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Transient Phenomena Specific to Gas Pipelines Exploitation

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Abstract

This paper presents the simulation of transient phenomena appearing in gas pipelines when the gas yields either at the pipeline inlet or outlet gets different values towards the prescribed ones due to exploitation, according to the primary normal stationary regimes. These new gas yields values disturb the stationary regime, transforming it in a transient one. The new regime has a transient character since it becomes stabile in time, returning to a stationary regime, according to the new hydrodynamic parameters: the pressure at the ends of pipeline and the flow. This paper is intended to determinate the duration of transient regime so it could be determined sooner by the operators of gas transportation and distribution systems.

Key words: *gas, pipelines, transient phenomena, exploatation*

Mathematical Simulation

We will consider below that all parameters characterizing the gas flow (velocity, pressure and specific gravity) has constant medium values in the pipe cross section, so the movement is one-dimensional. All the above parameters will generally depend on a single spatial variable, *x*, and on time, *t*, respectively

$$\mathrm{v} = \mathrm{v}(x,t),\ p = p(x,t),\ \rho = \rho(x,t), \tag{1}$$

where x represents the distance between the pipeline inlet section and the considered section.

Regarding the gas temperature, it is considered as a constant and its average value is T_m. Since the critical conditions determining huge disturbances in gas pipelines exploitation happen in winter seasons, we will consider an average value $T_m = 275\ \mathrm{K}$.

The deviation factor, *Z*, is a function of pseudoreduced pressure and temperature. It can also be stated a constant average value, $Z_m = 0{,}985$.

The friction factor, λ, is calculated in terms of *Reynolds* number and the pipeline roughness, *k,* using *Colebrook-White* formula:

$$\frac{1}{\sqrt{\lambda}} = -2\lg\left(\frac{2{,}51}{\mathrm{Re}\sqrt{\lambda}} + \frac{k}{3{,}71d}\right). \tag{2}$$

Regarding *Reynolds* number, we will use the definition, $Re = \frac{\rho v d}{\mu}$, which can also be written as follows , considering the weight rate $\dot{m} = \rho v \pi d^2 / 4$:

$$Re = 123080\frac{\dot{m}}{d} \tag{3}$$

because, for normal conditions characterized by p_N =1,0133 bar and T_N = 273,16 K, the dynamic viscosity μ_{273} = 10,35.10^{-6} Pa.s.

In this paper we will consider the normal conditions of pressure and temperature (p_N =1,0133 bar and T_N = 273,16 K) so the Reynolds number in terms of weight rate $\dot{m}$ expressed in kg/s and the pipeline diameter d, expressed in m, is

$$Re(d,\dot{m}) = 123080\frac{\dot{m}}{d}. \tag{4}$$

Obviously, the friction factor, λ, can now be written as a function of weight rate $\dot{m}$ and the pipeline diameter d:

$$\lambda(d,\dot{m}) = \lambda[\mathrm{Re}(d,\dot{m}),k]. \tag{5}$$

The Equation of Pressure

The mathematical simulation of gas isothermal slow transient flow in a pipeline consists of the following equation:

$$\frac{\partial P}{\partial t} = \frac{b}{\sqrt{a}}\sqrt{\frac{P}{\left|\frac{\partial P}{\partial x}\right|}}\frac{\partial^2 P}{\partial x^2}, \tag{6}$$

where $P(x,t) = p^2(x,t)$, *a* and *b* are "constant" resulted from the following equation

$$a = \frac{16\lambda R T_m Z_m}{\pi^2 d^5}, \quad b = \frac{4 R T_m Z_m}{\pi d^2}, \tag{7}$$

with appropriate initial and boundary conditions for pressure and weight rate.

The equation of pressure (6) can also be written

$$\frac{\partial P}{\partial t} = \alpha\sqrt{\frac{P}{\left|\frac{\partial P}{\partial x}\right|}}\frac{\partial^2 P}{\partial x^2}, \quad \alpha = \sqrt{\frac{R T_m Z_m d}{\lambda}}, \tag{8}$$

α is a constant which can be expressed in terms of weight rate and pipeline diameter

$$\alpha(d,\dot{m}) = \sqrt{R T_m Z_m}\, d^{0,5}\lambda(d,\dot{m})^{-0,5}. \tag{9}$$

or

$$\alpha(d,\dot{m}) = 375 d^{0,5} \lambda(d,\dot{m})^{-0,5} . \quad (10)$$

The original condition of the mathematical simulation is the pressure distribution in the stationary primary regime

$$P(x,0) = P_1 - a_0\, \dot{m}_0^2 x,\ P_1 = p_1^2 , \quad (11)$$

a_0 corresponds to the stationary regime and it can also be written

$$a_0 = 228418 d^{-5} \lambda(d,\dot{m}_0) . \quad (12)$$

The limit conditions depend on the pipeline exploitation, so we can have two situations:

