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Professional paper

SITE DEVELOPMENT IMPACT ON THE EXISTING GAS PIPELINE GRADIENT PRESSURE

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Development of residential sites, especially those found in the vicinity of large urban agglomerations, requires attention also in terms of connecting to media such as potable water, electricity and natural gas. In this context, the planned efforts of development of the area may also be included into the zoning plan of the respective municipality/city in the form of public works. In the present article the authors analysed impact of the development of choice on the operation of a high-pressure pipeline. Calculations were carried out for existing site high-pressure gas service pipeline to examine the pressure gradient from the main branch of the distribution pipeline to existing regulating stations. Subsequently, authors analysed possibilities of site development for the municipality of Vajkovce in accordance with documents: “Principles for the design of distribution systems with a working pressure up to 400 kPa (TPP 702 07)” of 2006 and “Technical conditions of SPP - distribúcia, a.s.” of 2012. Alternatives were proposed for the development in accordance with the zoning plan and potential construction of an industrial park / other special-purpose facilities.
Key words: gas industry, distribution of natural gas, pressure losses, midstream.

Utjecaj komunalnog razvoja na gradijent tlaka postojećeg plinovoda. Razvoj stambenih objekata, posebno onih koji se nalaze u blizini velikih urbanih aglomeracija, zahtjeva i pozornost u pogledu povezivanja s medijima kao što su pitka voda, struja i prirodni plin. U tom kontekstu planirani napori razvoja područja mogu se također uključiti u plan prostornog planiranja pojedinih općina / grada u obliku javnih radova. U ovom radu autori analiziraju utjecaj izbora razvoja na rad visokotlačnog cjevovoda. Izračuni su provedeni za postojeći plinovod za visokotlačnu plinovodnu mrežu za ispitivanje gradijenta tlaka iz glavne grane distribucijskog plinovoda na postojeće regulacijske stanice. Slijedom toga, autori su analizirali mogućnosti razvoja gradilišta općine Vajkovce u skladu s dokumentima: "Načela za projektiranje distribucijskih sustava s radnim tlakom do 400 kPa (TPP 702 07)" iz 2006. i "Tehnički uvjeti SPP - distribucija" iz 2012. godine. Za razvoj su predložene alternative u skladu s planom prostornog uređenja i potencijalnom izgradnjom industrijskog parka / drugih posebnih objekata.
Ključne riječi: plinska industrija, distribucija prirodnog plina, gubitci tlaka, srednji tok.

INTRODUCTION

In the field of energy use and consumption, both European and national legislation have focused on a more efficient use of all types of energy. “The fact that natural gas is a unique fuel and has an irreplaceable role in the energy mix as part of the decarbonisation era started by the UN COP21 Conference on Climate Change in Paris, 2015, is the key starting point [1].”

In accordance with the energy policy of the Slovak republic it is also appropriate to have solutions at hand for development of sites, particularly near major agglomerations. When looking for the implementation of projects focused on renewable sources of energy, it can be stated that it is another area where considering a certain need for natural gas to cover energy needs of consumers is appropriate.

Development planning is a lengthy process for any site in the initial phases; it entails a number of necessary legislative actions. In this case, surveys also play an irreplaceable role, whether geological or hydrological. Considering development project's environmental impact is another mandatory task. We also should not forget about history and, in this case, archaeology and the related survey. In this respect, we can uncover an interesting history as was described in reference literature [2] in the case of the project to build an interconnection high pressure ("HP") gas pipeline between Poland and Slovakia.

In the present article, authors would like to raise the problem which is not directly linked with the construction of a new gas pipeline. On the basis of forecasts for potential development, they analysed behaviour of pressure in a service line of a high pressure pipeline for a selected location. The aim was to verify whether an increase in capacity of an existing distribution pipeline may jeopardise the capability of the pipeline of supplying not only the selected site, to a satisfactory extent, but also connecting points of sites located along the distribution line of the gas pipeline. This scenario thus requires an analysis of the chosen site and alternatives of ensuring the supply.

