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ANALYSIS OF THE TEMPERATURE FIELD OF THE GAS PIPELINE COLLECTOR USING CFD MODELING

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Abstract: Article discusses about influence of natural gas flow through gas pipeline collector on the the surrounding temperature field. Gas pipeline collector is part of the transit transport networkand affects the total temperature profile of natural gas. Collector consists of several layers of materials, with different physical characteristics. In the article is stated a mathematical model, algorithm and relationsby means of which was set the temperature field. For analysis were used programs for design and simulation– Autodesk Inventor Proffesional, Autodesk Simulation Multiphysics. Temperature field around the gas-pipeline in a graphical view is output of modeling process.
Keywords: CFD model, gas pipeline collector, temperature field, natural gas

1. INTRODUCTION

The gas collector is designed to equalize pressures of each gas transit lines of the gas-pipeline.In the Slovak transit system there are four gas pipeline collectors. By the analysis of the temperature field we can determine the depth and intensity that affect the transported gas surrounding soil in terms of temperature.Analyzed collector is located between the compressor station KS01 in Veľké Kapušany and KS02 in Veľké Zlievce.For calculations of the temperature is important total analysis of all factors which affect transfer of heat from gas through the pipeline layersin the soil. Among the key factors belongs material composition of the transit gas pipeline and soil, size, shape and depth of the gas collector deposit, temperature of transported gas and surrounding temperature, flow and gas pressure.[1, 2]

2. TRANSIT GAS PIPELINECOLLECTOR

2.1. Characteristics of gas collector

As previously mentioned, the main task of the gas collector is pressure compensation during the transportation of natural gas. Five lines of transit pipeline enters the collector, in the collector there is a mixing of particles of gas and are redistributed into four lines, leaving the collector.Scheme of the collector is stated on Figure 1. The entire transit system, including collectors is stored in the ground (depth of about 1.2 m). [3, 4]

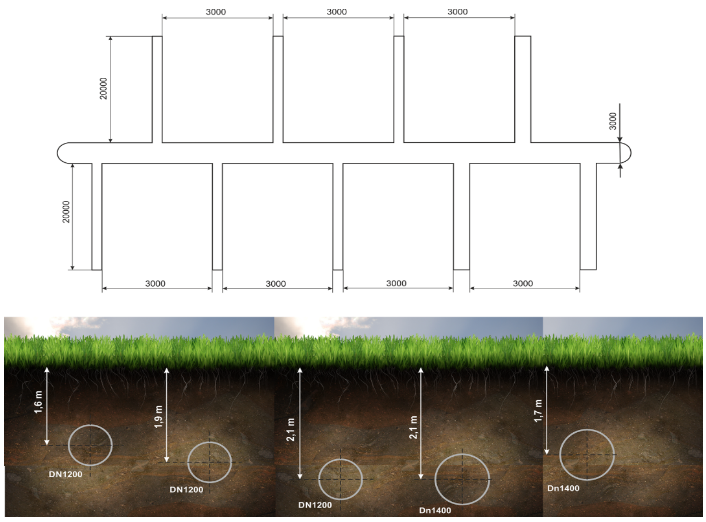

Figure 1. Dimensions of gas collector and depth deposit of individual lines of transit gas pipeline

Material composition of the linear part of the transit gas pipeline and collector is following (Figure 2.):

- ✓ Three-layer polyolefin insulation is being used, it is combination of thermoset epoxy powder (FBE) copolymer adhesives and thermoplastic outer packaging (polyethylene)
- ✓ Copolymer adhesive provides the connection with epoxy outer shell, which provides mechanical protection of the epoxy coating and steel pipes
- ✓ polyolefin insulation is applied to the outer surface of steel pipes
- ✓ Type of steel used for the transit gas pipeline is API X 70 Steel
- ✓ Physical properties and thicknesses of each material of gas pipeline are given in Table 1.

