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# Calculation of Natural Gas Losses through Buried Distribution Pipes Faults

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## Abstract

*Taking as starting point the corrosion of natural gas pipes in Romania and the appearance of faults, this paper presents an analysis made by the numerical simulation of gas leakage through buried pipes faults and the elaboration of a calculation methodology of gas losses.*

**Key words:** *losses, gas, fault, flow, distribution.*

The moment a fault occurs in a buried distribution pipe, the gas in the pipe runs through the fault section and is released in the surrounding soil. The gas flow that runs along the pipe is influenced by the soil properties in which the pipe is being placed, especially by porosity, permeability and saturations in gas and liquid, as well as the pressure in the pipe.

Due to the fact that a long period of time passes between the occurrence of a fault on a pipe and its detection, the numerical simulation is made for stationary regimes by using the stationary diffusion equation of the gas in the vicinity of the gas pipe.

The difference of pressure between the gas in the pipe and the pressure of the environment in which the pipe is being placed determines the occurrence of a pressure field near the fault itself.

If one determines the pressure gradient on the pipe wall in the fault area, one can therefore calculate the lost gas flow through the fault section, knowing the absolute permeability of the soil and the viscosity of the gas.

## Numerical Model Equations

The process of tridimensional isothermal gas flow through a porous, isotropic and homogenous medium is modeled by the equation

$$\nabla\left(\frac{k\,p}{\mu Z}\nabla p\right) = m\frac{\partial}{\partial t}\left(\frac{p}{Z}\right) \tag{1}$$

where $\nabla$ is the Hamilton operator, $m$ and $k$ represent the porosity, respectively the permeability of the porous medium, $p$, represents the gas pressure in its movement in the pipe to the fault via the environment through the porous medium, while $\mu$ and $Z$ represent the dynamic viscosity, respectively the deviation factor of the gas from the perfect gas model, both being constant in the usual pressure domains in distribution systems (below 6 bar).

Equation (1) can be written for the two-dimensional case as well, taking into account the stationary character of the gas flow

$$\frac{\partial}{\partial x}\frac{k}{\mu}\frac{\partial P}{\partial x}+\frac{\partial}{\partial y}\frac{k}{\mu}\frac{\partial P}{\partial y}=0\,, \tag{2}$$

where function $P$ represents the pressure square

$$P(x,y)=p^2(x,y). \tag{3}$$

As far as the gas flow rate (filtration) is concerned, this is derived from the Darcy equation and it can be written as follows

$$\mathbf{v}=-\frac{k}{\mu}(\nabla p-\rho\nabla\Omega), \tag{4}$$

where $\rho$ represents the gas density and $\Omega$ is the potentila of mass forces. It is only gravitation that manifests itself in the case studied, therefore

$$\Omega=-yg\,. \tag{5}$$

The hypothesis that gas density is constant is being accepted, while one can neglect its variation in pressure in the distribution networks and on the pipe burial depth.

Equations (2) and (4) represent the numerical model of the gas leakage process in the gas pipe through its fault, through the porous medium to the environment.

In order to solve equation (2) in the case of a buried pipe, we have used the ANSYS software, version 10.0. This is a program used to solve various types of differential equations with partial derivatives, employing the finite element method. The thermal conduction module was used for this problem, a module that is based on a formally identical equation with the equation of fluid flow through the porous medium.

## Defining the Geometry of the Problem

For this case we considered a perpendicular section through a distribution pipe buried at 1 m depth and with a diameter of 2 1/2”. Figure 1 shows the geometry of the model used for the simulation.

