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Changes in gas flow in the pipeline depending on the network foundation in the area

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ABSTRACT

The article presents an analysis of the results of overpressure distribution, velocity and gas streams obtained during the simulation of gas flow in the low pressure pipeline network. The calculations were made for the section of an existing gas network and the actual data describing gas consumption from the network by municipal customers and actual weather data characteristic to the specific city. Minimum and maximum overpressure of gas stream entering the network was determined, depending on the size of the network load and the difference in height between the gas station supplying the network and the most distant network connection (parameter ΔH). It was demonstrated that taking into account in the calculation the differences in the height of particular pipelines location in the network affects the selection of overpressure limit values of gas stream supplying the network. Moreover, gas overpressure distributions were compared in particular pipelines in the network for different cases of pipeline location in the area.

1. Introduction

Natural gas is defined as an ecologically clean fuel (Lueken et al., 2016; Faramawy et al., 2016), which use as an energy carrier or raw materials in the industry gradually increases (Al-Sobhi and Elkamel, 2015). Natural gas may be transported in a number of ways (Thomas and Dawe, 2003), but over long distances it is the most often realized using the tankers or pipelines. Various kinds of methods and computer-aided techniques are increasingly used in gas pipelines design, construction and operation, and in gas transport through the networks monitoring, so that many errors can be detected at an early stage of the work. Moreover, flow modeling is one of the main methods to obtain the information about the changes occurring in the flow and distribution of parameters characterizing the stream. The results obtained during gas flow simulation in complex network systems of pipelines can be used, inter alia, to predict fuel demand and in pipelines capacity planning (Amani et al., 2016; Reddy et al., 2006; Szoplik, 2015), in an increase of pipelines capacity and transport gas improvement (Monforti and Szikszai, 2010; Lochner, 2011; Voropai et al., 2012; Szoplik, 2010, 2012, 2016), fault detection and gas leaks from the network locating (Reddy et al., 2006; Sun, 2012; Kostowski and Skorek, 2012; Ebrahimi-Moghadam et al., 2016). In turn, the results of numerical studies performed in order to optimize the gas network structure (Nguyen and Chan, 2006; Űster and Dilaveroğlu, 2014) may be used to reduce the costs of gas transport (Wu et al., 2000; El-Mahdy et al., 2010; Najibi and Taghavi, 2011; Steinbach, 2007; Sanaye and Nasab, 2012; Ruan et al., 2009).

However, a number of assumptions and simplifications that significantly affect the results of calculations are adopted in the models of flow in the networks of pipelines and methods of model equations solving. The general model of fluid flow in complex network systems is based on the classic laws of mass, momentum and energy conservation. In turn, the detailed form of the flow model largely depends on the purpose of modeling. Therefore, different forms of model equations are often used in various scientific papers, which were achieved due to the use of certain simplifications or adding specific members. One of the criteria for the selection of the type of gas flow model in the pipeline may be the size of gas overpressure in the pipe. In this case, it was usually assumed that an unsteady state model should be used for the pipelines which send the gas under the high pressure (40 bar or more), since due to the transport of large gas streams the flow changes are slow. An effect of the model type (steady-state thermal model or unsteady thermal model) on a decrease in gas pressure in the high-pressure pipeline was confirmed by Osiadacz and Chaczykowski (2001). According to the authors, higher decrease

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in gas pressure is observed in the case of an adoption of the assumption of non-isothermal flow in the calculation. Also Chaczykowski (2010) points to the better results of numerical calculations for an unsteady heat transfer compared to the steady-state thermal model. Matko et al. (2000), on the basis of a comparison of experimental data concerning the stream size, and the gas pressure at the end of high pressure pipeline with the results of simulation in the non-steady state, demonstrated that higher consistency of the results is achieved in case of nonlinear distributed parameter and linear distributed parameter model using in the calculation compared to linear lumped parameter model. Chaczykowski (2009) in turn, did not observe any clear effect of the state equation on the quality of the results of simulation of basic dynamic flow parameters, when unsteady-state nonisothermal model was used in the calculations. To analyze transient flow in gas pipeline network, Alamian et al. (2012) used the state space equation, which was obtained using a transfer function equation. However, slow changes in the flow of high pressure gas pipeline can be sometimes accompanied by rapid changes in velocity or pressure caused, for example, by the sudden closure of the valve or damage to the pipeline. As demonstrated by Gato and Henriques (2005), untypical flow changes mainly depend on the dynamic characteristics of the control and safety valve, as well as pipeline capacity adopted in simulation calculations. Amani et al. (2016) analyzed the results of gas flow modeling in the transient state in the pipeline of serial, parallel and loop structure obtained on the basis of the steady state Weymouth equation. The author points out that due to the changes in stream volume at the inlet and outlet of the pipeline, a steady flow in the pipeline is rare, and steady state model adoption in the calculations can lead to calculation errors. The steady flow model was, however, used in the study by Fasihizadeh et al. (2014) for the optimization aimed at the reduction of operating costs of gas transport in high pressure network containing gas compressor stations. In the modeling of the flow of gas with different thermodynamic properties in high pressure network containing both the pipelines and non-pipe components, Li et al. (2014) applied the steady state model being the combination of hydrodynamic and thermodynamic models. In turn, Brkić (2009) used an improvement of Hardy Cross method to optimize the loop structure of the high pressure network. Based on the comparison of the results of gas flow modeling, assuming isothermal or nonisothermal model in the steady or unsteady state in the high pressure pipeline network, Osiadacz and Chaczykowski (2001) found that the choice of flow model should also take into account the structure and complexity of gas network. Herrán-González et al. (2009) also indicate that the decrease in gas pressure during the flow through the pipeline is significantly affected by the location of the pipeline in the area. Such relationship was confirmed by the calculations made for a straight section of high pressure pipeline, the end of which was located above ($\Delta H < 0$) or below ($\Delta H > 0$) than the entrance to the pipeline.