- V1- the pressure remains constant at the inlet and the flow varies at the outlet:

$$t > 0 \begin{cases} P(0,t) = P_1 ; \\ \dfrac{\partial P}{\partial t}(l,t) = -a\, \dot{m}_2^2(t). \end{cases} \quad (13)$$

where $\dot{m}_2(t)$ represents the gas weight rate distributed to the custom. $\dot{m}_2(t)$ differs from the weight rate in the stationary regime, $\dot{m}_0$.

- V2- the pressure remains constant at the inlet and the flow varies:

$$t > 0 \begin{cases} P(0,t) = P_1 ; \\ \dfrac{\partial P}{\partial t}(0,t) = -a\, \dot{m}_1^2(t). \end{cases} \quad (14)$$

where $\dot{m}_1(t)$ represents the gas weight rate entering in the pipeline. $\dot{m}_1(t)$ differs from the weight rate in the stationary regime, $\dot{m}_0$.

The non-linear character of the equation (8) is evidently due to the irrational factor which makes impossible an analytical approach to it. The equation can be numerically approached through a finite differences scheme together with an adequate iterative procedure for the irrational factor elimination.

Finite Differences Method

The continuous range of the pressure $C : [0 \le x \le l, 0 \le t \le T]$ in the discreet array

$R_{i,j} : \lfloor x_i = (i-1)h,\ i = 1 \div N+1;\ t_j = j\tau,\ j = 0 \div M \rfloor$ will be transformed, where i is the spatial factor, j -the temporal factor, h –the spatial pitch, τ-the temporal pitch, N –the number of the spatial pitches and M - the number of the temporal pitches. So, we can consider discreet approximation values $P_i^j = P(x_i,t_j)$ instead of the precise values of the pressure $P(x,t)$. A *Hyman Kaplan* type finite differences method will be used, a method which is well known as unconditional stabile and fully convergent defined by

$$\frac{\partial P}{\partial x}(x_i,t_{j+1}) = \frac{P_{i+1}^{j+1} - P_{i-1}^{j+1}}{2h},\ \frac{\partial P}{\partial t}(x_i,t_{j+1}) = \frac{P_i^{j+1} - P_i^j}{\tau},\ \frac{\partial^2 P}{\partial x^2}(x_i,t_{j+1}) = \frac{P_{i+1}^{j+1} - 2P_i^{j+1} + P_{i-1}^{j+1}}{h^2},$$

We will also use the discreet statement of pressure at the ends of the pipeline

$$\frac{\partial P}{\partial x}\left(x_0, t_{j+1}\right) = \frac{-3P_1^{j+1} + 4P_2^{j+1} - P_3^{j+1}}{2h}, \quad \frac{\partial P}{\partial x}\left(x_l, t_{j+1}\right) = \frac{P_{N-1}^{j+1} - 4P_N^{j+1} + 3P_{N+1}^{j+1}}{2h}$$

Using the finite difference method, the equation (8) becomes

$$P_i^{j+1} - P_i^j = \alpha c\, A_i^{j+1}\left(P_{i-1}^{j+1} - 2\,P_i^{j+1} + P_{i+1}^{j+1}\right) \tag{15}$$

where $c = \frac{\tau\sqrt{2}}{h\sqrt{h}}$, is a constant of digitization array and $A_i^{j+1} = \sqrt{\frac{P_i^{j+1}}{P_{i-1}^{j+1} - P_{i+1}^{j+1}}}$ is the irrational factor induced by the method. The equation (15) can also be written

$$\Phi_i^{j+1}\, P_{i-1}^{j+1} - \Psi_i^{j+1}\, P_i^{j+1} + \Phi_i^{j+1} P_{i+1}^{j+1} = -P_i^j\,, \tag{16}$$

where

$$\Phi_i^{j+1} = c\alpha\left(d, \dot{m}\right) A_i^{j+1}\;,\;\; \Psi_i^{j+1} = 2\,c\alpha\left(d, \dot{m}\right) A_i^{j+1} + 1\;,\;\; i = 2 \div N \tag{17}$$

