ISSN 1848-0071
UDC 622.691+620.9)=111
Recieved: 2012-03-22
Accepted: 2012-04-18
Preliminary communication

EFFECT OF TEMPERATURE DISTRIBUTION AROUND PIPELINES FOR TRANSPORTATION OF NATURAL GAS ON ENVIRONMENT

DÁVID SZÉPLAKY, ZSOLT VASZI, AUGUSTIN VARGA

Faculty of Metallurgy, Technical University in Košice, Košice, Slovakia
e-mail: zsolt.vaszi@tuke.sk

The article shortly presents in the first part the transit system of Slovakia, through that the natural gas flows to Czech Republic, Austria and Germany. The compressor station KS1 – Veľké Kapušany is also described. The throughput of this compressor station plays an important role, because this station is the entry to the transit system of the Slovak Republic. In the second part of the presentation shown are the results from the software application for finding the best combination of the aggregates used in gas transport. The theoretical foundation of the change of the temperature distribution around the pipeline and its impact upon the environment is described in the present paper.
Key words: temperature distribution, transportation of natural gas, effect on environment.

Utjecaj raspodjele temperature oko cijevi za transport prirodnog plina na okoliš. Članak u prvom dijelu ukratko prikazuje tranzitni sustav plinovoda u Slovačkoj kojim se prirodni plin transportira prema Češkoj, Austriji i Njemačkoj. Također, opisana je i kompresorska stanica KS1 – Vel'ké Kapušany. Propusni kapacitet te kompresorske stanice ima važnu ulogu jer navedena stanica predstavlja ulaz u tranzitni sustav Slovačke. U drugom dijelu članka prikazani su rezultati primjene programskog paketa za pronalaženje najpovoljnije kombinacije agregata u transportnom sustavu. U članku su također prikazane teorijske osnove promjene raspodjele temperature oko cijevi i njen utjecaj na okoliš.
Ključne riječi: raspodjela temperature, transport prirodnog plina, utjecaj na okoliš.

INTRODUCTION

Recently, a great attention is paid to the gas transport as an important energy media exploited not only for the heating but also for variety of technology purposes. The economical aspect of this transport plays major role. Transport is assumed by various driving aggregates and they may affect cost and safety related to their capacity and efficiency. The task of the transit system of natural gas transportation is to carry the large volumes of natural gas over the long distances, i.e. from the source to the consumers alone. Annual capacity of the transported network is more than 93 billions m^3 of natural gas, which is about 15 times more than the domestic consumption of natural gas in Slovakia [1-3].

The temperature distribution around the pipelines plays an important role in gas transit because following the compression, the natural gas has to be cooled down, and this affects the environment and mainly the soil around the pipeline.

CHARACTERISTICS OF COMPRESSOR STATIONS

There are four compressor stations representing the major technological complexes along the overall distance of about 115 km of the transit pipeline on the territory of Slovakia [4]. There are the technological devices called aggregates in these stations. These aggregates provide the required transport by increasing the pressure level to compensate the pressure loss in pipes and to ensure the contracted amount of pressure and volume of the natural gas to the border overtaking points. Characteristics of the individual stations with the number of aggregates are given in Tab 1.

Table 1. Distribution and number of aggregates
Tablica 1. Raspodjela i broj agregata

Major technological equipments	Veľké Kapušany	Jablonov nad Turňou	Veľké Zlievce	Ivanka pri Nitre
TS 6 MW	23	21	22	22
ES 25 MW	3	3	3	-
T 23 MW	1	1	2	4
R 28 MW	3	2	-	-

Compression station KS1 –Veľké Kapušany is the most important point in the transit system in Slovakia and therefore its throughput determines the performance of the transit system of the Slovak Republic. Information about compressor aggregates in the Tab 2.

