УДК 537.8
doi.org/10.15407/fmmit2024.39.072

System analysis of gas flow modes in pipeline systems

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A systematic analysis of the modes of motion of the gas and the factors influencing its parameters is carried out. The conditions that the mathematical model of gas motion in the pipeline and the method of its implementation must meet to ensure that the simulation results are obtained with minimum and given accuracy. The results of the numerical experiments that substantiate the obtained conclusions are presented.

***Keywords*—g**as flow in the pipeline, modeling, decoupling method, factors of influence, non-stationary process, identification.

1. Introduction. Many works both in Ukraine and abroad are devoted to modeling the gas flow regime in gas pipelines and analyzing it under different boundary conditions. [1-8]. Requirements for modeling accuracy and time of obraining the result may vary depending on goals and needs. These requirements are often interrelated and satisfaction of them depend on the same factors. Thus, simplifying the model can reduce the accuracy of the mode parameters calculation, but provide a reduction of time to obtain it. There are also method parameters change of them allows to find a compromise between accuracy and time of obtaining the result. Almost all mode analysis problems are interrelated. So finding accumulated gas volumes in gas pipelines is used to:

- constructing the algorithmic methods of leak test of the system;
- obtaining the estimate of volumes of leakages and their normalization;
- estimation of imbalance of gas volumes in subsystems and system as a whole;
- solving inverse problems of identifying the parameters of the gas motion model;
- researching the model adequacy and the estimation of degree of uncertainty based on the input data for modeling gas-dynamic processes;
- researching quality of metrological support.

The price of increase of the guaranteed accuracy of mode analysis is considerable. The accuracy of the calculation depends on the smallest accuracy of the individual parameters. The questions of expediency, in many cases, the allocation of significant computational resources to provide higher accuracy of calculation of this or that mode parameter constantly arises. In order to provide a valid answer to this question, a considerable amount of research with guaranteed accuracy of the measured and calculated inputs is required.

The main problematic issues are: model completeness, method of model implementation, empirical dependencies, informational support, etc. In addition to solve this or that problem, we must minimize the requirements of model complexity, method speed and completeness of informational support. The above will minimize computational resources to obtain satisfactory in accuracy and in time result.

The purpose of conducting the research is to ensure the guaranteed accuracy of the calculation of gas flow parameters in the pipeline section in a minimum time.

In order to achieve this goal, it is necessary to analyze the following problems – model adaptation, model and model parameters, gas law, method parameters, metrological support and boundary conditions, numerical experiments and simplification of numerical analysis, ensuring results in a minimum time.

2. Analysis of factors influencing the accuracy and speed of calculation

2.1 Analysis of gas motion models

The choice of the gas motion model is dictated by the problem conditions and boundary conditions. Sufficient accuracy of boundary conditions prognostication for gas flow and environmental parameters over a considerable period is problematic.

In the process of integrating the steady-state gas law [7,10,15,19], we obtain an expression for calculating gas parameters on a section of a gas pipeline in the isothermal case. Studies have shown that the coefficient that takes into account the effect of changing the linear velocity of a gas has little effect on the pressure distribution along the pipeline. In the equation of energy conservation in the stationary case, the main components are heat exchange through the pipe walls, the throttle effect and a component that takes into account the change of flow internal energy in the inclined pipelines. The accuracy of the calculation by stationary formulas is influenced by the averaging the nonlinear parameters of the models – hydraulic resistance and the coefficient of heat transfer from gas to the external environment and taking into account the profile of the pipe laying path. The interconnectedness of these factors, the accuracy of the input data and the uncertainty domain that generated by existing metrological support, the variability of gas flows and external factors don’t allow to set the adaptive parameters with sufficient accuracy. Such adaptive parameters have no physical meaning and can be interpreted as certain thermo-hydraulic equivalents.