The initial condition will be

$$P_i^0 = P_1 - a_0\, \dot{m}_0^2\left(i-1\right)h\,,\;\; i = 1 \div N+1\,, \tag{18}$$

and the limit conditions become:

$$\text{V 1: } P_0^{j+1} = P_1,\; P_{N-1}^{j+1} - 4P_N^{j+1} + 3P_{N+1}^{j+1} = -2\,h\,a\left(d, \dot{m}_2\right)\dot{m}_2^2\,. \tag{19}$$

$$\text{V 2: } P_{N+1}^{j+1} = P_2\,,\; -3P_1^{j+1} + 4P_2^{j+1} - P_3^{j+1} = -2\,h\,a\left(d, \dot{m}_1\right)\dot{m}_1^2\,. \tag{20}$$

The last three statements [(18), (10) and (20)] make up the system produced by the equation (17) allowing thus the calculus of pressure distributions P_i^{j+1} according to $j = 1 \div m$ and $i = 1 \div N+1$, respectively, for both of the exploitation methods.

The Numerical Model

In order to solve the linear algebraic equations system produced by the equation (16) completed with (18) and (19) or (20), we will consider $P0(i)$ as the distribution of the pressure square at a known moment j, $P0(i) = P_i^j$ and $P(i)$ as the distribution of the pressure square at an unknown moment j+1, that is $P(i) = P_i^{j+1}$. According to the solving method of the above linear algebraic equations system we will obtain successive approximated solutions, which lead to an accurate distribution of the system. The approximated solutions successively obtained by solving the algebraic system will be referenced as $P1(i)$ for the first approximation and $P2(i)$ and $P3(i)$ for the next two approximations, respectively.

Gas Pipeline Transient Regime Simulation

The TRANZGAZ software was established using the above algorithm in two different alternatives according to the above two situations. These lead to the pressure distribution along the gas pipeline during the transient regime produced by both pipeline exploitation conditions. The software is realized using Delphi 5.

Alternate 1. Let's consider a gas distribution pipeline working in a stationary regime and carrying a gas yield $\dot{m}_0$. The distribution of the pressure square along the pipeline is $P(x) = P_1 - a_0 \dot{m}_0^2 x$. At a given moment a new consumer comes into operation (or a consumer is coupled out), which leads to a gas yield at the end of the pipeline $\dot{m}_2 = \dot{m}_0 \cdot f$, where *f* is the yield variation factor, proper or improper. From now on, the gas motion has a non-steady character, a transient process establishing in the pipeline until the distribution of pressure square will be according to the new yield value $P(x) = P_1 - a\,\dot{m}_2^2\, x$. The gas pressure control value at the pipeline outlet will be $P_c = P_1 - a\,\dot{m}_2^2\, l$, that is the value controlling the process extent because the time when it is achieved corresponds to the end of the transient process.

To determine the extent of transient regime, a specialized software named **TRANZ-1** has been developed starting from TANZGAZ software. It is a conversational type, which can be coursed for the following input data from the operator.

TRANZ-1 software was coursed for the transient regime simulation in a gas pipeline Dn200 (*d*=0,164 m), 4.000 m length, 4 bar (5 bara) the entrance pressure – constant during the simulation. The initial gas production was 5443 m^3/h increasing with 5%. The diagrams in the *figure 1* indicate the simulation results, where both of pressure curves along the pipeline are indicated as well as the extent of the transient regime produced by the new gas flow value.

