Investigation of the gas losses in transmission networks

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Abstract

As air pollution has become a major issue in nowadays world, reducing methane emissions from the natural gas transmission systems is an issue that definitely has to be addressed. In order to do that, there are a few solutions available, such as the replacement of steel pipes with high-density polyethylene (HDPE) pipes. The main causes of these leaks are the corrosion defects and third-party interventions. The paper presents a new methodology for technological gas loss calculation from the natural gas transmission system. In order to obtain the most accurate calculation formulas, the flow coefficients for different cases were determined by experimental measurements. The paper presents the details regarding the construction and equipment of the experimental stand, as well as a new method for calculating the volumes of gas lost due to defects of this type. Thus, the aerial and buried defects were studied and the results obtained on statistical data were verified. Using the results of the study, the average emission of CH_4 per year in Romania was calculated, and it was proven to be about 30% bigger than the European average. The findings of this study can help for a better understanding of the level of the losses and the effect on the final costs for the population, as well as the negative impact on the environment, in case the transporter does not take any measures.

Keywords Sustainability · Environment · Natural gas · Transmission systems · Gas loses

Abbreviations

HDPE	High density polyethylene
LDAR	Leak detection and repair
CO_2	Carbon dioxide
CO_{2eq}	Equivalent carbon dioxide
CH_4	Methane

D_n	Nominal diameter
β^*	Critical pressure ratio
p_a	Atmospheric pressure, (bar)
p^*	Critical pressure, (bar)
p	Natural gas pressure in pipeline, (bar)
k	Adiabatic exponent;
T	Gas temperature, (K)
m	Gas mass, (kg)
V	Pipeline volume, (m^3)
R	Universal constant of the ideal gas, $R = 8.3145$ (J/mol K)
p^{n+1}	Pressure at the new time interval
p^n	Pressure at the current time
c_d	Flow coefficient, $c_d = 0.75$
A	Defect area, (mm^2)
p_{pipe}	Pipe pressure, (bar)
T_{pipe}	Pipe temperature, (K)
ρ_n	Gas density at normal state, $\left[\frac{kg}{Sm^3}\right]$
ρ_s	Gas density at the standard state, $\left[\frac{kg}{Sm^3}\right]$
V_s	Gas volume at the standard state, (Sm^3)
τ	Time, (s)

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Introduction

As a result of international and European trends in reducing the carbon dioxide emissions by changing from the use of hydrocarbons for energy production to technologies that use renewable and sustainable energy, this article addresses a very important issue from a technical, technological, economic and environmental protection (Neacsa et al. 2020).

One of the strategic objectives of the sustainable development of the natural gas transmission systems is the reduction of technological consumption, meaning that transport companies make continuous efforts to align with current environmental standards and the requirements of the legislation in force on technological consumption in the natural gas transmission system.

As a result of the entry into force on October 1, 2018 of the *Methodology for calculating the technological consumption of the natural gas transmission system* approved by Order no. 115 of July 4, 2018, in Romania it is expected to be established a unitary method for calculating the technological consumption of natural gas in the natural gas transmission system. Technological consumption was broken down into the two components, namely the localized technological consumption, which is determined and the unallocated technological consumption, which can be only estimated. According to art. 12 and 13 of the above-mentioned methodology, the volume of natural gas under standard conditions to be purchased by the transmission system operator, due to the wearing and tearing of the natural gas transmission pipelines and leaks of the removable joints, will be estimated on the basis of a technical expertise report, and will provide the volume of natural gas expressed as a percentage of the transported amount of natural gas.

The most important part of the technological consumption is represented by gas losses due to pipe defects as a result of corrosion, leaks, third party interventions or mechanical stress (i.e. cracks) (Casson et al. 1992; Eparu et al. 2014).

When the methodology was elaborated, the formulas used to determine technological losses were either taken from the literature or based on other studies carried out by the technical association of the European gas industry. Most of the coefficients used were not been determined by real measurements. The firms in the field have observed overtime a gap between the calculated values and the imbalance of the network.

The study starts with presentation of the problem of gas loss calculation and its implications. As the phenomenon of gas leakage through defects is particularly complex, a theoretical thermo-hydrodynamic model of the pipe emptying was also developed, generating a theoretical curve of pressure variation in the pipe for each defect. Furthermore, a specially designed stand was built and measurements were made regarding gas losses due to various defects and there resulted a formula for calculating the volumes of losses through defects from the comparison of the experimental curve with the theoretical one and the calibration of the flow coefficient for each type of defect. In the end of the paper, the impact on the costs paid by final consumers, be them population and economic agents was analyzed (see Fig. 1).
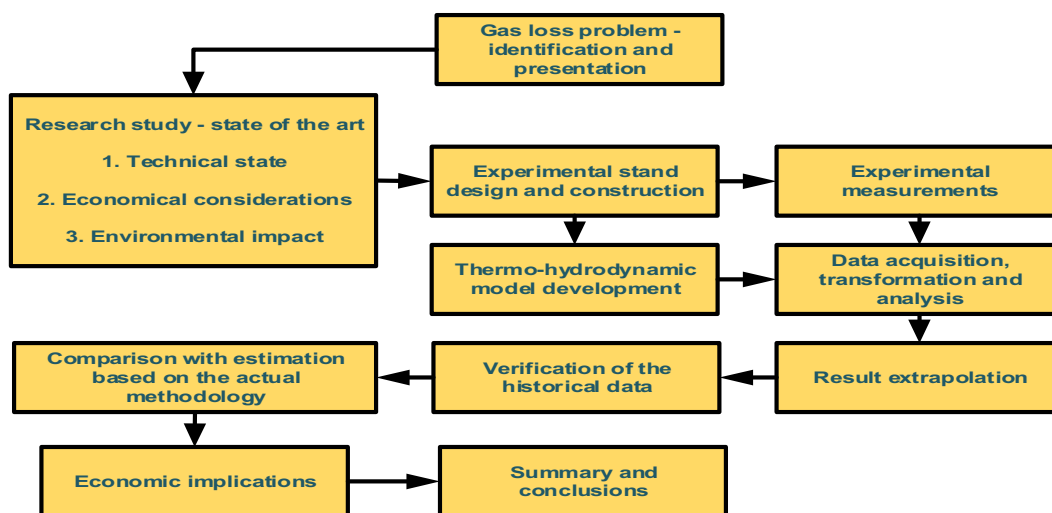

