Instantaneous gas flow rate estimation in the gas-gathering system flowline by indirect measurement method

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Abstract. Implementation of modern automation systems on the northern gas fields located at the final stage of operation, is unprofitable economically and is not always possible technically. At the same time, the competent operation of such deposits requires constant monitoring for the state of gas wells and the shelves of the gas transmission network. In particular, the pressure and temperature is obligatory at the mouth of the well and at the end of the shelf. Also an important parameter from the point of view of regulating the modes of the wells is the instantaneous flow rate of the shelf, which is currently not measured at the old deposits. The article proposes to assess the instantaneous consumption by an indirect method, according to the values of pressure and temperature. The algorithm for calculating the consumption is proposed, the testing of which at the Urengoy gas condensate field confirmed its adequacy. The monitoring system of technological parameters is built into gas fishery ACS. The algorithm visualization is implemented in the SCADA HMI / Cimplicity software package.

1. Introduction
Most gas deposits in Russia are located in the extreme north, which significantly complicates their development and operation. The beginning of their development accounted for at the time when automation systems were fairly simple local systems for individual technological objects with limited functional. The further development of the ACS of TP on the basis of microprocessor equipment, of course, did not pass the gas industry: new deposits are designed taking into account the concept of "Smart Field", which makes it possible to effectively manage a gas-bearing formation based on collecting and analysing a wide variety of data.

As for those deposits that go to the final stage of operation or have already switched to it, then the situation is a paradoxical one. On the one hand, the operation of such deposits is complicated by the fall in wells, their flooding, gradually destruction of drugs, increase the risk of hydrate formation and many other factors [1, 2]. Accordingly, it requires increasingly “advanced” automation systems. On the other hand, first, mining companies do not want to invest large funds in modernization, because the life cycle of such deposits is coming to an end, and secondly, it is often technically impossible [3, 4]. For example, in the Urengoy oil and gas condensate field (NGKM), gas wells are not electrified, which makes it difficult to equip them with the necessary sensors and technical means of automation [5].

Therefore, developments are relevant to increase the efficiency of using existing automation systems without significant economic investments, changes in project documentation, etc. The article proposes a system for monitoring the technological parameters of a bush of gas wells that allows an indirect
method to assess the instantaneous gas consumption in the gas selection network and promptly control wells in real time to optimize production, as well as its work algorithm.

2. Materials and methods

2.1. Theory

Almost all the northern gas condensate fields use a collector-bush gas collection scheme [6], in accordance with which several wells are connected to a total loop. The loops, in turn, are connected to the general collector, by which the gas is fed to the installation of comprehensive gas preparation (ICGP). A feature of the gas transmission network is that the gas moves through it due to the energy of the reservoir.

Regulation of gas well flow rate is a challenge for many reasons [7, 8]. One of them is the mutual effect of the wells included in the bush on each other through the layer. With incorrect control of the flow rate the wells can crush each other. It should be borne in mind that the flow rate of each well is measured only during hydrodynamic studies, i.e. once every six months. The gas flow rate in the loop is also not measured.

For measuring the gas flow consumption, three methods are usually used [9].

- Alternating pressure drop.
- Ultrasonic.
- Vortex.

In the pressure drop flow meters, the sensitive element is a standard or non-standard narrowing device, on which, when the flow is passing through it, the processing medium creates a pressure drop, a proportional to square of the flow values.

The principle of operation of ultrasonic flow meters is based on measurements of the time of passage of ultrasonic probe pulses in the flow and against gas flow. The difference in the measurements of the time is inversely proportional to the gas movement speed in the pipe, which allows to determine the volumetric flow rate of the gas.

In the vortex flow meters, a special body of flowing is established, forming stable vortices, the frequency of which is proportional to the flow rate.

Each of these flow meters has its own set of advantages and disadvantages, but one quality combines them all - they are all equally not applicable to work in the gas gathering system [10].

This is due to the fact that natural gas produced from wells is actually an aerosol, and all listed flow meters are designed to work on homogeneous media.

In addition, all of them require system power sources for their work, as a rule, missing on wells.

2.2. Measurement means, normally installed on wells

On all wells and in the plumes, a continuous measurement of temperature and pressure with a given accuracy and transmission of information on the following levels of TP ACS are performed. Most often, the measurement of these parameters is made using various multiparameter transducers connected to the gas fishery telemechanics system (STM GF).

One of these converters is the RTP-04 technological parameter recorder [11], which is intended for measurement and transmission to automatic operator of technological parameters (temperature and pressure). Measured parameters are written in digital form into the internal memory and are later read by a computer via cable or radio channel. Depending on the measurement objectives, it is installed directly on each well before the adjusting fitting (to measure the mouthpieces of this well) or on the loop (to measure the parameters of the group of wells as a whole).

