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The Steady-State Simulations for Gas Flow in a Pipeline Network

Jolanta Szoplik
Dept. of Chemical Engineering, West Pomeranian University of Technology, Szczecin
Al. Piastów 42, 71 065 Szczecin, Poland
jszoplik@ps.p

The paper presents calculation results of stream, velocity and gas overpressure obtained from steady state simulation of gas flow in pipeline network distributing natural gas. The calculations were performed for real section of pipeline network localized in city Szczecin. Total length of pipelines creating network was equal to 4,151 m. This network was filled with 51 m^3 gas with overpressure of approximately 2.4 kPa. Based on simulation results, received for various input data values, corresponding with different hours of the day, it was proved, that both gas flow rate and its velocity in pipeline network depend inter alia on the time of the day.

1. Introduction

One of the basic features of network systems is their uniqueness, in regard to the structure as well as transmission capability. In practice there are no two identical networks, and uniqueness leads to necessity of use individual approach to networks during designing and exploitation stage. In case of many real time systems, examination of its performance in conditions different from currently existing is impossible. In such a situation a mathematical model of such system is constructed (Osiadacz, 1987, 2001, Kralik et al, 1988) and is used to simulate behaviour of the system in reaction on extortion. Simulation is an example of experiment, performed with help of appropriate algorithm and computer. Gas network can be an example of a system, where from the technical point of view, it is difficult to perform direct measurements of parameters values characterising flow in pipeline networks. Analysis of network flow simulation results enables to estimate such network bandwidth reserves, define possibilities of network expansion directions, calculate maximal value of the gas flow rate in the pipeline of the network, gas parameters in output points. Analysis of flow issues, leakage detection in network systems, ensuring reliable working and problem of heat exchange between gas flowing through the pipe and the ground, that pipeline is located were so far the subject of several scientific papers (Osiadacz and Chaczykowski, 2001, Ke and Ti, 2000, Fakushima et al., 2000, Tao and Ti, 1998, Mahgerefteh et al., 2006). However these papers treated mainly of gas flow in high pressure network, that have much simpler structure than low pressure networks.

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The aim of the presented study was to determine the daily flow rate waves and the velocity of the gas in each pipeline and overpressure of the gas flow at each node of the network for various hourly values of the flow rates at output nodes. The simulation results of the gas overpressure were also compared with the real data obtained from the gas network.

2. The subject of the analysis in the study

The subject of analysis was the real pipeline network consisted of 319 pipelines of various diameters (from 0.05 m to 0.25 m). The whole length of the pipeline in this network was equal to 4,151 m and the overall amount of gas accumulated in the network was equal to 51 m^3. The low pressure gas pipeline network operates with overpressure in the range of 1.8 kPa to 2.5 kPa. The operating temperature was 283 K, the relative density of the gas was equal to 0.6. The velocity of the gas was always lower than 5 m/s in each pipe of the network.

The graphic representation of the analyzed in the study network consisted of 316 nodes and 319 branches. There was one supplier node (Z1), where gas was entered to network, 108 nodes, where gas left network (boundary or output nodes) and 207 internal nodes. There were also one input, 108 output and 210 internal branches. Boundary branches containing input or output nodes are respectively called input or output branches. The number of loops in this pipeline network was equal to 3. The graphic representation of this network illustrates Figure 1, but the detailed data for the network, diameter and length of the pipe in the network are collected in Table 1. There are only 13 nodes distinctly marked at the graph presented in Figure 1 (A2; A51; A61, A64, A65, A70, A71, A75, A92, A90, A80, A146, A147) where flow rate is divided or the diameter of the pipe is varied. The mathematical model of gas flow in the pipeline network consisting of equations (1-3) was performed with computer program GASNET, used to steady-state simulation of gas flow by means of loop method derived from the analogy between fluid and electrical networks.