The constituents of the non-stationary model, which characterize the inertia of the process and the change of kinetic energy at low gas flow velocities and in the absence of shock waves, can be neglected. In the case of maximum gas flows and transient modes, the impact of these additives should be evaluated.

It is obvious that each of the parameters included in the gas motion model has its influence on the accuracy of the hydrodynamic parameters calculation. Investigation of the factors of influence on the gas flow regime was performed for the motion eauation represented in the form

$$\frac{dp}{\rho}+\alpha \ d\left(\frac{v^2}{2}\right)+\lambda \ \frac{v^2}{2}\frac{dx}{D}+g \ dh=0\,, \qquad (1)$$

де v is the gas flow velocity; λ is the hydraulic resistance coefficient; z is the compressibility coefficient; ρ is the gas density; dh is the difference in the elevation marks of the beginning and end of the pipeline; g is thefree fall acceleration; x is the running coordinate; D is the pipeline diameter.

Taking into account or neglecting for certain additives included in the last equation leads to different pressure distribution along the pipeline. Provided that $dh=0$, $z=const$, $T=const$ the pressure distribution is determined by the formula [4,11,19]

$$p(x)=\sqrt{p_0^2-\lambda \ z\frac{gRT}{D}\left(\frac{M}{S}\right)^2 x}\,. \qquad (2)$$

Let's consider these three cases: 1) $z=z(p)\,,T=const$; 2) $T=T(x)$, $z=const$; 3) $T=const$, $z=1/(1+fp)$. For each of them the formulas (3), (4) and (5) with different complexity respectively, are obtained.

$$p^2(x)-p_0^2+\frac{2}{3}f\left(p^3(x)-p_0^3\right)-2RT\left(\frac{M}{F}\right)^2\ln\frac{p(x)}{p_0}=-\frac{\lambda RT}{2D}\left(\frac{M}{F}\right)^2 x\,. \qquad (3)$$

$$p^2(x)-p_0^2=-2\eta\left\{T_{gr}x+\left(T_0-T_{gr}\right)\frac{1-e^{-ax}}{a}-\left[\frac{D_i}{a}\frac{p_0-p_k}{L}+\frac{q\Delta h}{aLC_p}\right]\left[x-\frac{1-e^{-ax}}{a}\right]\right\}. \qquad (4)$$

$$\int\limits_{p_0}^{p}\frac{p^2(1+fp)-2a_{00}}{p(a_{10}+a_{20}p^2(1+fp))}dp=-x\,. \qquad (5)$$

If to consider that $z=z(p,T)$, $T=T(x)$ then the equation (1) is solved numerically by the Runge – Kutta method of second-order accuracy.

$$\frac{dp}{dx}=-\frac{\eta_3 p^2+\eta_2(zT)^2}{p^2+\eta_1 zT}\frac{p}{zT}\,. \qquad (6)$$

There

$$\eta_1=-\frac{\alpha R}{2}\left(\frac{M}{S}\right)^2,\ \eta_2=\frac{\lambda R}{2D}\left(\frac{M}{S}\right)^2,\ \eta_3=\frac{g\Delta h}{RL}\,.$$

Conducted researches have shown that the total effect of averaged nonlinear values is much smaller than the effect of averaging one of them. Within a certain range of regime gas-dynamic parameters change, such an influence can be achieved by refining the hydraulic resistance.

The analysis of the non-stationary gas motion model was performed using the finite elements method. To ensure a quick result, we should ensure that:

- evaluation of the degree of non-stationarity of the gas-dynamic process under boundary conditions;

- select the number of elements of the partition, depending on the length of the pipeline section and step by time variable (step by time variable must be tied to the degree of non-stationarity of the gas-dynamic process);
- setting the frequency of recalculation of the temperature mode of gas movement (the temperature mode changes much slower than the hydraulic one).

For pipes of small length (less than 1000 m), the pressures difference at the ends of the pipe will in most cases be within the accuracy of the pressure measuring devices at the maximum gas flow and the inaccuracy of the gas pressure calculation in the small limits corresponds to significant fluctuations in flow, which may effect the stability of the iterative process of calculating the regime parameters of the main gas pipelines.