Table 1. Material composition of the transit gas pipeline [4]

Material	λ [W.m-1.K-1]	c_p [J.kg-1.K-1]	ϱ [kg.m-3]	β [K-1]	a [m2.s-1]	Thickness [mm]
X 70 Steel	21	490	7850	13	$5{,}45.10^{-6}$	15
Epoxid	0,45	1200	1200	55	$3{,}12.10^{-7}$	0,25
Polyetylén	0,2	2250	1400	200	$6{,}34.10^{-8}$	5

λ – thermal conductivity, c_p – heat capacity, ϱ – density, β – coefficient of thermal expansion, a – temperature coefficient of conductivity

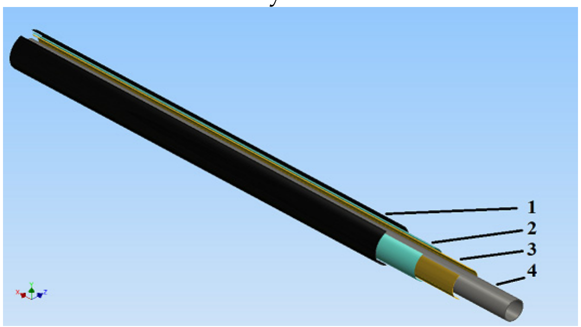

Figure 2. Material composition of the transit gas pipeline [3]. 1 – polyethylene thermoplastic outer protective covering, 2 – copolymer adhesive, 3 – thermoset epoxy cover, 4 – steel pipe (API X 70 Steel)

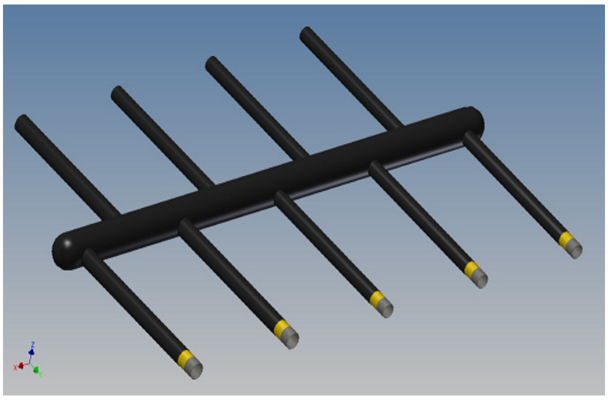

Figure 3. Design of the gas collector

2.2. Design of the gas pipeline collector

The collector was designed in Autodesk Inventor Proffesional 2013, with special attention to the compliance of the actual geometry and dimensions (Figure 3).

In the next steps we worked only with simulation program Autodesk Simulation Multiphysics. After designing the model on its of each parts created computer network.

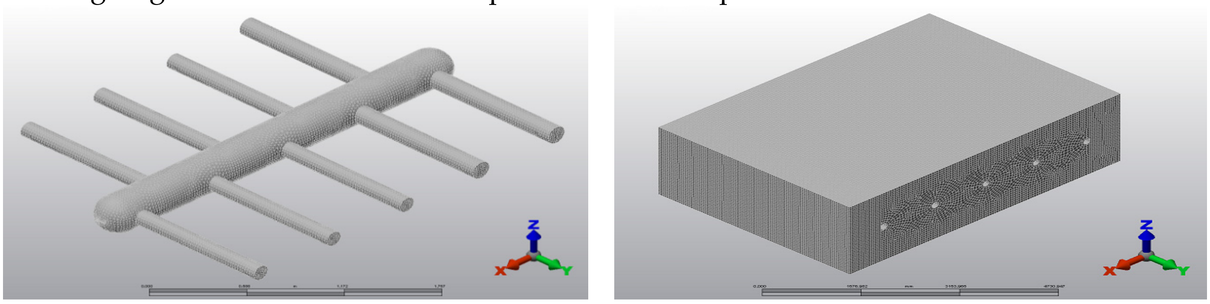

Figure 4. Created grid in the collector (left) and models (right)

When designing the network it had to be done from the analysis for which the calculations were carried out.As seen in the Figure 4. selected network type is tetrahedral, network is relatively sparse, because hardware computer equipment had to be considered, at softer net the calculation is more accurate but also more demanding on computing power as well. The biggest problems at networknig were at arc endings and collector connections on each line.[4, 5]

3. MATHEMATICAL DESCRIPTION OF THE CALCULATION OF THE TEMPERATURE AND PRESSURE PROFILE OF NATURAL GAS

3.1 Temperature and pressure regime of natural gas

During transportation of natural gas, pressure significantly affects decrease in temperature. For calculation of pressure losses in each elementary sections formula for horizontal gas-pipeline was used (1).