The Kirchhoff's laws express respectively - equation of continuity for each network node and equation of energy for each loop of network. The matrix form for first and second Kirchhoff's law (Osiadacz, 1987, 2001, Kralik et al., 1988) represent the following equations:

$A_1 \cdot Q = q$ (I Kirchhoff's law) (1)

$B \cdot \Delta p = 0$ (II Kirchhoff's law) (2)

where:

$A_1 = [a_{ij}]_{(n-n1)\ x\ m}$ – reduced nodal – branch incidence matrix,

$B = [b_{ij}]_{k\ x\ m}$ – loop – branch incidence matrix,

$Q^T = [Q_1, Q_2, \dots Q_m]$ – vector of flows in the branches,

$q^T = [q_1, q_2, \dots q_{(n-n1)}]$ – vector of stream at the output nodes,

$\Delta p^T = [\Delta p_1, \Delta p_2, \dots \Delta p_m]$ – vector of pressure drops in the branches,

Equations (1) and (2) complete with the following form of flow equation

$\Delta p = \Phi(Q)$ (3)

where: $\Phi(Q)$ is the vector of flow functions in the branches

are the matrix form of the mathematical model and describe the gas flow in the network.

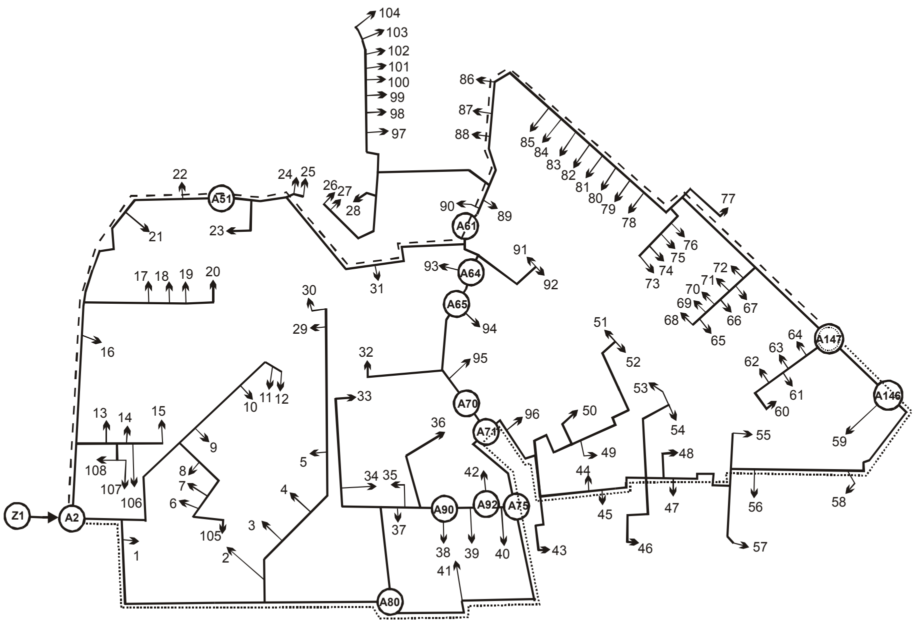

Figure 1: The graph of the gas pipeline network

Table 1 The diameter nominal D_{nom}, inner D_{in}, length L and thickness s of the wall for the pipes of the network presented in Figure 1

No.	$D_{nom} \cdot 10^3$ *[m]*	$D_{in} \cdot 10^3$ *[m]*	$s \cdot 10^3$ *[m]*	*L [m]*
1	250	204.6	22.7	18.7
2	225	184.0	20.5	687.6
3	180	147.2	16.4	1280.7
4	160	130.8	14.6	80.2
5	125	102.2	11.4	517.1
6	90	73.6	8.2	813.5
7	63	51.4	5.8	735.8
8	50	40.8	4.6	17.8

