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STUDY OF THE NON-PROJECT OPERATING MODES OF THE GAS PIPELINE TRANSPORTATION SYSTEM

For decades, it was shown that pipelines are the safest and most convenient way to transport natural gas. The requirements of smooth operation are extremely important for them as the gas supply is made in a large volume for long distances. An unsteady gas flow is a characteristic feature of the gas pipelines. Its pressure and flow rate are changing along the length of the pipeline and over time as a result of uneven consumption and outflow, start and stop of the compressor stations, valves closing, the emergence of gas leaks etc. [1, 2].

The appearance of damages on the pipelines leads to their malfunction, occurrence of leaks as well as they create a great threat to people and objects near the pipeline route. The magnitude of accidental losses depends on the location and size of the accident and the speed of its detection and elimination.

Emergency leaks can be divided into three categories:

1) small leaks, which are detected by analyzing the air for the presence of hydrocarbons,
2) average leaks, which are detected by indirect evidences,
3) large leaks – detected by readings of regular devices [2].

Knowledge of the laws of change of process main parameters while pumping gas via pipelines in non-project modes has a significant interest in practice. In order to improve the overall safety and to reduce the risk of emergencies on gas pipelines it is important to assess the safety and risks of the operation [1, 3], namely detection of emergency leaks, appearance of illegal gas selection and other emergency situations in the operation of the pipeline. With this task, in general, deal pipeline systems dispatchers, who are constantly watching for indications of devices using telemetry. An important part in this work is to

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understand the processes and to interpret correctly visual information, namely, being able to recognize whether in the system were proper connections or disconnections of the consumers, or possibly a large emergency leak has appeared etc. For this the dispatcher should be aware of possible situations and their visualization in the work software. However, because accidents or non-project modes are not tested on a real pipeline, the dispatcher can learn how they appear on the screen only through their simulations in the software.

Nowadays there are many technologies for detecting leaks in pipelines. In general, they can be divided into two groups:

1) Externally based methods that operate on the non-algorithmic principle of physical detection of an escaping commodity.
2) Internally based methods that utilize field sensor outputs to monitor internal pipeline parameters such as: pressure, temperature, viscosity, density, flow rate, product sonic velocity, etc. These inputs are then used for inferring a commodity release by computation [3].

The main methods of the first group are fiber optic cable, vapor sensing tube, liquid sensing cable, acoustic sensor, vapor sensor, infrared camera, remote measurement of soil temperature change, inspection of line rider with gas analyzer.

The methods of the second group include volume balance, rate of pressure/flow change, real time transient model, statistical analysis, negative pressure wave.

Of course, each of the above methods has its advantages and disadvantages that must be considered in their application in practice.

The aim of this paper is to investigate the reaction of the gas transport system to a sudden gas flow stop, appearance of the emergency leaks as well as to increasing of the consumption gas flow rate.

Research objectives:

– To investigate the system response to a sudden gas cut caused by closing a line valve that can occur in an accident on the single-strand pipeline.
– To determine the minimum flow rate of gas selection, at which the pressure drops below a specified value of 5% and the location on the pipe where it does, and how much time it can take to detect this pressure drop by regular devices at that shifting a position of the gas outflow along the pipeline with an increment of 10% of its length and studying the change of pressure drop detection time.
– To determine an effect of gas outflow rate increasing on the operating mode of the gas transport system and the pressure drop detection time.

The object of the research is a model of a single-strand pipeline section of the gas transmission system, consisting of three compressor stations (CS) and four line segments.

Methods of researching. To obtain and analyze the results by means of mathematical modeling of the gas transmission system and dynamic programming.

To implement the tasks an imaginary entirely horizontal single-strand pipeline (Fig. 1) was taken for the consideration. A mathematical model of the system is based on the classical equations of unsteady gas flow, continuity and energy together with the Soave-Redlich-Kwong equation of state of a real gas, which form a closed system [4, 5, 6]. The pipeline consists of two main nodes – inlet and outlet. These nodes simulate compressor stations, control of which is carried out manually by setting initial conditions, namely entering the values of pressure and temperature of the natural gas at the inlet of the pipeline and its outlet. In this paper, the values of these nodal parameters were as follows:

– inlet: *P*: 71.8 bar, *T*: 40^{o}C,
– outlet: *P*: 52.05 bar, *T*: 20^{o}C.

