NATURAL GAS TRANSPORT THROUGH MAIN PIPELINES. THE INFLUENCE OF DIGGING-IN ON GASES PRESSURE AND TEMPERATURE IN FINAL EDGE OF PIPELINE

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Abstract: This paper proposes a genuine mathematical model which takes into account all gas dynamic parameters that are involved in the steady state gas transport process through the pipeline. In order to notice the influence of pipelines digging – in on pressure and temperature according to the medium temperature variation, the paper presents variation of the gases pressure and temperature at the final edge of the pipiline.

Keywords: gas, pipeline, pressure, temperature, soil.

1. INTRODUCTION

In approaching the steady movement of gas through pipelines we will start from the hypothesis that the hydrodynamic parameters have the same values on the entire flow section, exclusively depending on the x distance when entering the pipeline. The paper will present a mathematical model which takes into consideration the variation of all hydrodynamic parameters through the whole pipeline.

2. THE PROPOSED MATHEMATICAL MODEL

The gas steady flow process through pipelines is set by the movement, continuity, state and energy equations:

$$\frac{\mathrm{d}v}{\mathrm{d}x}v=-\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x}-\frac{f\,v^2}{2D},\; f=\left[1{,}74+2\lg\left(\frac{D}{2k}\right)\right]^{-2} \tag{1}$$

$$\rho v = M \tag{2}$$

$$\frac{p}{\rho}=ZRT,\; Z=1-\frac{9}{128}\frac{p}{p_c}\frac{T_c}{T}\left(6\frac{T_c^2}{T^2}-1\right) \tag{3}$$

$$\frac{1}{c_p}\left(\frac{1}{\rho}-T\left.\frac{\partial(1/\rho)}{\partial T}\right|_p\right)\frac{\mathrm{d}p}{\mathrm{d}x}+\frac{\mathrm{d}T}{\mathrm{d}x}=\frac{\pi K D}{\rho c_p Q}(T_a-T) \tag{4}$$

where f is the hydraulic friction coefficient, D - the inner diameter of the pipeline, k - the absolute harshness of the inner wall of the pipeline's pipe, M - the specific mass of gas flow, in kg/(m$^2\cdot$s), Z - the deviation factor from

the perfect gas law, p_c =46,5 bar - the critical pressure, T_c =190,5 K - gas critical temperature. c_p – gas specific mass isobaric heat, K - thermal transfer global coefficient from the gas to the medium, Q - the gas volumetric flow through the pipeline, T_a - absolute temperature of the medium where the pipeline is digged-in.
In order to calculate the global transfer coefficient K from equation (4) it is considered the serial transfer of heat for gas through forced convection to the pipe wall, through conduction in the pipe wall and the isolating stratum at soil and through soil to the medium. So we obtain the following relation:

$$\frac{1}{K}=\frac{1}{\alpha}+\frac{1}{\lambda_o}\ln\frac{De}{D}+\frac{1}{\lambda_i}\ln\frac{Di}{De}+\frac{1}{\lambda_s}\ln\left(2\frac{h}{Di}+\sqrt{4\left(\frac{h}{Di}\right)^2-1}\right) \tag{5}$$

where α is the forced thermal convective transfer coefficient between the gas and the inner wall of the pipe, λ_o λ_i λ_s - thermal conductivities of the steel, isolation and soil, *De*, *Di*- the external diameters of the pipe, respectively of the isolation, *h*- the deepness of pipeline digging - in. The forced convective thermal coefficient, between the gas and the inner wall of the pipe, is determined by using the formulas:

$$\alpha=\frac{Nu\,\lambda}{D};\ Nu=0{,}023\,Re^{0,8}\,Pr^{0,4};\ Re=\frac{v\,D}{\nu};\ Pr=\frac{\rho\,c_p\,\nu}{\lambda} \tag{6}$$

where *Nu Re* and *Pr* are the *Nusselt, Reynolds* and respectively *Prandtl* criteria, and λ ν , c_p and ρ- thermal conductivity, cinematic viscosity, isobaric specific heat and, respectively, gas density.
After a series of simple calculations, the movement equation (1) can be written,

$$\left(\frac{1}{p}-\frac{1}{Z}\frac{\partial Z}{\partial p}-\frac{1}{M^2R}\frac{p}{ZT}\right)\frac{\mathrm{d}p}{\mathrm{d}x}-\left(\frac{1}{T}+\frac{1}{Z}\frac{\partial Z}{\partial T}\right)\frac{\mathrm{d}T}{\mathrm{d}x}=\frac{f}{2D}, \tag{7}$$

and the energy equation (4) becomes

$$\frac{1}{T-T_a}\frac{T^2R}{p}\frac{\partial Z}{\partial T}\frac{\mathrm{d}p}{\mathrm{d}x}-\frac{c_p}{T-T_a}\frac{\mathrm{d}T}{\mathrm{d}x}=\frac{4K}{MD}. \tag{8}$$