Table 2. Compressor aggregates
Tablica 2. Kompresorski agregati

Aggrega-tes	Range speed (rev.min^{-1})	Max usable speed (rev.min^{-1})	Pursuit of the projec. (MW)	Max capacity		Number of aggregates		Maximum compre-ssion ratio
				Summ er (MW)	Winter (MW)	Max.	Immedi at. use	
GT750-6 MW	3.800-5.600	5.300	6	5,5	6	19	16	1,22$^{3)}$
NP PGT 25	3.250-6.500	6.200	22,67	19$^{1)}$	20,5$^{1)}$	1	1$^{2)}$	1,46
Cooper – Rolls	3.120-5.050	4.700	27,426	25	28	3	2	1,45
Electrical drives	2.600-3.900	3.700	25	25	25	3	2	1,45
GE **	4.250-6.405	6.300	34			3		1,75

1) Restrictions on the quantity of emissions generated in the further improvement to performance exceed the limit sets
2) Under operation may also be 3CR with 1NP, but in practice only 3 aggregates operate and one is left in reserve.
3) In the two-stage operation the compression ratio is 1.44 max.
**) New aggregates in KS1

SOFTWARE FOR THROUGHPUT SIMULATION

To find the best combination of the aggregates used in compressor station KS 1 – Veľké Kapušany software was designed based on mathematical model. The inputs to this software were: ambient temperature, temperature of natural gas before compressing, natural gas flow through the compressor and pressure of the natural gas. The results from the solution were: the natural gas flow through the aggregate as depending on the input parameters, nominal gas consumption by the turbine and nominal consumption by the compressor, and the compressor type for the inlet flow. The results are shown on Fig. 1 where p_1 is the inlet pressure to the aggregate, ε is the compression ratio and T_1 is inlet temperature to the aggregate.

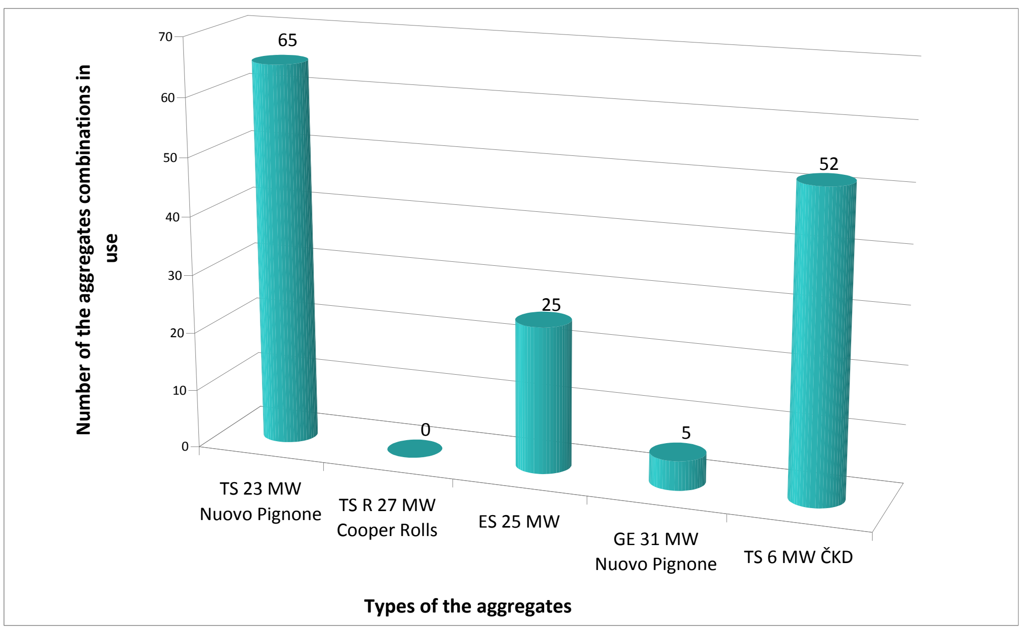

Figure 1. Aggregates combination in use for the inlet parameters p_1=4,3 MPa, ε=1,25, T_1=15^{o}C
Slika 1. Kombinacija agregata u upotrebi za ulazne parametre: p_1=4,3 MPa, ε=1,25, T_1=15,0°C