$$p_p^2 - p_k^2 = \frac{\lambda.m^2.Z.r.T_s.x}{F^2.d}\,[MPa] \qquad (1)$$

where p_p is initial pressure [MPa], p_k is final pressure [MPa], λ is resistance coefficient, m is mass flow of the gas in the pipeline [kg.s^{-1}], Z is compressibility factor, r is specific gas constant [J.K^{-1}.kg^{-1}], T_s is middle gas temperature [K], x is elemental section of pipeline [m], F is pipeline surface [m^2], d is internal diameter [m]

The basic prerequisite for the calculation of pressure drop in the pipeline is to determine the appropriate value of the coefficient of resistance, which in itselt implies the complex nature of flow effects resulting from the properties of the pipe (diameter, surface roughness of the pipe). Equation for the area of roughness pipes, re > re_{k2}[6]

$$\lambda = 0{,}111.\left(\frac{e}{d}\right)^{0{,}25} \qquad (2)$$

Temperature of the flowing gas in the pipeline depends on physical conditions of the gas movement and heat exchange with surrounding. For the calculation of the gas temperature decrease after each elementary section is valid following formula:

$$T = T_{ok} + \left(T_p - T_{ok}\right).e^{-A.l} - D_{J-T}.\frac{p_p - p_k}{l}.\frac{1-e^{-A.l}}{A}\,[K] \qquad (3)$$

where T_{ok} is temperature of the surrounding area [K], T_p is natural gas temperature [K], A is base flat [m], l is total length of the pipeline [m], D_{J-T} is Joule-Thomson coefficient [K.MPa]

Equation (3) characterizes the temperature distribution along the length of the gas-pipeline. The last term in equation characterizes the Joule-Thomson effect. The influence of Joule-Thomson effect causes a temperature drop in the interval 4 – 6°C.

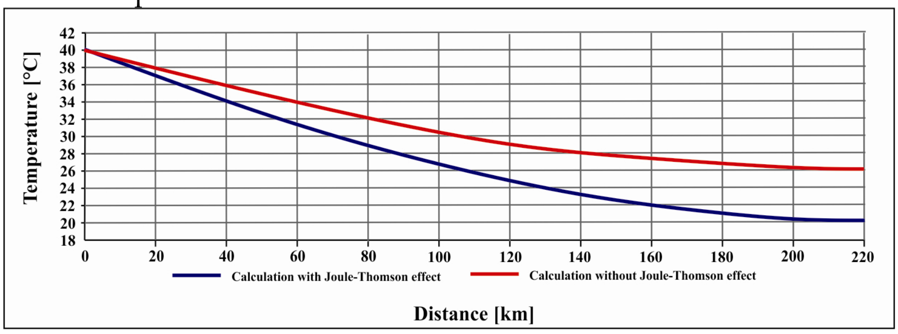

Figure 5. The temperature drop with and without affecting the Joule-Thomson effect

Fig. 6 shows temperature and pressure drop along the whole length of the gas-pipeline (Places with rapidly increasing temperature and pressure because of the increase both physical parameters at the outlet of the compressor station).

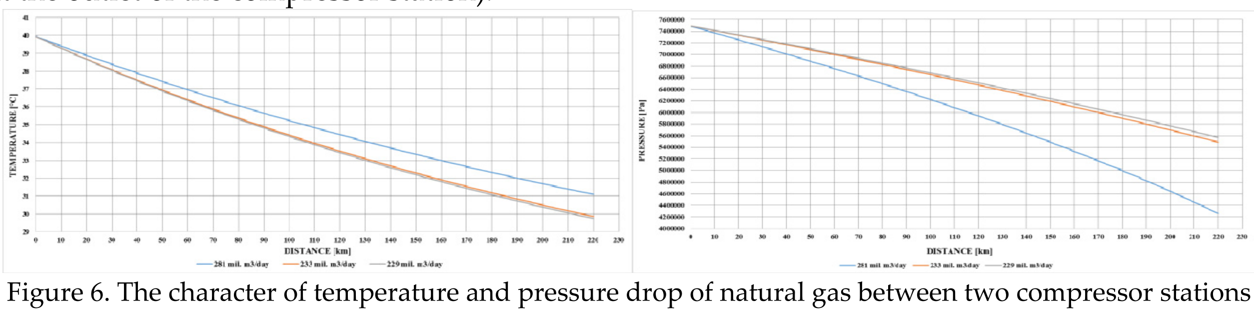

Figure 6. The character of temperature and pressure drop of natural gas between two compressor stations