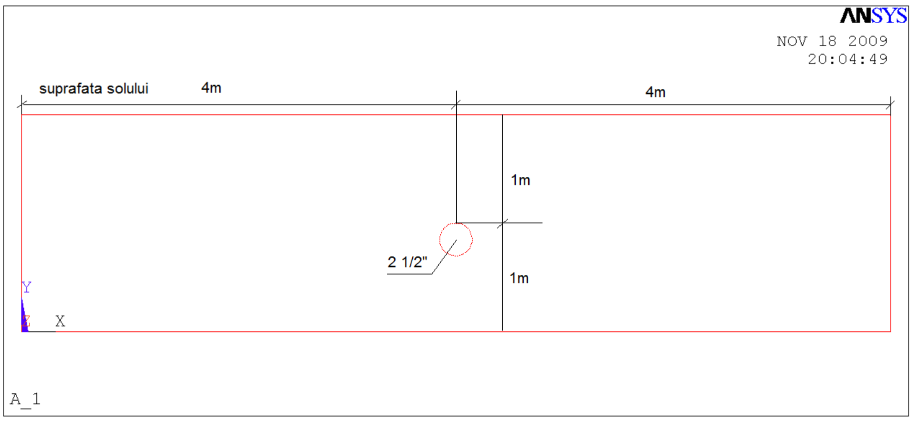


**Fig. 1.** The geometry of the model

A rectangular area, represented by a perpendicular section on the gas pipe was considered in order to study the spatial development of the model. The pipe was placed according to the drawing above, in the soil considered homogenous and isotropic with the height of 2m and width of 8m.

## Numerical Solutions for Various Types of Faults

Various solutions for the distribution of the pressure field near the fault have been obtained, solutions based on the previous model defined by the ANSYS program.

Figure 2 shows in detail the distribution curves of the pressure around the fault.

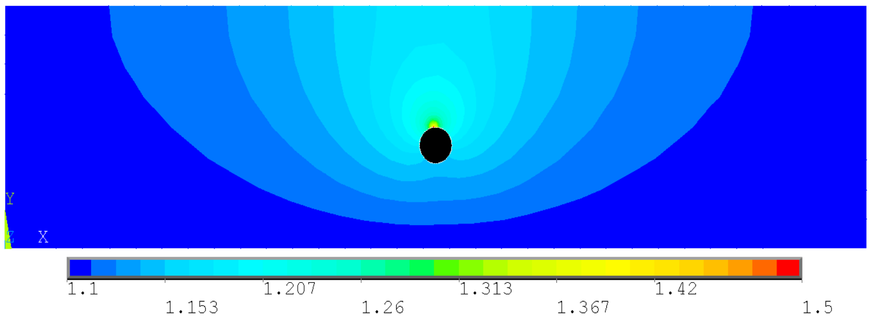


**Fig. 2.** The pressure field around the fault at the upper part of the pipe

Various positions of the fault are being shown in figures 3 and 4, a side fault and a fault placed below the pipe. After analyzing the qualitative results, one may conclude that irrespective of the fault position, gas leakage occurs due to the pressure gradient which appears locally around the fault, in a small portion.

The problem that has to be solved from a quantitative point of view consists in defining an analytical relation based on numerical data, by which one can determine the gas flow that runs through the fault depending on the size of the fault and the pressure gradient.

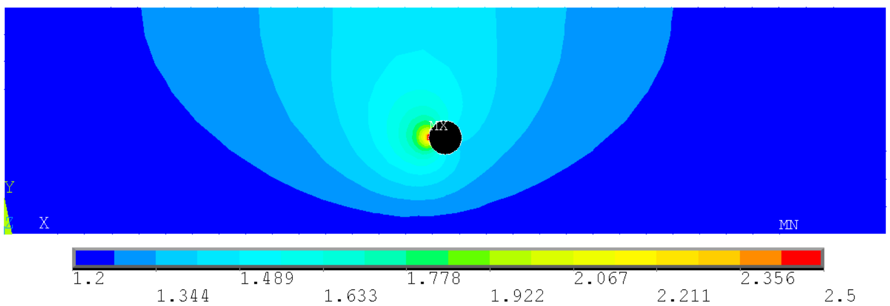


**Fig. 3.** The pressure field near the fault located at the side of the pipe

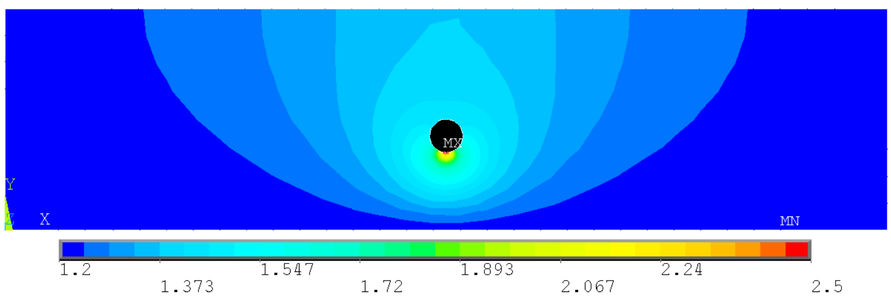


**Fig. 4.** The pressure field near the fault located at the bottom of the pipe

## Defining a Relation to Calculate the Pressure Gradient around the Fault

In order to define an analytical relation of the pressure gradient around the fault, the numerical values of the pressure have been analyzed, correlated with node points on a perpendicular direction on the pipe, starting from the fault itself.