2.2. Assessment of gas leaks volumes impact because of the pipeline untightness on modeling accuracy

The construction of a leakages diagnostic technique requires additional research of relationship of the existing uncertainty generated by measurement errors and the identification of model parameters with the accuracy of leakages identification by magnitude and location. The interval of observation of the gas-dynamic process has significant influence on the accuracy of identification.

An analysis of long-term data shows [16-18] that natural gas (methane) emission volumes into the atmosphere controlled by the environmental service are small (about 10%). The bulk of natural gas emission are fairly stable during all the time of the exploitation of GTS and its magnitude is set fairly accurately throughout the year. This accuracy is commensurate with the accuracy of the calculation of the volumes of accumulated gas in GTS objects.

Methane emission volumes in the process of regular work and in the case of depressurization of GTS objects are calculated according to the empirical formulas established at the stage of leak proofing of newly constructed main gas pipelines and are given in the appropriate methodologies.

The performed calculations of accumulated gas volumes by the methods obtained on the basis of the data obtained as a result of the research of newly built main gas pipelines and research of leakages by existing newest technical means, have shown some discrepancy. Thus, the total leakages in the GTS of Ukraine is quite wide –175-265 million m^3 per year.

The analysis of the data obtained has shown [12-14,16-18] that the volumes of methane leakages detected by gauges at the compressor stations (CS) don’t exceed 10% of the total number of possible methane leakages points, and the number of candles with nonleak-proof candle valves is about 45% the total number of candles examined. Estimation of methane emission volumes with leaks has shown that the total leakages volume does not exceed 1% of the transported gas volume (0.33% of the volume of gas transportation abroad), and for gas transport objects, at which instrumental researches have been carried out, not more than 0.01% of the volume of transported gas by that object. Long-term studies have shown that the average value of methane leakages volumes is 2.7 m^3/(hour*MW) at the compressor stations, and 0.3 m^3/(hour*km) at the sections of main gas pipelines.

If the average total volume of accumulated gas at the GTS is about one billion m^3, and the average daily leakages is no more than 0.6 million m^3 per year, then in such case the proportion of leakages volumes is on average 0.06% of the volume of accumulated gas. Existing pressure and temperature measurement accuracy does not does not provide the detection of the magnitude of most gas leaks at the daily time interval.

2.3. Metrology and imbalance in the GTS subsystems

The claimed accuracy of gas parameters measurement, as research has shown, is often untrue. Existing metrological support creates problems in the process of identifying the model parameters and the study of the influence of distributed and averaged parameters on the model accuracy of modeling.

The calculation of the accumulated gas volumes allows to find the value of imbalance in the GTS subsystems. The accuracy of such estimation is significantly influenced by gas flow measurements. Often, there is no more than one flow measurement at the inputs and outputs, and in such cases, a systematic measurement error in one of them, or both, simultaneously generates a calculated gas imbalance. Such imbalance, as real research results have shown, is often significant.

Here is an example of the calculation of the GTS subsystem – the point of measurement of gas flow (PMGC Dovhe – CS Dolyna). The data for the calculation are taken for the period 19.11.2018 - 26.11.2018. The simulation results are presented in Table 1.

The following numerical experiment was performed. The change of consumption, pressure, temperature, gas density over time (during set period of time 19.11.2018 - 26.11.2018) at PMGC Dovhe and change of consumption, pressure, temperature over time at all points of subsystem exit are set. To calculate the non-stationary gas motion, the pressure change over time at CS Dolyna, the gas consumption change over the time at all other inlet and outlet points of gas flow of subsystem are used. The pressure change over time at PMGC Dovhe and the consumption change over time at PMGC Dolyna are analyzed. The analysis performed of the calculated and measured consumption changes over time at PMGC Dolyna has shown the existence of a systematic error in at least one of the measuring devices.