During transport of the natural gas in transit pipeline, ball valves, gas collectors and other gas systems there is a change of pressure and temperature of transported natural gas in consequence of expansion or compression of natural gas. This phenomenon is characterized by the Joule-Thomson effect and the value μ_{J-T} and it is called the Joule-Thomson coefficient. In the process of expansion when the gas is in thermodynamic equilibrium, this process is called isentropic expansion. In this case gas performs work during expansion and its temperature is lowered. In the expansion gas does not do any work, and it does not absorb any heat, internal energy of the gas is maintained. Ideal gas temperature remains constant, but the real gas temperature may change depending on the temperature and the pressure. If the gas pressure drops to 0,1 MPa, its temperature drops to 0,25°C.[7]

$$\mu_{J-T} = \left(\frac{\Delta T}{\Delta p}\right)_H$$

3.2. Calculation of temperature field in cylindrical wall

The method of elementary balances was used to resolve unsteady heat transfer in three dimensional temperature field. For each element is formulated balance equation and from the way of solving it is possible to create an algorithm for whole temperature field. For values *Δr, Δϕ, Δz* uses the following simplifications:

- ✓ inside each element are isothermal surfaces parallel
- ✓ heat flux passing through within the interval (*i.Δτ, (i+1)Δτ*) by specific area is proportional to the temperature gradient at time (*i.Δτ*)
- ✓ enthalpy change of element is a function of temperature change in the middle of an element

Transient heat transfer by conduction in the element is in interval <*i.Δτ, (i+1)Δτ*> characterized by:

- ✓ enthalpy change due to the heat transfer by conduction between neighboring elements through each layers of element
- ✓ by the enthalpy change of element there is a change of temperature in element

Transit pipeline has a cylindrical shape so it is necessary to perform a calculation in cylindrical coordinates. The beginning of the coordinate system is placed in a thermally isolated suface of the cylinder, the axis of the cylindrical coordinates will by placed on the axis of the cylinder. System of equation of heat transfer in a cylindrical wall has the form:

$$\tau > 0;\ r_1 < r < r_2;\ 0 < \varphi < 2\pi;\ 0 < z < L \qquad (4)$$

$$\frac{\partial T(r,\varphi,z,\tau)}{\partial \tau} = a\left[\frac{\partial^2 T(r,\varphi,z,\tau)}{dr^2} + \frac{1}{r}.\frac{\partial T(r,\varphi,z,\tau)}{dr} + \frac{1}{r^2}.\frac{\partial^2 T(r,\varphi,z,\tau)}{d\varphi^2} + \frac{\partial^2 T(r,\varphi,z,\tau)}{dz^2}\right]$$

The principle is to create elements, in which temperatures are monitored. Each element has determined spatial coordinate system at a distance Δz diversions according to the angle Δϕ and spacing depending on the radius Δr. Points corresponding to the individual surfaces of the element are indicated as 0, a, b, c, d, e, f (Figure 7), while the value of the temperature at the point 0 is determined by the listed points.[8]

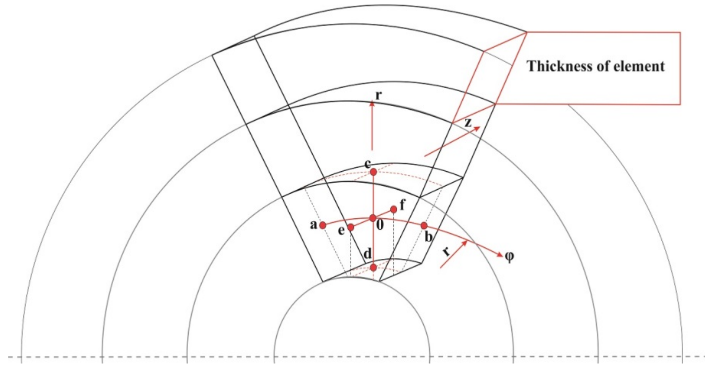

Figure 7. Calculate of element of computing mesh

Computing mesh:

- ✓ In the direction of the radius 0, 1, 2, 3, ... i-1, i, i+1
- ✓ In the direction fo the axis z 0, 1, 2, 3, ... m-1, m, m+1
- ✓ In the tangential direction 0, 1, 2, 3, ... n-1, n, n+1
- ✓ $T_{i,n,m,k}$ – temperature value at the point of computing mesh 0 (r_i, ϕ_n, z_m)
- ✓ $T_{i-1,n,m,k}$ – temperature value at the point of computing mesh d (r_{i-1}, ϕ_n, z_m)
- ✓ $T_{i+1,n,m,k}$ – temperature value at the point of computing mesh c (r_{i+1}, ϕ_n, z_m)
- ✓ $T_{i,n-1,m,k}$ – temperature value at the point of computing mesh a (r_i, ϕ_{n-1}, z_m)
- ✓ $T_{i,n+1,m,k}$ – temperature value at the point of computing mesh b (r_i, ϕ_{n+1}, z_m)
- ✓ $T_{i,n,m-1,k}$ – temperature value at the point of computing mesh e (r_i, ϕ_n, z_{m-1})
- ✓ $T_{i,n,m+1,k}$ – temperature value at the point of computing mesh f (r_i, ϕ_n, z_{m+1})

For the temperature in the next time step is:

$$T_{i,m,k+1} = \left[1 - 2\left(\Delta Fo_r + \Delta Fo_\varphi + \Delta Fo_z\right)\right]T_{i,m,k} + \Delta Fo_r\left(1 - \frac{\Delta r}{2r_i}\right)T_{i-1,m,k} + \Delta Fo_r\left(1 + \frac{\Delta r}{2r_i}\right)T_{i+1,m,k} + \Delta Fo_\varphi\left(T_{i,m-1,k} + T_{i,m+1,k}\right) + \Delta Fo_z\left(T_{i,m-1,k} + T_{i,m+1,k}\right) \quad (5)$$

and:

$$\Delta Fo_r = \frac{a.\Delta\tau}{\Delta r^2};\ \Delta Fo_\varphi = \frac{a.\Delta\tau}{r_i^2.\Delta\varphi^2};\ \Delta Fo_z = \frac{a.\Delta\tau}{\Delta z^2} \quad (6)$$

The equation shows that, when the temperature at the point 0 is known, as well as in neighbouring points that surround this point in time τ_k temperature field in the layer of the cylinder at the moment of time τ_{k+1} is counted.

4. ANALYSIS OF THE TEMPERATURE FIELD

After creating a computing network in the next step boundary conditions for each of the model were defined. Since this is a flow of fluid and heat transfer in the current environment,simulation of flow followed by mixing particles of natural gashad to be done. The result of the analysis is the pressure and velocity field.

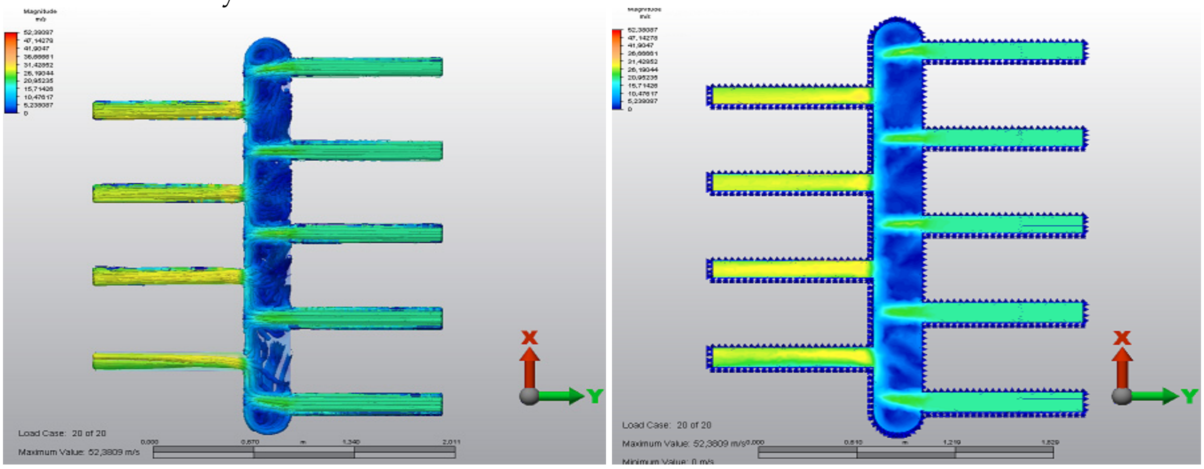

Figure 8. Velocity field of natural gas

Boundary conditions for the flow (Figure 9):