The line used for this analysis is presented in figure 5. The numerical values of the pressure in the nodes in figure 5 are graphically represented in figure 6.

The curves are created for various values of the gas pressure in the pipe. The values of these pressures represent the starting points of these curves on the ordinate axis.

One can notice that the pressure gradient represented by the curve of the first segment increases with the gas pressure in the pipe.

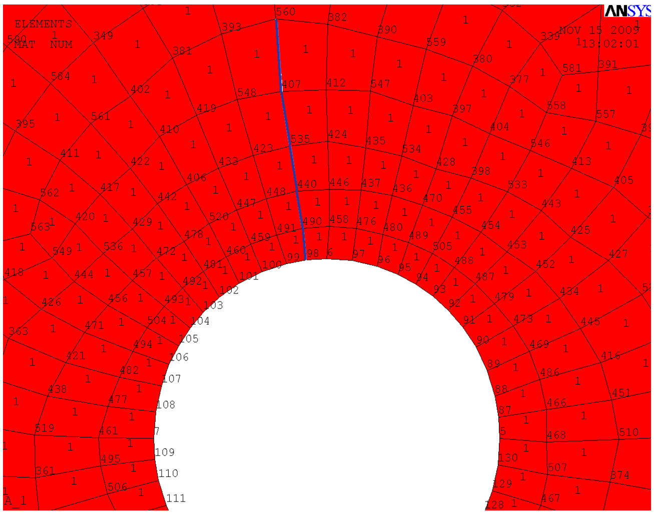


**Fig. 5.** The analyzed direction

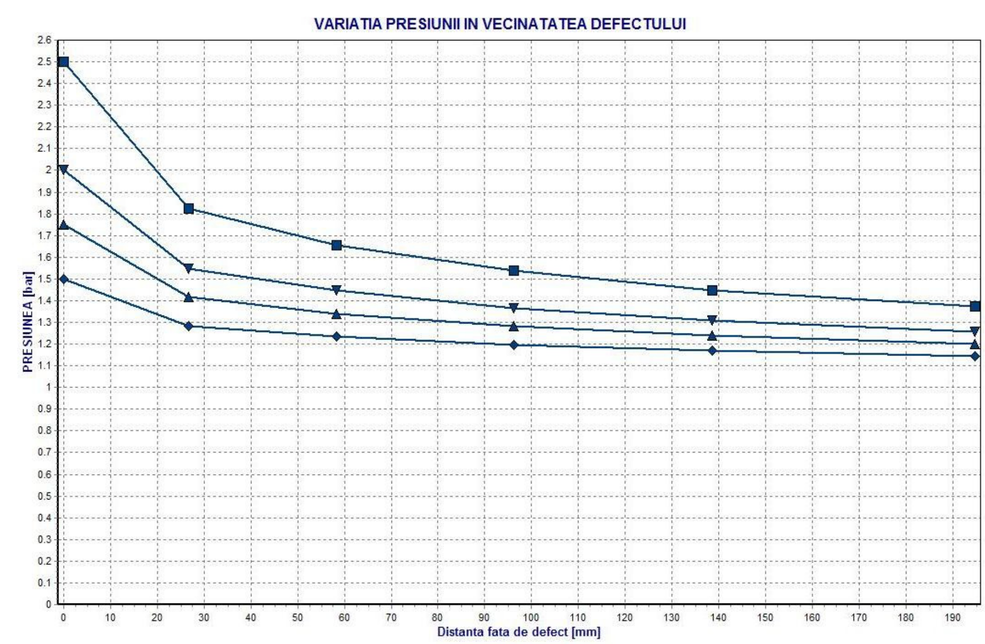


**Fig. 6.** Pressure values in nodes on the analyzed direction

In order to find an analytical expression of the gradient, all the curves have been analyzed, using, from a mathematical point of view, a linear regression which is based on the least square method to calculate gradients.

The analysis was performed for the pressure variation data near the pipe fault, values calculate dup to the distance of 25-30 mm. Due to the fact that the calculation of the derivative values at the pipe wall was taken into consideration, the tangent was therefore represented by a straight line whose coefficients were determined.