For the analysis, the municipality of Vajkovce became the site of choice along with its nearby surroundings, all located just a few kilometres to the north-east of the region's capital - Košice. The site was chosen because it has excellent conditions for development of industrial and, in particular, a residential sector because of enlargement of such a large agglomeration as is the city of Košice. As has already been mentioned, the municipality of Vajkovce is located near the city of Košice, which is positive in particular for housing development in terms of building new family houses as well as residential units. Therefore, development of such sub-urban municipalities/sites is planned in the near future.

The favourable placement is another reason. Vajkovce is situated near the motorway, which in future is planned to connect Košice with the national capital - Bratislava. This road is also a backbone route to Košice and in the future it is also planned to link to an expressway to Hungary to the south, as well as to the Ukrainian border to the east. Similarly, the proximity of Košice is beneficial for the development of the industrial sector at this site in that the city can provide a sufficient professional and educational base for industry to develop and operate. Another benefit for industry to develop in Vajkovce involves the fact that its cadastral territory includes unused farm land that might be used for industry after being removed from registered land resources.

There is a river near the site, the properties of which can disturb compactness of materials; an anti-corrosion study would also deserve a deeper analysis. Risk being currently evaluated in this context involves not only threats by corrosion of steel pipes; corrosion by biological agents may also play an important role here. This is however not the objective of this paper; for instance, more detailed information are available in [3, 4].

LOCATION ANALYSIS AND OPPORTUNITIES FOR THE SITE DEVELOPMENT

In Vajkovce, gas supply is fully available. It has its own regulating station (“the RS”) with an output of up to 1,200 m^3 per hour, situated at the end of the municipality, direction to the municipality of Kráľovce located in the north. To this RS, natural gas is supplied via a high-pressure pipeline opening into the main distribution branch line west of the municipality of Budimír. This HP distribution system (“DS”) is linked, via a backup interconnection line, with the transmission system in the surroundings of the municipality of Belža; near the municipality of Drienovská Nová Ves, the DS branches off towards Bardejov and to the west (Poprad - Žilina). The DS serves for gas supply nearly throughout the region of Eastern Slovakia. To get near to the site of choice, the analysis will focus only on that part of the gas pipeline which branches off the main distribution line west of the municipality of Budimír. It is a high-pressure gas pipeline (HP, DN 150, PN 40) with a maximum pressure of 4 MPa, passing through south of the municipality of Budimír and continuing to the east, i.e., to the municipality of Kráľovce. This pipeline serves the municipalities of Budimír, Kráľovce and Ploské, as well as other smaller municipalities to which the distribution lines are routed via the municipality of Ploské. East of Budimír, at the point where the gas pipeline splits in two branches, the pipeline changes the dimension to become DN 100 with operating pressure of 3 MPa. In the calculations, however, we are to consider the maximum pressure of 4 MPa. Branch 1 leads to the municipalities of Kráľovce and Ploské, while branch 2 serves Vajkovce. After branching, from which a feeder line leads to a co-operative near Kráľovce, the gas pipeline dimension turns to DN 80.

Figure 1. Gas distribution pipeline routing in the location of choice
Slika 1. Usmjeravanje plinovoda na odabranoj lokaciji

Vajkovce RS adjusts natural gas from HP - 4 MPa to a medium-pressure gas line (100 kPa) which opens the distribution system of gas distribution network of the municipality. Inside Vajkovce, there are mainly medium-pressure distribution pipelines (MP DN 100, 80, 50 and 40, made of steel), each of them of pressure up to 100 kPa, but low-pressure systems (LP DN 80, 50, 40, made of steel) are found there as well with pressures of up to 5 kPa. There are also two more - smaller - regulators, up to 40 kPa, and two larger regulators (up to 160 kPa) adjusting pressure from medium-pressure branches to low-pressure lines. Currently, there are 135 domestic and 8 retail feeders.