Introducing the non-dimensional parameters by $\boldsymbol{P}=P/p_c$; $\boldsymbol{T}=T/T_c$; $\xi=x/L$, equation (7) becomes

$$\left(\frac{1}{\boldsymbol{P}}-\frac{1}{Z}\frac{\partial Z}{\partial \boldsymbol{P}}-\frac{1}{M^2R}\frac{\boldsymbol{P}}{Z\boldsymbol{T}}\right)\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}\xi}-\left(\frac{1}{\boldsymbol{T}}+\frac{1}{Z}\frac{\partial Z}{\partial \boldsymbol{T}}\right)\frac{\mathrm{d}\boldsymbol{T}}{\mathrm{d}\xi}=\frac{f\,L}{2D}, \tag{9}$$

and the energy equation (8) has now the expression

$$\frac{1}{\boldsymbol{T}-\boldsymbol{T}_a}\frac{\boldsymbol{T}^2R}{\boldsymbol{P}}\frac{\partial Z}{\partial \boldsymbol{T}}\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}\xi}-\frac{c_p}{\boldsymbol{T}-\boldsymbol{T}_a}\frac{\mathrm{d}\boldsymbol{T}}{\mathrm{d}\xi}=\frac{4KL}{MD}, \tag{10}$$

$\boldsymbol{T}_a$ being the adimensional temperature od the medium.
Regarding the thermal transfer global coefficient, we can notice the fact that its value is not constant through the pipeline, its value being essentially affected by the thermal dynamic properties variation of gases.

In order to solve the differential equations system (9) (10) we will use Runge-Kutta method, order four of numerical integration of ordinal differential equations systems. in order to numericcally approach the sytem we will write the movement equation (9) as

$$m_1 \frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}\xi} + m_2 \frac{\mathrm{d}\boldsymbol{T}}{\mathrm{d}\xi} = m_0 \tag{11}$$

where

$$m_0 = \frac{\lambda L}{2D},\ m_1 = \frac{1}{\boldsymbol{P}} - \frac{1}{Z}\frac{\partial Z}{\partial \boldsymbol{P}} - \frac{p_c^2}{M^2 R}\frac{\boldsymbol{P}}{Z\boldsymbol{T}},\ m_2 = \frac{1}{\boldsymbol{T}} + \frac{1}{Z}\frac{\partial Z}{\partial \boldsymbol{T}} \tag{12}$$

The energy equation (10) becomes now

$$e_1 \frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}\xi} + e_2 \frac{\mathrm{d}\boldsymbol{T}}{\mathrm{d}\xi} = e_0\,, \tag{13}$$

where

$$e_0 = \frac{4KL}{MRDc_P}\frac{\boldsymbol{P}}{Z\boldsymbol{T}}(\boldsymbol{T} - \boldsymbol{T}_s)\,;\ e_1 = \frac{\boldsymbol{T}}{Z}\frac{\partial Z}{\partial \boldsymbol{T}};\ e_2 = -\frac{1}{R}\frac{\boldsymbol{P}}{Z\boldsymbol{T}} \tag{14}$$

so that we can now express the solution of the differential equations system as

$$\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}\xi} = \frac{m_0 e_2 - m_2 e_0}{m_1 e_2 - m_2 e_1};\ \frac{\mathrm{d}\boldsymbol{T}}{\mathrm{d}\xi} = \frac{m_1 e_0 - m_0 e_1}{m_1 e_2 - m_2 e_1} \tag{15}$$