The registrar can be applied in two versions.

- Communication with a personal computer in real time when the current pressure values and temperatures are displayed.
• Autonomous when digital pressure and temperature references generated in accordance with the specified operator of the data recording mode are recorded in the non-volatile recorder memory, followed by reading on the computer.

To measure pressure, a strain gauge is used, and to measure the temperature - a platinum thermistor is used. Information is provided in the form of continuous graphs of pressure dependences and temperature from time \( P(t) \) and \( T(t) \). All reports of the registered parameters are “tied” to real time, the data on which is stored along with the references. To transmit data RTP-04, uses a radio channel operating in a license-exempt frequency bands (868-870) MHz.

Also, the wells are installed measuring torch lines with a diaphragm meter of critical flow, which are used in hydrodynamic studies, and shut-off valves.

### 2.3. Setting research objective

Thus, to increase the efficiency of deposits in the final stage of the life cycle, it is necessary to investigate the possibility of building an automatic system for monitoring the technological parameters of the well in real time based on existing measurement and automation tools to avoid large economic and technical costs for its implementation. One of the functionals of such a system should be an estimate of the instant gas consumption for each loop, necessary for the operational control of the performance of gas wells (kgf). The direct measurement of the flow rate in the loop is impossible, so it is necessary to determine the speed of movement of the gas along the loop indirect measurement method, i.e. by any parameters, for example, by pressure and temperature. The developed algorithm for an instantaneous consumption assessment in the gas gathering system loop will be based on the basis of the structure of the automatic continuous monitoring system for gas wells.

Consider the solution of this task on the example of Urengoy NGKM.

### 3. Results and discussion

#### 3.1. Mathematical description of the movement of gas along the loop

When the gas moves through the pipeline, the pressure drops at its length. The cause of this phenomenon is hydraulic resistance. Gas is a compressible medium, therefore its density \( \rho \) depends on pressure. Then, when the gas moves, the density value will gradually decrease from the beginning to the end of the loop [12].

In accordance with the law of conservation of mass \((V - \text{gas volume})\)

\[
\rho \cdot V = \text{const},
\]

the linear speed \( v \) of the flow will be, on the contrary, increase from the initial portion to the final.

The installed isothermal gas movement \((T=\text{const})\) in the gas pipeline is described by the system of three equations.

1. Bernoulli equation (energy conservation law):

\[
\frac{dP}{dP_r} + \frac{v \cdot dv}{g} + dz + \lambda \cdot \frac{dx \cdot v^2}{2g} = 0,
\]

2. Status equation:

\[
P = \rho_r \cdot R_r \cdot T \cdot z.
\]

where

\[
R_r = \frac{R}{M}
\]

3. The law of conservation of mass expressed in the constancy of the mass flow:

\[
G = \rho_r \cdot v \cdot s = \text{const}.
\]

The isothermal process is described by the Boyle-Marriott equation:
Mass flow rate can be found from equation

\[ P_1^2 - P_2^2 = 1.2687 \cdot 10^{-4} \cdot \lambda \cdot \frac{G^2}{d^5} \cdot \rho_0 \cdot l \]  

as

\[ G = \frac{\pi d^2}{4} \cdot \sqrt{\frac{(P_1^2 - P_2^2)d}{\lambda \cdot R_c \cdot T \cdot L}}. \]  

Formulas (1) - (8) indicate:
- \( G \) – a mass consumption of gas, kg/s;
- \( d \) – the inner diameter of the pipeline, m;
- \( P_1, P_2 \) – pressure at the beginning and at the end of the gas pipeline, respectively, Pa;
- \( \lambda \) – the coefficient of hydraulic resistance;
- \( R_c \) – gas constant, J / (kg‧K);
- \( R \) – a universal gas constant, \( R = 8314 \) J/(Kol‧K);
- \( T \) – the absolute gas temperature, K;
- \( L \) – the length of the gas pipeline, m;
- \( v \) – a linear gas velocity, m / s;
- \( \rho_0 \) – gas density, kg / m\(^3\).

State equation for gas and air:

\[ \frac{R_\text{Г}}{\rho_\text{Г}} = \frac{R_\text{В}}{\rho_\text{В}}, \]

\[ R_\text{Г} = \frac{R_\text{П} \cdot \rho_\text{П}}{\rho_\text{Г}} = \frac{R_\text{В}}{\rho}. \]  

Volumetric flow rate under standard conditions

\[ V_t = \frac{G}{\rho_c y} = \frac{G}{\rho^2 y}. \]  

where \( \rho_{sc} \) – the gas density under standard conditions

\[ V_t = k_0 \sqrt{\frac{(P_1^2 - P_2^2)d^3}{\lambda \cdot R_c \cdot T \cdot L}}. \]  

where \( k_0 = \frac{\pi}{4} \cdot \frac{1}{\rho_\text{В} \cdot \sqrt{R_\text{В}}}. \)

Standard conditions: \( t = 20 ^\circ C, P = 760 \) mm Hg, air density \( \rho_\text{В} = 1.205 \) kg / m\(^3\), \( R_\text{В} = 287 \) J / (kg‧K), \( k_0 = 3.87 \cdot 10^{-2} \).