SITE DEVELOPMENT ALTERNATIVE 1

The first development option contemplates enlargement of the municipality and its close surroundings with new family houses and construction of a shipping warehouse south-west of the municipality. In the south-western part, there is a smaller area containing undeveloped land situated in that part of the site giving the potential of direct development (Fig. 2. RD1 area). It could allow for building up to 30 family houses. To the south of the village, outside Vajkovce Zoning Plan, there is a territory which could be used for the construction of houses (Fig. 2. RD2 area). This site would allow 60 family houses to be built. To the north-east of the municipality, there are rather great lots as well. Here, construction of new houses is already underway at the moment. Whereas these lots are contained within the zoning plan, family houses could be built throughout this area (Fig. 2. RD3 area). In terms of zoning, 200 houses could be built in this territory. According to the estimates mentioned above, up to 290 houses could be added to the municipality. Currently, family houses are being assigned feeders depending on whether the feeder connects to a medium-pressure line or a low-pressure line; to this end, a feeder being connected to a medium-pressure pipeline is assigned an average off-take value up to 1.4 m^3 per hour and a feeder connected to a low-pressure line has an average value of up to 1.4 m^3 per hour as well. The zoning plan envisages that around all the territories where development of family houses would be situated, with a single exception, there are medium-pressure distribution systems. This means that the system is ended with a low-pressure line only in the proposed south-western part of the municipality (Fig. 2, RD1 area) - in the northern part of the delimited area, while in the south and east of this territory there is a medium-pressure line. It will therefore be assumed that half of the houses to be built here will be supplied with a low-pressure pipeline, while all other houses will be fed from a medium-pressure pipeline. This implies that all the 290 houses will have an average supplied amount of 1.4 m^3 per hour. As has already been mentioned, this alternative includes the construction of the transportation warehouse facility (Fig. 2. PS area). Such warehouses can use gas for heating or supplying the facility with hot water. If only such type of use is contemplated for natural gas, the warehouse can be classified as a medium-sized customer - a category, for which the off-take volume is set in the range from 6.85 to 45.66 m^3 per hour. The correct value depends on multiple factors such as the dimensions of the warehouse, the manner of use of the gas, etc. According to preliminary findings, tariffs for maximum off-take around 15-20 m^3 per hour apply to such delivery warehouses. Rather, a value was chosen outside this range, i.e. 36 m^3 per hour, to secure a sufficient allowance. This value will be a maximum consumption of gas for the warehouse in the case of peak (e.g. during heating in winter). For the first development alternative, calculations will work with a theory of increase in maximum off-take capacity of the municipality:

- 290 family house feeders with an off-take volume of 1.4 m^3 per hour;
- 1 "medium-size customer" point of off-take, the off-take capacity of 36 m^3 per hour.

On the basis of the above, the maximum consumption of the municipality would increase by 442 m^3 per hour.

Figure 2. Potential development areas of the site
Slika 2. Razvojni potencijal razvoja područja

SITE DEVELOPMENT ALTERNATIVE 2

This alternative will consider, in addition to the already mentioned enlargement of the municipality with new family houses and a warehouse added, the situation of development of an industrial park or a production plant in the territory found north to north-east of Vajkovce (Fig. 2. PP area). An industrial park may, in addition to the normal use of natural gas for heating and hot water, use the gas in technological processes as part of production of its own products, as well as part of technological procedures. Such a park is placed in a category of medium-sized to major customer; for these categories, the average off-take value has been set in the following range:

Medium-sized customer 6.85 to 45.66 m^3 per hour
Major customer Over 45.66 m^3 per hour

Since the area designated for construction of this park is not that big, construction will be considered of a rather small nature with the tariff of choice being one for medium-sized customers. For simplification, a specific value will be selected from this range. Whereas it will still involve an industrial park, the higher off-take value from the range will be chosen. For this park, the selected maximum off-take value will be assumed to be 40 m^3 per hour. However, since this industrial park will be placed on the gas pipeline route before the line enters the municipality, it will be treated as a separate off-take point, not included in the municipality's off-take capacity. Its location on the route before the municipality will result in reducing gas flow to the municipality. It will also decrease the pressure by incorporating valves (e.g. branch line) into the gas pipeline, which will create a local loss of pressure in the gas pipeline supplying the municipality with gas.

PRESSURE LOSS CALCULATION

The calculations made use of components of natural gas as provided at the website of SPP-Distribúcia, a. s., where the company publishes figures with respect to composition of gas for individual months of the year.