- ✓ inlet pressure 7 MPa
- ✓ flow 50 mil.m³/hourfor each line
- ✓ Velocity 30 m³/s for each line

Boundary conditions for temperature course (Figure 10):

- ✓ Temperature of natural gas 30°C
- ✓ The temperature on the ground (surface) 40°C
- ✓ Physical parameters for the tube material
- ✓ Heat flow for each material (program involves another subroutine for calculation)

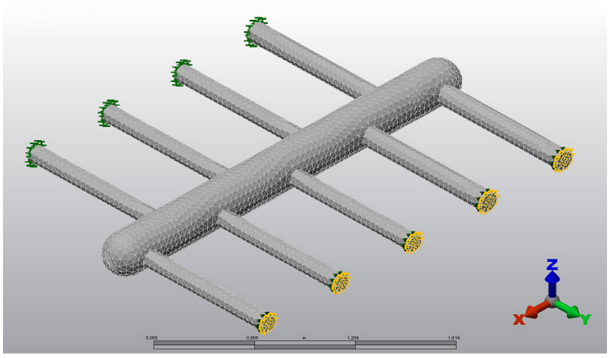

Figure 9. Boundary conditions for flow analysis

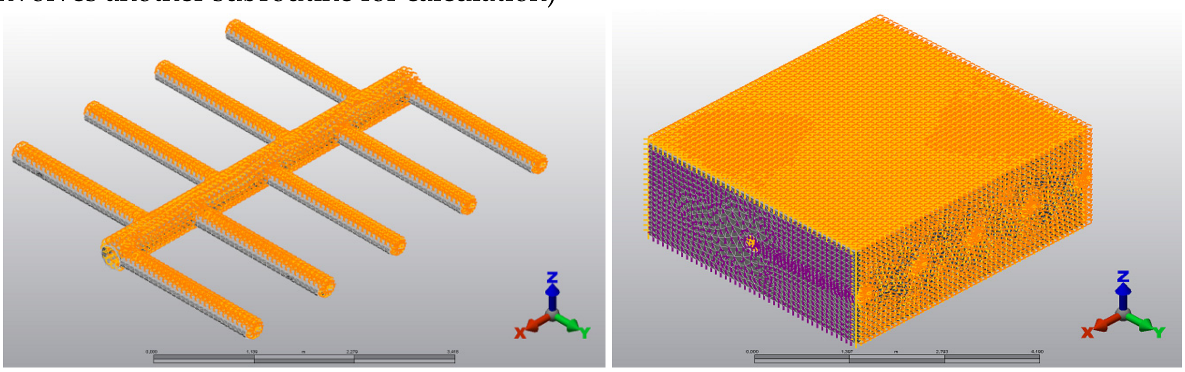

Figure 10. Boundary conditions for heat transfer analysis

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For a better understanding of the temperature field solution, simplified algorithm calculation procedure from Autodesk Simulation Multiphysics is given below (Figure 8).

