Improvement of approaches to dispatch control on the main high-pressure gas pipelines to ensure reliability and safety of natural gas supply

Sergey Pankratov (JSC “Gazprom”),
Alexander Kazak, Sergey Korshunov
(LLC “NIIgazeconomika”)

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Basic subject matter of the report

The pipeline gas transport takes the important place in the global gas industry. Grids of main gas pipelines (MGP) become more and more complex uninterruptedly, its' working pressure goes up and gas pipelines are being built under difficult climatic and engineering-geological conditions.

At present, the great number of large-scale projects of main gas transport, as, for example, "The Blue stream", "The North stream", "The South stream" and others are on the stages of operation and development. The execution of such projects puts forward many practical tasks, one of which is the development of Automatic Dispatch Control System (ADCS) of gas transport.

It is not sufficient to use only stationary simulation of normal steady regimes of gas pipelines functioning for the dispatch decision-making support under the conditions of significant technical risks of up-to-date main high-pressure gas pipelines operation, connected with the increased indeterminacy on the markets of natural gas sales.

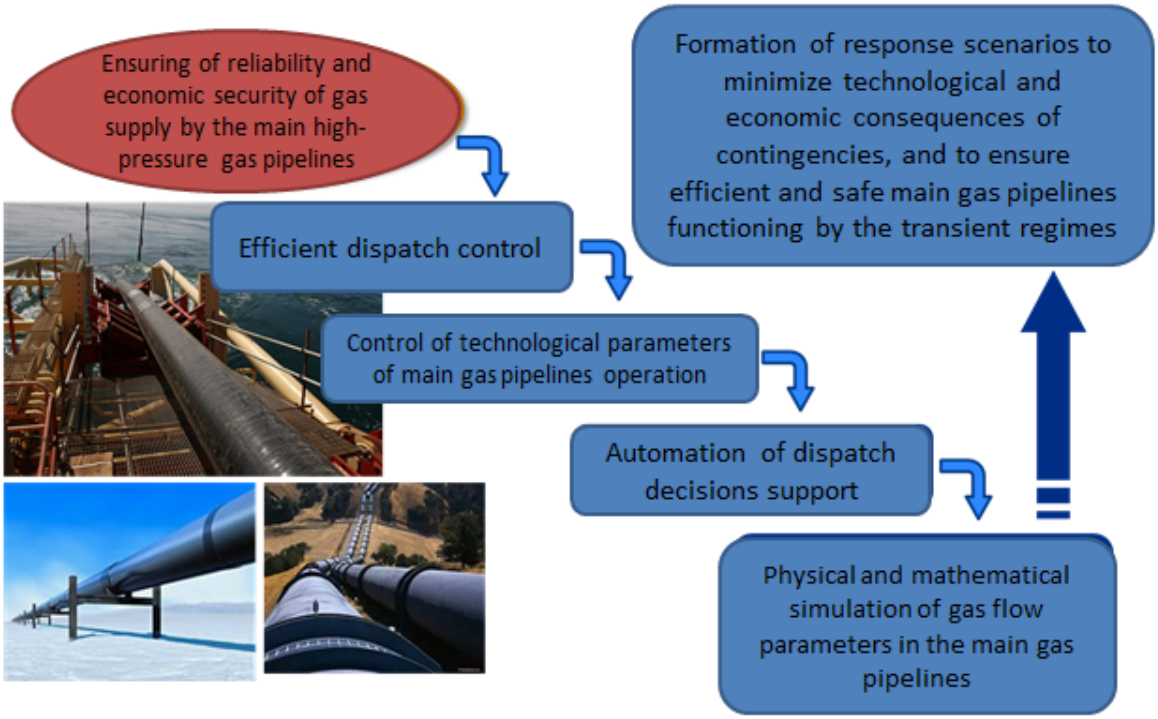
For example, the gas temperature (as well as the temperature of pipeline´s steel wall) could decrease significantly lower than acceptable project values and raise the risk of contingency´s appearance, under the conditions of abnormal shutdown of gas supply to marine main gas pipeline and the absence of opportunity to control the flow parameters on the receiving terminal. Though, the point, in which the least value of temperature is reached, could be located not at the end of marine linear section of gas pipeline, and it means that direct measurements cannot be executed by means of telemetry. Monitoring of such situations is the integral part of efficient dispatch control and is not possible without the usage of up-to-date ADCS.