Table 1. Components of natural gas [5]
Tablica 1. Komponente prirodnog plina [5]

Components	Methane	Ethane	Propane	Butane	Pentane	Hexane	CO_2	N_2
% by volume	95.5823	2.5027	0.6222	0.1994	0.0363	0.0187	0.3276	0.7108

Using gas mixture components, it is also necessary to calculate additional gas parameters, including dynamic viscosity. Viscosity calculation made use of Chapman-Enskog relationship that is available, among others, in the STN 38 5509 Gaseous fuels standard. Physical constants Calculating additional parameters needed for the calculations are part of the mathematical model.

The correct pipeline pressure gradient is a factor affecting the operation of a gas pipeline to the greatest extent. It is possible to determine through calculating pressure loss and comparing pressures at the beginning and at the end of the pipeline. However, the calculation needs to include all the factors affecting the change in pressure/flow along the length of the pipeline section studied, e.g. off-take along the length, fitting quantity and types, vertical superelevation, etc. All of these factors cause pressure loss to some extent by changing either flow velocity or flow direction. Therefore, the pressure loss calculation was split into sub-calculations as follows:

- Pressure loss along the length;
- Local pressure loss through valves;
- Local pressure loss through changed line dimension.

A mathematical model was prepared for calculating in which the analysed branch of the distribution pipeline was split into minor sections. With concentrated off-take into the individual regulating stations (RS) being a decisive criterion, 5 smaller sections were obtained for separate calculations.

Factors definitely affecting pressure loss calculations are flow velocity *w* and pipe diameter *d*; from these, pressure loss coefficient λ is derived (see [6.7,6.7, 10] for more details).

Defining different gas off-takes in these sections as well as changed dimensions and associated changes in gas flow velocity defined entry conditions for the calculations within each of the sections. Creating a computing module for each section also makes it possible to determine quantity as well as the number of individual valves in a clearer manner, thus gradually calculate local pressure for each of the sections.

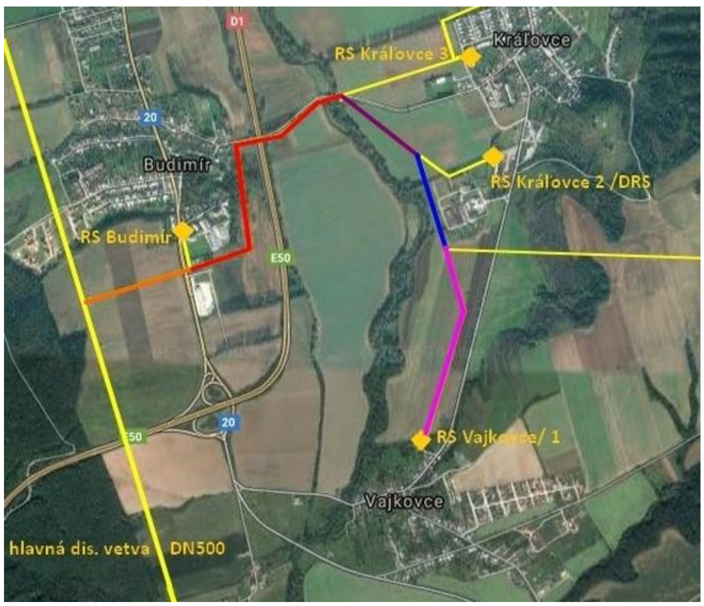

Figure 3. Routing and splitting the gas pipeline into sections (by colours)
Slika 3. Usmjeravanje i razdvajanje plinovoda u dijelove (po bojama)

PRESSURE LOSS ALONG THE LENGTH

Pressure loss along the length of a gas pipeline arises in any pipeline system in which there is a flow of any liquid. The loss is due to the roughness of pipes, as well as due to the flowing liquid velocity alone, i.e., type of flow. „Therefore an important role in calculating this type pressure loss is played by identification of pressure loss λ in each section of the pipeline." [6, 7, 9, 10, 11] Subsequently, pressure loss along the length of the pipeline - taking superelevation into account - is calculated by using the following relationship [6, 7, 10]:

$$\boldsymbol{p_p^2 . e^{-b} - p_k^2 = \frac{\lambda . m^2 . Z . r . T . l}{F^2 . d} . \frac{1 - e^{-b}}{b}} \quad (1)$$

p_p - gas pressure at the beginning of the pipeline, (Pa)

p_k - gas pressure at the end of the pipeline, (Pa)