Table 1

The results of gas motion modeling at the section of GTS PMGC Dovhe – CS Dolyna

Date 2018 p.	PMGC Dovhe, thousand m^3 per day	PMGC Dolyna, thousand m^3 per day	The volume of gas in the pipe, m^3	The change of gas reserve, thousand m^3	Imbalance, thousand m^3	Imbalance, %
19.11			1076860,9			
20.11	4824,637	4764,243	1077331,5	0,47	60,86	1,26
21.11	4630,896	4598,164	1077254,9	-0,08	32,66	0,71
22.11	4523,345	4502,727	1070048,2	-7,21	13,41	0,30
23.11	4418,959	4396,848	1062803,2	-7,25	14,87	0,34
24.11	4305,878	4284,349	1059190,5	-3,61	17,92	0,42
25.11	4197,183	4157,118	1066291,2	7,10	47,17	1,12
26.11	4045,486	4020,659	1062652,5	-3,64	21,19	0,52
	30946,384				208,07	**0,672**

2.4. The temperature mode of gas transportation

The distribution of the temperature in the plane of the pipe cross-section and along the pipeline is heterogeneous. The temperature field is set over a considerable period of time and its noticeable change takes a long time. The accuracy of the temperature field calculation is complicated by the inability to obtain the required accuracy of the distributed input parameters of the external environment – soils. In addition, such parameters are sensitive to changes in soils moisture, which are constantly changes. Since the accuracy of the predicted boundary conditions for more than a few days is insufficient, modeling at significant time intervals is meaningless. At such time intervals, the temperature field does not undergo significant changes. Therefore, in order to calculate the gas pressure distribution in the pipeline, a stationary temperature distribution over the length of the pipeline is mainly used.

There are two controversial studies. They are verified by real data. It is believed that the coefficient of temperature transfer to the external environment is nonlinear and significantly depends on many factors. Its averaging and calculation inaccuracy for long pipes can affect the accuracy of gas temperature calculation. Often, taking into account the Joule-Thomson effect for long pipes results in a false result – the gas temperature is higher than the soil temperature. Basically, the problem of gas temperature calculation in pipelines is a Cauchy problem, and therefore, the instability of the calculation process should be expected.

1. In the energy conservation equation for different diameters of gas pipelines, its components make a different contribution to the creation of the temperature field. So the numerical experiments have shown that for pipes up to 800 mm it is sufficient to use the Shukhov equation, for the pipes 1000 and 1220 mm it is already necessary to take into account the Joule-Thomson effect, and for a pipe of 1420 mm the friction of gas against the wall of the pipe is significantly affected.
2. There are other results that are presented in the paper [11].The authors of the work have carried out numerical experiments, which follows that the calculation by the Shukhov formula with the addition of the member that takes into account the mechanical operation of the gas flow friction, gives the best results. The results of other calculation variants, for example, only by the Shukhov formula and with the member that takes into account the Joule - Thomson effect, were significantly different from the real measured values.

The numerical experiments carried out and the analysis of real measured data have shown:

- the change of the temperature regime of gas transportation essentially depends on the gas consumption value;
- significant fluctuations in air temperature (greater than 20 ° C) on the soil surface have little effect on the soil temperature at its depth (less than 0.1 ° C per day), so the change in air temperature has almost no effect on the gas transport temperature (see calculations in n.);
- significant fluctuations of air temperature (greater than 20 ° C) on the soil surface have little effect on the soil temperature at depth (less than 0.1 °C per day), so the

change of air temperature has almost no effect on the temperature regime of gas transportation (see calculations above);

- the consumption change effects change of temperature field (time of formation of stationary temperature field is less than 1,5 months;
- the impact of the consumption change on the gas temperature change at the outlet of the section for several days (up to a week) is almost impalpable;
- the coefficient of thermal conductivity of the soil is nonlinear and significantly depends on the structure, composition, density, moisture of the soil and mass consumption of the coolant (gas consumption).

