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Modeling Gas Flow through Pipes' Bracks

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Abstract

This paper presents a calculation procedure for gas losses through the bracks appeared on the interred gas pipelines. The mathematical model of gas flow through the bracks of the pipelines buried in soil is solved by a numerical finite-element procedure, using the ANSYS 10.0 software, for various diameter and pressure values. By means of this procedure, for a wide range of pipe diameters, brack sizes and pressure values, the pressure gradient in the brack area and lost gas flow rate can be calculated.

Key words: *gas losses, pipe, brack, soil, pressure*

Introduction

When a brack appears on an interred gas pipeline for transport or distribution, the gas passes from the pipe through brack's cross section and diffuses into the surrounding soil. The gas flow rate that flushes out the pipe is influenced by the properties of the soil in which the pipeline is set as well as the pressure in the pipeline. Because the time elapsed between the appearance of a brack on the pipe and its detection in view of repairing is quite long, we introduce the hypothesis of considering the gas flow through pipe's brack and its diffusion into the soil as being stationary processes. The pressure drop between the gas in the pipe and the soil surrounding the pipe determines the appearance of a pressure field near the brack. If the pressure gradient at pipe's wall, in brack's area, is determined, the rate of gas loss by the brack's cross-section can be calculated, assuming that soil permeability and gas viscosity are known.

Mathematical Model

The process of gas radial-plane flow through a homogeneous and isotropic porous medium is described 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 ∇ is Hamilton's operator, m and k – porosity and permeability of the porous medium respectively, p – pressure of gas moving out the pipe through the brack to the environment, and μ, Z – gas dynamic viscosity and deviation (from perfect-gas law) factor, both constant in the pressure range usual for gas transporting pipelines.

Taking into account the steady character of gas flow, equation (1) can also be written as

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

where the function P is the pressure's square i.e. $P(x,y)=p^2(x,y)$.

Gas filtration velocity can be derived from Darcy's equation under the form

$$\boldsymbol{v}=-\frac{k}{\mu}(\nabla p-\rho\nabla\Omega)\ , \tag{3}$$

in which ρ is gas density, and Ω – mass-forces potential. In the case under analysis, only gravity is acting, so we can write $\Omega=-y\,g$. he hypothesis of constant gas density is accepted, because its variation in the pressure range encountered into the gas distribution networks and for pipeline digging depths can be neglected. Relationships (2) and (3) constitute the mathematical model of the process of gas flow through pipe's brack and porous medium to the environment.

Numerical Approach of the Model

To solve equation (2) in the case of an interred pipeline, we used the ANSYS software, version 10.0. This software package was developed for solving various types of differential equations with partial derivatives by means of the finite-element method. For this problem, the thermal modulus for conduction, which is based on an equation identical to the fluid flow through porous media relationship, was used. The software allows the setting of the porous medium properties and the selection of elements appropriate to the desired problem. In this case we considered a cross-section of a pipe having the diameter of 300 mm and buried at 1 meter depth. Figure 1 shows the geometric schema of the model.

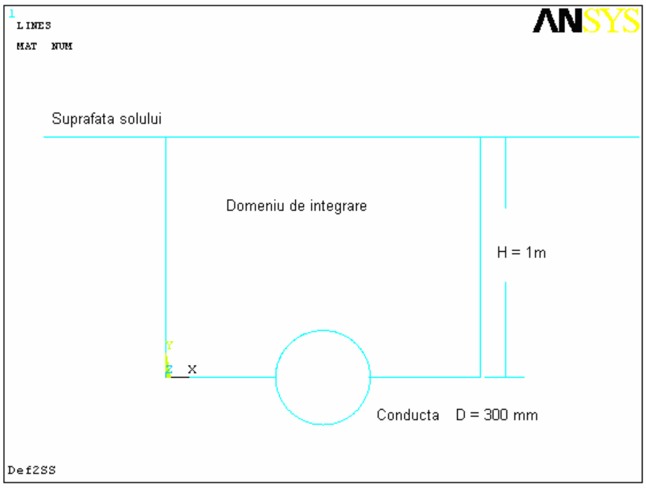

Fig. 1. Geometric schema of model

To see model's spatial extension, we considered a domain having a width of 1 meter, with the pipe at its middle. For reducing model's dimensions, only the upper half of the pipe was considered, because the phenomenon is identical on the other half, due to symmetry.

