Gas network improvement proposal using numerical simulation

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Abstract. Simulation software packages are very useful tools for evaluating hydraulic conditions in gas systems, and therefore for supporting the design process, network maintenance and decisions about rerouting or modernisation of a network. In the range of this paper, a model of a real branched gas network covering 3 towns was created in the GAZNET software. At first, actual hydraulic conditions of gas flow in the pipes were simulated to evaluate distributions of flow velocity and pressure in the pipes. The obtained results indicated meaningful pressure drops and increase in flow velocity in some sections of the model, which not only constitutes a threat to provide required parameters of gas to consumers, but also forecloses connecting new consumers to the network. Thus, two variants of improvements were proposed: (1) expanding the network by building two additional sections or (2) increasing the number of gas sources by building additional pressure reduction and measuring unit. Conducted simulations indicated that changes of the network proposed in both variants clearly improve hydraulic conditions in the network model. However, the first variant was chosen as a better alternative, because distribution of hydraulic parameters in the model was more homogeneous than in the second variant, as well as because of economic considerations.

1. Introduction
Gas network is the most efficient and convenient logistics to deliver natural gas. Numerical simulations of gas systems operation enable verification of existing or intended solutions of gas distribution networks. Moreover, they give a broader view of investments related to gas systems modernisation, extension or building by considering different technical aspects [1–5]. Nowadays, computer simulations are widely applicable in each branch of engineering science, including environmental engineering. They enable not only the assessment of networks and installations maintenance [e.g. 6–10], but also visualisations and analyses of phenomena connected with the systems operation [e.g. 11–15].

The software packages for environmental engineering include programs enabling simulation of hydraulic conditions in gas, water and wastewater systems, and therefore supporting the design process, network maintenance and decisions about rerouting or modernisation of a network [16–19]. Programs of this kind base on mathematical models – systems of equations – that reflect actual network operation having regard to necessary simplifications [1, 20]. If variables in the model depends on time, simulation of the network operating is dynamic, otherwise it is in steady state [21].
Steady state analysis is common for models of low- and medium-pressure gas networks [1, 2]. Simulation of gas networks at steady state enables to determine pressure at nodes and gas flows in individual pipes for known source pressures, composition of natural gas and gas load demand. The determined hydraulic parameters must satisfy first and second Kirchhoff’s laws. Methods, that are commonly used in this kind of simulation, covers Newton-nodal, Newton-loop and Hardy Cross methods [1, 22–23]. Theoretical information on a steady-state simulation is described in detail in the publication of Osiadacz [1].

Using numerical simulations at the design stage simplifies elaboration of several design variants and selection of one of them as an optimal proposition, and thereby limits the risk to bear inflated costs of investment. The aim of our paper is the analysis of two variants of modernisation of the selected gas network, using the GAZNET software simulation. Modernisation is necessary to improve hydraulic conditions in the network and guarantee the undisturbed network operation.

2. Materials and methods
Investigations were conducted for the selected real branched medium-pressure gas network for 1247 consumers in three towns – A, B and C. The network consists of PE-HD pipes (25–180 mm in outer diameter) and steel pipes (200 mm in inner diameter). The total length of the network equals 75534.7 m. The network is supplied by the pressure reduction and measuring unit located in town C. The capacity of the unit equals to 667 m³/h and pressure at the outlet – 292.5 kPa.

Investigations included:
- creating a model of the gas network described above, with the GAZNET software,
- computer simulation of actual hydraulic conditions during gas flow in the pipes,
- evaluation of the actual hydraulic conditions,
- creating models of the modified gas networks (2 variants),
- computer simulations of hydraulic conditions in the modified gas networks,
- analysis of obtained results and selection of a better alternative.

The software used to build the network model and to conduct the simulations was GAZNET – an application implemented by the module SONET [24]. The GAZNET is similar to other programs intended for calculations of hydraulic parameters and simulations of gas networks operation [e.g. 16, 25–27]. The model of the analysed network covers 781 links and 782 nodes (figure 1). The model reflects actual conditions noted on 27th November 2017, at the moment of maximal gas off-take and maximal pressure drop in the network. Data including gas off-takes measured by consumers’ gas meters were obtained from the PSG company.

The created model was calibrated and then, the steady state simulation was conducted. A steady-state simulation in the GAZNET software bases on Kirchhoff’s laws. Creation of the model and steady-state simulations were repeated for two variants of the network modernisation.

3. Results
The simulation of hydraulic condition in the actual network model indicated existence of pipes, in which gas flow velocity was close to maximal value (20 m/s) or even exceeded this value. The highest value of gas flow velocity (24.5 m/s) was observed in town A. Distribution of gas flow velocity in the entire analysed network model is given in figure 2.

The values of gas pressure in all pipes in town B and partly in town A occurred also not satisfactory (figure 3). Although all simulated values were covered by the range of 10–500 kPa characteristic for medium-pressure gas networks, pressure clearly lower than 100 kPa observed in the large part of the network indicates a risk of failure to provide required parameters of gas to consumers, as well as indicates inability to connect new consumers to the network.

Unsatisfactory hydraulic conditions in the gas network are the result of large gas off-take from the network (430 m³/h) by the new industrial consumer in town A (figure 1). Such a large off-take (64% of the whole gas supplied to the network) located in the central section of the network disturbs the gas system operation.
Figure 1. Analysed gas network model.

Figure 2. Distribution of gas flow velocity in the network model for actual conditions.

Figure 3. Distribution of gas pressure in the network model for actual conditions.
Two variants of gas network modernisation were proposed to improve the conditions of its operation. First one included expansion of the network and conversion of its structure from branched to branched and looped by building two additional sections (figure 4):

- pipe PE-HD, SDR 11, \(OD = 110\) mm, length 2226 m, in town B,
- pipe PE-HD, SDR 11, \(OD = 180\) mm, length 3390 m, connected the chosen node in town A with the chosen node in town C.