The analysis of the calculations carried out has shown that the coefficient of thermal conductivity set during the data processing (heat transfer gas - environment) as a function of gas consumption has provided an increase of the accuracy of the gas temperature calculation at the outlet of the pipeline sections; in order to maximize the accuracy of the gas temperature calculation at the outlet of gas pipeline sections, a functional relationship (as a function of time) between the thermal conductivity coefficient and the consumption must be set.

Let's consider the coefficient of soil thermal conductivity a_{gr}. Its value can be estimated by the formula [8,11]

$$a_{gr} = \frac{\lambda_{gr}}{c_{gr}\rho_{gr}},$$

where λ_{gr} is the coefficient of soil thermal conductivity, c_{gr} is the specific heat capacity of soil, ρ_{gr} is the soil density. All these parameters depend significantly on the composition of the soil, its structural properties and humidity. For soil, the dry part of which consists of granules of two fractions: sand (granule size is 0.002 - 2 mm) and clay (particle size is less than 0.002 mm), the coefficient is calculated by the formula:

$$a_{grv} = \frac{a(\lg s_h + b)}{\rho_{gr}(c_{gr} + 41.9 s_v)} 10^c,$$

$a = 0.1424 - 0.000465 s_v$, $b = 0.419 - 0.000313 s_v$, $c = 6.24 \cdot 10^{-4} \rho_{gr}$, $\rho_{grv} = \rho_{gr}(1 + 0.01 s_v)$,

s_h is mass fraction of clay, s_v is the volume fraction of moisture that is attributed to the entire dry soil component.

The thermal conductivity of sand and clay increases nonlinearly in the case of increasing the soil humidity. The coefficient a_{gr} in the case of humidity ing up to 10% rapidly increases and decreases slowly a_{gr} in the case of further increasing water content.

2.5. The gas state equation

In contract terms for gas supply, formulas for calculating gas volumes by their chemical composition in mass fractions, pressure, and temperature are always agreed. Among the formulas is the formula for calculating the compressibility coefficient, which is included in the gas state equation

$$P = \rho z R T\,. \qquad (2)$$

Here R is the gas constant, J/(kg×^{0}K), T is the gas temperature, ^{0}K, z is compressibility coefficient, which characterizes the difference between the real gas and the ideal and is determined on the basis of established empirical dependencies. The formulas for calculating the compression coefficient are cumbersome and time-consuming to calculate the parameters of gas flow modes. It is advisable to use a simple formula

$$z = \frac{1}{1 + f\,(a - bp)\,p}\,, \qquad (3)$$

where a and b are the coefficients of approximation of calculated z by known procedures - Hall-Hamburg and Redlich-Kwong methods of calculating the compressibility coefficient of gas. So after approximation of the calculated values, expression (3) will take the form

$$z = \frac{1}{1 + (24.0 - 0.210t)10^{-4}(0.970 - 0.000441p)\,p}.$$

The Redlich - Kwong procedure is considered to be more accurate. The Hall-Hamburg procedure gives somewhat reduced results (a discrepancy can be seen in the third significant figure). For pseudo-critical temperature of 192.308 (K) and a pressure of 4.595124 (MPa), the calculations by the latter two methods in the range of 4 to 9 MPa give results that coincide with three significant figures.

In the range of change of real pressures and temperatures and accuracy of their measurement, the value z (calculated by the Redlich - Kwong procedure) depends linearly on the specified parameters with a sufficiently high accuracy. The given results substantiate the possibility of constructing fairly simple calculation z algorithms.

For thermo-hydraulic calculations, other empirical formulas are also used – adiabatic index, isobaric heat capacity, kinematic and dynamic viscosity, Joule-Thomson coefficient, and so on. The accuracy of the calculation of most of the gas-dynamic parameters in the real ranges of the GTS work is within 1-3%, without taking into account the errors of the input measured data. As a rule, their influence on modeling accuracy is not investigated, but compensated by the coefficient of refinement of the thermo-hydraulic equivalent.