Fig. 1 General chart of the present study

Table 1 Natural Gas Spot Price (US Dollar per 1.055 GJ)—Historical Annual Data (Macrotrends 2021a)

Year	Average [1$/1.055 GJ]	Annual % Change	Year	Average [1$/1.055 GJ]	Annual % Change
2021	$3.81	125.85%	2009	$3.94	3.37%
2020	$2.03	12.92%	2008	$8.86	− 20.82%
2019	$2.56	− 35.69%	2007	$6.97	29.27%
2018	$3.15	− 11.92%	2006	$6.73	− 42.23%
2017	$2.99	− 0.54%	2005	$8.69	58.14%
2016	$2.52	62.72%	2004	$5.89	4.51%
2015	$2.62	− 27.39%	2003	$5.47	25.49%
2014	$4.37	− 27.15%	2002	$3.38	91.25%
2013	$3.73	25.66%	2001	$3.96	− 77.10%
2012	$2.75	15.10%	2000	$4.31	355.65%
2011	$4.00	− 29.38%	1999	$2.27	17.95%
2010	$4.37	− 27.49%	1998	$2.09	− 14.10%
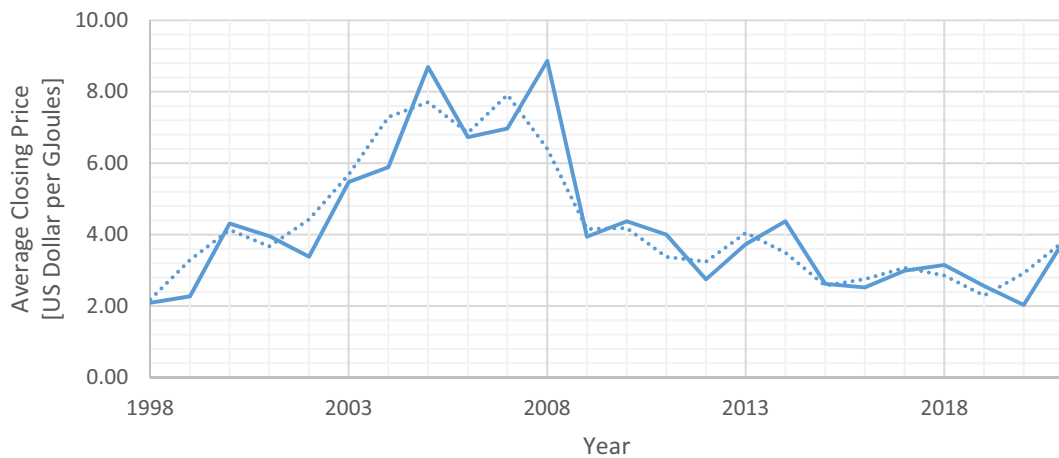
(a) Souce data: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_202
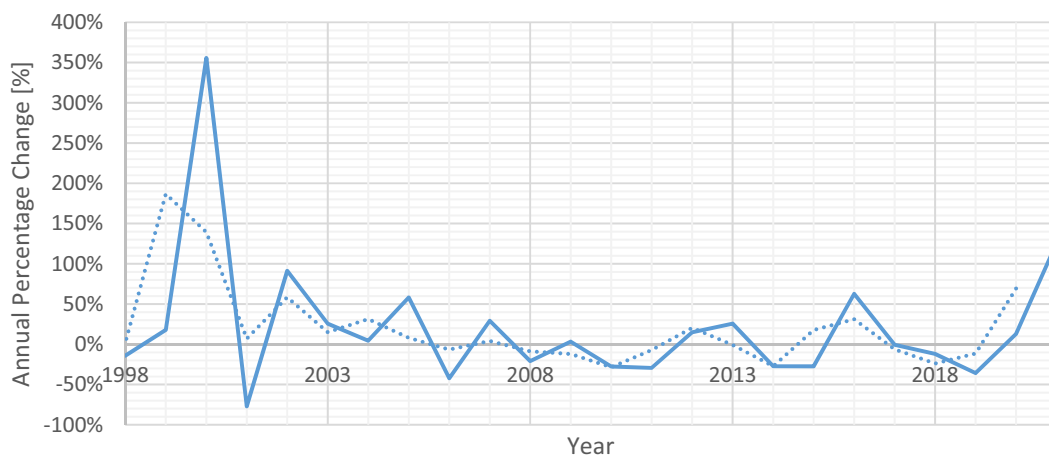
(b) Souce data: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_202

Fig. 2 Natural gas prices—historical chart (Macrotrends 2021a): **a** annual average closing price in USD; **b** annual percentage changes closing. **a** Souce data: https://appsso.eurostat.ec.europa.eu/nui/show. do?dataset=nrg_pc_202, Souce data: https://appsso.eurostat.ec. europa.eu/nui/show.do?dataset=nrg_pc_202

Problem presentation

Taking into account the recent upward trend in natural gas prices, expressed in US Dollar per 1.05505585 GJ (see Table 1 and Fig. 2), it can be stated that the problem of the technological operation of pipeline systems in optimal conditions is a very important one (Neacsa et al. 2020, 2016). There were considered economic conditions and safety in operation, in terms of eliminating technical risks due to accidental losses or the depreciation of the components of these systems.