λ - pressure loss coefficient, (-)

m - mass flow, (kg/s)

Z - compressibility coefficient, (-)

r - specific gas constant, (J/kg.K)

T - gas temperature, (K)

F - pipe cross-section area, (m^2)

d - inner pipe diameter, (m)

b is a coefficient which is calculated under the following relationship [6, 7]:

$$\boldsymbol{b = \frac{2g\ .\Delta z}{Z.r.T}} \qquad (2)$$

g - gravity acceleration, (m^2/s)

Δz - vertical superelevation (gas pipeline height difference between the beginning and the end of the observed section), (m)

Pressure loss along the length needs to be calculated for each section separately. This was the basis according to which the relationship was adjusted to take a form taking into account the parameters of each section. Now total pressure loss along the length is calculated as follows:

$$\boldsymbol{\Delta p = p_p^2 - p_k^2 = Z.r.T.\ \sum \frac{\lambda_i.m_i^2.l_i}{F_i^2\ .d_i}\ .\frac{(e^{b_i}\ -1)}{b_i}\ .\frac{1}{e^{b_i}}} \qquad (3)$$

LOCAL PRESSURE LOSS THROUGH VALVES

This type of local pressure loss arises as a result of changes in gas flow direction through various types of valves and fittings. Local pressure loss is generally expressed as follows:

$$\boldsymbol{\Delta p = \zeta\ .\frac{w^2\ .\rho}{2}} \qquad (4)$$

ζ - local pressure loss coefficient, (-)
w - gas flow velocity, (m^3/s)
ρ - gas density, (kg/m^3)
Δp - local pressure loss, (Pa)

The local pressure loss coefficient ζ can be determined experimentally for specific fittings and valves. In many references, e.g. [6,7,10,11,12 and a number of others), there such data already available, processed into tables, and direct reading on a case by case basis is everything what has to be done.

LOCAL PRESSURE LOSS THROUGH CHANGED LINE DIMENSION

This type of local pressure loss arises from local changes in parameters of pipe diameter. As regards calculation of such type of loss, it is determined on the basis of sudden reduction of pipe diameter when determining local pressure loss ζ, and is calculated as follows:

$$\zeta = 1 - \frac{S_2}{S_1} \qquad (5)$$

Both gas pipeline behaviour and the related factors affecting the operation of the pipeline alone are well described/ summarised in references [10].

All the sub-calculations of pressure loss were done using computing modules, separately for individual sections; counting them together obtained the total pressure loss along the length of the HP gas distribution pipeline. The same technique was applied in the case of development of the site. The calculations referred to the increased off-take and change in new parameters for specific alternatives of development of the specified area.

RESULTS AND DISCUSSION

Pressure gradient refers to the difference of pressure between the gas pipeline beginning and end. The summary calculation of the pressure gradient for the entire gas pipeline was determined from the individual sub-calculations and, subsequently, subtracted from the pressure at the entry of the 4 MPa line to obtain pressure at the end of gas pipeline, p_k. The same steps were taken to calculate gas line pressure gradient after considering a specific type of development.

Fig. 4 makes it possible to compare an increase in the quantity of natural gas in considering site development alternatives compared with the existing situation.

In the paper, the authors focused on the calculation and analysis of pressure gradient for a specific high-pressure gas pipeline. Site-specific development was considered of the municipality of Vajkovce, and a pressure gradient was analysed for the supply line of the high-pressure gas pipeline as it is now and after implementing alternatives of site development as proposed.