TEMPERATURE DISTRIBUTION IN SOIL AROUND PIPELINES

After the natural gas compression exploiting the aggregates used in compressor stations the temperature of the transported gas increases. The cooled gas leaves the compressor station with temperature around 30°C. This value is not a constant for the entire length of the pipeline between the compressor stations, but after a certain distance it decreases. The gas temperature affects the environment, pressure losses during transport, maintenance of the pipeline insulation and soil characteristics (fertility). The soil temperature affects also the physical, chemical, physico-chemical reactions in the soil, soil moisture and its viscosity. If the soil temperature drops below 9°C or rises above 50°C, such conditions lead to the lower soil fertility [5].

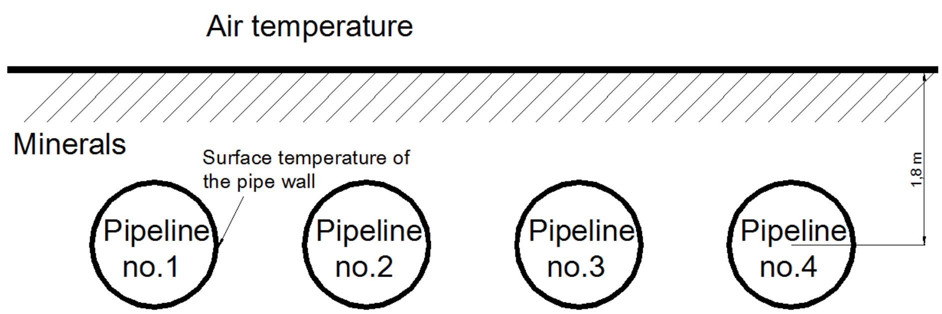

Figure 2. The pipeline distribution in soil
Slika 2. Raspored cijevi u tlu

Heat transfer analysis

In general, the heat transfer between the gas and the environment involves these basic modes:

1. Convection between the gas and wall of the pipe
2. Conduction of heat in the layers of the wall pipe
3. Heat conduction in soil
4. Convection between the surface of the soil and air
5. Radiation

An important issue in the analysis of heat transfer is that which of the above methods is essential and which are negligible. The importance of this issue is not only the accuracy of the model of transmission, but in the ways of handling input and output variables.

Heat conduction in soil varies with soil composition and water contect. Convection from the soil surface depends on the shape of the soil surface, the season of the year, the prevailing direction and velocity of the wind, planted crop, etc.

The analysis of heat transfer did not include the point 4 (convection between the surface of the soil and air) and point 5 (radiation), because they are not considered as having a significant effect.

Generally, heat transfer is determined by the following equation:

$$\mathbf{Q = k \,.\Delta T \,.\, A} \qquad (1)$$

where:
Q - is heat flow [W];
k – heat transfer coefficient[W.m^{-2}.K^{-1}];
ΔT - temperature difference [K];
A - area [m^2].

Heat transfer by convection

Fig. 3 temperature shows the heat transfer by convection between gas and the wall of pipe, where the values are thermal conductivities λ_1, λ_2, λ_3 and λ_4; diameters d_1 to d_4 and temperatures of the pipe T_1 to T_4. This type of heat transfer is realised through the movement of macro-particles (clusters of molecules) of gas which collide reciprocally and with the wall of pipe.

When the gas flow due to external forces, this mode is called forced convection. The gas in the transit pipeline flows almost at a very high Reynolds numbers and within the turbulent or transition range.

Such flow is characterized by chaotic motion of gas macro-particles and their mutual mixing. When addressing the problems of heat transfer in engineering practice, mainly applied are the methods of the physical similarity.

Their advantage is the reduction of the number of unknown variables that describe the observed phenomenon.

