Energy 109 (2016) 105–116

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Improving the natural gas transporting based on the steady state simulation results

Jolanta Szoplik

West Pomeranian University of Technology, Szczecin, Dept. of Chemical Engineering, al. Piastow 42, PL-71-065 Szczecin, Poland

ARTICLE INFO

Article history:
Received 21 November 2015
Received in revised form
22 April 2016
Accepted 23 April 2016

Keywords:
Natural gas pipeline network
Steady-state simulation
Steering
Improving the natural gas transporting

ABSTRACT

The work presents an example of practical application of gas flow modeling results in the network, that was obtained for the existing gas network and for real data about network load depending on the time of day and air temperature. The gas network load in network connections was estimated based on real data concerning gas consumption by customers and weather data in 2010, based on two-parametric model based on the number of degree-days of heating. The aim of this study was to elaborate a relationship between pressure and gas stream introduced into the gas network. It was demonstrated that practical application of elaborated relationship in gas reduction station allows for the automatic adjustment of gas pressure in the network to the volume of network load and maintenance of gas pressure in the whole network at possibly the lowest level. It was concluded based on the results obtained that such an approach allows to reduce the amount of gas supplied to the network by 0.4% of the annual network load.

1. Introduction

Natural gas is used as a raw material in chemical industry, as fuel in combustion engines, and to generate electricity or heat. Such versatile application causes that the demand for gas in many countries is much higher than the national resources, and the possibility of supply from countries rich in gas resources are limited due to insufficient capacity of pipelines constructed many years ago. As demonstrated by Thomas and Dave [1], gas transport can be implemented in many different ways: e.g. in the form of electricity or other products created on the basis of natural gas. However, it is assumed the most often, that transportation of gas in LNG (liquefied form) is the most cost-effective on a long distance, while gas transport under an increased pressure using pipelines network is unrivaled within the country.

Depending on the size of gas pressure, gas networks are referred to as the high-pressure or low-pressure networks and they differ with equipment. The main components of high-pressure networks include steel pipelines and compressor stations, while the low-pressure networks contain pipelines made of PE (polyethylene) and reduction stations. Gas transport using optimally designed and operated pipeline network can significantly contribute to reduction in gas transport costs, better use of gas pipelines storage capacity, reduced risk related to the danger of gas-air mixture explosion, reduced losses caused by possible pipelines leaks or failures. Optimization is mainly carried out on the basis of the results of gas flow simulation on the basis of mathematical models solved analytically or numerically. The aim of optimization is most often to maximize the flow and minimize transport costs. Moreover, the results of flow simulation in the form of pressure, flows or velocity distribution greatly assist the analysis of the problems associated with gas flow through the network and can be used to control the network.

In this work, based on the results of gas flow modeling in low-pressure gas network, one attempted to address the question whether it is possible to formulate mathematical relationship between the required high pressure of gas supplying network and the network load for different weather and calendar conditions. Thus, high pressure of gas in the network will be maintained at possible low but safe level, and gas losses due to leakage of gas pipeline, will be decreased. On the basis of the results it was concluded that such an approach allows to reduce the amount of gas supplied to the network by 0.4% of the annual gas flow through the network.

2. Literature review

The models used to describe gas flow in the network should take into account all elements of the network, and relatively truly reflect

E-mail address: jolanta.szoplik@zut.edu.pl.

http://dx.doi.org/10.1016/j.energy.2016.04.104
0360-5442/

the dynamics of the flow. According to [2], adiabatic flow model can be assumed for the pipelines in which the flow dynamics is fast, while isothermal flow model can be used for slow flow dynamics. An effect of thermal model type on the basic parameters (flow, temperature and pressure) characterizing gas flow in a high pressure pipeline was analyzed by Ref. [3]. They used steady-state thermal model or unsteady thermal model to describe the heat exchange between transported gas and the ground. The authors of [3] demonstrated that higher decrease in gas pressure in the pipeline is observed when gas temperature is the same as the temperature of the ground. In the case of isothermal gas flow through the pipeline, greater stream is transported by the pipeline due to an increased gas density, which causes that gas pressure at the end of the pipeline is lower than case of non-isothermal flow without gas cooling at the exit of the compression station. Chaczykowski [4] analyzed the effect of thermal model type on the accuracy of the solution of numerical model of gas flow in high-pressure pipeline. Based on the results of flow simulation in the form of pressure, temperature and flow, he demonstrated that the use of unsteady heat transfer model allows to obtain better quality results than on the basis of t steady-state thermal model. However, in paper [5] Chaczykowski demonstrated the results of the calculation of gas flow simulation in high-pressure pipeline made for different models of state equation. The author tested model AGA-8, SGREG-88, SRK (Soave-Redlich-Kwong) or BWR (Benedict-Webb-Rubin) for the assumed unsteady and non-isothermal flow. The calculation results showed no significant effect of the applied state equation on the change of parameters such as flow, temperature or pressure.