There are four line sections and three compressor stations between these nodes. The length of each such section is 120 km. The inner diameter of the pipeline line section equals to 1400 mm.

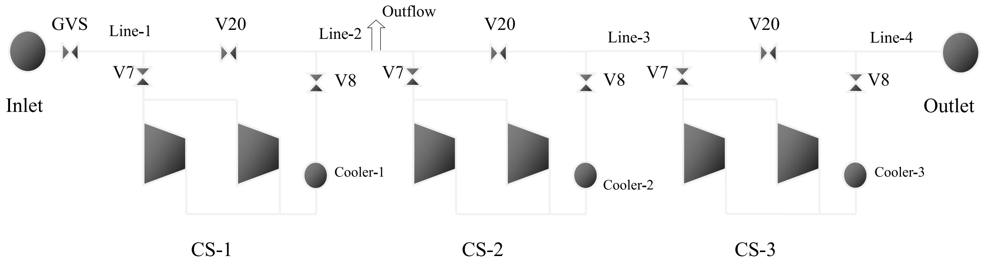

Fig. 1. A scheme of the research pipeline

Each compressor station comprises two working compressor units of a model 650-22-2 and a cooler unit. The inner diameter of the CS pipelines is 1000 mm. The input and output pipes of compressor stations have a length of 100 meters, piping lines between compressor lines – 50 m, compressor lines – 40 m. Control of the gas flow through the compressor station or bypassing it can be done by using station valves V7 and V8 and line valve V20 respectively at each compressor station.

At a distance of 5 km from the inlet node a line valve GVS is set to simulate a complete stop of gas supply via this pipeline in case of an emergency stop.

At the beginning of each line section the initial pressure transducers are mounted that transmit information about the pressure at these points to controllers with a view to opening and closing valves V20, V7 and V8 if no gas flow, thus simulating emergency prevention at compressor stations. Pressure settings (Tab. 1) for changing a position of closing element of the above mentioned valves can be changed if necessary.

There is also a gas outflow (consumer gas selection) at the line section after CS-1 for investigating its effect on the work of the gas system.

Table 1

Pressure settings for opening/closing of valves V7, V8, V20

Valve	Opening [bar]	Closing [bar]
V7	67	64
V8	67	64
V20	64,5	68

Problem 1. During the first hour of simulation gas is transported with a constant mass flow rate without any change in the process. The value of the mass flow rate is 718 kg/s. Compressor revolutions are adjusted automatically. The values of pressure at the beginning and end of line sections are presented in Table 2.

Table 2

The values of pressure at the beginning and end of line sections

Line section	Inlet pressure [bar]	Outlet pressure [bar]
Line-1	71.80	51.23
Line-2	72.48	52.37
Line-2	72.48	52.33
Line-4	72.48	52.37

The GVS valve is being closed on the 60^{th} minute, simulating gas cut in case of the emergency stop of the single-strand pipeline. Its closing time is 2 minutes. As a result, there is a pressure drop in the pipeline after this valve, which leads to the implementation of measures to prevent emergency operation of compressor stations on each line section. The procedure is as follows.

Primary pressure transducers on each line section at a specified point of the pipeline monitor pressure value. When pressure drop to the corresponding values of pressure settings for valves V7, V8 and V20 is detected, controllers send signals to these valves of compressor stations, which are closing and opening respectively. Time of their opening/closing equals to 10 seconds. Beside that to simulate a complete stop of compressors, valves before and after them are closed on each pipe. Thus there is a change of gas transportation route through the line valve V20 bypassing compressor station and its mass flow is reduced significantly.

After the pipeline has not being operated for 4 hours, gas supply is restored by opening the valve GVS on the 5^{th} hour of simulation. Gas pressure in each line section grows and, in turn, the valves V20 are being closed and the valves V7 and V8 are being opened for moving of gas through the compressors. Mode of gas transport returns to the normal parameters that were before the termination of supply.