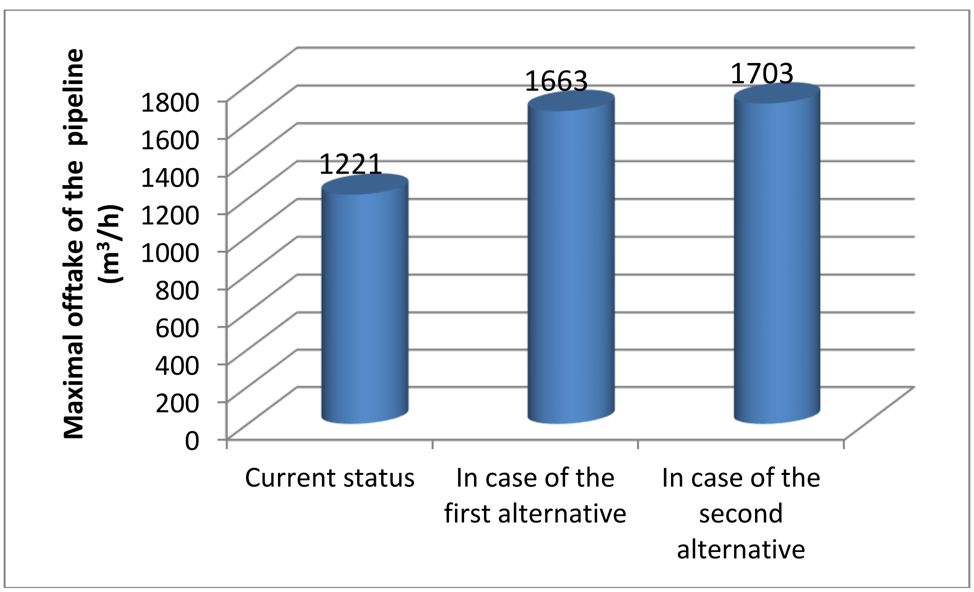

Figure 4. Comparison of gas off-take for the specific site as it is currently and taking alternatives of site development into account

Slika 4. Usporedba isporuke plina za određeno mjesto kao što je trenutno i uzevši u obzir alternativne komunalne razvoje

Tab. 2 makes it possible to compare summary overviews of increase in pressure gradient after implementing the individual alternatives of site development. Similarly, it is possible to observe how the pressure changes at the end of the envisaged gas pipeline in relation to the increase in total consumption (off-take) of the site.

Table 2. Comparison of pressure loss, total off-takes and pressure at the end of the pipeline
Tablica 2. Usporedba gubitka tlaka, ukupne isporuke i tlaka na kraju cjevovoda

	Pressure drop Δp (Pa)	Pressure at the end of the pipeline p_k (Pa)	Overall off-take of the pipeline (m^3 per hour)
Current status	152,432.72	3,847,567.28	1,221
After the first alternative	389,456.69	3,610,543.31	1,663
After the second alternative	412,013.6	3,587,986.4	1,703

Fig. 5 shows the calculated pressure gradient along the length of the gas pipeline, both in the existing state and following the implementation of site development alternatives as considered. It clearly presents how pressure gradually decreases along the length of the pipeline following the envisaged development, while the difference in pressure gradients increases. Initially, there minimum differences, but toward the pipeline end, they become clearly visible. This is caused by increased off-takes in the area of regulating stations (off-take points) and pressure losses along the length of the gas pipeline analysed.

Fig. 5 shows visible leaps at section interfaces; they are chiefly due to the increased off-take of natural gas at the points of connection. Here, it is possible to observe that it is the concentrated gas off-take at connection points which has the greatest influence on the pressure drop, besides the changed cross-section of the piping as another factor. There was a special calculation for the section beyond the river which links sections 2 and 3. It is rendered between the values of distance 1909.07 to 2018.24 m.

Differences in pressure / pressure drops within section 4 are greater for increased off-take than those of the other sections, which is particularly a result of a change in the pipeline dimension. Along with the change in dimension, in this case, one can also consider a change in the nature of natural gas flow.

Between sections 4 and 5 there are the least pressure differences; they are almost not visible in the chart and provided between the values of distance 2507.78 to 3854.45 m).