One of the key components of ADCS is the rated kernel, based on the physico-mathematical simulation of gas flow in the pipeline. At the same time, the operating experience of up-to-date main high-pressure gas pipelines (with working pressures under 30 MPa) in Russia and abroad, demonstrates more and more frequently that the improvement of existent methods and algorithms of thermal and hydraulic computation of gas pipelines is necessary for ensuring of optimal conditions of gas transport systems functioning. In addition, currently, the conditions of main pipeline transport become more complex: gas supplies depend more and more on varying gas prices and availability of unused capacity for

gas transport, and existent routes of supplies have become more hazardous, as far as the reliability of gas distribution to the final consumers is concerned.

Purpose of the report

The main purpose of the report is the interpretation of actual approaches to the gas flow simulation within the scope of tasks of gas transport by main high-pressure gas pipelines dispatch control for the evaluation of dynamics of technological parameters of main gas pipelines functioning, forecasting of possible contingencies development and prevention of its consequences (refer to pic. 1).



Pic. 1 – Ensuring of reliability and effectiveness of gas supplies by the main high - pressure gas pipelines

Gas flow model in main high pressure pipelines

The usage of simplified gas-dynamic simulators and models, widely applicable for the operational evaluations of gas flow in the pipeline technological parameters significantly reduces the reliability and reasonableness of dispatch decisions-making support by the natural gas transportation. Current level of development of computer engineering and hardware-in-the-loop equipment of gas pipelines requires the usage of the models which

could provide with high-accuracy evaluations of actual distributions of gas –dynamic parameters for different regimes of natural gas transportation by main gas pipelines.

Such model has been elaborated in JSC "Gazprom" especially for computation of gas flow in up-to-date main high-pressure gas pipelines (under 30 MPa) parameters. This model differs in the science-based minimization of adopted simplifications and modular structure (the brief description of this modular structure's special features is given below).

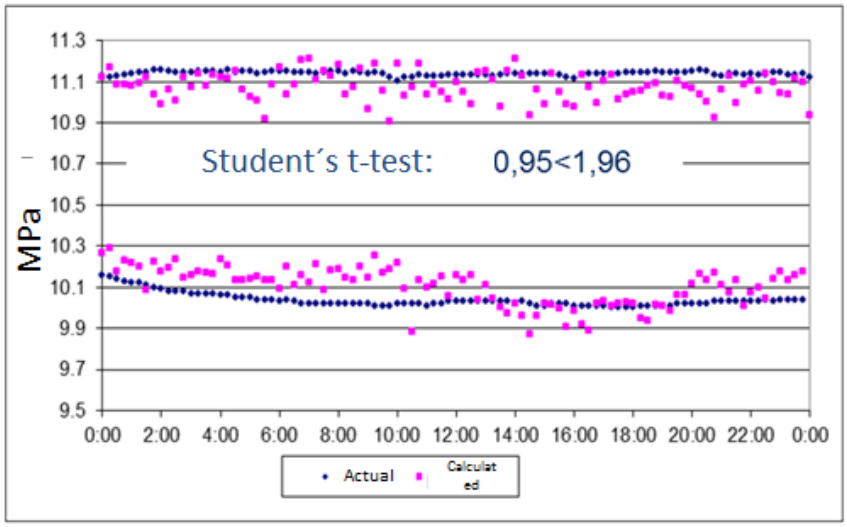
1. Complete one-dimensional equations of gas dynamics are used in the model, and these equations permit to describe steady gas flows, as well as the transient processes in gas pipeline with high accuracy and in real-time mode.
2. The model provides for the opportunity of selection from several the most accurate and widely applicable state equations for determination of thermal physic gas properties and also includes the optimizer of velocity of mentioned properties numerical computations.
3. The model provides for the opportunity of selection of computing formula for hydraulic resistance in gas pipeline. At the same time, the analysis of applicability of selected formula on the experimental data of regimes of real main high-pressure gas pipelines functioning is carried out in every case.
4. The axisymmetric model of environment´s description, which takes into account the longitudinal components of heat flow and proper heat capacity of gas pipeline´s walls, has been used for the first time in the course of development. The mentioned effects have a great influence on flow´s parameters distribution, as the computations for main high-pressure gas pipelines have demonstrated and it has been expressed by unsteady gas flow regimes.

The block of model´s regular adaptation to the real objects (main gas pipelines), based on the identification of nonmetering parameters which carry the integral information concerning the current state of gas pipeline and environment with the purpose of computations accuracy´s rise and also the account of data incompleteness.