Natural gas prices have continued their upward trend in recent years, as a result of the global economic recovery fueling travel demand (Natural Gas Prices (FocusEconomics) 2021b). The mean price has been up 125.85% this year compared to 2020.

Moreover, expectations of uncomfortably hot weather, as well as the concerns about the lack of storage inventories ahead of winter, have also increased the demand for natural gas. Simultaneously, the supply of the commodity has tightened recently, which has further fueled price increasing (Natural Gas Prices (FocusEconomics) 2021b).

Due to the increase of prices, as it can be seen in the graph representing their evolution, estimating or calculating loss volumes, from the operation of pipeline systems for natural gas transmission for the distribution to the population and economic agents, can materialize in engineering instruments to reduce the costs and, implicitly, the final prices paid by final consumers.

Furthermore, such complex studies can lead to the identification and application of maintenance measures for the components of hydrocarbons and natural gas transmission systems with the same positive impact on reducing operating costs, as well as the volumes of polluting emissions with a negative impact on the environment (Chen et al. 2021).

Within the EU's borders, as a sustainability requirement for the future generations, it is recommended that each Member State should propose measures to reduce both carbon dioxide and other emissions resulting from polluting technologies. The methane emissions from transmission grids (EU28), expressed in CO_2 equivalent, are estimated at 3.724 kT CO_{2eq} per year (Marcogaz 2018). Obviously, these measures need to be adapted to suit the national reality within each Member State. Currently, Romania has gaps in the correct assessment of the level of carbon dioxide emissions and pollutant emissions. Moreover, the operations of natural gas exploitation, transmission, storage and distribution play a very important role in sizing the volume of polluting emissions with a major impact on the costs paid by final consumers, be them population or economic agents, as well as on the environment.

In order to increase the calorific value of gases and to substantially reduce carbon dioxide emissions, with good results in sustainability, it has been introduced a new technology that implies introducing an amount of 5 … 10% hydrogen in the transmission/distribution systems of natural gas, by means of modern compressors (Neacsu et al. 2019a, 2019b; Eparu et al. 2019a, 2019b). Considering this aspect, the losses in the piping systems affect the amount of hydrogen introduced in the systems because it is the first phase that will leave the inside of the pipeline through leaks and holes. Therefore, this article is of particular interest to specialists in the field of natural gas exploitation, transmission, storage and distribution, as well as in terms of sustainability, safety and environment protection.

The research conducted in this article addresses the important issue of losses in natural gas transmission systems. Determining the volume of losses in pipeline systems, in general, should be an important goal of each country, both at the level of the European Union and worldwide due to the above-mentioned considerations. For the beginning, in the Romanian industry of exploitation, transmission, storage and distribution of natural gas, pilot actions have been undertaken in order to establish the volume of losses in the transmission systems, following that researches should be extended to the other components, production, distribution and storage.

Gas losses through defects were analyzed in this study as follows:

- There was developed an experimental device that allowed the measurement of certain flow hydrodynamics parameters;
- A numerical model was developed attached to the experimental device in order to allow the calculation of loosed gas volumes by default;
- There were compared experimental data with the theoretical ones for flow coefficients calibration of the defect;
- It was developed a method to calculate defective gas leaks for any pipeline and pressure regime for gas transmission;
- There was analyzed economic and environmental impact of the gas loss volume.

Experimental stand description

An experimental stand was designed in order to calculate gas leaks due to small defects (diameter: 2–6 mm), to calculate flow regime and to calibrate flow coefficients (see Fig. 3).

It consists of a 10-m 12″ pipe, buried at a depth of 1.2 m. Gas is supplied by a connection with a nominal diameter D_n of 50 mm and a length of 8.5 m. The maximum loading pressure of the experimental device is 6 bars. Pressure measurement in the system was carried out with the absolute

Fig. 3 Natural gas leaks calculation experimental stand: 1—buried pipeline; 2—filling nozzle; 3—rotary piston counter; 4—absolute pressure transducer; 5—defect

pressure transducer of a Delta rotary piston meter equipped with PTZ4 CONVERTER at which the recording time was set to 1 min.

Figure 3 shows the experimental stand built for natural gas leaks calculation. In the pipe, near this end, defects in the form of holes with a diameter of 2, 4, 5 and 6 mm were made by turn. For each type of defect, the pipe was loaded through the gas supply system at a pressure of 6 bars and its variation was afterwards measured during the emptying of the pipe through defect with the pressure transducer in the rotary piston meter.

Similar experiments were performed for buried defects. After the first defect was made, the pipe was buried and then the measurements were made. To change the size of the defect, the pipe was partially uncovered, changing the diameter of the defect.

Results of the experimental measurements

From an experimental point of view, the aim was to partially empty a gas pipeline with a known volume by a defect of a determined size.

The experimental results consist in the values of absolute pressure in the pipe measured minute by minute. For the 2 mm aerial defect, the pressure values are presented in

Fig. 4, points representing the pressure variation. The corresponding interpolation function is also shown.