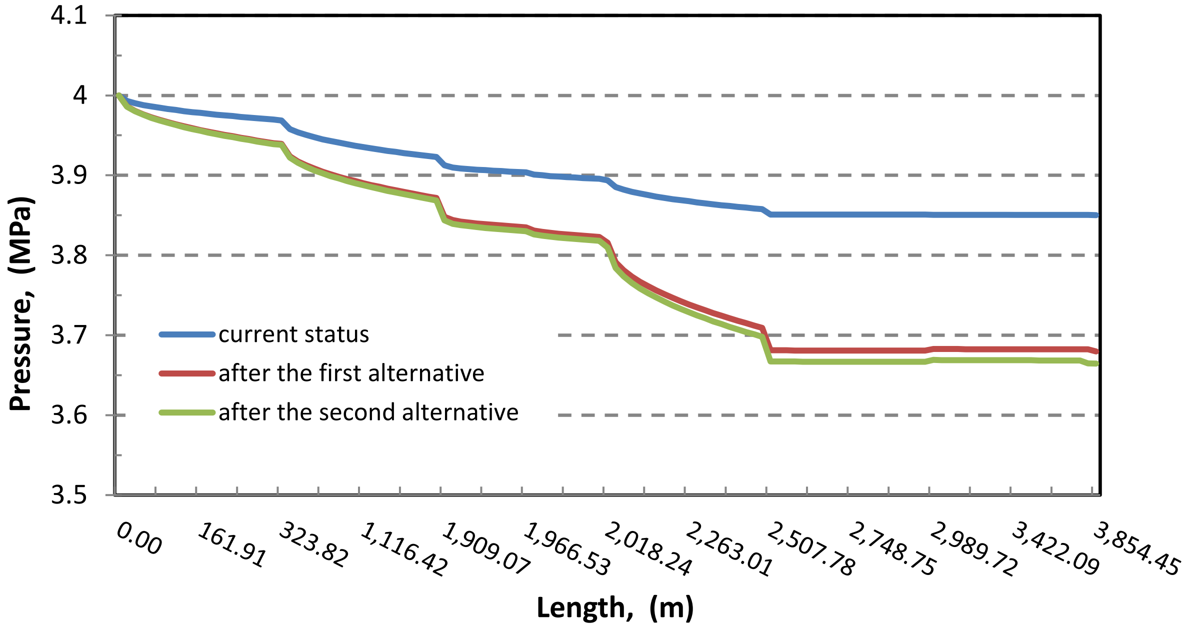

Figure 5. Comparison of the pressure gradients within the gas pipeline studied
Slika 5. Usporedba promjene tlaka u plinovodu

The model results obtained were used to prepare graphic relationships between pressure drop and pressure gradient according to the increased site off-take. The results shown in Fig. 6 make it possible to observe how the pressure gradient changes along with the pressure at the end of the selected distributing branch of the gas pipeline after applying the alternatives of development for the site, i.e., in case of changed off-take. The pressure gradient and end pressure figures are related to the total off-take in the area. It can be observed how the pipeline branch pressure gradient rises with increasing off-take in the proposed alternatives, the figure being up to 155% for Alternative 1 and 170.3% for Alternative 2 compared with the existing status. The line end pressure drops by 6.16% for Alternative 1 and by 6.75% for Alternative 2.