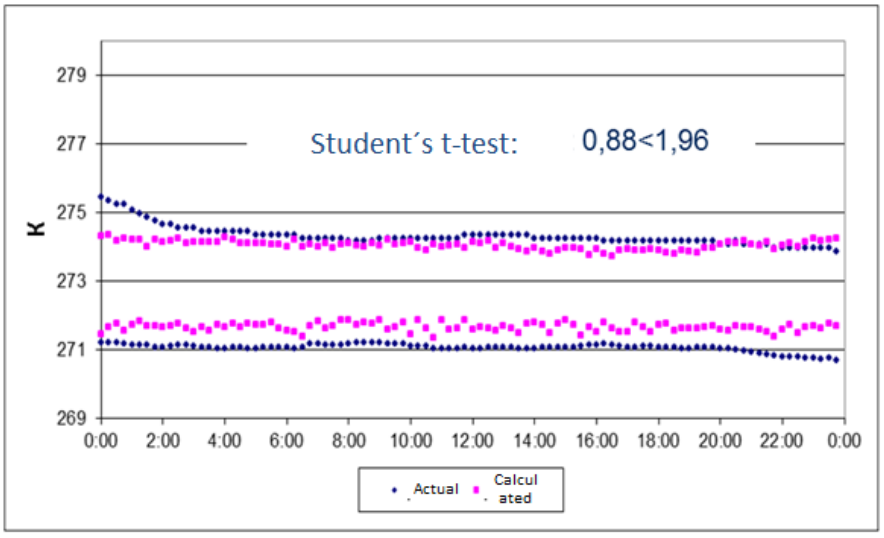
Methods of analysis

The evaluation of model´s adequacy has been executed on the base of real data for different regimes of existent main high-pressure gas pipelines functioning. Estimated values of pressure, flow rate, temperature and others technological parameters of gas pipelines operation have been compared with real data of measurements, received on telemetering stations. Executed comparative analysis of calculated and actual data has allowed to affirm that the developed gas flow model could be applicable for the computation of technological parameters of main high-pressure gas pipelines (under 30 MPa) functioning.

The example of test computation for the analysis of model´s functioning correctness with regard to the existent main high-pressure gas pipeline in the case of steady functioning regime is given on the pictures 2,3. Statistical methods have been used for the confirmation of adequacy with the consideration of great number of statistical fitting criteria.



Pic.2 – Pressure at the end of main high-pressure gas pipeline



Pic. 3 – Temperature at the end of main high-pressure gas pipeline

Analysis of the results

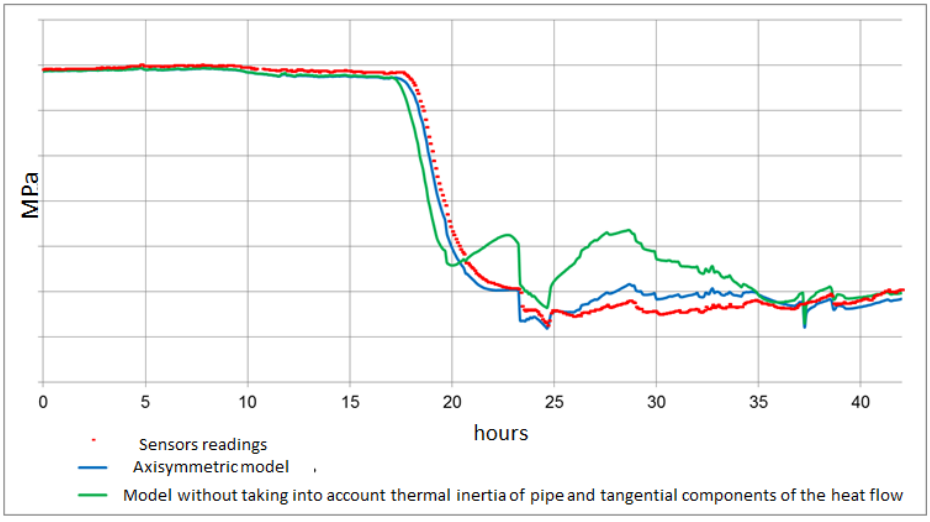
The developed model has demonstrated the high accuracy of computations of gas flow in main high-pressure gas pipelines technological parameters distributions, including in the case of unsteady regimes of its' functioning, which are typical for the contingencies.

The mentioned model has been successfully used for the computation of different regimes of main high-pressure gas pipelines functioning as "The Blue stream" and "The North stream" and has demonstrated a great coordination with the experimental data.