3. The results and discussion

Simulation results presented in the paper were received based on input data characteristic for February 11, 2007 (Sunday) and for city of Szczecin. The temperature during that day in Szczecin was (-4 ^{o}C), whereas at night was (-9 ^{o}C). Input data for simulation calculation constitute gas streams, left network in 108 output nodes variable in time that depends on time of the year, temperature and hour of the day. Based on steady state simulation of flow in the network, only one set of results can be obtained, that correspond with one state of the network and is characteristic for one hour of the day. Whereas performing analogous calculations for various input data sets, information was received regarding gas flow rate and gas velocity in all pipelines of the network and gas overpressure in all nodes of the network in particular hours of the day. Figure 2 presents gas flow rate (Q) and its velocity (w) in several chosen pipelines of the network (with different nominal diameter D_{nom}) corresponding with individual hours of the day. Analysis of these results showed that, gas flow rate and its velocity to a large extend depend on hour of the day. Highest values on that day (Sunday) are characteristic for the 10 am, whereas lowest for the night's hours (from midnight to 4 am). Differences between maximal and minimal values can reach even 60 %. Presented in the paper results relate only to one, particular day (February 11, 2007), whereas performing analogous calculations for different days of the year we can receive detailed information of load of the entire network in particular days of the year (depending on air temperature and day of the week).

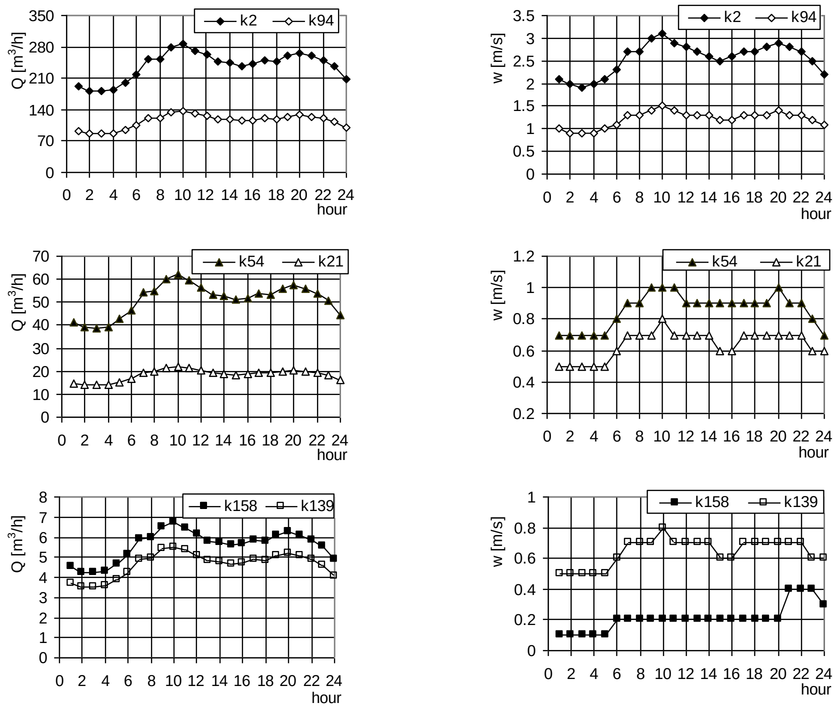

Figure 2: The changes of the volumetric gas flow (Q) and velocity gas flow (w) calculated for various hour of the day; a) $D_{nom;k2}$ = 225 mm, $D_{nom;k94}$ = 225 mm; b) $D_{nom;k54}$ = 180 mm, $D_{nom;k21}$ = 125 mm; c) $D_{nom;k158}$ = 90 mm, $D_{nom;k139}$ = 63 mm

During correct work, the network provides required size of the gas flow with appropriate overpressure and required velocity to each output node, regardless of its location in the network structure. In analyzed network, in the most distance from the source Z1 is node corresponding with output node 60, preceded with the node A147, joining gas streams flowing from upper and lower side of the network, which are marked on Figure 1 with dashed or dotted line accordingly. Volumetric gas flow in node A2 is divided into two smaller streams that supply accordingly output nodes situated along upper and lower line, joining node Z1 with A147 node. Lengths of trip and gas flow rate left network vary. Pipeline length connecting node A2 with the A147 node through the node A51 is $L_{A2\text{-}A51\text{-}A61\text{-}A147}$ = 745.2 m, whereas analogous calculated length of the pipeline of the network through the node A71 equals to $L_{A2\text{-}A71\text{-}A75\text{-}A80}$ = 949.7 m. Figure 3 presents gas flow simulation results of gas flow in network pipelines from the node A2 to the node A147, accordingly upper and lower line of the network presented in Figure 1. Results were received for six exemplary gas stream sizes (Q) supplying network and correspond with six different hours of the day (i.e. h2 correspond with 2 am). Analyzing results from Figure 3 one can see, that definitely larger stream Q flows in pipelines in lower line of the network rather than in upper line, and it is larger at 10 am (h10) than at 2 am at night (h2).

