Автоматизовані системи управління та прилади автоматики. 2026. № 2 (189) *ISSN 3083-7715 (online)*
Management Information System and Devices. 2026. No. 2 (189) *ISSN 3083-7650 (0135-1710) (print)*

UDC 533.6 + 519.8:004 DOI: https://doi.org/10.30837/0135-1710.2026.189.267

Dmytro Dymertsov

COMPUTER SIMULATION OF GAS-DYNAMIC PROCESSES: A ONE-DIMENSIONAL APPROACH

The relevance of this work derives from the need for effective information technologies and software tools for modeling gas-dynamic processes in technical systems. Under modern conditions, the use of full-scale multidimensional models is associated with significant computational costs and complexity of software implementation, which limits their application in practical problems. In this context, one-dimensional models gain particular importance as a basis for developing optimized numerical solution algorithms that provide a reasonable balance between accuracy, computational efficiency, and implementation complexity. The **objective** of the study is to develop a one-dimensional mathematical model and a software package for numerical simulation of thermogasdynamic processes in flow elements of technical systems, as well as to verify and analyze the accuracy of the developed model. The **aim** of the study is to develop, implement, and verify a unified method for investigating gas-dynamic processes based on one-dimensional mathematical modeling using modern numerical analysis techniques. Special attention is paid to the development of efficient computational algorithms that take into account key physical processes (gas flow, heat and mass transfer, energy transformations, turbulence, and hydraulic losses), as well as ensure stability, convergence, and computational efficiency in software implementation. The **object** of the study is the processes of numerical modeling of gas-dynamic phenomena in flow elements of technical systems (pipelines, channels, heat exchangers, piston units), which are characterized by unsteady behavior, wave effects, and intensive heat and mass transfer processes. The **subject** of the study is methods based on a generalized one-dimensional mathematical model for calculating gas-dynamic processes in flow elements of technical systems. The results of the study showed that methods for improving numerical stability and reducing computational errors have been investigated and implemented, which ensured stable operation of algorithms in modeling unsteady gas-dynamic processes. The developed model is implemented as a software package designed for computational experiments and further analysis of simulation results. The **performed** verification, based on comparison with known analytical, numerical, and experimental data, confirmed the correctness, accuracy, and efficiency of the proposed algorithms. The **conclusion** confirms the feasibility of using one-dimensional computational models as an effective tool for computer modeling of complex physical processes. The proposed approach can be applied in the development of modern information technologies and in further scientific research in the field of gas dynamics and thermophysics, while the relative error does not exceed 5%.

Keywords: modeling; numerical methods; mathematical modeling; software implementation; computational systems; systems analysis; technologies; design.

1. Introduction

A current trend in computer science is the development of algorithmically efficient software tools for modeling gas-dynamic processes. The use of modern numerical methods and computational approaches makes it possible to create software systems capable of accurately reproducing complex non-stationary phenomena in technical systems. Mathematical modeling is a fundamental tool of computer science that formalizes complex physical processes into computational models suitable for implementation in a software environment. In today's context, the development of effective numerical methods and algorithms for modeling processes in technical and energy systems [1] is of particular relevance, where high calculation accuracy must be ensured with limited computational resources. This necessitates the creation of optimization models focused on performance, scalability, and integration into application software packages.

In this work, as part of a project to develop a software package for calculating gas-dynamic processes in gas-jet acoustic generators, a unified computational model of gas-dynamic processes is proposed, focused on studying the filling and emptying of closed containers in technical systems. Particular attention is paid to the algorithmization of the model, the selection of discretization methods, and the implementation of efficient computational procedures. The developed model was verified by comparing the results of numerical simulations with known experimental and calculated data, which confirms its correctness and suitability for use as part of engineering analysis software tools. Further development of this approach opens up opportunities for creating intelligent decision-support systems, parameter optimization, and the automation of the analysis of complex energy processes.

The aim of the study is to develop a generalized mathematical and computational model of thermogasdynamic processes in gas-jet cooling-heating acoustic generators with subsequent software implementation. The main focus is on constructing an efficient numerical solution algorithm that provides a comprehensive description of the interaction of wave, thermal, and hydrodynamic phenomena in a technical system.