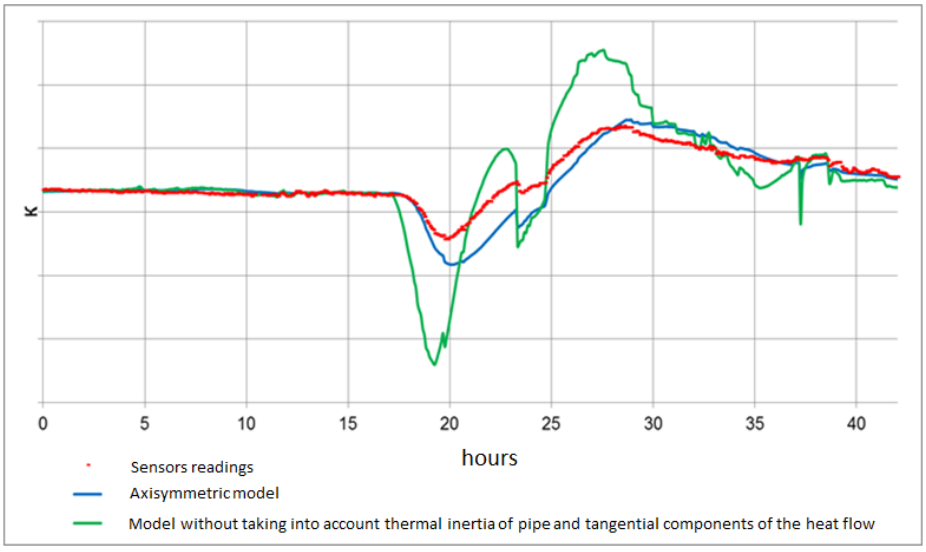
In the course of researches we have carried out the test computations (based on the usage of real data of measurements of main high-pressure gas pipelines' operation technological parameters), and these computations have demonstrated the advantages of axisymmetric model of environment's description usage, account of pipe's thermal inertia and heat flow's tangential components by unsteady regimes of main gas pipeline's functioning. The comparative results of computations of flow´s parameters for unsteady regime of operating main high-pressure gas pipeline with the usage of developed model and so-called the model of "thin pipe", that is the model which does not account physical effects, mentioned above, are given on the pictures 4, 5. According to the measurement data, the gas pipeline operation has been counted during 43 hours, including the consecutive shutdown of gas supply per day for 2 hours and then for 1 hour (here and hereinafter on the given diagrams the real values of technological parameters have been hidden, because all data is the commercial secret of JSC "Gazprom").

It is not worth the trouble, looking at the presented diagrams, make sure that the effects, considered by us, exist and influence on gas flow´s parameters. The mentioned influence is very significant not only for temperature´s distribution, but also for pressure´s distribution.

Also it can be seen in the diagrams, that the account of all effects, described on the previous slide, has the greatest significance by unsteady regimes of pipeline´s functioning. At the same time we have received the dependencies which permit to separate out analytically the thermal inertia´s effect and to take into account integrally the heat flow's longitudinal components, at the expense of execution of nonmetering model's parameters regular identification, and the timing could be reduced manifold, because the mentioned model of "thin pipe" could be used for the operative evaluations by the execution of online computations.



Pic. 4 – Comparison of results of different models usage for pressure's computation at the end of main high-pressure gas pipeline



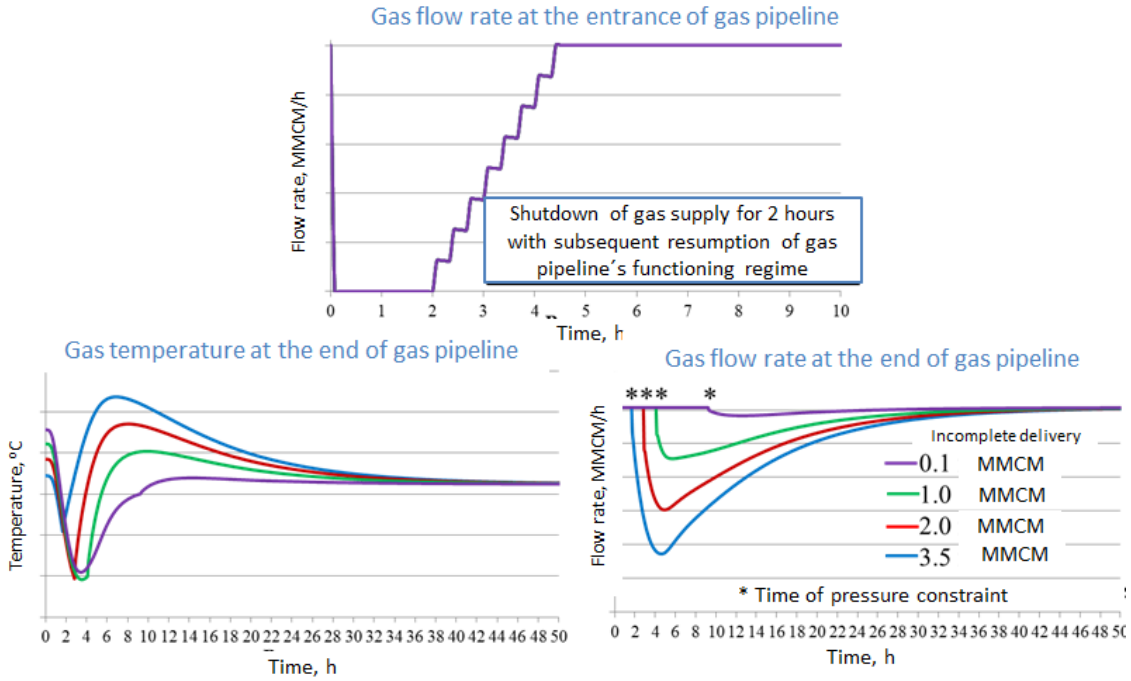
Pic. 5 – Comparison of results of different models usage for temperature's computation at the end of main high-pressure gas pipeline