We also introduce the functions:

$$\Phi(\boldsymbol{P},\boldsymbol{T}) = \frac{m_0 e_2 - m_2 e_0}{m_1 e_2 - m_2 e_1},\ \Psi(\boldsymbol{P},\boldsymbol{T}) = \frac{m_1 e_0 - m_0 e_1}{m_1 e_2 - m_2 e_1} \tag{16}$$

which help at solving the differential equations system (16) by using Runge-Kutta numerical method order four. In order to numerically approach the problem we will sectionalize the transport pipeline into n sections of 1000 m length. The values of the two gaseous-dynamic non-dimensional parameters when entering the section will be $\boldsymbol{P}(\xi_i) = P_i$ and $\boldsymbol{T}(\xi_i) = T_i$, and when getting out of the section, $\boldsymbol{P}(\xi_{i+1}) = P_{i+1}$ and $\boldsymbol{T}(\xi_{i+1}) = T_{i+1}$, calculated by using the algorithm of Runge-Kutta method order 4. On the basis of the shown algorithm it has been elaborated the specialized software **RUNKUT4** that traces the pressure variation curves and respectively the gas temperature through the transport pipeline

In order to experimentally check the proposed pattern irt has been selected the main gas pipeline Coroi-Şinca-Bucureşti Titan, whose total length is of 320 km of steel pipe Φ 813x11 mm, and it is designed with a compression station in Şinca, at 100 km. The measurements have been realized on the Coroi-Şinca section, whose length is of 100 km, and their aims were:

-the real flow of the transported gas, measures when entering the pipeline; that was 275.000 $\mathrm{Nm^3/h}$;

-gas pressure when entering the pipeline which was e 26,25 bara;

-gas temperature when entering the pipeline, which was 30 $^{\circ}$C

-gas pressure when getting out of the section, which was 17,0 bara;

-gas temperature when getting out of the section, which was 10 $^{\circ}$C.

-medium temperature, in the marchland of gas entrance in the pipeline, which was 10 $^{\circ}$C. This was considered to be the medium average temperature.

The specialization software"**RUNKUT4**" has been used for these values, obtaining the curves shown in figure 1. The resulted pressure of the gas when getting out (Şinca) is 17,1456 bara and the gas indicated temperature is 9,54 ^{o}C. We can conclude that the obtained values are **very close to** those obtained by measurements.