Considering the existent conditions: buried or surface gas pipelines, with large diameters, high transport pressures and small-area defects, a specific experimental device and a thermo-hydrodynamic method for calculating the pressure losses were designed in order to determine gas losses from natural gas transmission pipelines.
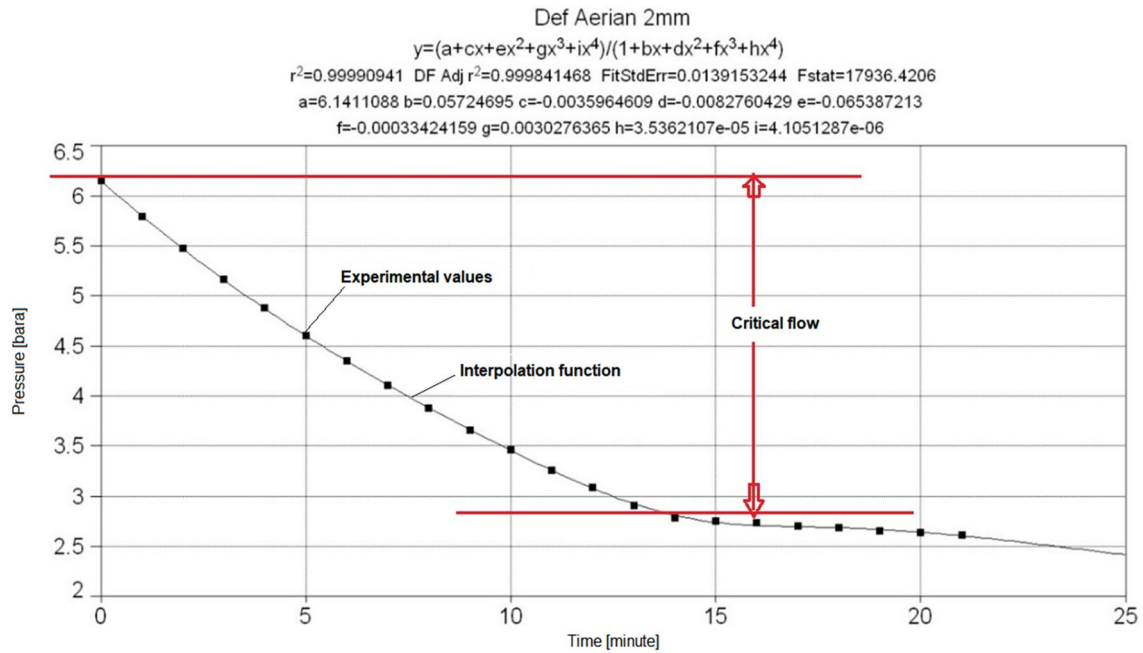
As it is known from the literature (Eparu et al. 2014; Neacsu 2009; Oroveanu et al. 1981; Oroveanu 1966; Saad 1985; Arya 2021), as long as the transport pressures are high, gas leakage through defects is made in critical regime because the condition $\frac{p_a}{p} \leq \beta^*$ is fulfilled, where

$$\beta^* = \frac{p^*}{p} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}, \tag{1}$$

where β^*—critical pressure ratio; p_a—atmospheric pressure [bar]; p—natural gas pressure in pipeline [bar]; p^*—critical pressure [bar]; k—adiabatic exponent.

In view of the above, the critical flow was tested and there was an attempt to obtain flow coefficients from the experimental data.

In order to be easier to use, the experimental values were the basis for the generation of interpolation functions used

Def Aerian 2mm

$$y=(a+cx+ex^2+gx^3+ix^4)/(1+bx+dx^2+fx^3+hx^4)$$

$r^2=0.99990941$ DF Adj $r^2=0.999841468$ FitStdErr=0.0139153244 Fstat=17936.4206

a=6.1411088 b=0.05724695 c=-0.0035964609 d=-0.0082760429 e=-0.065387213

f=-0.00033424159 g=0.0030276365 h=3.5362107e-05 i=4.1051287e-06

Fig. 4 Pressure variation for 2 mm aired fault pressure transducer; 5—defect

in the paper. This has also allowed values to be obtained in points where no experimental values were available.

Measurements showed the existence of critical regime in all cases analyzed and coincidence between the used model and the measured experimental values, which validates the model we used.

The calculation method of the lost gas volumes through these types of defects

As the gas leakage through pipeline defects is unusually complex, a thermo-hydrodynamic model of pipeline draining was designed in order to generate a theoretical curve of the pressure variation in the pipeline for each defect. From
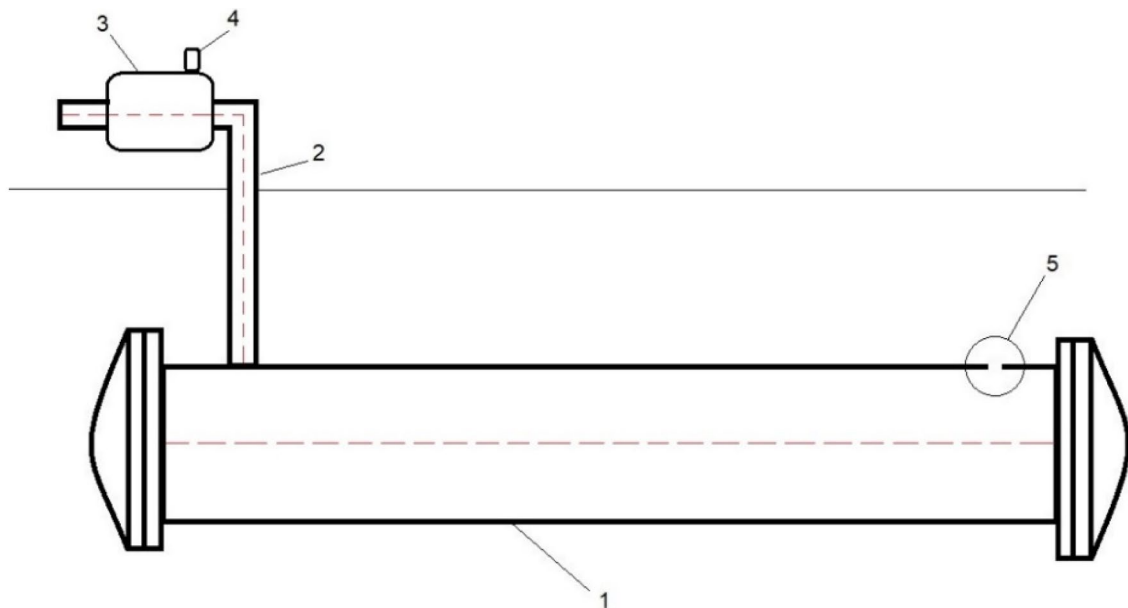
Fig. 5 Experimental stand: 1—buried pipeline; 2—filling nozzle; 3—rotary piston counter; 4 – absolute