Simulation of contingencies on main gas pipelines

The developed model also could be used successfully for the imitation of possible contingencies on marine main high-pressure gas pipelines, while the direct control of technological parameters via computation is impossible because of the inaccessibility of gas pipeline´s route. The example of computations of flow´s parameters distributions by the similar imitation is given on the picture 6. In this case it has been required to estimate the consequences of temporal shutdown of gas supply at the entrance of gas pipeline's linear section by the absence of opportunity to influence on the receiving terminal´s control by the way that gas temperature should not decrease lower than acceptable limit for stable and continuous regime of gas pipeline´s functioning. The computations have been executed for different options of pressure's initial value at the end of gas pipeline.

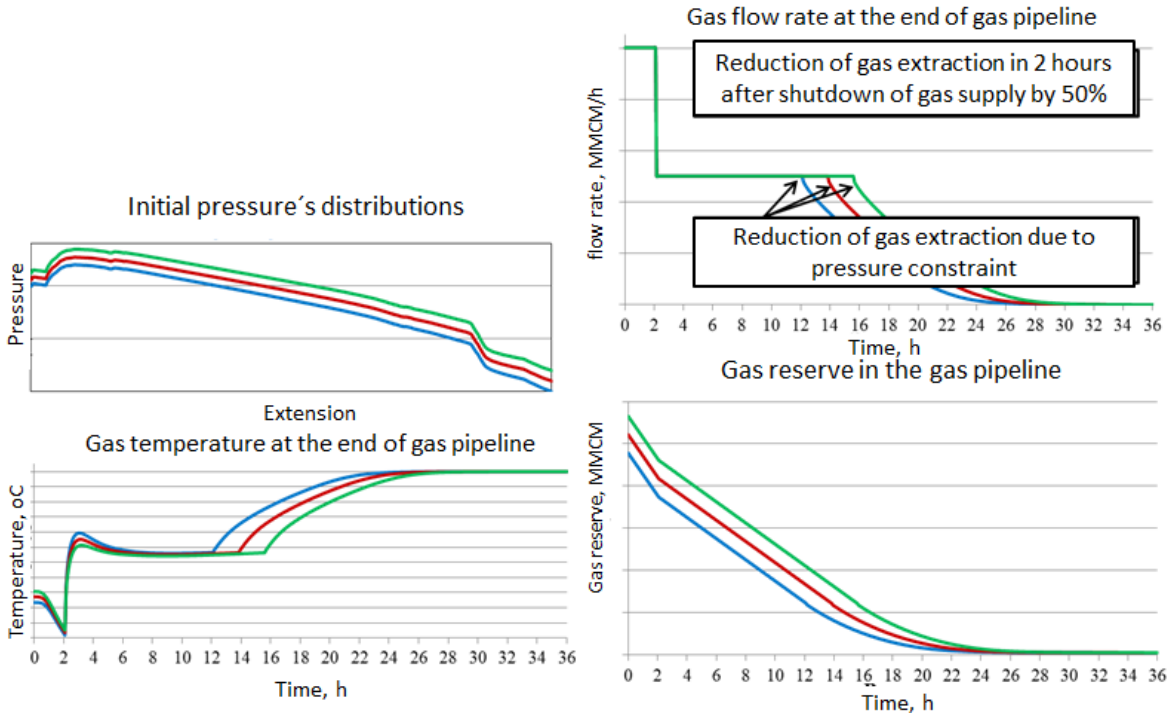
Note. Additionally, we have considered the restriction of minimum pressure at the end of gas pipeline, which has been used as the boundary condition on its reaching during the contingency´s development. The gas supply renews in two hours after it's shutdown. At the same time, the boundary condition is the gas flow at the entrance of gas pipeline which grows stepwise: per 8 steps, each for 20 minutes.