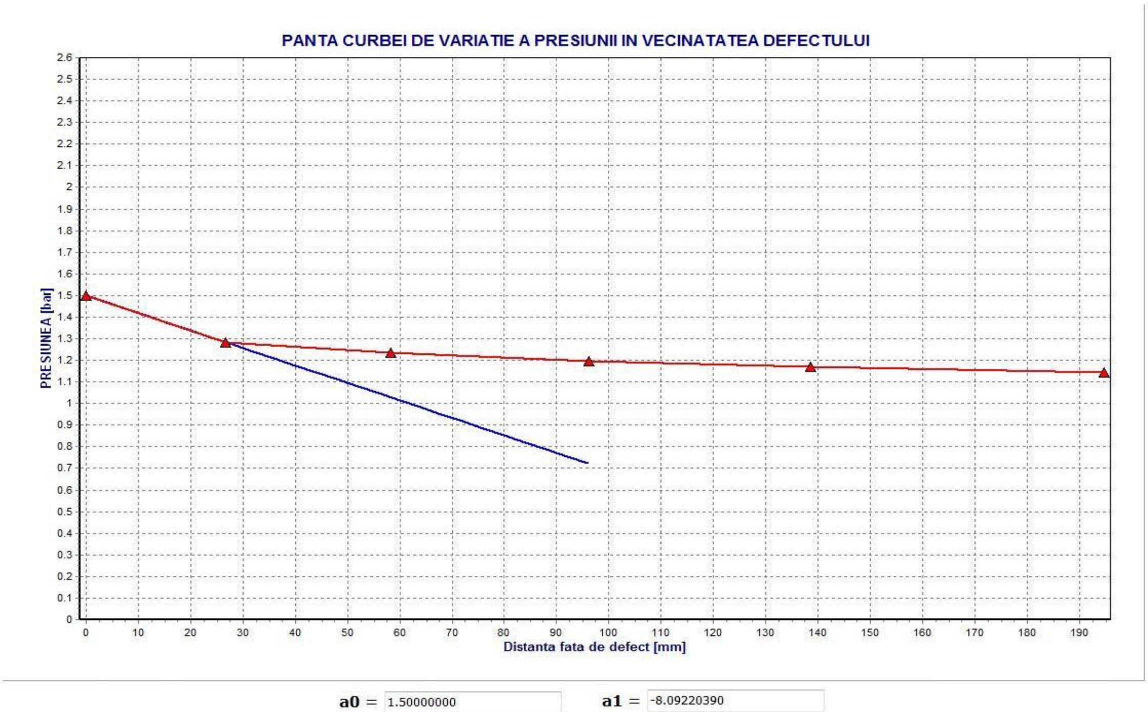


**Fig. 7.** The pressure variation curve near the fault

As one can notice, the coefficients $a_0$ and $a_1$ vary depending on the pressure in the pipe. In order to define an analytical relation of the gradient depending on the gas pressure in the pipe, a variation following a function with variable coefficients is being considered, such as:

$$Y = a_0(p) + a_1(p)X \tag{6}$$

where $Y$ represents the gradient and $X$ – the distance from the defect and

$$a_0(p) = b_0 + b_1 p,\ a_1(p) = b_0 + b_1 p + b_2 p^2 \tag{7}$$

The numerical analysis of the data showed that the first coefficient $a_0$ can be represented by a linear function whose coefficients are determined based on the least square method, while coefficient $a_1$ can be expressed by a second degree function whose coefficients are determined using a second degree polynomial regression. The results of the calculation are presented both graphically and as values in figures 8 and 9.

The function that can be used to determine the pressure gradient can be written analytically based on the results above as:

$$Y = 1 + \left(20{,}952020627 - 20{,}6320664p + 0.851845672p^2\right)X \tag{9}$$

The formula is valid provided that the numerical simulations were made for the absolute permeability of the soil $k = 10^{-10}$ m$^2$ and the dynamic viscosity of the gas $\mu = 1{,}8 \cdot 10^{-6}$ Pa.s.