2.6. The energy balance

Not much works has been devoted to the study of the energy balance of gas flow in pipes [12-14,18]. Such a balance is simply established by a method of modeling the process of gas compression and its motion in the main gas pipeline. It can be reduced to setting the connection between energy resources consumptions and gas transportation volumes. Such a balance makes it possible to justify the efficiency of exploitation of the main gas pipelines (MGP) according to the experimental data – the cost of supporting

MGP in working condition, depreciation and the cost of transportation of a gas volume unit.

Calculating experiment. The system consisting of a compressor station and the adjacent section of the gas pipeline is set. The following pipe parameters and input data are known: length - 116.2 km, internal diameter - 1388.6 mm, inlet pressure - 70 atm, soil temperature - 279 ^{0}K, inlet temperature - 313 ^{0}K. The result of the calculation is the pressure and temperature at the outlet of the pipe.

The input data for calculation of the mode of compressor station (CS) operation are: pressure at the outlet of the CS - 70 atm, at the inlet - the pressure is equal to the pressure at the outlet of the pipe, the gas temperature is equal to the temperature at the outlet of the pipe. The following mode parameters of the CS were calculated: the number of gas pumping plants (GPP), the revolutions of the centrifugal supercharger, the consumption of fuel gas, the remoteness of the working point of the GPP from the pumping zone.

Table 2

The calculation of the system of a compressor station and the adjacent section of the main gas pipeline

Consumption, million m^3 per day	Inlet pressure, kgs/cm^2	Gas temperature at the outlet of the pipe, ^{0}C	Fuel gas consumption, million m^3 per day	Consolidated costs, kgs/cm^2
50	64.4	11.5	-	-
60	61.7	13.9	0.198	0.0033
70	58.5	16.5	0.278	0.0040
80	54.4	19.4	0.345	0.0043
90	49.3	22.8	0.480	0.0053
100	43.4	27.0	0.659	0.0066

Consolidated energy costs increase because of the greater volume of gas transport, the gas temperature at the inlet of the CS increases and the hydraulic pressure losses increase.

The results of calculation of the mode of operation of the CS are presented on Fig. 1 (see right vertically from top to bottom):

- gas consumptions – 60.00 million m^3 per day;
- pressure at the inlet of CS – 61,70 кgs/cm^2;
- pressure at the outlet of CS – 70,00 кgs/cm^2;
- gas temperature at the inlet of the CS – 13.5 ^{0}C;
- fuel gas consumption – 0.198 million m^3 per day;
- remoteness of the centrifugal supercharger from the pumping zone – 1.46 (46%);
- number of gas pumping plants – 3;
- gas temperature at the outlet of the CS – 25.844 ^{0}C.

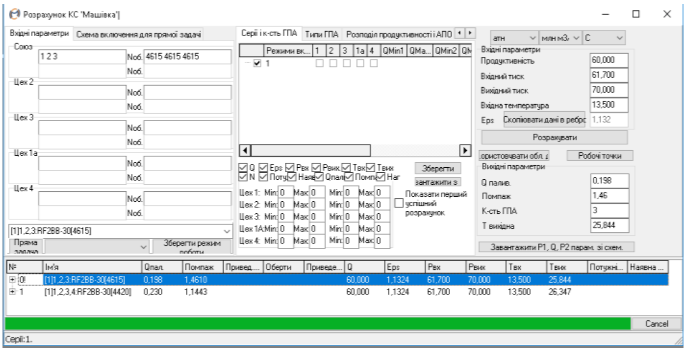

Fig. 1. The user interface of the software complex for calculation of the modes of operation of multi-shop compressor stations of different types of gas pumping plants.