The integration domain was defined on the basis of figure 1 and contains the upper half of the pipe along with the surrounding soil which represents the medium in which the flow of gas leaving the pipe through a brack and diffusing into the environment will be modeled. Soil's absolute permeability was set as constant all over the domain.

The element named PLANE 55 was used to model the domain into the ANSYS software. This element is defined by 4 nodes and by the orto-tropic properties of the material. The orto-tropic directions of the material correspond to the directions of element's coordinates. This type of element can be used to model not only thermal diffusion but also steady fluid flow through a porous medium by setting the property KEYOPT9 = 1.

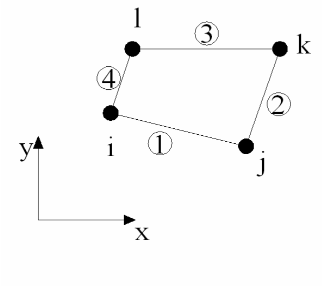

Fig. 2. Element PLANE 55

Due to the fact that the absolute permeability was considered as constant, the same permeability value was introduced for all directions.Based on the finite-element defined above, the software freely divided problem's domain into finite elements, and the resulted network is shown in figure 3.

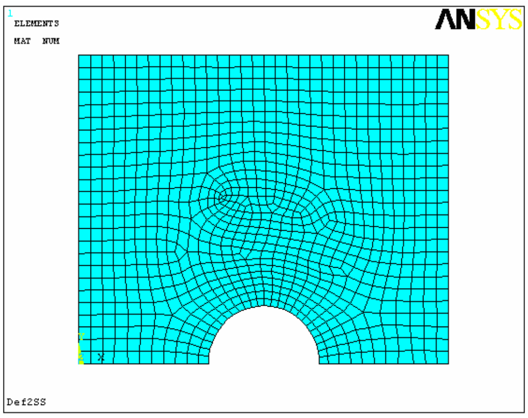

Fig. 3. Divided domain into finite elements

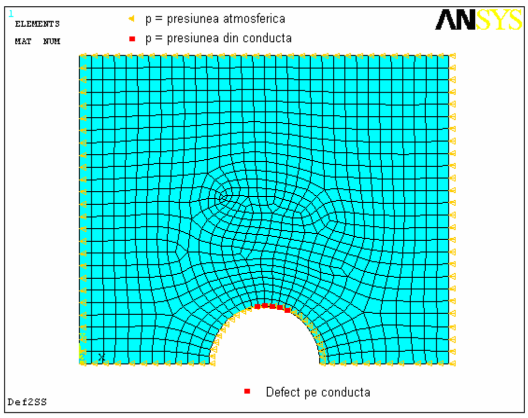

Fig. 4. Boundary condition definition

To individualize the problem the boundary conditions are set. On domain's perimeter, the pressure was defined as equal to the atmospheric pressure. This fact was admitted as possible because the pipe is buried at a small depth. The same conditions were defined on pipe's outer wall, excepting the points in which bracks are present. We considered the brack as a rupture in pipe's wall, so that the boundary condition into the brack is defined by a pressure value equal to pipe's internal pressure. We invoked this Dirichlet-type condition because we want to establish the flow rate of gas leaving the brack. The flow rate will be a function of the pressure field around the brack which yields by model calculation according to the boundary conditions on both domain's perimeter and pipe's outline.

The red squares in figure 4 indicate the nodes on pipe's outline into the brack. In fact, in this area, the pipe's wall is missing. The number of points which define the brack was set as variable, so that both geometrically small and very large (extending on almost half of pipe's diameter) bracks can be defined.

As it can be seen, the model defined above closely approaches the actual phenomenon that occurs in the case of gas leaking through buried pipes' bracks.

Using this model and the ANSYS 10.0 software, various solutions for the pressure field distribution around the brack were obtained. Figure 4 suggestively presents pressure distribution around the brack, while figure 5 shows in a vector manner the gas flux leaving the pipe.