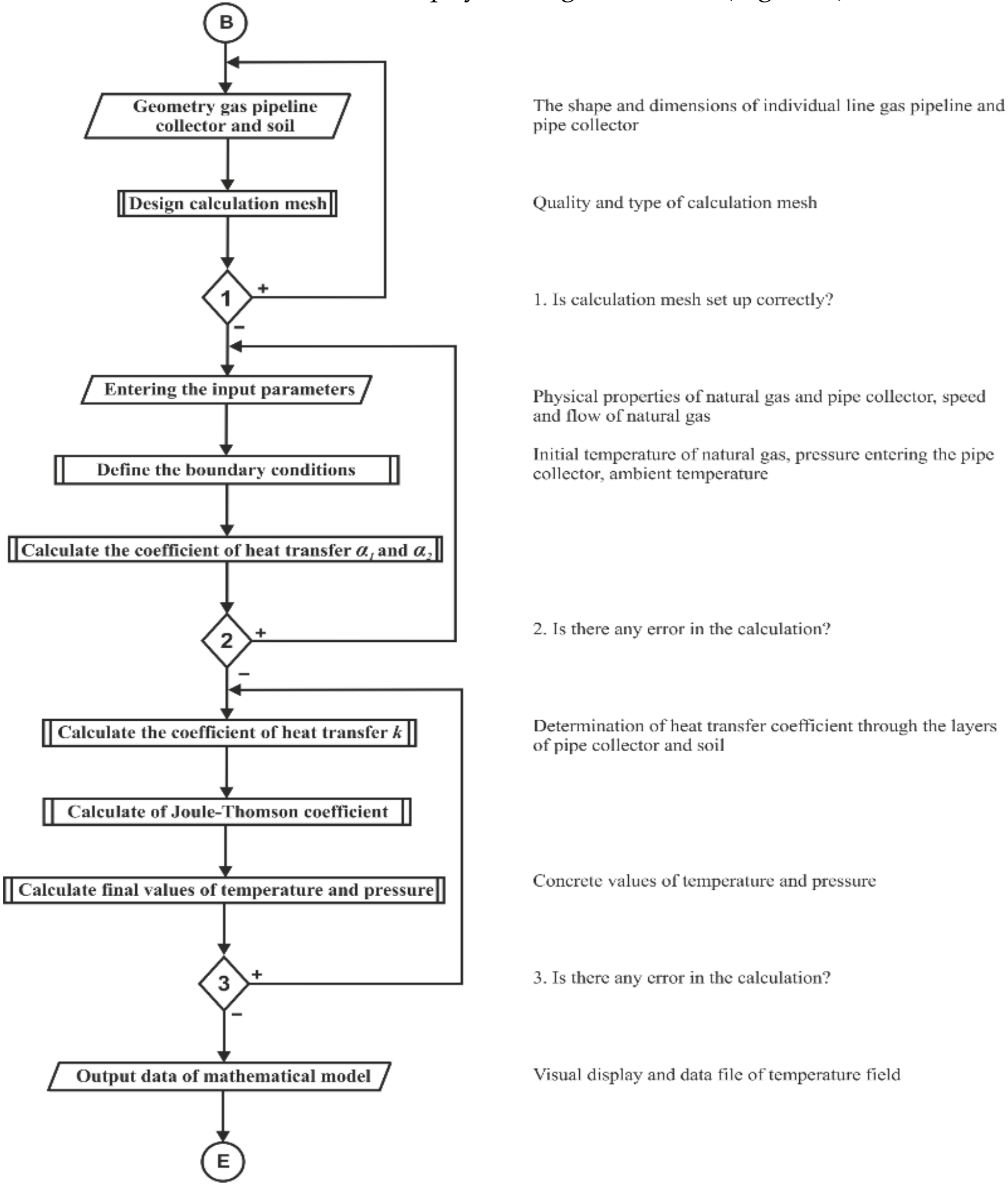

Figure 11. Simplified algorithm computation of the temperature field

5. RESULTS AND CONCLUSION

This contribution was being devoted to determination of the temperature course and identifying the impact of natural gas temperature transported in the transit gas pipeline collector on the surrounding environment. After designing the collector, the computing network was being created under which the analysis of boundary conditions for the modelwas being performed.

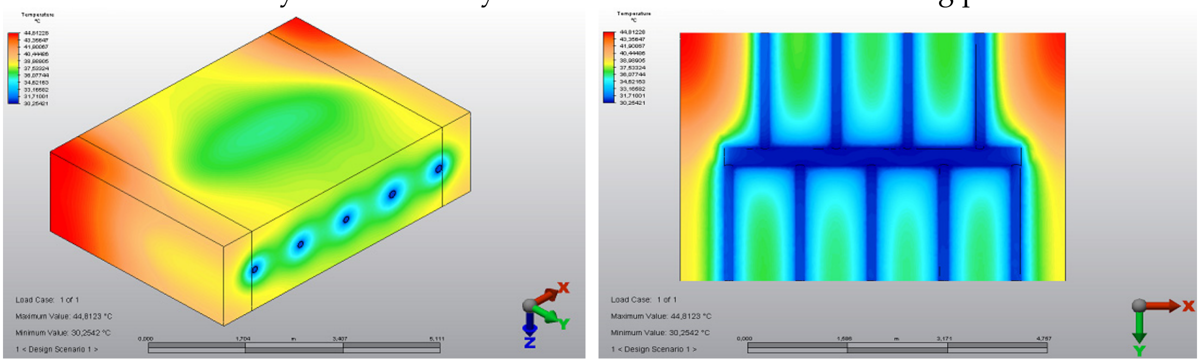

Figure 12. Graphical representation of the Temperature Field on the earth's surface (left) and temperature course in cut (right)

