	1.65E-07	4.06E-06
close	1.28E-06		1.65E-07	1.45E-06
VCE	2.44E-06	1.66E-07		2.61E-06
JF	2.09E-05	2.75E-05	5.10E-05	9.94E-05
FF		2.92E-06	9.50E-06	1.24E-05

Conclusion

Trends in natural gas extraction, including new deposits and new technologies, suggest that in the years to come, its consumption will continue to grow. This is likely to lead to new gas transport projects. These new projects must also be safer than before.

For conventional pipe conveyance, the analysis of the incidents outlines the following main conclusions:

As the depth of laying increases as well as the wall thickness of the main pipelines, the incidents decrease. Modern solutions are rightly oriented to anti-corrosion protection - both internal and external, in view of the events (Fig. 2).

Increasing the age of existing pipelines increases the likelihood of incidents caused by corrosion.

Incidents caused by the movement of earth masses and of unexplained nature have increased in recent years.

The extensive study of accidents in the natural gas facilities has led to constantly decreasing incidents in the growing gas pipeline network across the EU.

The EU's clear policy of achieving energy independence for its member states, including Bulgaria, recommends of interconnector links in the Union. The implementation of these projects is related to the assessment of safety risks in the design, construction and operation of the facilities.

New natural gas facilities will require a thorough examination of the problems related to the lack of standards for emergency (short-term) planning of atmospheric pollution from natural gas combustion products in incidents.

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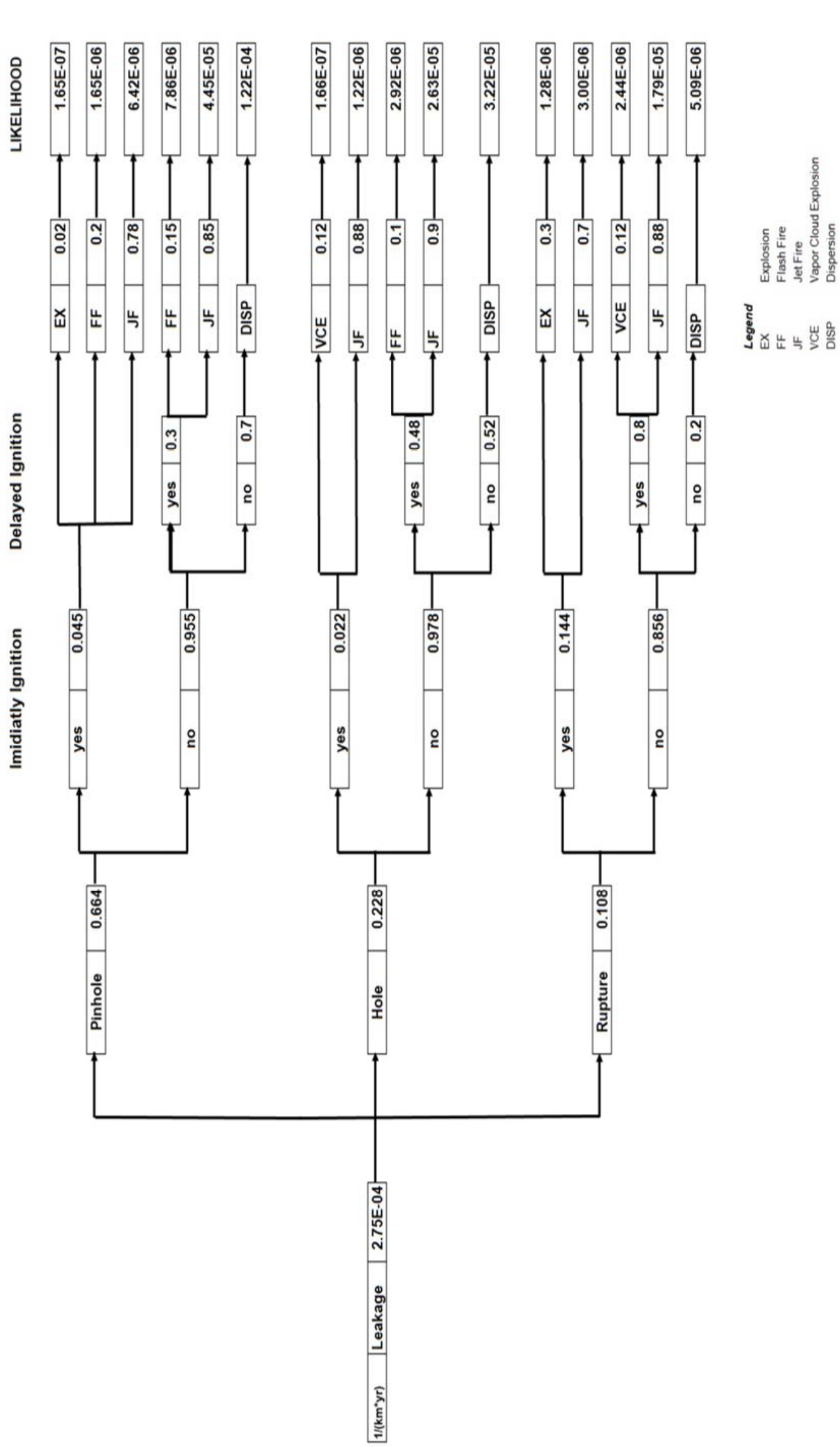

Fig. 7. Emergency natural gas event tree with probability in cases of kilometer per year [events/ (km-year)