In case of gas flow modeling in low pressure pipelines, it is sufficient to use the steady-state model in order to obtain a satisfactory quality of the results, since flow changes are fast, and the time to reach the steady state is very short. Model equations can be solved using the methods based, for example, on an analogy to the current flow in electrical circuits (Tao and Ti, 1998; Sun, 2012). An example of practical use of flow modeling in low pressure network to control an overpressure of the gas stream entering the network, depending on the magnitude of the stream, is presented in the study by Szoplik (2016). In addition to knowledge of the network structure, flow modeling in low pressure networks with a complex structure requires the knowledge about all the streams collected from the network and the size of an intake pressure. Other parameters in the form of overpressure distribution, gas flow and velocity in all pipelines of the network can be determined during the simulation conducted in an appropriate computer program.

Models of gas flow in the pipeline network can be developed for individual pipelines or may include other network components, such as compression stations (Ríos-Mercado et al., 2006; Najibi and Taghavi, 2011), valves and other fittings used for closing the flow (Gato and Henriques, 2005), material or roughness of the pipe wall (Abdolahi et al., 2007; Ruan et al., 2009), or take into account the complexity of the network structure (Brkić, 2009; Amani et al., 2016) and its positioning in the area (Herrán-González et al., 2009). All of these parameters can affect the quality of the results of gas flow modeling in the network.

The results of flow modelling presented in the literature mainly relate to the flow of gas in high pressure pipeline networks, in which gas pressure drop in the pipeline mainly depends on the length of the pipeline, and it is virtually impossible to obtain a gas pressure too high for this type of network. The main problem is to provide the pressure higher than the minimum one, which is achieved installing gas pressure compressors on high pressure pipeline networks within a specified spacing, which task is gas stream compression. In turn, in the low pressure networks, in which smaller volumes of gas are transported and stream parameter changes are fast, omitting the differences in individual pipelines height in the network in the calculations may lead to large errors in the results of gas pressure in the network nodes. In this case, it is easy to lead to a situation of an exceeding the maximum, or default to maintain the minimum gas pressure in the network, which will result in an improper functioning of the equipment installed at the gas consumers. Therefore, experimental determination of limit values of overpressure in the low pressure network is so important, taking into account the actual data on the uneven load on the network and the ordinate of network position in the area.

The aim of the study is a comparative analysis of basic parameters characterizing the dynamics of gas flow in the pipeline network, depending on network location in the area. On the basis of simulation calculations performed in the GasNet software, the size of minimum and maximum overpressure of gas stream feeding the network of low pressure pipelines supplying the gas to municipal customers, was selected empirically depending on pipelines inclination in the network. Five ways of network foundation were examined: one case of horizontally positioned network ($\Delta H = 0$), and two cases, when the supply gas reduction station is located lower than the rest of the network ($\Delta H < 0$), and two examples of the networks in which the supply station is arranged above with respect to the rest of the network ($\Delta H > 0$). The limit overpressure of gas stream feeding the network was selected individually for each case, depending on the network load, i.e., the size of gas stream entering the network in order to cover the demand for gas by the consumers. The study was conducted for the fragment of the actual gas network in one of Polish cities, and actual data about gas consumption from the network by individual customers connected to that network and the actual weather data. Moreover, the unevenness in gas consumption by the customers depending on the temperature and hour of the day was taken into account in the calculations. The results of the calculations of overpressure feeding the network, obtained for the real network, which is characterized by the horizontal arrangement of all the pipelines, were previously verified using the data acquired from the network operation. Based on the analysis of the results of gas overpressure distribution in the network, an effect of taking into account in the calculations of the difference in heights of each of pipelines location in the network on proper network operation and safe gas transport was demonstrated. It was additionally demonstrated that the use of the dynamic system of overpressure adjustment to the volume of gas