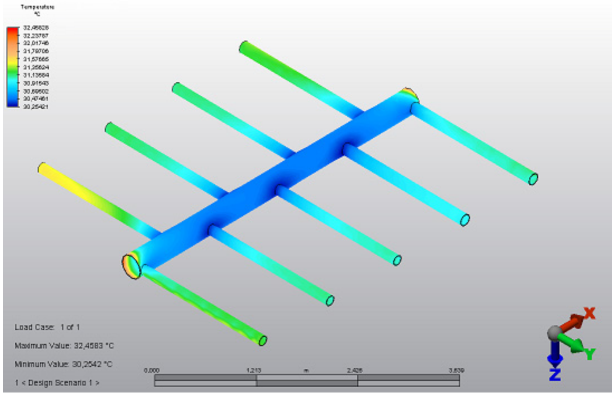

Figure 13. Temperature distribution on the actual gas collector and each transit lines

First calculation was made for the flow in order to determine velocity and the pressure field and then set the boundary conditions for the heat transfer and start the calculation.Based on the analysis we can deduce the following conclusions:

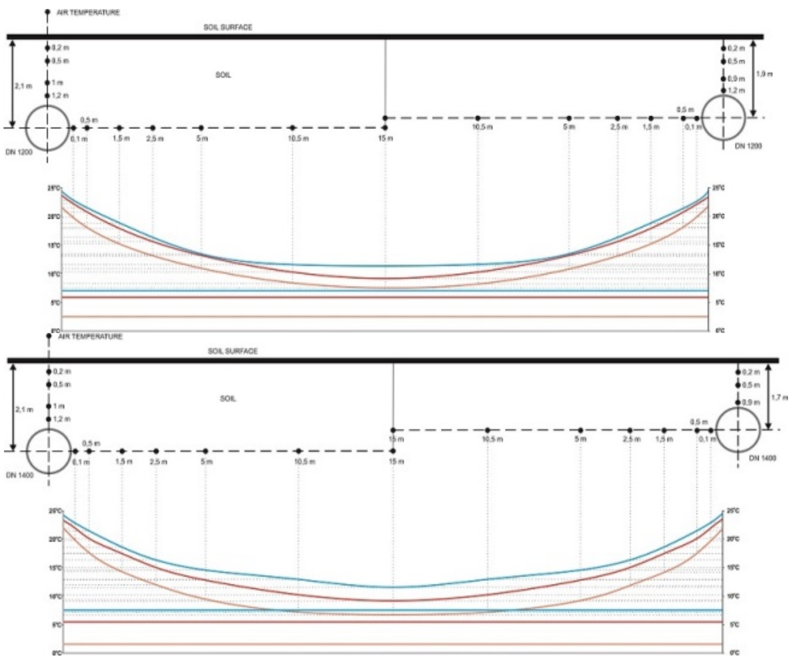

Figure 14. Temperature course between 2. and 3. line (left), 4. and 5. line (right) of transit gas pipeline

- ✓ Temperature of natural gas has a direct effect on the isotherms around gas pipeline
- ✓ At gas temperature 30°C and soil temperature 40°C leads to cooling of the soil as it is shown in Figure 12., each line of the transit gas pipeline do not affect temperatures on the ground surface so significantly. In the case of shared pipeline where is mixing of natural gas from each line, there is considerable temperature decrease, it is related to the pressure decreases, which is proportional to temperature.
- ✓ According to the analysis result, line also influence each other (Figure 12.view in cut) and so there is a temperature decrease between the lines in their surrounding area.
- ✓ Figure 13. shows temperature course on the gas collector, where surface temperature is between 30 - 32°C at ambient temperature 40°C
- ✓ It can be said that the transit gas pipeline itself does not affect the temperature field into high rate, but collectors positioned between the compressor stations significantly cools the surrounding soil, which can have a negative impact on production potential

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