the comparison of the experimental curve with the theoretical one, the flow coefficient calibration for each type of defect was made, in the end resulting a formula for loss calculation through defects.

In Fig. 5, the model for the experimental device and its functionality are presented. The device consists of one buried pipeline (1) with a 12-inch diameter and a length of 10 m. The pipeline is fitted with a filler nozzle (2), a rotary piston counter (3) equipped with an absolute pressure transducer (4). Analyzing the device, we observe that there is quite a distance between the place where the pressure was measured and the place where the defect was situated.

On the one hand, this had beneficial consequence because the pressure in the pipeline was considered uniform. On the other hand, because of the small experimental pipeline volume (10-m length) and of the high phenomenon dynamics, the pipeline pressure near the defects area may be a little different from the average measured pressure at the point of measurement. Another problem that could affect the results was the sampling rate of the measured values (1 min). This was done by programming the acquisition time from the counter, which was very useful.

The experimental determinations were carried out as follows:

- The pipeline was filled with gases to a pressure of approximately 6 bars;
- A defect with a certain diameter (area) was made;
- The line supply was closed;
- The pressure variation in the pipeline during the pipeline draining was measured.

The gas leak pressure curve was compared with a pressure curve resulted from a modelled gas leak through defects. The proper flow coefficients were determined from the comparison of the two curves.

We consider the next thermodynamic gas parameters from the pipeline:

- p—gas pressure [bar];
- T—gas temperature [K];
- m—gas mass [kg];
- V—pipeline volume [m^3];
- k—adiabatic exponent of gas;
- Z—the non-ideal factor;
- R—Universal constant of the ideal gas, $R = 8.3145$ [J/mol K].

The gas state equation is:

$$p \cdot V = m \cdot Z \cdot R \cdot T \tag{2}$$

The gas leak by defect determined a pressure variation in the pipeline. Differentiating the Eq. (2) results in:

$$V \cdot \frac{dp}{d\tau} = m \cdot R \cdot \frac{dT}{d\tau} + R \cdot T \cdot \frac{dm}{d\tau} \tag{3}$$

where τ is time.

The process of gas leak through defects was considered adiabat:

$$\frac{T}{p^{\frac{k-1}{k}}} = \text{const} \tag{4}$$

when going to logarithm results:

$$\ln T + \frac{k-1}{k} \cdot \ln p = \text{const} \tag{5}$$

or

$$\frac{\mathrm{d}T}{T} + \frac{k-1}{k} \cdot \ln \frac{dp}{p} = 0 \tag{6}$$

When we derivated based on time:

$$\frac{\mathrm{d}T}{d\tau} = \frac{1-k}{k} \cdot \frac{T}{p} \cdot \frac{dp}{d\tau} \tag{7}$$

relation (3) became:

$$V \cdot \frac{dp}{d\tau} = m \cdot R \cdot \frac{1-k}{k} \cdot \frac{T}{p} \cdot \frac{dp}{d\tau} + R \cdot T \cdot \frac{dm}{d\tau} \tag{8}$$

$$\frac{dp}{d\tau} \cdot \left(\frac{V}{R \cdot T} + m \cdot \frac{k-1}{k} \cdot \frac{1}{p}, \right) = \frac{dm}{d\tau} \tag{9}$$

The term $m \cdot \frac{k-1}{k} \cdot \frac{1}{p}$ in experimental device conditions was approximately $7,57 \cdot 10^{-7}$, and therefore, it can be neglected. In the end we obtained:

$$\frac{dp}{d\tau} = \frac{R \cdot T}{V} \cdot \frac{dm}{d\tau} \tag{10}$$

We noted with $\dot{m} = \frac{dm}{d\tau} \left[\frac{\text{kg}}{\text{s}} \right]$ the mass flow of the natural gas leaked by defect. The gas mass flow rate by defect was to be calculated according to the flow regime and momentary parameters. From Eq. (10), pressure variation could be determined.

If $\Delta\tau$ is the time interval (in the experiment this was 1 min); relation (10) written in finite differences became:

$$\frac{p^{n+1} - p^n}{\Delta\tau} = \frac{R \cdot T}{V} \cdot \dot{m} \tag{11}$$

$$p^{n+1} = p^n \pm \frac{R \cdot T}{V} \cdot \dot{m} \cdot \Delta\tau \tag{12}$$

where p^{n+1}—pressure at the new time interval; p^n—pressure at the current time.

The sign + or—in front of $\frac{R \cdot T}{V}$ is chosen by the gas leak direction.

If the gas leaks through defect, we used—(minus), if the gas enters through the defect, we used + (addition). The mass flow which leaks at a certain moment through defect was calculated by the flow regime. Analyzing the experimental data, we noted that most of the curves representing the pressure variation from the pipeline present a significant change in slope (see Fig. 4), which was due to the modification in the flow rate.