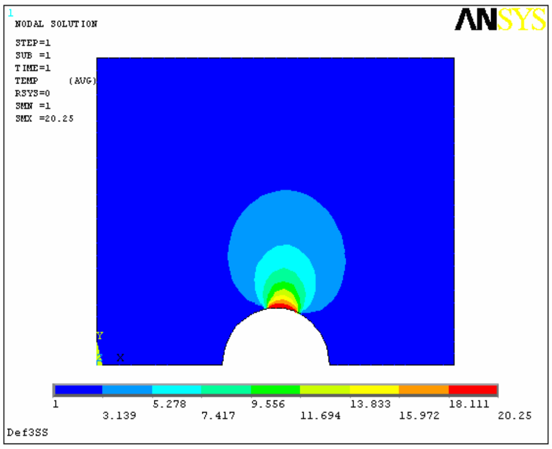

Fig. 5. Pressure distribution around the brack

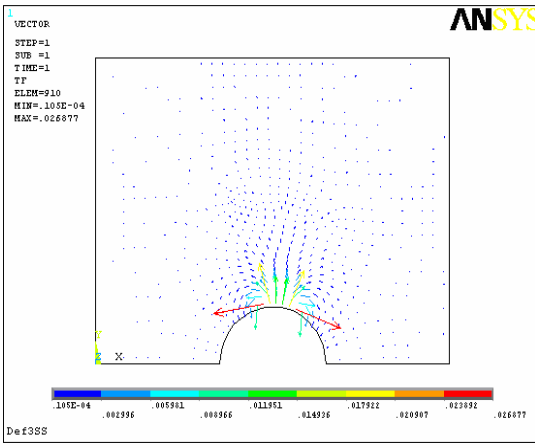

Fig. 6. Gas flux leaving the pipe

By changing the boundary conditions on the pipe, bracks of various dimensions can be defined.

The analysis of these results shows that brack's size directly affects both the pressure field distribution around the brack and the gas flux that leaks from the fissure. Consequently, we can conclude that, in the case of gas leaking through bracks on buried pipes, the flow rate of gas leaving the pipe is determined by the permeability of the soil around the pipe. This makes a pressure field near the brack to appear, which determines the maximum value of the lost rate.

Comparing this situation to the case when the perforated pipe is on soil's surface, the velocity of gas coming out the brack is determined by the difference between the pressures inside and outside the pipe.

When the pipe is interred, the medium around it induces the apparition, in pipe's vicinity, of a pressure distribution that limits the value of the flow rate getting out the brack. The leaking flow rate is determined, in this case, by the value of the pressure field gradient at pipe's wall in brack's area.

Determining the Pressure Gradient in Brack's Area

This calculation is done only in brack's area, so that we considered a small region near the brack for which nodal pressures were computed according to various boundary conditions defined by pressure values into the pipe.

The cases in which the pressure into the pipe is 5, 4.5, 4, 3.5, 3, 2.5, 2 and 1.5 bar were analyzed. For each of them, the boundary conditions on the brack and along five radial directions, for which the analysis of pressure variation around the defect is done, were defined.

As an example, in figures 7 and 8 the results for the pressure of 5 bar are shown. It has to be mentioned that, in these figures, the values of the pressure square are listed, according to the mathematical model.