As a result, the calculated formulas for the monitoring system algorithm will be

\[ P_1^2 - P_2^2 = 1.2687 \cdot 10^{-4} \cdot \lambda \cdot \frac{G^2}{d^5} \cdot \rho_0 \cdot l. \]  

\[ G = 3 \cdot \frac{(P_1^2 - P_2^2)d^3}{\sqrt{4.4911198 \cdot 10^{-6} \cdot \rho_0 \cdot l}}. \]  

3.2. Algorithm for an instant gas consumption assessment in the loop

The block diagram of the developed algorithm is shown on figure 1. When calculating are used as measured (pressure values and temperature at the yield of the KGS (conditional start of the loop), the pressure at the entrance to the switching reinforcement building (soup), the conditional end of the loop) and the constants for the data of the loop and the measured value of the parameters (pipeline diameter, loop length, compressibility coefficient, hydraulic resistance coefficient, relative density). In addition, it is necessary to control the lack of unreliability of declared variables.

The algorithm can work in two modes.
- Direct automatic control (analysis of the algorithm based on the consumption values, calculating the productivity of the group of wells based on the data obtained).
- Operational manual control (the operator monitors the current readings and makes a decision on the reduction or an increase in well productivity based on the data).
Figure 1. Algorithm for calculating the Instantaneous gas flow rate on the loop.

The algorithm for calculating the instant gas flow rate is made step by step.

Step 1. The variables “Pressure at the yield of KGS (MPa)”, “The temperature at the yield of the KGS (° C)” system of telemechanics of gas wells based on RTP-04 are initialized.

Step 2. The variables “Pressure at the input of the plume (MPa)” automated automation system of the automation process of UKHPG based on SCADA Cimplicity (Pressure at the entrance to ZPA) are initialized.

Step 3. The constant parameters are initialized (pipeline diameter, pipeline length, compressibility coefficient, hydraulic resistance coefficient, relative gas density).

Step 4. The reliability of the technological parameters “Pressure at the yield of KGS (MPa)”, “The temperature at the yield of the KGS (MPa)”, ”Pressure at the inlet of the plume (MPa)” is checked.
Step 4.1. If at least one of the signs of inaccuracy (“open”, “short circuit of the input channel”, “no connection from the PLC”), then the corresponding emergency warning message is displayed on the operator’s video camera (the technological parameter value is highlighted with pink colour).

Step 4.2. If the technological parameters are reliable, then an algorithm for calculating the parameter “Instant gas consumption with KGS” is performed.

Step 5. The results of the calculation of the parameter “Instant gas consumption with KGS” are displayed on the operator’s video frame.

Step 6. The conformity of the “Instant gas consumption with a KGS” parameter is checked with a given setpoints of emergency warning alarm.

Step 6.1. If the parameter value came out for warning settings (upper and lower limit), then the value of the parameter is accompanied by sound signalling.

Step 6.2. If the parameter value came out for the emergency settings (upper and lower limit), then a red tint value of the parameter is also accompanied by sound alarm.

3.3 Check adequacy of the instantaneous gas flow rate operation calculation algorithm in the loop
To test the adequacy of the operation of the algorithm, data of the daily measurements of the pressure on the KGS and the input in the SPU shown in figure 2 was used. The instantaneous gas flow rate values were calculated by the equation (14) using SCADA HMI / Cimplicity software.

Figure 2. Results of daily pressure measurements at the beginning (KGS) and at the end (soup) of the loop.

Figure 3. Comparison of actual and calculated on the model of instantaneous gas flow rate values.
The results calculated on the basis of these data on the equation (8) of the instantaneous flow values were compared with the measurement results by the overhead ultrasonic flow meter RG601.

Comparison of the actual and calculated on the model of instantaneous gas flow rate values is provided on figure 3. As can be seen, the resulting model adequately reflects the actual change in the instantaneous consumption in the loop.