RUNKUT4

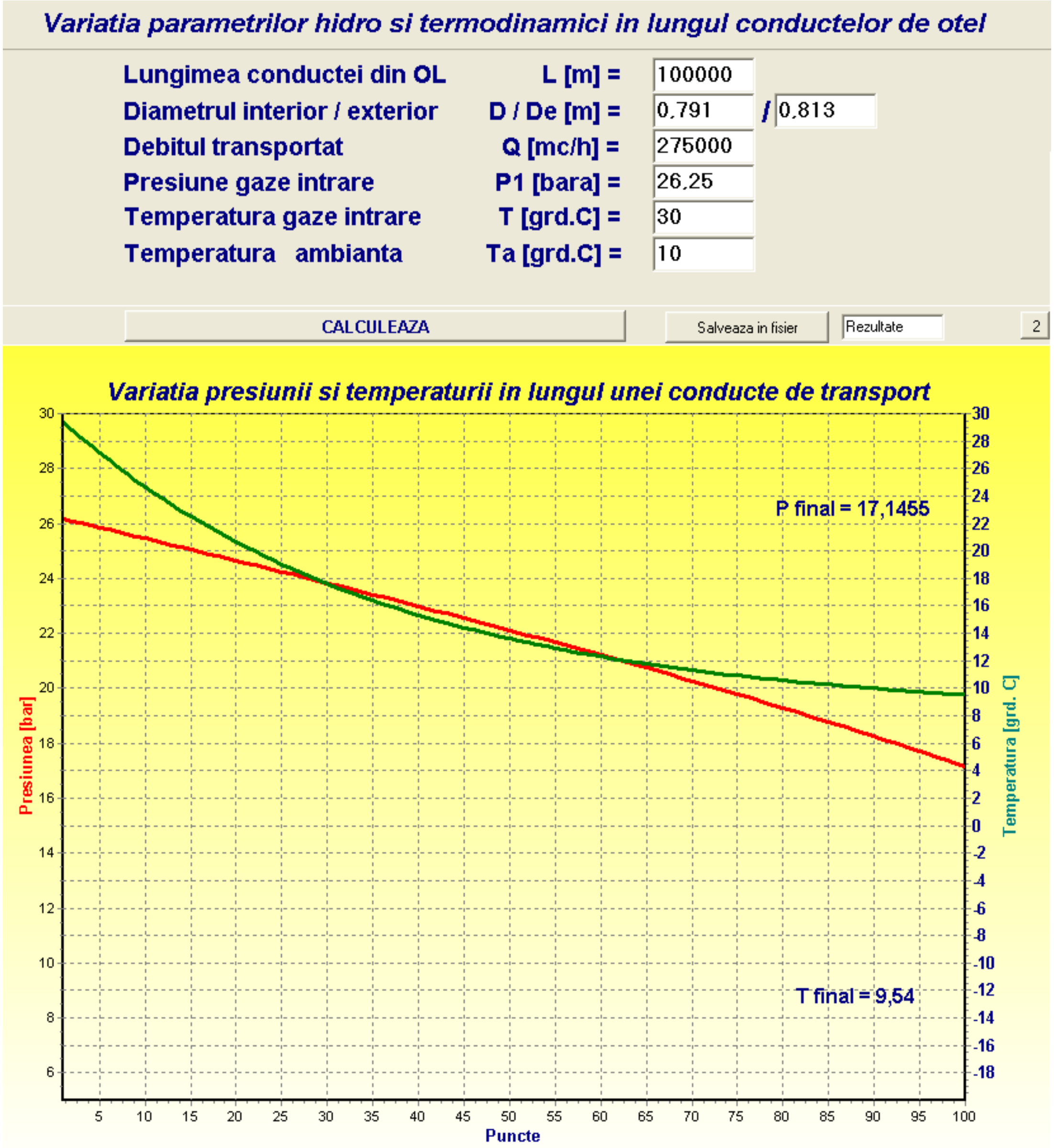

Figure 1

3. RESULTS OF THE SIMULATIONS

In order to notice the influence of pipelines digging – in on pressure and temperature according to the medium temperature variation, the specialized software **RUNKUT4** was used for the same data base, but for different medium temperature.

The curves of variation of the gases pressure and temperature at the final edge of the pipiline are shown in figure 2. For medium temperature variation between -20 ^{o}C and +20 ^{o}C gas pressure varies from 18,05 bara to 16,83 bara and temperature from -18,69 ^{o}C to +18,84 ^{o}C.

By analysing the two curves we can notice the fact that the thermal effect of the pipeline digging in the soil is significant on the real pressure and temperature from the final edge of pipeline

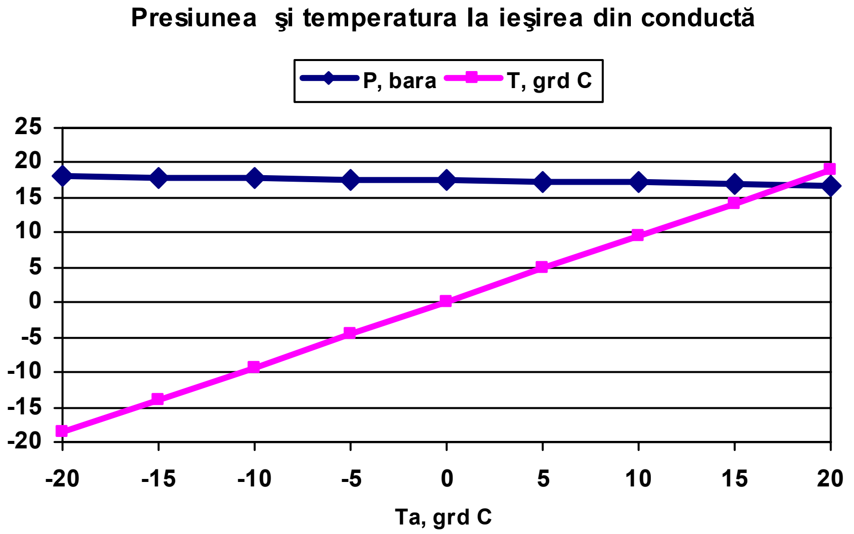

Figure 2

4. CONCLUSIONS

The proposed mathematical pattern takes into consideration the variation of all gaseous-dynamic parameters in the pipeline. Its experimental checking with an insignificant error gives it its correctness.
The medium temperature plays an important role in the gas temperature allotment through the pipeline, at the end having close values (even lower) to the medium temperature. During the cold season there may appear cryohydrates if the gases are wet.
As a conclusion, the proposed pattern offers accuracy for the calculation of pressure and temperature allotment through the natural gas pipelines.
The specialized software **RUNKUT4** can be easily used both in the research field and in the design field when such accuracy is required.

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