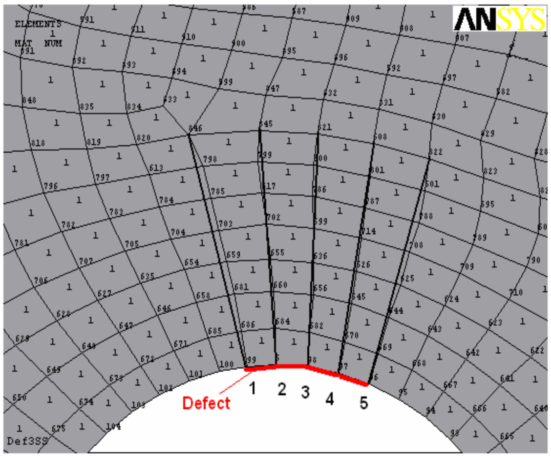

Fig. 7. Boundary condition for a 5 bar inner pressure

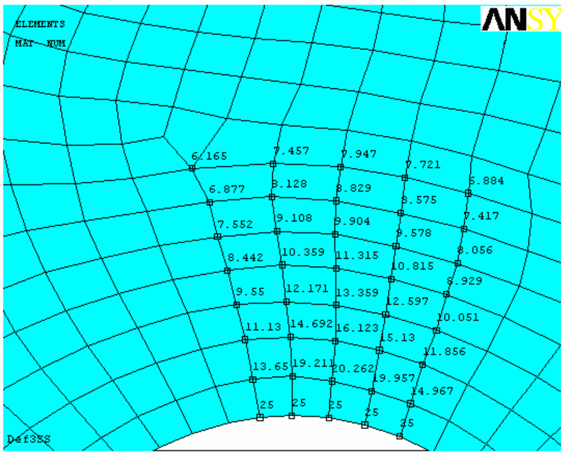

Fig. 8. Pressure square values for a 5 bar inner pressure

To calculate the pressure gradient, five directions were defined for the brack chosen (see figure 8). For all these five directions, the corresponding pressure variation curves were determined. As an example, in figure 9 the curves along the five directions for the pressure value of 5 bar are drawn.

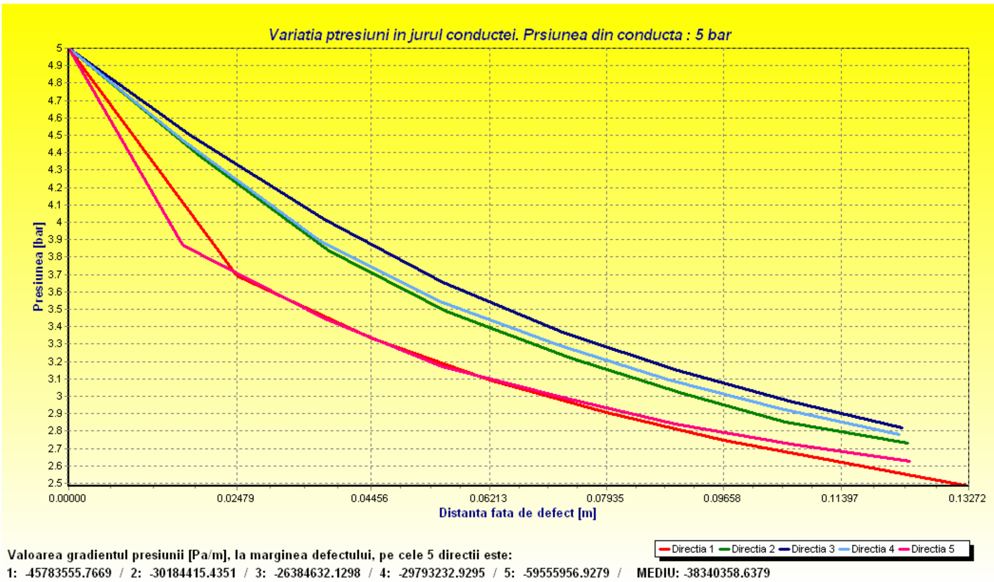

Fig. 9. Pressure value around the pipe

One can notice that the pressure varies more widely along the side directions 1 and 5 (figure 8), but less intensely on the middle directions 2, 3 and 4. At the bottom of every plot, the values of pressure gradients along each direction and the average pressure gradients are listed. By analyzing the whole set of results for various pressure values, we observe that the average pressure gradient at pipe's wall changes according to pipe's inner pressure; that leads to lower gas flow rates with inner pressure decreasing.

An interesting synthesis is shown in figure 10 which plots pressure gradient values at pipe's wall in the defect versus gas pressure. At the top of this figure, a simple function, derived by the least squares regression method, together with its coefficients, is listed; this function approaches very closely the pressure gradient variation numerically established. We notice that the function above is valid only for a specific value of soil permeability; practically, for each type of soil a new plot has to be drawn.