The second variant included building the additional pressure reduction and measuring unit for town B (figure 4). The network would be connected with the unit by a steel pipe \(DN = 200\) mm. The assumed capacity of the unit equalled to 167 m\(^3\)/h and pressure at the outlet to 220 kPa. All the parameters assumed in both variants (pipes dimensions in variant I, unit capacity and pressure in variant II were selected according to knowledge and competences of the experts from the PSG company).

The proposed variants of the network modernisation clearly improved the hydraulic conditions of gas flow. The conversion of the network structure according to variant I caused that velocity in all but one link in the model did not exceed 8 m/s (figure 5). Only two values higher than 8 m/s (12.5 m/s and 12.6 m/s) were observed in town A in two nodes 674 and 673 bounding the link supplying the new consumer, and they were the highest values of velocity observed in the model in variant I. Taking into account the rest of nodes, velocity was lower than 5 m/s in 99.00% of them (8 nodes with velocity 5–8 m/s).

Pressure in all gas pipes in the model for variant I exceeded 200 kPa with the lowest value 235.9 kPa in the node 673, to which the new consumer has been connected (figure 6). The highest value equalled 292.5 kPa for node 168 located in town C directly at the pressure reduction and measuring unit. Pressure was higher than 290 kPa in 51.85% of all nodes in the gas network model and lower than 240 kPa in 28.09%.

![Figure 4](image_url)
Similar results were observed for the model with the additional pressure reduction and measuring unit in town B according to variant II. Second source of gas supplying the network caused lowering velocity in the model (figure 7). Maximal values (13.6 and 13.7 m/s) were higher than for variant I, but they were observed in the same endpoints (nodes) of the link supplying the new consumer. Similarly as in variant I, these nodes were the only ones with velocity higher than 8 m/s. Velocity in the vast majority of the rest nodes (all but 5) was lower than 7 m/s.

Pressure determined for variant II covered greater range than for variant I: 209.6–292.5 kPa. The upper end of the range was the same, but the lower end was clearly lower – the difference equalled to 26.2 kPa (11.12%). Values higher than 290 kPa were obtained in 48.27% of all nodes and lower than 240 kPa in 34.44% (figure 8).

A more detailed analysis of calculated values indicated that distribution of both, velocity and pressure in the network model was more homogeneous for variant I than for variant II. Comparison of velocity and pressure for the actual conditions and for both of the proposed variants of the gas network modernisation is given in figures 9 and 10. The parameters are shown for selected nodes: 673 – a node to which the new consumer is connected, 740 – a node for which the lowest value of pressure was observed for actual conditions, 643 and 142 – nodes being endpoints of additional section \( OD = 110 \) mm in variant I, 402 and 734 – nodes being endpoints of additional section \( OD = 180 \) mm in variant I, 036 – a node to which the additional pressure reduction and measuring unit is connected in variant II, and nodes 407, 410 and 423 – selected nodes located near the node 673, characterised by adverse hydraulic conditions – relatively high gas flow velocity and low gas pressure.
Figure 7. Distribution of gas flow velocity in the network model modernised according to variant II.

Figure 8. Distribution of gas pressure in the network model modernised according to variant II.

Figure 9. Comparison of gas flow velocity in selected nodes for actual conditions and two variants of network modernisation.
Figure 10. Comparison of gas pressure in selected nodes for actual conditions and two variants of network modernisation.

Conducted research indicates that both of the proposed variants clearly improve hydraulic conditions in the gas network supplying consumers in towns A, B and C. The obtained values of hydraulic parameters for both variants demonstrate that not only the gas system works properly in its current form, but also that system can be expanded to include new consumers from neighbouring communities. It is profitable for the PSG company, because of possible increase in volume of sold gas. The detailed analyses indicate a bit of an advantage of hydraulic conditions for variant I, but it should be underlined that differences between results obtained for variants I and II are minor. Although the results accuracy is enough to access the efficiency of the network modernisation, it is not enough to select a better alternative according to hydraulic conditions, with such small differences in simulated hydraulic parameters.

However, the choice of variant I is not only suggested by hydraulic analysis, but also supported by economic conditions. For variant I, the investment costs cover expenditure on designing and pipes installation only. For variant II the costs cover not only expenditure on designing and building the unit, but also on supplying the unit (designing and building a medium- or high-pressure gas network). Moreover, building a pressure reduction and measuring unit or a high-pressure gas network requires obtaining a decision concerning environmental conditions of the enterprise, which entails additional costs. Thus, the solution proposed in variant I is more profitable for the PSG company, because it enables proper operation of the network in both current and possibly expanded forms, at lower investment costs. Although it seems that variant I is a better alternative, a multi-criterial analysis is necessary to fully conclude.

4. Conclusion
Building the gas network model and computer simulation of its maintenance enabled to evaluate actual hydraulic conditions in the network supplying gas in three towns (A, B and C), and to locate the places where the gas system operation was disturbed. Moreover, computer simulation enabled to evaluate two proposals of gas system modernisation to improve hydraulic conditions in the system.

The conducted analyses indicated that both proposed methods for hydraulic conditions improvement were efficient and gave similar results – gas flow velocity did not exceed 20 m/s in network models and in vast majority of nodes was lower than 7 m/s, and gas pressure exceeded 200 kPa in all nodes. However, the first variant covering expansion of network and conversion of its structure from branched to branched
and looped seemed to be slightly better because of less range of simulated values of gas flow velocity and pressure in the network model. Initial economical estimates also indicated the first variant as more beneficial, mainly for lower investment costs. However, a multi-criterial analysis is needed to make a full assessment of the proposed variants and select better alternative.

5. References

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