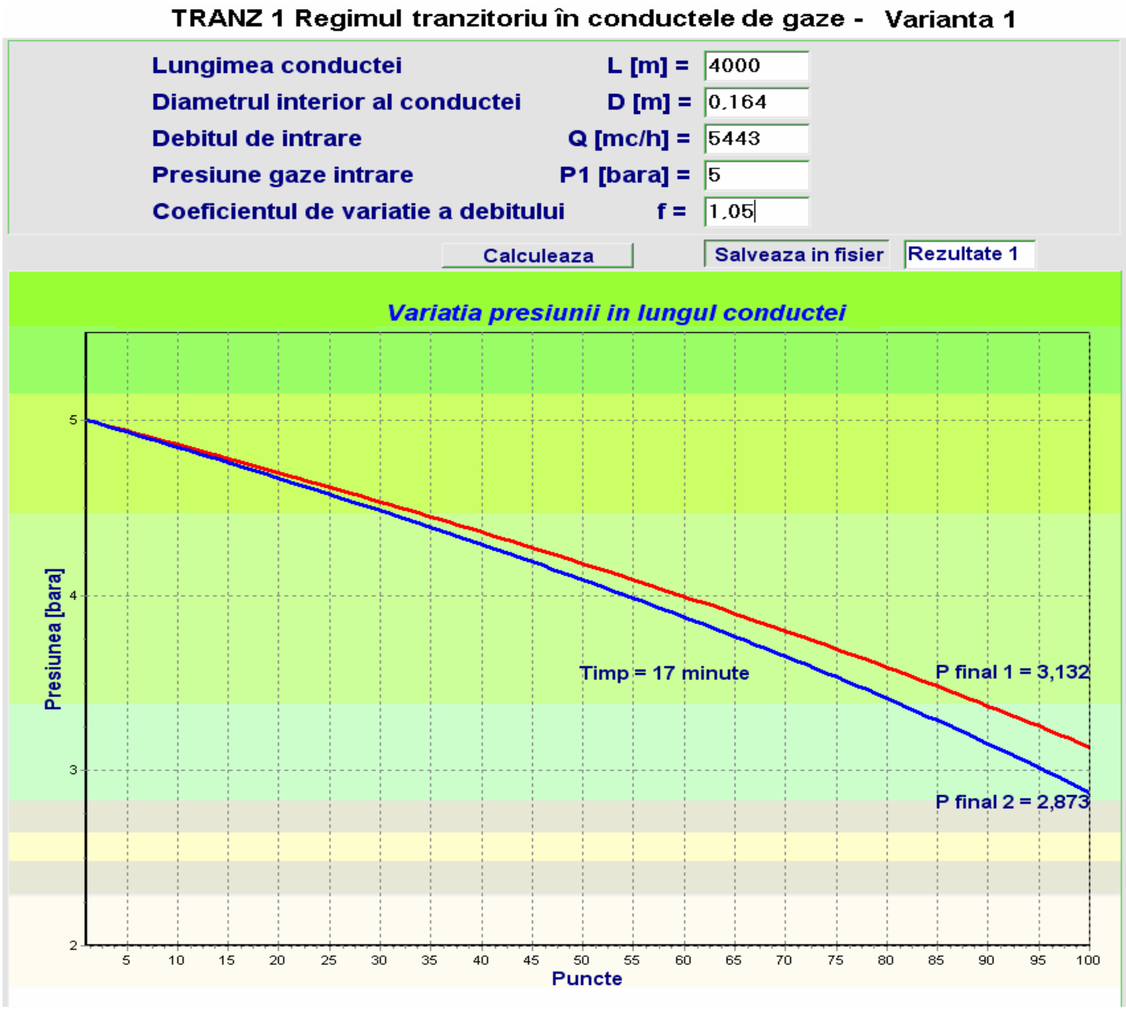

Fig. 1. The pressure variation along a Dn 200 gas pipeline – transient regime, Alternate 1

Alternate 2. Let’s consider a gas distribution polyethylene pipeline, working in a stationary regime and carrying a gas yield $\dot{m}_0$. The distribution of the pressure square along the pipeline considering the outlet pressure is $P(x) = P_1 - a_0 \dot{m}_0^2 x$. At a given moment, at the entrance of the pipeline the gas yield gets a new value $\dot{m}_2 = \dot{m}_0 \cdot f$, where *f* is the yield variation factor, proper or improper, the pressure P_1 keeping constant. From now on the gas motion has a non-steady character, a transient process establishing in the pipeline until the distribution of pressure square will be according to the new yield value $P(x) = P_1 - a\,\dot{m}_2^2\, x$. The gas pressure maximum value at the pipeline outlet will be $P_m = P_1 - a\,\dot{m}_2^2\, l$, that is the value controlling the process extent because the time when it is achieved corresponds to the end of the transient process.

To determine the extent of transient regime in this case, a specialized software named **TRANZ-2** has been developed starting from **TANZGAZ** software.

TRANZ-2 software was coursed for the transient regime simulation in a gas distribution pipeline Dn200 (*d*=0,164 m), 4.000 m length, 4 bar (5 bara) the entrance pressure – constant during the simulation. The initial gas production was 5445 m^3/h decreasing with 20%.

The diagrams in the *figure 2* indicate the simulation results, where both of pressure curves along the pipeline are indicated as well as the extent of the transient regime produced by the new gas flow value.