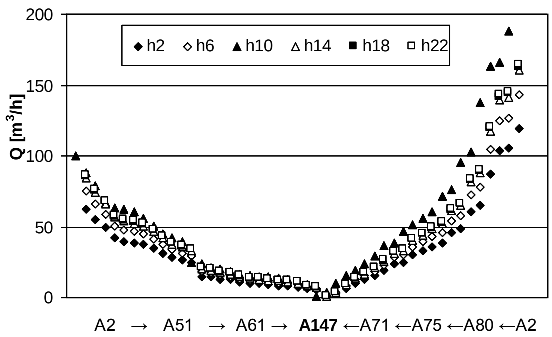

Figure 3: The simulation results of the volumetric gas flow Q in the upper and lower lines from supplying node Z1 to node A147 in the network presented in Figure 1

To supply gas stream with overpressure of $p_{min,60}$ = 1.7 kPa to output nodes 60 (Figure 1), the gas overpressure in node A147 have to be higher than $p_{min,A147}$ = 1.8 kPa. The absolute pressure of the gas flow in the pipes does not depended on the gas flow Q (in the range of performed calculations), but depends on the overpressure of the gas entered to the network in node Z1. Figure 4 presents the simulation results of overpressure of the gas flow in the pipeline network obtained for various values of gas overpressure. The above mentioned node A147 is located in the middle part of the X axis. Points located on left side of the A147 node correspond with gas overpressure value in particular nodes of the network located in upper line, whereas points located on the right side of this node - correspond with gas overpressure values in particular nodes of the network located in the lower line supplying node A147. Analyzing calculation results from Figure 4 we can note, that entering into network gas flow with overpressure of $p_{we,Z1}$ = 2.2 kPa it is impossible to provide gas supply to all output nodes with overpressure of p > 1.7 kPa (as gas overpressure in node is p_{A147} < 1.8 kPa). Gas overpressure increase in supplying node Z1 influences gas overpressure increase in all pipelines of the network. Based on simulation results, received for various values of $p_{we,Z1}$ it was established, that the lowest gas flow overpressure value supplying network, ensuring gas supply with appropriate overpressure is equal to $p_{we,Z1}$ = 2.3 kPa. In real conditions this network is supplied with gas stream with overpressure of $p_{we,Z}1$ = 2.4

kPa. Assuming, that measurements precision equals to 100 Pa, we can presume that simulation results are comparable with real data, characterizing the network.

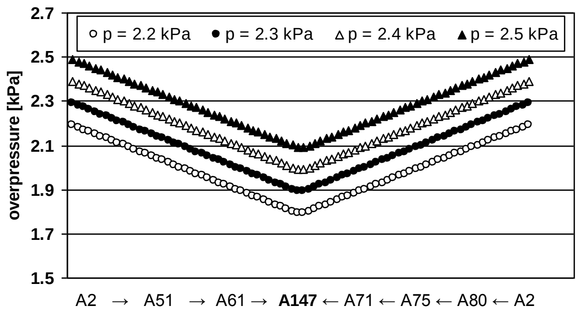

Figure 4: The simulation results (for h10) of the overpressure of gas flow in the upper and lowerlines from supplying node Z1 to A147 in the network presented in Figure 1

4. Conclusions

Based on results, received from steady state gas flow simulation in the network for numerous input data sets, we can say, that both gas stream size and gas velocity in network pipelines depend on time of the day. It can also be concluded, that network load is not identical not only during the day, but also depends on time of the year. Optimal gas stream overpressure value supplying the network, received from simulation is similar to real value that was determined experimentally.

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