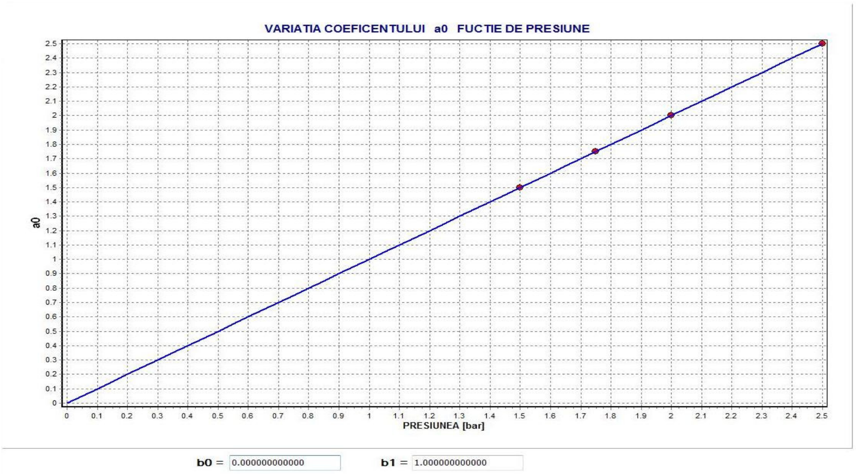


**Fig. 8.** Variation of coefficient $a_0$ depending on the pressure

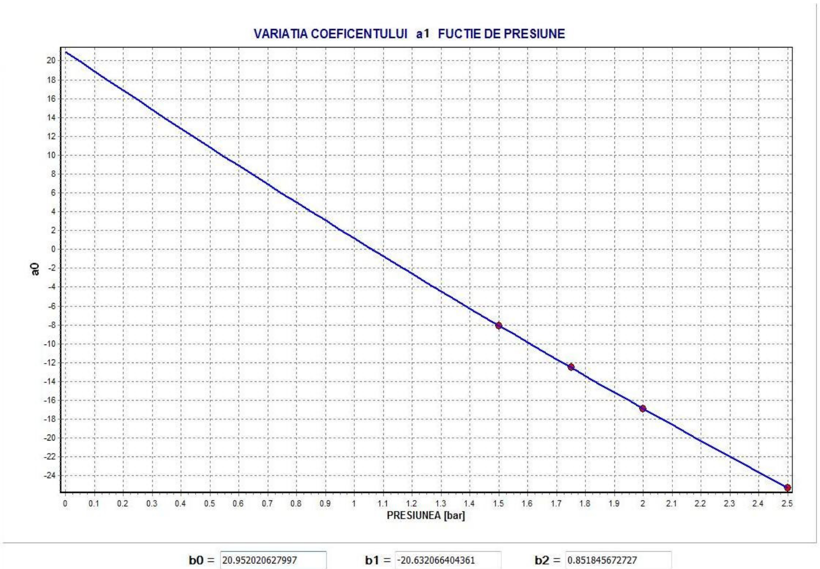


**Fig. 9.** Variation of coefficient $a_1$ depending on the pressure

## Calculating the Gas Flow that Is Lost Due to the Fault

Taking into consideration the model presented above, the gas flow that runs through the fault is a stationary fault.

One can determine the gas flow lost due tothe fault depending on the pressure value in the pipe, using the following relation

$$Q = -A\frac{k}{\mu}\frac{\partial p}{\partial x}, \tag{10}$$

where: $A$ is fault section, $k$ – absolute permeability, μ - viscosity, and $\frac{\partial p}{\partial x}$ - value of pressure gradient at the pipe wall in the fault area. The steps for this calculation are the following:

**1.** Calculate the gradient value corresponding to the gas pressure in the pipe.

Let us consider this pressure as $p$ = 2.5 bar and the distance $X$=*25*mm. Hence,

$$\frac{\partial p}{\partial x} = 1 + \left(20{,}95202062 - 20{,}6320664\,p + 0.85184567\,p^2\right)X = 1330 * E6 \ \text{Pa/m};$$

**2.** Determine the stationary gas flow that runs through the fault on the basis of teh fault section value. Let us consider the fault section equal to 2 mm$^2$. The flow is $Q = 53.2$ m$^3$/h.

Next we present graphically the results of the calculations for the gas flows that are lost through the buried distribution pipes for the pressures of 1.5, 2 and 2.5 bar and for faults with a section size starting from 1mm$^2$ to 10mm$^2$.