The ultimate goal is to create a software-oriented complex for conducting numerical experiments, analyze operating modes, and optimize the performance parameters of gas-jet acoustic generators, which will improve the energy efficiency of the systems, enable adaptive adjustment of operating modes, and expand their application potential in modern information-controlled technical systems. The use of the developed software complex within the scope of this research will allow for the creation of a database of operational characteristics and results of numerical experiments for further analysis and systematization of the object's operating parameters.

2. Analysis of Recent Publications

In modern computer science research, mathematical modeling is a key tool for analyzing complex dynamic systems, particularly physical and gas-dynamic processes, as it allows for the formalization of equations into computational models and their implementation as software algorithms within software packages [2]. Computational models are based on numerical methods for solving nonlinear differential equations, including approaches such as the finite difference method, the finite volume method, and other algorithmic schemes that enable the construction of approximate solutions [3, 4].

Modern approaches in computer modeling include multidimensional (2D, 3D) computational models, which provide a detailed reproduction of the spatiotemporal dynamics of processes, but are characterized by high computational complexity and significant demands on resources and optimization of implementation algorithms [5]. In turn, one-dimensional models are viewed as a method for reducing the complexity of the problem, allowing for reduced computational costs, simplified algorithm structures, and efficient software implementation while maintaining acceptable accuracy for analyzing general trends in system behavior [6]. Such approaches are widely used in the development of software for modeling technical systems, ensuring a balance between computational productivity and accuracy of results.

Within the framework of modern information technologies, hybrid and adaptive computational models are actively being developed, combining various numerical methods to improve algorithm stability and resource efficiency. Such approaches allow for the dynamic adaptation of the discretization of the computational domain depending on the complexity of the process, which is particularly important for optimizing the operation of software simulators of complex physical systems [4, 5].

A key role in such approaches is played by the algorithmic implementation of models, the selection of numerical methods, and the optimization of computational procedures. This includes the use of finite difference methods, finite volume methods, solvers for hyperbolic systems of equations, as well as their integration into software environments using modern programming languages and libraries (Python, C++, Lazarus, etc.). The result is the creation of flexible software packages that provide numerical modeling, visualization, and analysis of the dynamics of complex processes.

An analysis of contemporary scientific sources shows that computer modeling methods are a fundamental tool of information technology in scientific and engineering problems, as they combine high computational accuracy, algorithmic efficiency, and the ability to automate process analysis across various applied areas. Based on such approaches, it is possible to develop formalized mathematical and computational models of complex physical processes, which provides the foundation for the development of effective software systems for simulation and optimization.

3. Materials and Methods for Modeling Technical Systems

Methods for modeling technical systems involve representing one-dimensional unsteady gas flow as a formalized system of computational gas dynamics equations (see Equations 1–3) [6–8], which enables their algorithmization and subsequent software implementation within the framework of numerical methods for computer modeling. This approach allows for the creation of computational models suitable for integration into software packages for simulating dynamic processes and forms the basis for performing numerical analysis, optimizing system parameters, and supporting decision-making in information-controlled technical systems [9, 10].

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho\omega)}{\partial x}=0 \tag{1}$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial\left(p+\rho\omega^2\right)}{\partial x}+\frac{\xi}{2d}\rho\omega^2=0 \tag{2}$$

$$\frac{\partial y}{\partial t}\left[\rho\left(u+\frac{\omega^2}{2}\right)\right]+\frac{\partial y}{\partial x}\left[\rho\omega\left(u+\frac{p}{\rho}+\frac{\omega^2}{\rho}2\right)\right]-\left[\frac{4}{d}q+\frac{\partial}{\partial x}\left(\alpha\frac{\partial T}{\partial x}\right)\right]=0 \tag{3}$$

where ρ is the density of the working fluid; ω is the flow rate; p is the pressure; α is the thermal conductivity coefficient; ξ is the gas resistance coefficient; T is the temperature; d is the tube diameter.

The model for calculating technical processes is based on the use of linear approximations, which allows the system to be formalized as a set of elements with concentrated parameters, provided that its characteristic dimensions are significantly smaller than the wavelength. Within this approach, the computational description of processes boils down to the numerical solution of the equations of unsteady gas flow in vessels of constant cross-section (see Equations 4–6) with given boundary conditions, which are determined by the operational logic of the technical system [10]. Implementing this approach as a computational model allows for the reproduction of the main patterns of process dynamics while significantly reducing computational complexity and optimizing the use of software system resources.

$$\frac{\partial p}{\partial x}=\frac{\partial(\rho\omega)}{\partial t}+2\alpha(\rho\omega) \tag{4}$$

$$-\frac{\partial p}{\partial t}=C_u^2\frac{\partial(\rho\omega)}{\partial x} \tag{5}$$

$$C_u^2=\frac{dp}{d\rho}=\frac{P_0}{\rho_0} \tag{6}$$

where ρ is the density of the working fluid; ω is the flow velocity; p is the pressure.