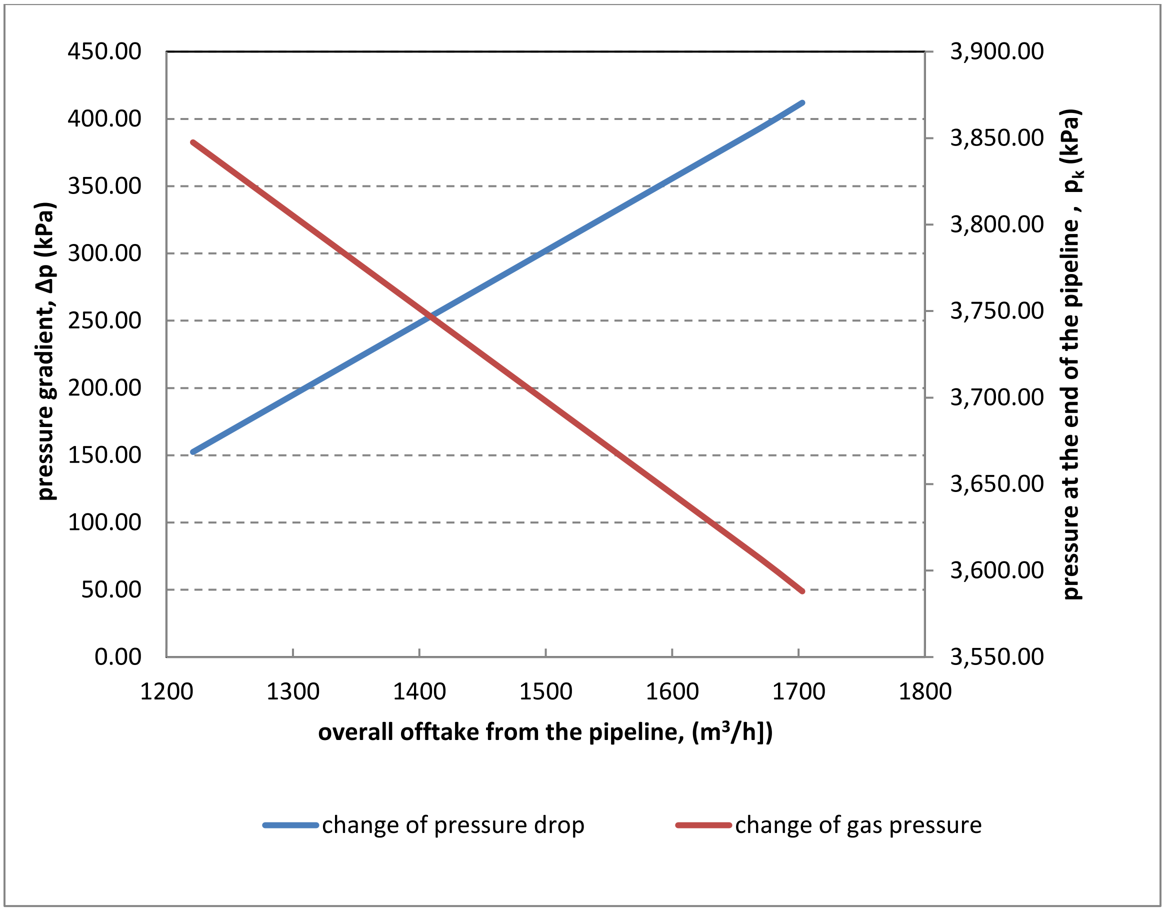

Figure 6. Comparison of changes in the gas pipeline pressure
Slika 6. Usporedba promjene tlaka u plinovodu

The created mathematical model can be used when calculating pressure loss in lines of HP pipelines within natural gas distribution systems. The calculations considered figures obtained from SPP - distribúcia, a. s., and the results obtained serve only as an illustrative example for examining development of a single site in a visual manner. More factors could be defined as part of the mathematical model and significantly affect the pressure loss throughout the gas pipeline studied. The calculations considered a constant maximum pressure at the entry into the HP gas pipeline. Actually, this pressure may vary during the year as well as over shorter periods of time.

CONCLUSION

The initial assumption of sufficient service for points of connection, particularly the outermost customers, considered alternatives of additional pressure increase, or other interconnections should the gas pipeline became insufficient.

The analysis of the results obtained shows that even after the development as considered, the line end gas pressure is high enough for connected local gas systems to run steadily.

On the basis of calculations and modelling, we need to conclude that the development of the specified site, thus the gas distribution branch, are sufficient for ensuring the supply of gas quantity as required; there is even a possibility, to some extent, to accumulate gas in the pipeline to achieve sufficiently high pressure at the end of the pipe. It is thus not necessary to increase the pressure in this gas distribution branch even following the proposed upgrade and development of the site making use of any other external action, whether it would involve producing a circuit or using a pressure-boosting equipment.

The results obtained indicate the influence of a single site on the operation of an HP gas pipeline. There are however more off-take points for other sites along this pipeline branch. Further analysis is needed to discuss development / development perspectives of those sites as well and incorporate them into the mathematical model mocking the behaviour of the pressure gradient within the HP distribution pipeline branch described.

The authors wished to make use of the issue discussed herein to point to possible problems that may arise as part of development at similar sites despite the fact that the existing status is satisfactory in terms of natural gas supply.

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