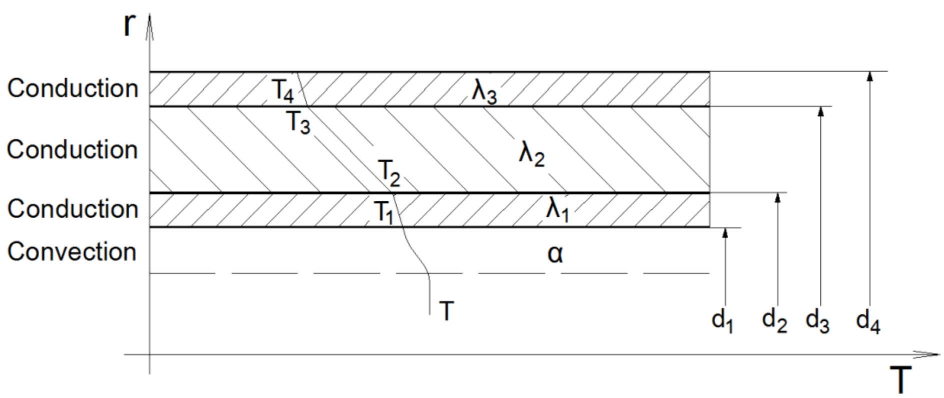

Figure 3. Heat transfer in the pipeline wall
Slika 3. Prijenos topline u stjenci cijevi

Heat transfer through the pipeline wall

Heat transfer through the wall of the pipe is realized by the conduction. The conduction is a typical method of heat transfer in solid materials. The forms of heat transfer by conduction were studied in the case of gas pipeline section:

1. Conduction through the pipe wall layers (coating – wall – protective coating)
2. Conduction to the ambient surround-ding in which the pipeline is placed (soil).

It is assumed that the volume V (the considered volume is in our case in the pipe wall thickness times section length) with no internal heat source.

The phenomenon is considered to be stationary, the material of pipe as an isotropic one (thermal conductivity λ is constant). Under so stated conditions the temperature distribution is described by Laplace equation:

$$div(gradT) = \nabla^2 T = 0 \qquad (2)$$

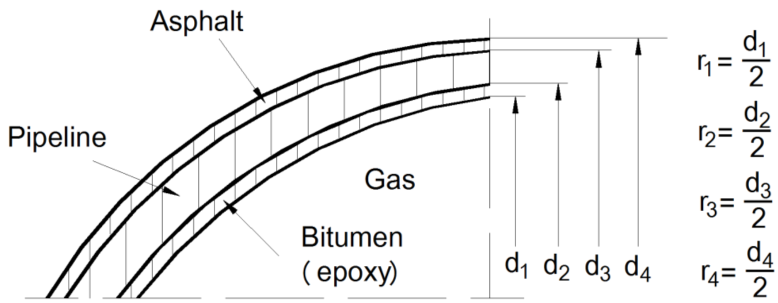

Figure. 4 The cross section of the pipeline wall
Slika 4. Poprečni presjek stjenke cijevi

Heat transfer by conduction is carried out in each layer of pipeline – epoxy, steel, asphalt. The resulting resistance to the heat conduction within the pipeline wall represents the sum of all partial resistances of individual layers (Fig. 4).

Heat transfer between the pipeline surface and the surrounding soil

The pipeline portrayed in Fig. 5 is placed in the depth h. Since the outer surface of the pipeline and the surface of the soil have different temperatures, the heat transfer is realized by conduction. The basis for the calculation of the thermal resistance to the heat transfer by conduction is to compute the temperature distribution in the pipeline surrounding, where two isotherms are known. One is of a cylinder shape (pipe surface with a radius r_4 at T_4 temperature) and the second one is of the plane shape (the surface of the soil at a temperature T_{ss}).