2.7. Calculation of accumulated gas volumes. Impact factors

The existing methodology of calculation of the accumulated gas volume doesn't take into account the nonstationarity of the gas motion process, the variability of the gas pipeline route profile, etc. The average pressure is calculated using a formula that also doesn't take into account the variability of the gas pipeline route profile.

This or that approach to the accuracy of the calculation of the accumulated gas volumes is possible provided that the need for achieving this or that goal is clearly stated, in particular - taking into account the calculation in other problems, such as tightness of the system, optimal control of the flow distribution, optimization of predicted modes, establishment of gas imbalance, establishment of systematic errors of flowmeters, etc..

Present gas extraction and supplies also affect the accuracy of the calculation of the volume of gas stored in the pipe.

Table 3

The results of calculation of average pressure for different pressures at the ends of the pipeline and different differences of altitude marks

Gas pressure at the ends of the pipeline section	The average gas pressure at a section of the gaspipeline at atgiven difference sinelevationin meters					
	1m	100m	-100m	200m	-200m	500m
	1	100	-100	200	-200	500
70 - 30	52.916	52.605	53.231	52.306	53.539	51.423
70 - 40	56.473	56.179	56.763	55.898	57.049	55.083
70 - 50	60.582	60.306	60.839	60.050	61.109	59.286

Table 4

The results of the calculation of the impact on the calculation accuracy of the average pressure by formulas for horizontal and inclined pipelines

Gas pressure at the ends of the pipeline section	Th eaveragedeviationin % of the calculation of the average pressure for formulas for horizontal and in clined pipelines				
	100 m	-100 m	200 m	-200 m	500 m
70 - 30	-0.59	0.60	-1.15	1.18	-2.82
70 - 40	-0.52	0.51	-1.02	1.02	-2.46
70 - 50	-0.46	0.42	-0.88	0.87	-2.14

3. Conclusions

It is possible to provide a more accurate calculation for stationary models (without significant additional costs) by:

- taking into account altitude marks (beginning and end of the pipeline section);
- splitting long sections of gas pipelines into several parts – allows to take into account, to some extent, the nonlinearity of some parameters;
- the calculation of the temperature regime must be alternated with the hydraulic one after the convergence of the hydraulic calculation (no more than three iterations are required).

Problems of calculation by non-stationary models:

- insufficient frequency of pressure measurement for some sections of gas pipeline;
- insufficient number of flowmeters;
- multifaceted representation of data in databases (bringing to regime times, which affects the synchronization of measurement values);
- correction of measured data;
- calculation of non-stationary temperature mode of gas transportation.

Non-stationary models allow to provide:

- higher accuracy of calculation of the change of the accumulated gas volumes, since the accuracy of the identification of the parameters of the gas flow model has little effect on this;
- constant algorithmic control of tightness of subsystems with certain accuracy.

The calculation of the accumulated gas volume in distribution networks with small pipe diameter (for diameters less than 820 mm, which make up less than 8% by volume of accumulated gas) taking into account the pressure, density and temperature of the gas in the controlled places should be made by stationary models.

Existing problems such as calculation of accumulated gas volumes and its change per unit of time, analysis of causes of excess gas imbalance in the system and its subsystems, tightness monitoring of the system and its technological objects, maintenance of optimal volume and its distribution in the system of main gas pipelines, etc., should be integrated into a single problem with appropriate information support.

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Системний аналіз режимів руху газу в трубопровідних системах.

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Анотація. *Проведено системний аналіз режимів руху газу та факторів впливу на його параметри. Досліджені умови, яким має відповідати математична модель руху газу в трубопроводі та метод її реалізації, щоб забезпечити отримання результатів моделювання за мінімальний час та із заданою точністю. Приведені результати числових експериментів, які обґрунтовують отримані висновки.*

Ключові слова **-** *потік газу в трубопроводі, моделювання, метод роз'єднання, фактори впливу, нестаціонарний процес, ідентифікація.*

Отримано 07.06.2024