The flow rate is based on the ratio between external pressure and the one from the pipeline. If it is lower or equal with the critical regime, the gas leak through defect is critical, i.e. it occurs with the speed of sound. If the ratio β is bigger than ratio β*, the flow is subsonic.

The analysis of experimental data

For the processing of experimental data, a software was developed, which allowed the rapid obtaining of results. The properties of the used gas components were according to the literature in the field (Neacsu 2009; Romanian Standards Association (ASRO) 2010; Romanian Standards Association (ASRO) 2005).

A chromatographic bulletin related to the delivery point was used for gases composition. The data from the bulletin used in the processing software are presented in Table 2.

Table 2 Gases composition related to chromatographic bulletin

No	Component name	% Volume	% Mol	% Mas	g /m³N
	Methane	96.664	96.670	94.316	693.527
	Ethane	0.0513	0.0517	0.0946	0.6953
	Propane	0.0000	0.0000	0.0000	0.0000
	ISO-Butane	0.0000	0.0000	0.0000	0.0000
	N-Butane	0.0000	0.0000	0.0000	0.0000
	Neo-Pentane	0.0000	0.0000	0.0000	0.0000
	ISO-Pentane	0.0000	0.0000	0.0000	0.0000
	N-Pentane	0.0000	0.0000	0.0000	0.0000
	N-Hexane	0.0002	0.0002	0.0013	0.0095
	N-Heptane	0	0	0	0
	N-Octane	0	0	0	0
	N-Nonane	0	0	0	0
	Azote	3.2810	3.2749	5.5792	41.0254
	Oxygen	0	0	0	0
	Carbon dioxide	0.0033	0.0033	0.0089	0.0653
TOTAL	100	100	100	735.323	

Analysis of loss through aerial defects

In order to determine the lost gas flow rates through defects, the pressure variation determined with the theoretical model must be close as value to the pressure variation experimentally determined. The theoretical curve was calibrated by flow rate coefficients in order to coincide with the experimental curve.

As the pressure evolution causes two flow regimes, the curve was calibrated with two flow rate coefficients, one for the critical flow and the other—for the subcritical flow.

In Fig. 6, it is presented an example of a 2-mm defect. As it can be seen from the comparative presentation of the pressure variation curves (real and simulated), the exemplary succeeds to get very close to the real pressure variation from the faulty pipeline. Moreover, after the results comparison, the flow rate coefficients were revealed, C1- for the sonic flow and C2—for the subsonic one, for a 2-mm defect which was used in calculations.

In every analyzed case, the results revealed the existence of the critical regime by a huge coincidence between the used exemplary and the measured experimental values (Fig. 7).

The advantage is that with a calibrated model we can easily calculate with accuracy the gas loss for different diameters and pressures. Future work needs to be carried out in order to improve the results obtained in the area where the gas pass from sonic to subsonic flow. Moreover, it is desirable to verify this model with experimental data at higher pressures, even though we consider that this will pose no problems (Fig. 7).

Calculation of lost gas volumes through defects with other diameters than the analyzed ones

According to the experimental results presented above, a mediation of flow rate coefficients on the sonic flow side was made because the operating pressures in transport were higher than 6 bars. Thus, a function which generates the flow rate coefficient of the defect which only depends on the equivalent diameter of the defect was created (see Fig. 8) and extended for other diameters that were not analyzed in this paper (see Fig. 8).

We need to continue our research in analyzing very small defects (less than 1 mm), especially for buried defects, in order to check if the model is efficient in that area as well.