Such simulation permits to estimate possible managerial decisions, directed on the reduction of penalties for the incomplete gas delivery to the consumers (temporal shutdown of gas extraction, analysis of opportunity of gas reserve in the pipeline usage; reasonability of preliminary pressure's increase before the shutdown of gas supply to the entrance.)



Pic. 6 – Simulation of contingencies on main high-pressure gas pipelines: shutdown and subsequent resumption of gas supply at the entrance to gas pipeline

The developed model also permits to determine how to response more efficiently to the contingency's appearance on main gas pipeline (shutdown of gas supply at the entrance) by the means of extraction's reduction on the receiving terminal. At the same time, it is strictly required to control the gas flow parameters (temperature and pressure) no matter what option of transient regime is considered (refer to pic. 7).

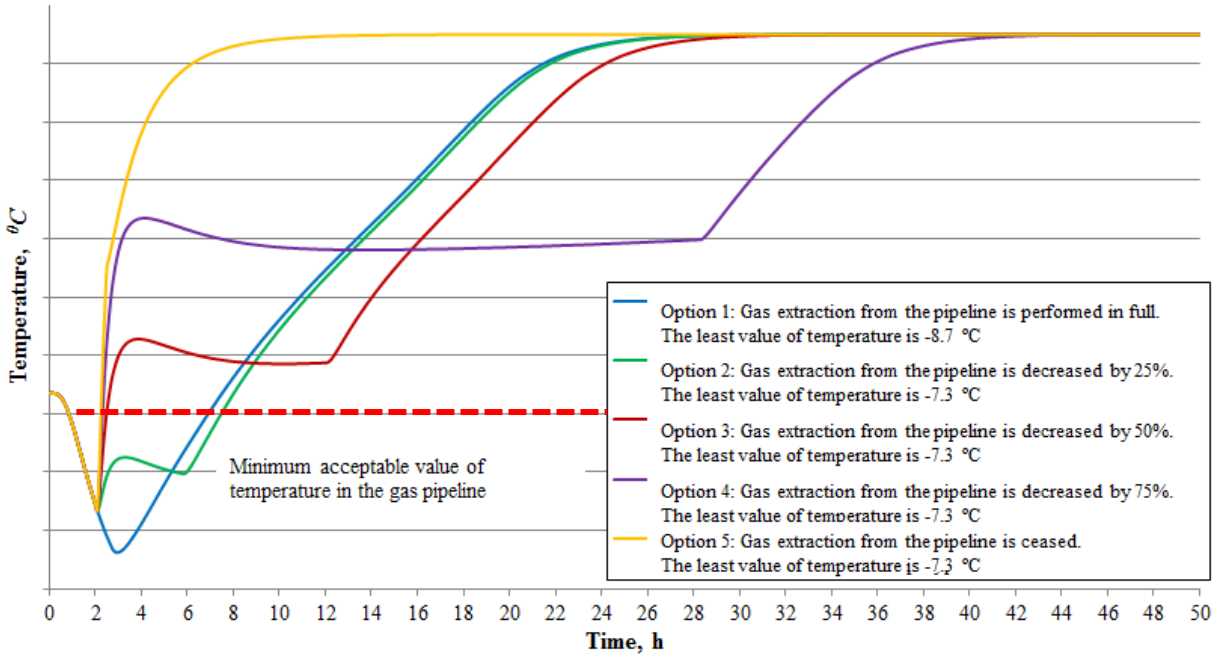


Pic. 7 – Simulation of contingencies on main high-pressure gas pipelines: shutdown of gas supply and subsequent response by the extraction's reduction