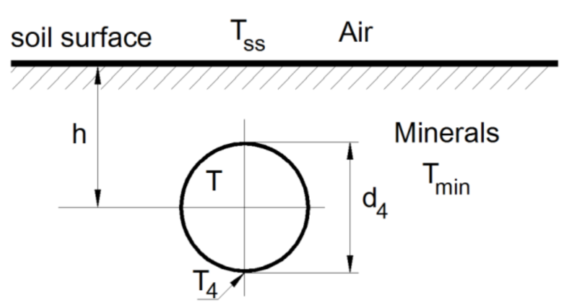

Figure 5. Pipe placed in the soil
Slika 5. Cijev smještena u tlu

Temperature distribution has to satisfy the differential equation of the heat transfer by conduction, which after simplification by introducing the Laplace equation takes form:

$$\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \qquad (3)$$

For the entire length of the pipeline, the equation can be considered as two-dimensional, and therefore it can be written in the plane with the coordinates x, y. The fact holds that the thermal resistance for the pipelines wall to convection in the pipeline may be neglected with regarded total conduction resistance R_0 to R_L in the soil, heat transfer coefficient k as shown Tab. 3 and Tab. 4 [6].

The resource values as velocity v; temperature T; pressure p; the specific gas constant R; the thermal conductivities of epoxy, pipeline material, protective coating, asphalt and soil: thermal conductivities λ_1, λ_2, λ_3 and λ_4; diameters d_1 to d_4 and depth h, are given in Tab. 3. These values represent a typical case for the natural gas flow in the transit pipeline.

Table 3. Characteristic values of the physical properties for the pipeline and natural gas
Tablica 3. Karakteristične vrijednosti fizikalnih svojstava za plinovod i prirodni plin

r [J.kg^{-1}.K^{-1}]	d_1 [m]	d_2 [m]	d_3 [m]	d_4 [m]	h [m]
508,543	1,219	1,2192	1,247	1,253	2

λ_1 [W.m^{-1}.K^{-1}]	λ_2 [W.m^{-1}.K^{-1}]	λ_3 [W.m^{-1}.K^{-1}]	λ_4 [W.m^{-1}.K^{-1}]	t [°C]	P [MPa]
0,2	21	0,1	1,6	30	5

Table 4. Thermal resistance of the soil in the individual steps
Tablica 4. Toplinski otpor tla u pojedinim koracima

R_0 [m.K.W^{-1}]	R_1 [m.K.W^{-1}]	R_2 [m.K.W^{-1}]	R_3 [m.K.W^{-1}]	R_4 [m.K.W^{-1}]	R_L [m.K.W^{-1}]	k [m.K.W^{-1}]
0,0017	0,0004	0,0005	0,024	0,5714	0,5981	1,3344

CONCLUSION

Based on the calculated values, the resistances R_0, R_1, R_2 and R_3, can be neglected because they represent only a small portion of the resistance R_4. Resistance R_4 depends on the composition of the soil which cannot be accurately determined because it is changing along the entire length of the pipeline.

The soil conditions are changed too, because they depend on climatic conditions, this means that the value of resistance R_4 is provided according to a rough estimate. The thermal conductivity of the soil is also difficult to determine because it varies with the soil composition and change of water content.

REFERENCES

[1] J. Pinka, G. Wittenberger, T. Brestovič, Nabucco gas pipeline - possible solution of natural gas to the Slovak Republic, OIL-GAS AGH' , Cracow, 2009.

[2] J. Hužvár, R. Nosek, Impact of fuel supply to concentration of emissions in domestic boiler, Fourth Global Conference on Power Control and Optimization, 2010.

[3] M. Kostúr, M. Laciak: The development of technology for the underground coal gasification in a laboratory conditions, Metalurgija, 47 (2008) 3, 263-269.

[4] B. Knížat, J. Rajzinger, P. Tóth, Prenos tepla medzi plynovodom a okolím, Slovgas, 2 (2005), 11 – 14.

[5] M. Demo, Z. Poláková, Effects of transit pipeline system on soil temperature depending on term of data collection, distance form gas pipes and soil layer, Acta regionalia et environmentalica 2 (2011), 38-42.

[6] Zs. Vaszi, A. Varga, "Design and verification of the mathematical model for detecting the throughput of the compressor stations, Acta Metallurgica Slovaca, 15 (2009) 2, 117-125.