The flow leaked through a defect can be calculated with the formula (13) which connects the pipeline gas parameters (p, T) with the defect area and the gas properties. The flow rate was calculated in critical conditions, more exactly for sonic flow through defect, fact demonstrated by experimental determinations.
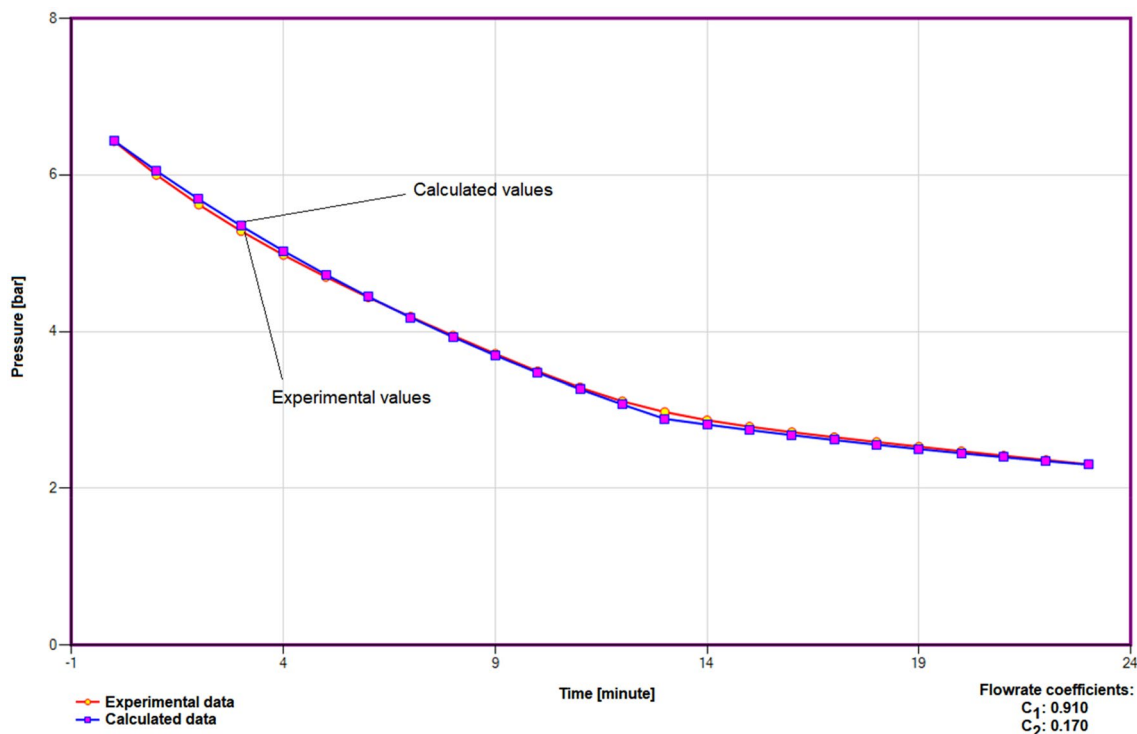
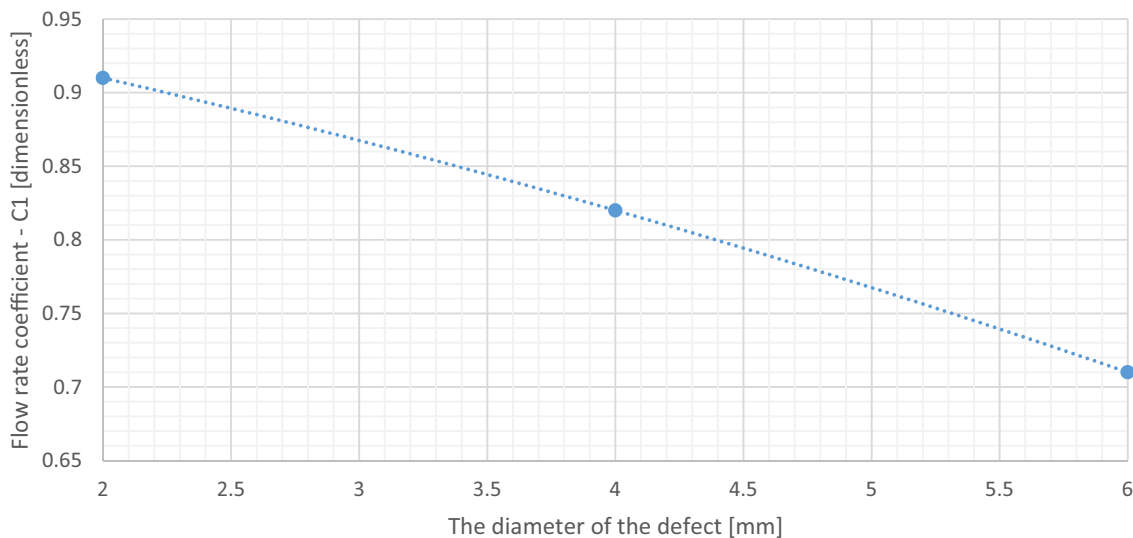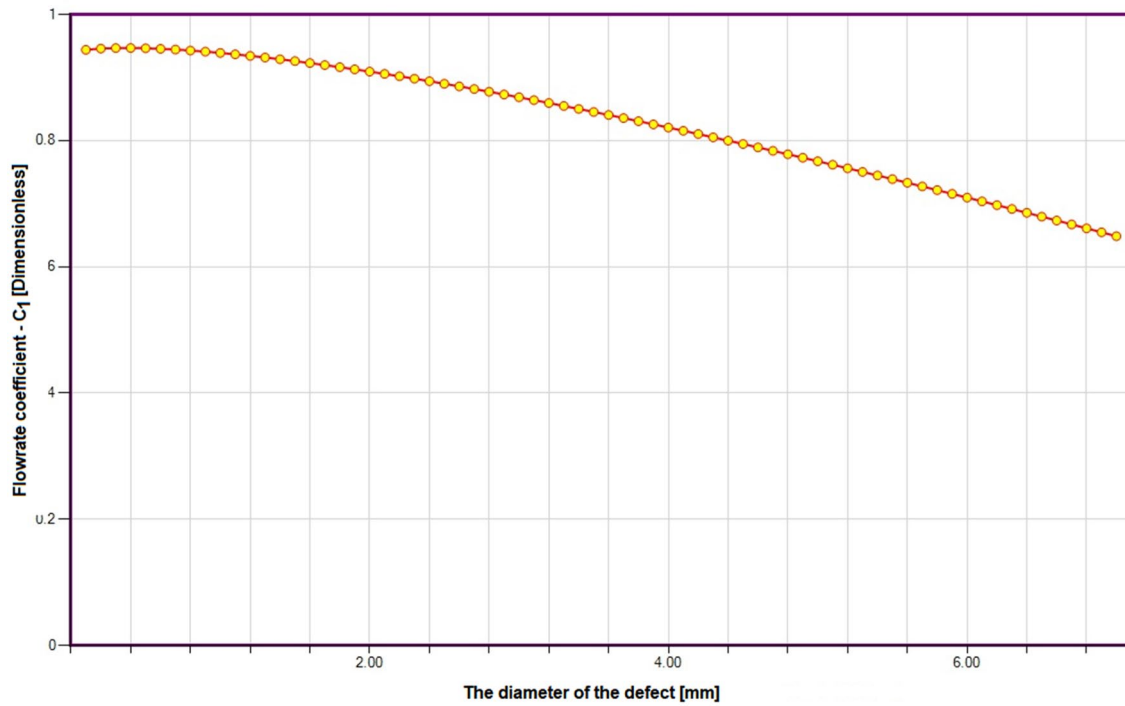**Fig. 6** Comparative pressure for the defect variation with 2-mm defect