Figures 2 and 3 show how after line valve closing pressure in the pipeline drops sharply and at the same time since the compressor stations continue to work for some time, gas mass in each section of the pipeline is significantly reduced, notably in the last section. However, after the system is restored, process is reversed – sections are filled from end to beginning, but much slower.

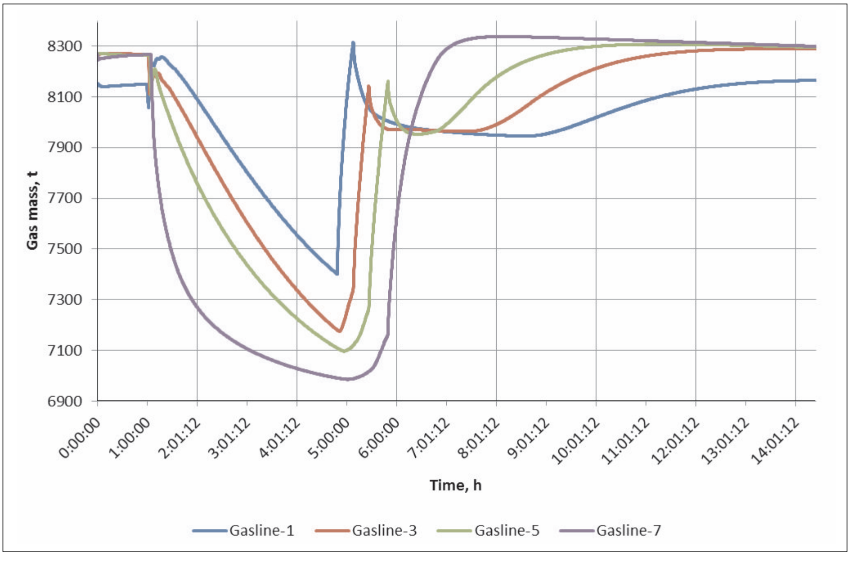

Fig. 2. Gas mass change in the pipeline during the simulation process

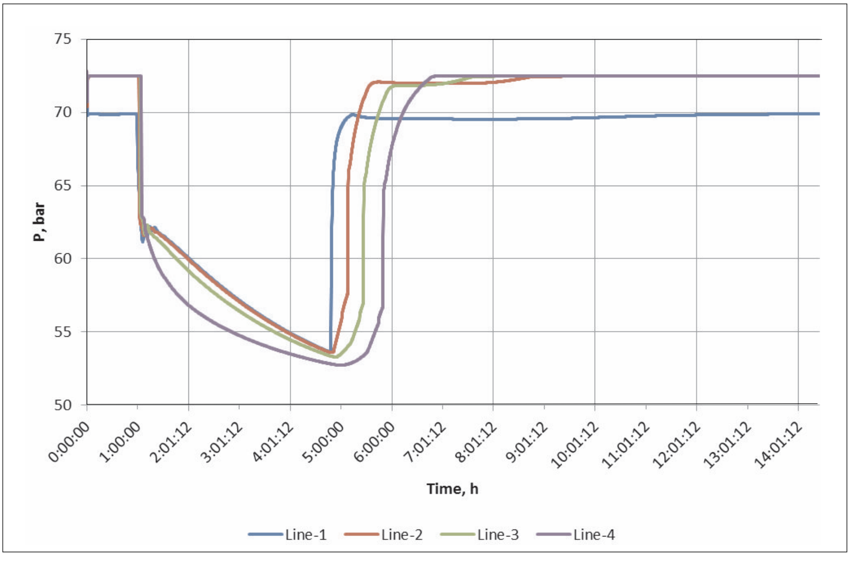

Fig. 3. Gas pressure change in the pipeline during the simulation process

It worth to note, when the line valve is closed, simulating emergency stop of the pipeline, downstream compressor stations stop working in less than 1.5 minutes (Fig. 4), but the restoration of their work is slower due to the speed of pressure wave propagation in the pipe before and after a hypothetical accident.