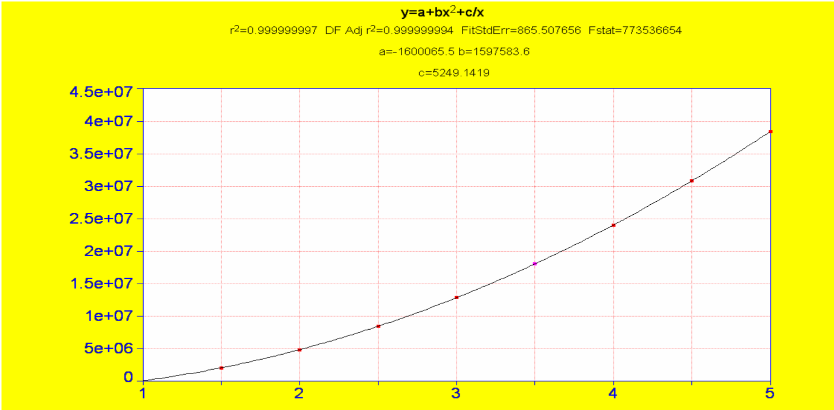

Fig. 10. Pressure gradient values at pipe's wall in the defect versus gas pressure.

By analyzing the curve in figure 10 we observe that the pressure gradient value at pipe's wall in brack's area changes uniformly versus gas pressure value in the pipe. According to figure 9, the equation describing the pressure gradient is

$$Y = a + bX^2 + \frac{c}{X}, \tag{4}$$

where Y is the gradient value, Pa/m, X – pipe's inner pressure, Pa, a = 1600065.5, b = 1597583.6, c = 5249.1419. The relationship (4) is valid for the soil absolute permeability $k = 10^{-10}$ m^2 and the gas viscosity $\mu = 1.8 \cdot 10^{-6}$ Pa·s.

Case Study

Taking into account the model previously described, the flow rate passing through the brack is a steady flow rate, so that the gas rate leaking through the defect can be determined, as a function of the pressure value into the pipe, with the formula

$$Q = -A \frac{k}{\mu} \frac{\partial p}{\partial x}, \tag{5}$$

where A is the cross-section of the brack, k – the soil absolute permeability, μ – the gas viscosity, and $\partial p / \partial x$ – the pressure gradient value at pipe's wall in brack's area.

This case study uses the following experimental data, obtained in a pipe defect encountered at Braşov Gas Distribution Branch: pipe diameter 300 mm, gas pressure 2.7 bar and brack cross-section 40 mm^2. The computed pressure gradient value corresponding to pipe's inner pressure is

$$\left.\frac{\partial p}{\partial x}\right|_{p=2.7\ \text{bar}} = -1600065.6 + 1597583.6 \cdot \left(2.7 \cdot 10^5\right)^2 + \frac{5249.1419}{\left(2.7 \cdot 10^5\right)} = 10.048 \cdot 10^6 \ \text{Pa},$$

the steady gas flow rate leaking from the brack, according to defect cross-section value, equals

$$Q = -40 \cdot 10^{-6} \frac{10^{-10}}{1.8 \cdot 10^{-6}} 10{,}048 \cdot 10^6 = 223.3 \cdot 10^{-4} \ \text{m}^3/\text{s},$$

while the amount of gas lost during one hour by pipe's defect is

$$Q_h = 3600Q = 80.39 \ \text{m}^3.$$

Experimental measurements confirmed the hourly loss of 80 m^3.

Conclusions

This paper presents a procedure for calculating gas losses by bracks on buried pipes, based on a mathematical modelling of the gas flow process.

The equation describing gas flow through the porous medium surrounding the defect is approached using a finite-element method into the ANSYS 10.0 software.

The procedure introduced here allows the calculation of pressure gradient around the brack and the gas flow rate lost from the pipe, for various pipe diameters, defect sizes and pressure values.

The uprightness of the hypotheses on which this procedure is based was proven by a case study on an actual gas loss situation.

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Modelarea curgerii gazelor prin defectele conductelor

Rezumat

Lucrarea prezintă o metodologie de calcul a pierderilor de gaze prin defectele conductelor îngropate. Modelul matematic al curgerii gazelor prin defectele conductelor îngropate în sol este rezolvat printr-o metodă numerică cu elemente finite cu programul ANSYS versiunea 10.0. pentru diverse diametre şi presiuni. Cu ajutorul acestei metodologii, pentru diverse diametre de conductă, mărimi ale defectelor şi presiuni se poate calcula gradientul presiunii în zona defectului, precum şi debitul de gaze ce se pierde.