Fig. 7 Equation for the flow rate coefficient of the defect

$$\dot{m} = c_d A \frac{P_{pipe}}{Z} \sqrt{\frac{k}{RT_{pipe}} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \left[\frac{kg}{s}\right], \qquad (13)$$

$$\rho_s = \rho_n \frac{273.15}{288.15} \left[\frac{kg}{Sm^3}\right], \qquad (15)$$

$$\rho_n = \frac{M}{22.414} \left[\frac{kg}{Nm^3}\right], \qquad (14)$$

$$V_s = 3600 \frac{\dot{m}}{\rho_s} \tau \left[Sm^3\right], \qquad (16)$$

Fig. 8 The use of the function for the C_1 coefficient and for diameters other than the experimentally verified ones

where c_d—flow coefficient, $c_d = 0.75$; A—defect area [mm^2]; p_{pipe}—pipe pressure [bar]; T_{pipe}—pipe temperature [K]; ρ_n-gas density at normal state $\left[\frac{kg}{S \cdot m^3}\right]$; ρ_s—gas density at the standard state $\left[\frac{kg}{S \cdot m^3}\right]$; V_s—gas volume at the standard state $[S \cdot m^3]$.

Table 3 Results from 3 cases

Characteristics	1	2	3
Molecular Mass—M, [kg/kmol]	19.237	16.152	18.124
Gas constant—R, [J/kg/K]	432.205	514.743	458.746
Critical Pressure—P_c, [bar]	46.961	46.016	46.301
Critical Temperature—T_c, [K]	207.4	190.7	200.8
Acentric factor—Acc	0.02754616	0.00861839	0.01980216
Pressure—P, [bar]	16	8.086	14.51
Diameter—d, [mm]	0.5	2	1
Temperature—T, [°C]	8.5	16.46	17.36
Time—t, [h]	504	193	8.5
Reduced Pressure—P_r	0.362002513	0.19745306	0.334981966
Reduced Temperature—T_r	1.358003857	1.518668065	1.446762948
Non-ideal factor – Z	0.950953062	0.981446237	0.962680108
Aria [m^2]	1.9635E-07	3.14159E-06	7.85398E-07
Flow Coefficient—C_d	0.94656031	0.90956621	0.93916149
Mass flow rate—m, [kg/s]	0.000634576	0.004565662	0.002169245
Normal Density—ρ_n, [kg/N·m^3]	0.858258231	0.72062104	0.808601767
Standard Density—ρ_s, [kg/S·m^3]	0.813580552	0.683108232	0.766509015
Loss Volume—V_s, [S·m^3]	1,415.194179	4,643.805304	86.59897147
Loss Volume according to old regulation calculation	1,154	4,121	72

The formulas (14), (15), (16) relate the mass debit with the volume debit in standard pressure and temperature conditions.

The results analysis for statistic defects

We had more than 100 cases at disposition for calculating the lost gas volumes through defect. In Table 3 below, the results obtained for 3 such cases are presented.

As one can observe, when comparing the last two rows of the table, the values we obtained are higher than the ones from the current normative.

A total volume of gas lost through pores of 39,130 Sm^3/year resulted from the calculation. As the average annual gas volume transported is 12.65 billion m^3, there results that the lost gas volumes through pores represents 0.000309364% from the annual volume transported. Analyzing the data in terms of average values, we obtained a lost volume of 1151 $S m^3$ per defect, a number of 0.0025 defects/pipeline km/year and a lost gas volume/pipeline km/year of 2.924 $S m^3$ per defect.

If we calculate the economic implication of this gas loss volume in terms of money, we get 133,433 Dollars or 112,084 Euro, which impacts the costs paid by final consumers, population and economic agents. There are countries where either this volume is not recognized by the regulations, or there are simplified methods of calculation based only on statistical pipeline network data.

Summary and conclusions

The results of the study showed that the average emission of CH_4 per year in Romania was calculated, and it was proven to be about 30% bigger than the European average. The findings of this study can help for a better understanding of the level of the losses and the effect on the final costs for the population, as well as the negative impact on the environment, in case the transporter does not take any measures.

As resulted from the previous sections of this study, we can highlight the following conclusions related to gas losses through pipeline defects.

The experimentally calibrated model used for determination of the gas leak through defect, with the flow rate coefficients experimentally determined can be used for calculating the technological losses from the transmission pipelines, regardless of their pressures and the diameter of the defect;

We consider that the experimental results are relevant and the calculations for technological losses made by the proposed model are accurate enough, given the technological conditions;

Future investigation will be conducted in order to analyze the influence of the gas humidity on the gas losses through pipe defects;

Considering the transmission network operation at high pressures, in case of occurrence of these types of defects and of continuous pipeline operation, even during the repair of the defect, the subcritical flow will not exist.

Because most of these defects are caused by corrosion, the switch to HDPE will make a difference for the environment in terms of pollution;

In Romania, even the process is very elaborate with a lot of paperwork involved, as long as the transporter recovers the costs of the gas loss, everything worths in the end;

Based on our study, the average emission of CH_4 per year in Romania is about 30% higher than the one in the European transmission pipeline network (568 kg CH_4/km). Because of these regulated returns, transporters are not eager to modernize the pipeline infrastructure in order to diminish this gas loss, fact that affects the final costs for the population and has a negative impact on the environment. Things are similar in the gas distribution systems.

Directed inspections and maintenance of the underground pipelines and of the above ground installations, such as LDAR (Leak Detection and Repair) programs and fugitive leaks detection and quantification programs will help minimizing the gas loss.

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