Determination of dynamics and control of minimum temperature in gas pipeline

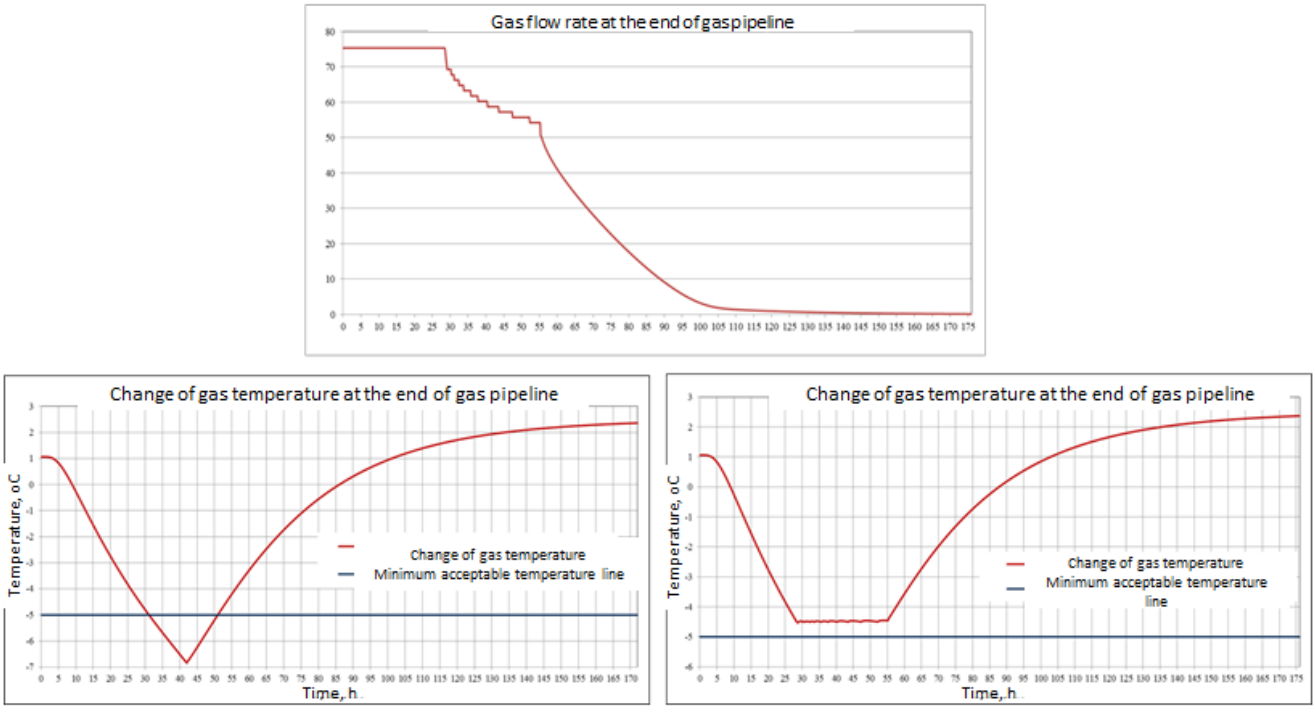
As it has been stated above, the control of technological parameters of main gas pipeline operation is very important by every response scenario to the contingency via the dispatch control. Further, the developed gas flow model is considered as the means of assistance by the control of minimum gas temperature in the pipeline. In the case of contingency, described above (temporary shutdown of gas supply at the entrance of gas pipeline), the gas temperature could fall significantly lower than acceptable values and could be located in the prohibited area during continuous period of time (several hours), so the risk of contingency´s appearance would significantly rise. At the same time, the point in which the least value of temperature is reached, could be located not at the end of marine linear section of gas pipeline, and it means that it would be impossible to carry out the direct

measurements by means of telemetry. Executed computations demonstrate the significance of high-accuracy models usage, which take into account all important physical effects which influence on gas flow parameters' computations to prevent the potentially dangerous regimes of main high-pressure gas pipelines functioning (picture 8).



Pic. 8 – Dynamics of minimum gas temperature in pipeline for various response scenarios to reduce the level of gas extraction