Tao and Ti [6] demonstrated that modeling of unsteady gas flow in the pipeline network can be based on an analogy to current flow in electrical circuits. In this case, the ordinary differential equation system is solved, which greatly simplifies and reduces the computation time. Matko et al. [7] compared the results of simulations for unsteady fluid flow and actual volumes of gas flow and pressure at the ends of the pipeline. The comparison demonstrated that experimental data and results from nonlinear model and linear distributed parameter are comparable, while the results of calculations made based on linear lumped parameter model are clearly different from the measurement data. Reddy et al. [8] presented an example of an application of transfer function model for developing a dynamic simulator for a single gas pipeline, and proposed the use of the model to estimate unknown demands and on-line leak detection and identification. Wu et al. [9] proposed a mathematical model of the fuel cost minimization problem and derived two model relaxations that allowed to develop a lower bounding scheme. According to [9], a global optimization of the network can reduce fuel consumption costs by compression stations even up to 20%. El-Mahdy et al. [10] tested an effectiveness of genetic algorithm model to optimize the diameters of gas network pipelines of a predetermined structure. The objective function was only the cost of gas network construction without the changes in its structure. Also no effect of the type of simulation model or type of optimization method was analyzed. The results obtained by the authors were comparable to the results of experienced engineers involved in gas pipeline network designing, and the use of genetic algorithms to optimize the size of the pipeline allowed to reduce the cost of investment by about 12%.

Brkić [11] based the simulation of flow and pressure distribution in gas network pipelines of a ring structure with the known size of the feed stream and the streams received from the network on the improved version of Hardy Cross method. The improvement of this method over the original Hardy Cross method, involving the introduction of influence of adjacent contours in Jacobian matrix, resulted in a reduction in the number of iterations needed to obtain satisfactory results of calculations. Depending on cost and time of computation, this method can also be used for optimum structure of gas network designing.

Structure of the pipeline network is important for the total cost of gas transport, because according to [12], 1% network improvement can bring a profit of $ 49 million, and the main task of network optimization is to minimize transport costs with concurrent maximization of network performance. The cost of gas fuel transport [13] includes the cost of investment and maintenance of both pipelines and devices assisting the transportation (e.g. compressor or reduction stations). The cost of fuel consumed should be additionally taken into account in the case of compressor stations. Many authors [9,12,13] indicate that the compressor stations consume about 3–5% of the transported gas, while the cost of compressor station maintenance accounts for about 25–50% of the total cost of gas network maintenance.

The authors [12] analyzed an effect of network configuration and process variables on the gas pressure and gas streams distribution in the network. The paper presents a detailed form of model equations for the compression station, presenting the characteristics of the compressor using a third-degree polynomial. The advantage of the proposed network model is possibility to obtain a solution already after 4–6 iterations, and the model can be used for an analysis of the flow in the networks also for other liquids. Based on the results of the simulation of gas flow in the network, the authors [14] analyzed an effect of the pipe roughness, thermal conductivity for the ground, on the size of pressure and temperature of the gas at the end of the pipeline for various volumes of transported gas flow. The study demonstrated, that for the high Reynolds numbers, the pressure and temperature of gas are to a high degree dependent on the coefficient of drag, thus the heat transfer coefficient for the ground has negligible impact on pressure and temperature profile. In turn, Najibi and Taghavi [15] analyzed an effect of diameter, wall thickness and pipe length, as well as the stream pressure and compression coefficient, on the cost and life time of gas transportation system. The study conducted for one of main gas pipelines in Iran demonstrated inter alia, that the increase in gas pressure and the use of better materials for pipelines construction can reduce the cost of gas transmission. It was demonstrated in the paper [2] how important it is to take into account in the model of gas flow the element related to the height difference between the particular points of the pipeline or pipeline network. Calculations made for a straight pipeline section for variable pipe load sizes and for different differences in height between the start and end point of the pipe ΔH demonstrated that higher gas pressure at the end of the pipe for the ascending pipeline is characteristic for higher ΔH values. According to Gato [16], two types of flow changes are observed in pipelines. Slow changes in pressure and flow in the pipeline are caused by non-uniformity of the pipeline load. Such changes can be analyzed using simplified flow models, which normally omit the changes in fluid kinetic energy. However, fast changes in the flow resulting from a sudden closure of the valve or pipeline rupture require an application of less simplified model and more advanced calculation methods (differences or finite volume method). Numerical calculations of fluid flow dynamics in the high-pressure pipeline situated between reduction-metering station and the safety valve made using Runie-Kutta discontinuous Galernik method demonstrated that the volume of gas pressure in the pipeline depends on the characteristics of dynamics of regulator and safety valve, as well as pipe volume and flow cross-section changes.

Studies on network structure optimization including both the pipelines and the compressor stations were described by Fasihizadeh et al. in Ref. [13]. They analyzed an effect of network structure and load on the size of power of the compressors installed in the compressor stations and the size of energy consumed by them