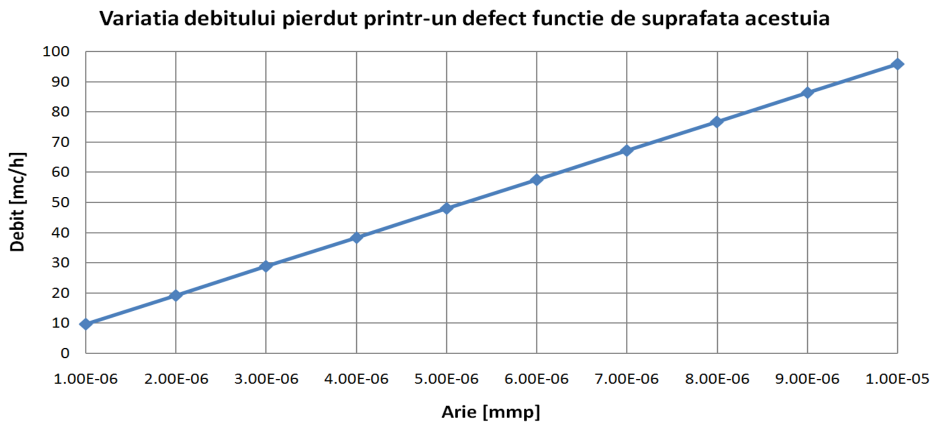


**Fig. 10.** Pressure 1.5 bar

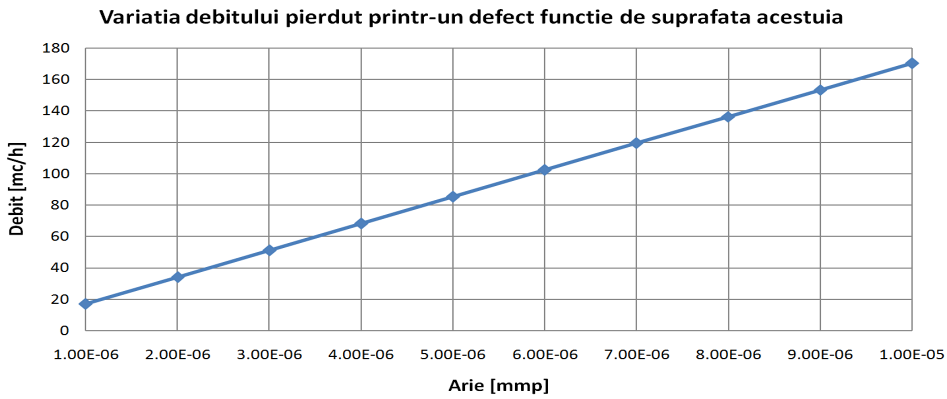


**Fig. 11.** Pressure 2 bar

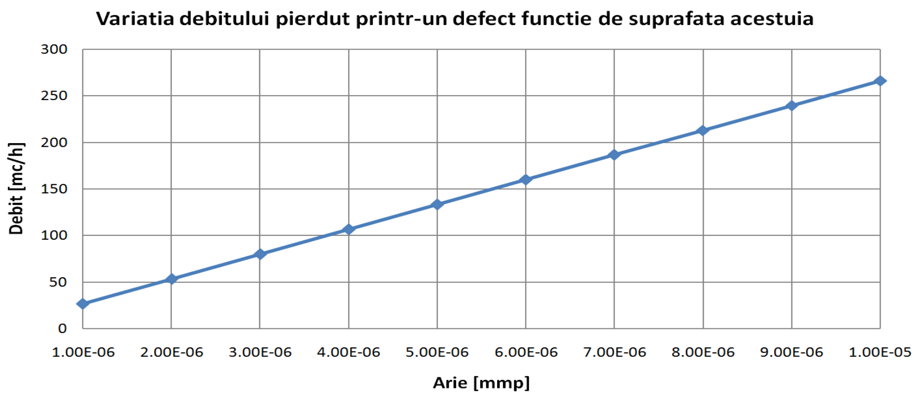


**Fig. 12.** Pressure 2.5 bar

## Conclusions

Most of the distribution pipes are made of steel and they are quite old in Romania. Duet o the corrosion on the pipes, there may appear faults through which the gas is released in the surrounding areas.

The natural gas flow that is lost due to the faults in the buried distribution pipes represents an important component of technological losses. The calculation methodology presented in this paper, together with a statistical analysis of the faults that appear on distribution pipes allows the calculation of these losses.

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# Calculul pierderilor de gaze naturale prin defectele conductelor de distribuție îngropate

## Rezumat

*Plecând de la problema corodării conductelor de gaze naturale din România şi apariția defectelor, lucrarea prezintă o analiza făcută prin simulare numerică a scurgerii gazelor prin defectele conductelor îngropate şi elaborarea unei metodologii de calcul a pierderilor de gaze.*