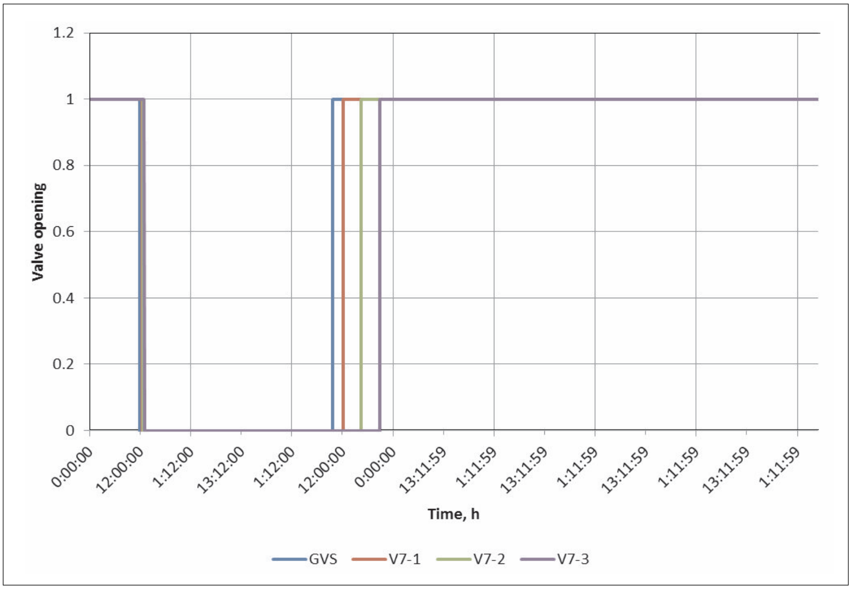

Fig. 4. Opening/closing of line and compressor station valves

Problem 2. During the first two hours of simulation gas is transported in a steady state with a constant flow rate. The value of mass flow in the system is equal to 720 kg/s. The speed of compressors is set in manual mode and the revolutions of both compressors at each station are as follows: at CS-1 – 3605 rev/min, at CS-2 and CS-3 – 3505 rev/min respectively. The values of pressure at the beginning and end of each line segment are presented in Table 3.

Table 3

Values of pressure and temperature at the beginning and end of each line section

Section	Pressure [bar]		Temperature [^oC]	
	inlet	outlet	inlet	outlet
Line-1	71.76	51.20	39.7	23.1
Line-2	72.51	52.25	39.6	23.6
Line-3	72.49	52.24	39.6	23.6
Line-4	72.49	52.29	39.6	23.6

The process of gas selection from the pipeline is started on the 121th minute with a specified at the beginning flow rate. As a parameter, which would characterize changes in the mode of transportation, was selected time of detection of the pressure drop in the system by more than 5%. This per cent is explained by the accuracy of devices that are installed on the pipeline. Positions where this parameter will be controlled are 50 m after CS-1, 50 m before CS-2 and the place of gas selection. Maximum waiting time is 48 hours which is four shifts of dispatchers.

At the beginning of the study the gas selection position is at 60 km of the section Line-2. By changing different values of the outflow it was discovered that within a specified time minimum selection, which causes the pressure drop by more than 5%, is 65 kg/s (8,1 MSm^3/d), what corresponds to 9% of the total mas flow in the pipeline.

The next step was to study the effect of outflow location on the detection time of pressure drop. For this reason, it was positioned every 10 km along the length of the pipeline, ranging from 10 km to 110 km. The obtained results are presented in Table 4.

Table 4

The dependence of the detection time of pressure drop on the position of outflow

No.	Distance from CS-1 *L* [km]	Detection time of 5% pressure drop *t* [h]
1	10	–*
2	20	–
3	30	–
4	40	–
5	50	–
6	60	15:34
7	70	10:10
8	80	8:35
9	90	7:27
10	100	6:34
11	110	5:51

* "–" – not available, time exceeds specified initial conditions of 48 hours.

To perform the third task the obtained minimum gas selection flow rate was being increased with a step of 5% of its value. The results of calculations with different values of outflow and on its different positions are shown in Table 5 and their graphical comparison is shown in Figure 5 as well.