3.4. Automatic monitoring system of technological parameters KGS

The concept of constructing modern ACS of gas fields reflects the modular principle of their construction [13]. With such an organization, individual subsystems ensure the functioning of some separate technological process, for example, the supply of methanol into the well and the loop [14] or regulating the operation mode of the individual well [15], are combined at the next level into a single system. The proposed system for monitoring the technological parameters of the KGS is just such a module. The interaction of this system with the existing ACS of TP UKHPG is shown on figure 4. The visualization of its work on the operator's workflow is performed in the SCADA HMI / Cimplicity software environment. As an example, figure 5 shows a video editor of the operator at normal operation of the loop.

**Figure 4.** Structural scheme for interaction of the KGS parameters monitoring system with ACS TP.

**Figure 5.** An example of a video frame to the operator's automatic operations during the normal operation of the loop.
4. Conclusions

The studies carried out allow us to draw the following conclusions.

The assessment of the Instantaneous gas flow rate in the loops in the indirect method, according to the measured in real-time values of the pressure and temperature on the group of wells and at the inlet in the ZPA, i.e. at the beginning and at the end of the loop, allows you to quickly respond to changing the operating modes of the group of wells connected to the loop, as well as evaluate the condition of the plume itself, which is equally important. The change in the speed of the gas movement may indicate the beginning of hydrate formation, any deposits on the walls of the pipeline, etc.

The algorithm developed to perform the calculations and its implementation in the SCADA HMI / Cimplicity software environment ensures the effective interaction of the monitoring system of the process parameters of the KGS with the existing ACS of TP UKHPG.

References

[1] Prakhov M Yu, Krasnov A N and Khoroshavina E A 2016 Method for diagnosing flood flooding gas wells SOCAR Proceedings 3 19-26
[2] Prakhov M Yu, Krasnov A N, Khoroshavina E A and Shalovnikov E A 2016 Prevention of hydrate formation in systems of fishing gases of the Yamburg gas condensate field Proc. Int. Conf. on Problems of Automation of Technological Processes of Production, Transport and Refining Oil and Gas (Ufa: UGNTU) pp116-23
[3] Arno O B 2015 Technical and technological solutions and innovation at different stages of the life cycle of the Yamburg fields Scientific Journal of Russian Gas Society 2 3-14
[4] Kudiyarov G S, Istomin V A and Rotov A A 2017 Features of the work of gas collection systems Senomanian deposits of the Yamburg field at the final stage of development Transport and Storage of Oil Products and Hydrocarbons 5 5-13
[5] Zhuravleva A S 2017 Problems of operation of gas fields of Western Siberia, located at the final stage of the development Proc. Int. Conf. on New Technologies - Oil and Gas Region vol 2 (Tyumen: TIU) pp 64-6
[6] Prakhov M Yu, Shalovnikov E A, Krasnov A N and Fedorov S N 2019 Automation Systems in the Gas Industry (Moscow; Vologda: Infra Engineering) p 68
[7] Krasnov A N, Prakhova M Y and Khoroshavina E A 2018 Automatic system for measuring gas stream velocity in gas collection system flow-lines IOP Conf. Ser.: Earth and Environmental Science. Proc. II Int. Conf. on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering IPDME 2018 p 022017
[8] Trushnikov D N, Lopatin R R, Kharitonov A R, Yushkov A Yu and Strekalov A V 2019 The system of automatic regulation of gas and gas condensate modes - element of the concept of intelligent fishery Automation, Telemechanization and Communication in Oil Industry 10 (555) 5-11
[9] Baembitov E A 2014 Methods and Means Measurement of Natural Gas Flow Proc. Int. Conf. on Problems of Automation of Technological Processes of Production, Transport and Refining Oil and Gas (Ufa: UGNTU) pp 99-102
[10] Lanchakov G A, Marinin V I and Koshelev A V 2009 Operational control of the gas condensate flow rate wells with information and measuring systems "Potok-5" Gas Industry 9 45-51
[11] Murzagalin A T 2018 Optimization of the RTP-04 telemetry system to work in the unlicensed frequency range Automation, Telemechanization and Communication in Oil Industry 12 17-22
[12] Deych M E 1968 Gas Dynamics of Two-Phase Environments (Moscow: Energiya) p 57
[13] Ivanov A N and Zolotarev S V 1998 Building ACS TP on the basis of the concept of open systems ComputerWorld 01
[14] Prakhova M Y, Khoroshavina E A, Krasnov A N and Zakirnichnaya M M 2017 Cognitive model application for automatic system of methanol supply to flowlines IOP Conf. Ser.: Earth and Environmental Science. Proc. Int. Conf. on Innovations and
Prospects of Development of Mining Machinery and Electrical Engineering - Mining and Exploration of Mineral Resources p 052023

[15] Stolyarov V E, Eremin N A, Eremin Al N and Basnieva I K 2018 Digital gas wells: status and perspectives Oilfield Engineering 7 48-5