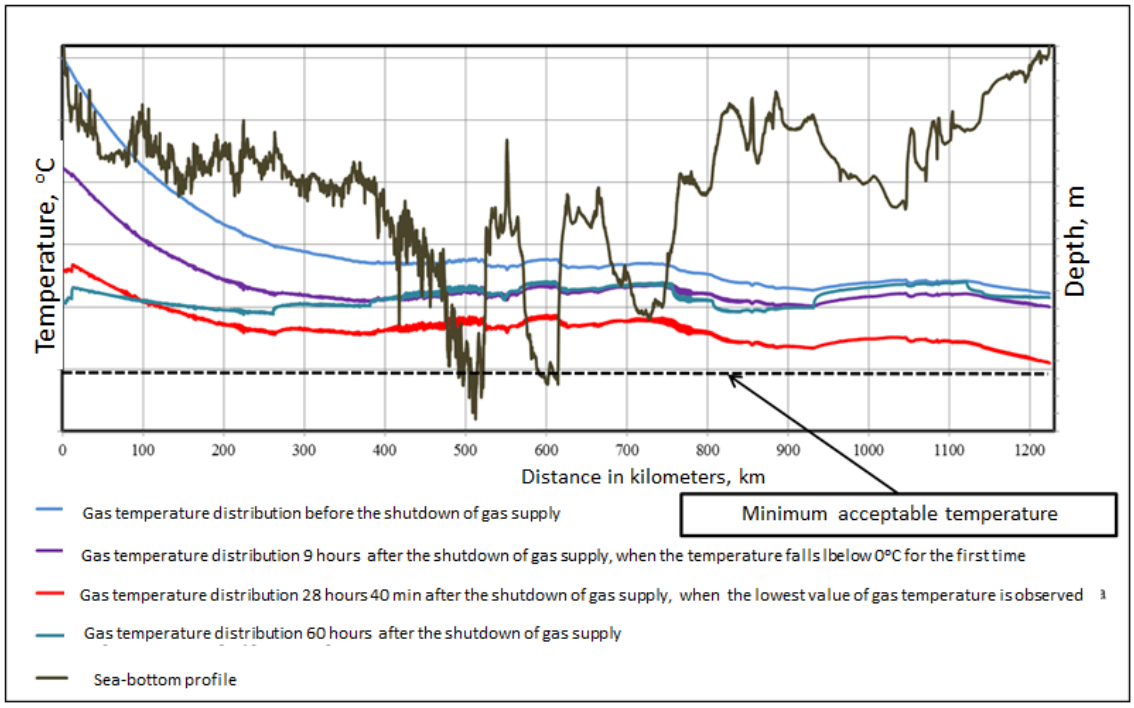
Thereby, the developed model could be used as the means of efficient dispatch decisions support during contingencies to minimize possible ecological damage, because it permits to control the gas pipeline's minimum temperature constraint with the subsequent selection of control action (pic. 9).



Pic. 9 – Control of gas pipeline's surface minimum temperature constraint with the subsequent selection of control action;

Without control action: temperature at the end falls lower than minimum acceptable value for 20 hours;
With control action: by the reduction of gas extraction the temperature doesn´t fall below the constraint

Picture 10 also demonstrates the opportunities of gas-dynamic simulation with the usage of high-accuracy methods to minimize ecological penalties on the example of computations of wall´s temperature distributions for the operating marine main high-pressure gas pipeline.



Pic. 10 – Gas pipeline´s wall temperature's distributions in different points of time

The executed computations clearly have demonstrated that under present-day conditions of gas pipeline transport by the ultrahigh pressures and spreading main gas pipelines routes, difficult of access, it is necessary to have the reliable means for computations of gas flow parameters in the pipeline, based on the high-accuracy methods of gas-dynamic simulation to maintain reliability and safety of natural gas supplies to the consumers.

Conclusion

Due to the principle of minimization of adopted simplifications by the description of gas flow through the pipeline, the developed physico-mathematical model has high accuracy in computations of gas flow parameters' distributions, which are necessary for dispatching decision-making support and formation of response scenarios for the contingencies.

The usage of axisymmetric model of environment's description made it possible to precise significantly the computation of technological gas flow parameters in the up-to-date main high-pressure gas pipelines at the expense of account of important physical effects, which have been neglected by the simulation of main gas transport until now.

The application of methods of regular model´s adaptation to the real gas pipelines not only raises the accuracy of operational flow parameters computations, as well as permits

to get the additional information about the simulated object and to take into account the systematic sensors' errors of flow parameters measurements.

The developed model could be used as the dispatch decision-making support and formation of response scenarios which are necessary to prevent the consequences of potential contingencies, to except potentially dangerous regimes of gas pipelines functioning and to ensure the most efficient regimes of shutdown and startup of gas pipelines by the execution of planned repair works.

The simulation results permit to create the contingencies event log in order to ensure the sustainable operation of high-pressure gas pipelines, as well as the reliability of gas supply. From the economic point of view, such approaches permit to select the most efficient way from one gas pipeline operation's regime to another, to reduce possible penalties for incomplete gas deliveries to the consumers, by minimizing the operation time of gas pipeline in off-design conditions or in the case of a downtime, as well as minimize the ecological risks and penalties, related to the significant change of gas pipeline surface's temperature by the transient regimes.