Table 5

The dependence of the detection time of pressure drop on the position of outflow and its value

No.	Distance from CS-1 L [km]	Detection time of 5% pressure drop t [h] at a specified outflow rate M [kg/s]					
		65	68.25	71.5	75.75	78	81.25
1	10	–*	–	–	12:10	9:00	7:32
2	20	–	–	–	9:57	7:57	6:49
3	30	–	–	11:35	8:36	7:10	6:15
4	40	–	16:44	9:34	7:38	6:32	5:46
5	50	–	11:08	8:13	6:51	5:57	5:18
6	60	15:34	9:06	7:16	6:11	5:25	4:52
7	70	10:10	7:39	6:20	5:29	4:52	4:24
8	80	8:35	6:47	5:42	5:00	4:28	4:01
9	90	7:27	6:05	5:11	4:34	4:04	3:42
10	100	6:34	5:27	4:40	4:09	3:42	3:21
11	110	5:51	4:54	4:15	3:45	3:21	3:02

* "–" – not available, time exceeds specified initial conditions of 48 hours.

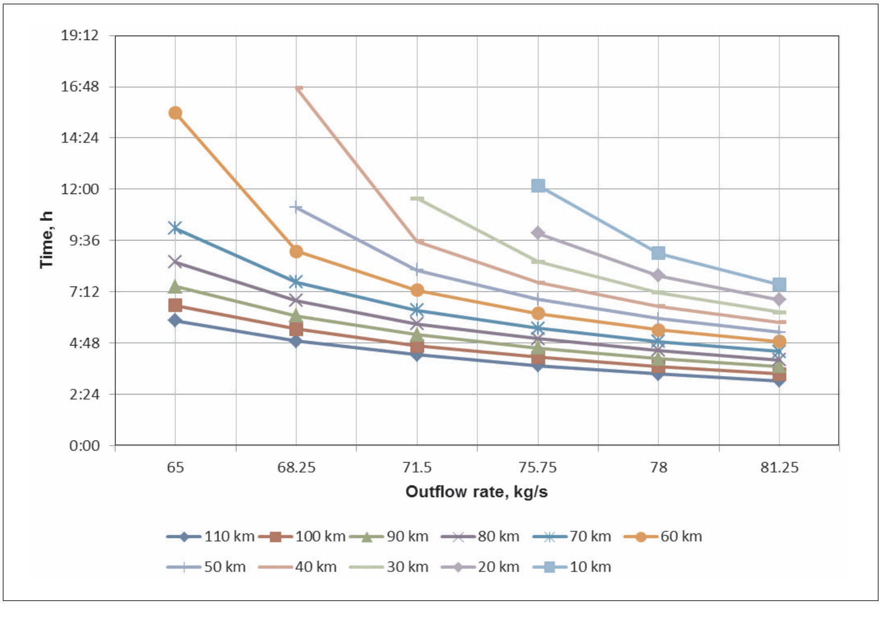

Fig. 5. The dependence of the detection time of pressure drop on the position of outflow and its value

Taking into account the data in Table 5 on the time required to detect leakage, the losses of gas can be approximately estimated. Thus, in case of selection with flow rate 65 kg/s at 110 km of the pipeline they may be 22 815 kg (32 906 m^3). Consequently, this leads to considerable financial losses. With greater values of gas selection these losses certainly only increase.

CONCLUSIONS

During simulation of the accident on the line section of the single-strand pipeline and line valve closing it was found that due to the rapid propagation of pressure wave the first downstream compressor station will stop its work in less than 5 minutes, and the next stations – after 1,5 min. one after another. After pipeline is restarted, this time increases to approximately 4 minutes between starts of each CS. As for the gas in the pipeline, its mass decreases sharply due to reduced pressure. After restoring the pressure wave spreads more slowly, leading to a slow setting of the mass balance before and after the accident at opposite ends of the pipeline. This situation, for example, can cause some speculations about unsanctioned diversion of gas from the international transit pipelines.

It was also analyzed in this paper that the emergency gas leak from the pipeline or illegal selection can be detected regular devices much faster if a leak/selection is closer to the end of the line segment. In addition, it can be stated that there is a limit (in per cent) between the values of the outflows which can be found and those which cannot. Thus, for example, in this study at the normal operation conditions of the pipeline this limit is about 9% of the total mass flow.

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