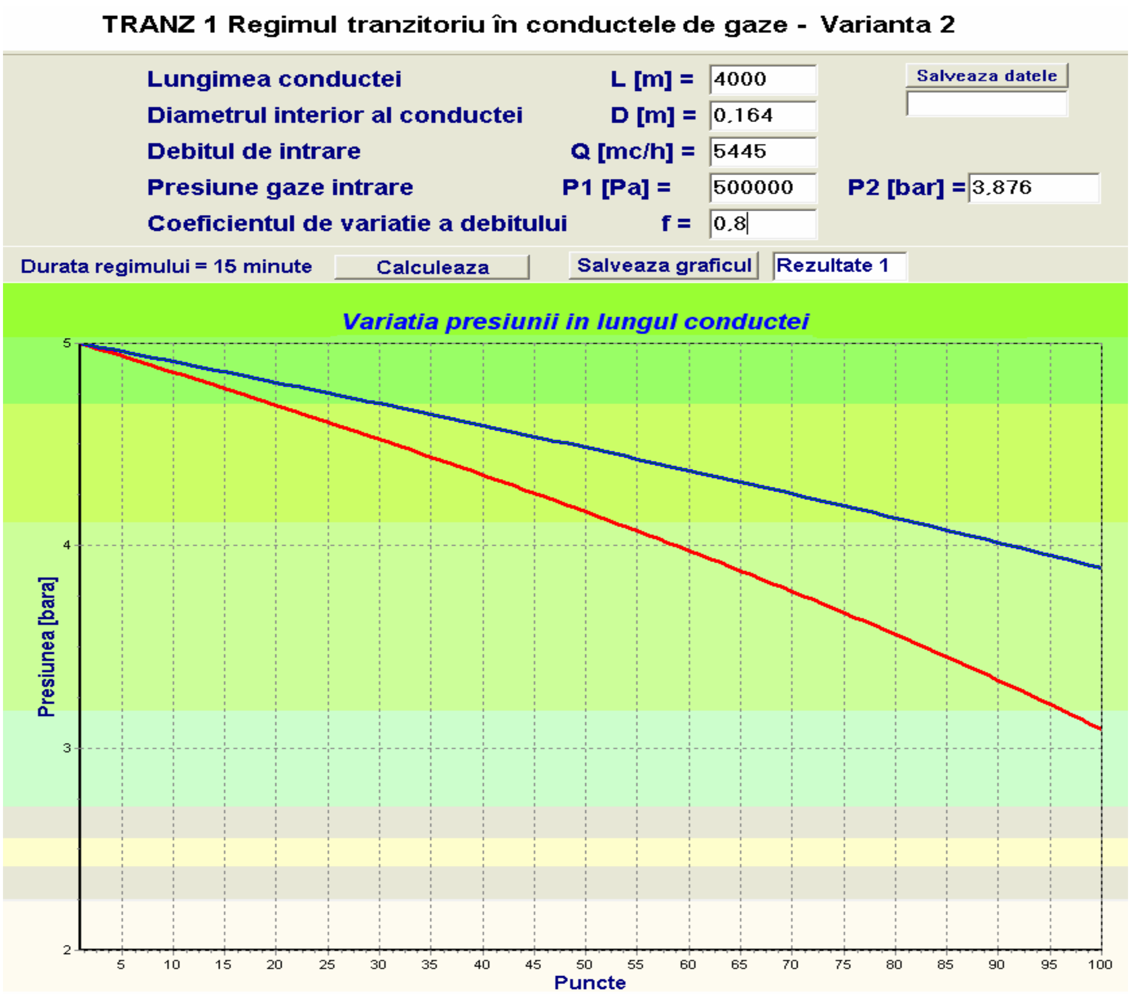

Fig. 2. The pressure variation along a Dn 200 gas pipeline – transient regime, Alternate 2

Conclusions

The TRANZ-1 software and **TRANZ-2** software was coursed for transient regime simulation in different geometry gas pipelines and different exploitation conditions, achieving the corresponding recovery times. The results give points to the following:

- 1. The pipeline geometry essentially influences the extent of the transient regime. Thus, with similar exploitation conditions (entrance pressure and initial gas production), the recovery period grows with the pipeline length and a high diameter corresponds to a less period.
- 2. The exploitation conditions also influence the recovery period if the pipeline geometry is the same. Thus, the increasing of yield variation factor leads to a transient process duration growing.

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Fenomene tranzitorii specifice la exploatarea conductelor de gaze

Rezumat

Lucrarea prezintă modelarea fenomenelor tranzitorii ce apar în conductele de gaze atunci când, datorită exploatării, debitele de gaze vehiculate, fie la intrare, fie la ieşire, capătă valori diferite de cele prescrise, corespunzătoare regimurilor staționare inițiale, normale. Aceste noi valori ale debitelor de gaze perturbă regimul staționar de curgere, transformându-l în regim nestaționar. Noul regim are caracter tranzitoriu deoarece, după o anumită perioadă de timp se stabilizează, revenind la un regim staționar, corespunzător noilor parametri hidrodinamici, presiunile la capetele conductei şi debitul vehiculat. Scopul lucrării este determinarea duratei regimului tranzitoriu pentru a putea fi cunoscută din timp de operatorii din sistemele de transport şi distribuție a gazelor naturale.