Of particular interest in the context of computer modeling is the analysis of processes in high-pressure technical systems [10], which requires accounting for nonlinear effects in mathematical and computational models. Research on the influence of nonlinear components shows that as system parameters increase, the contribution of nonlinearity to the state equation becomes dominant, leading to significant deviations in the numerical representation of physical characteristics compared to the contribution of nonlinear terms in the equations of motion and continuity.

To solve such problems in software packages, an iterative (successive approximation) method is used, which is implemented within the system of equations via a reduced computational subsystem (see Equations 7–8). This algorithmic approach ensures a step-by-step refinement of the numerical solution and allows for the integration of the influence of key physical parameters into the process of computer modeling of gas system dynamics [9, 10].

$$\frac{1}{\rho}\frac{\partial\rho}{\partial x}+\frac{\partial\omega}{\partial t}+\omega\frac{\partial\omega}{\partial x}+\xi\frac{\omega^2}{2d}=0 \tag{7}$$

$$\frac{\partial\rho}{\partial t}+\rho\frac{\partial\omega}{\partial x}+\omega\frac{\partial\rho}{\partial x}=0 \tag{8}$$

where ρ is the density of the working fluid; ω is the flow velocity; p is the pressure; ξ is the gas resistance coefficient.

4. Structure and implementation of the composite one-dimensional model

Based on the methods discussed, a mathematical model is developed that implements the ideal gas equation of state (see Equation 9) and provides a formalized description of the key parameters of the working medium as it moves and interacts with the system's characteristics. Within the scope of computer modeling, this model is used as a basis for developing computational algorithms for the analysis and simulation of dynamic processes in technical systems.

$$p=\rho RT \tag{9}$$

where p – is the pressure; ρ – is the density; T – is the temperature; R – is the gas constant.

The implementation of this model involves a number of assumptions, according to which the working medium is treated as a system of material points, and the internal energy is determined solely by temperature. This formalized representation allows for a significant reduction in the complexity of the mathematical description of processes while maintaining acceptable accuracy over a wide range of material parameters, which is important for the subsequent software implementation of computational models.

To numerically describe the dynamics of the processes, a one-dimensional system of gas dynamics differential equations is used (see Equations 1–3), while thermal processes are modeled using a one-dimensional unsteady heat conduction equation (see Equation 10). Within the framework of computer modeling, the technical system is considered as a thin-walled cylinder with one end closed, which allows the spatial problem to be reduced to a one-dimensional formulation and simplifies its numerical implementation in the software environment.

$$\frac{\partial T}{\partial t}=a\frac{\partial^2 T_c}{\partial x^2}+\frac{1}{\delta C_c\rho_c}\left[\alpha_g\left(T_g-T_c\right)+\alpha_o\left(T_c-T_o\right)\right], \quad (10)$$

where α is the heat transfer coefficient; δ is the tube wall thickness; C_c is the heat capacity of the tube wall; α_g – thermal conductivity coefficient; ρ_c – density of the tube wall; T_g – gas temperature; T_c – tube wall temperature; T_o – ambient temperature.

5. Methods for the numerical solution of gas dynamics systems

Computational algorithms that take into account the discretization structure and the specific characteristics of each model element are used for the numerical implementation of the system of equations. The state parameters of the working medium in the pipe are determined using the finite difference method, implemented as a discrete computational grid with a time step t and a spatial step h, as well as an additional offset grid with a step size of $h/2$ (see Figs. 1, 2). Based on this discretization, an explicit central-difference scheme is constructed, which provides first-order accuracy in time and second-order accuracy in the spatial variable h, which is a typical approach in the numerical modeling of dynamic processes.

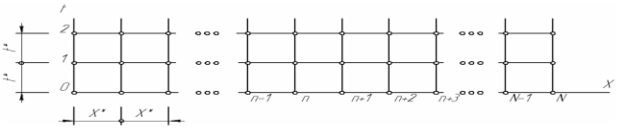


Fig. 1. Flat grid for process calculation:
Δt – time step; x – spatial step

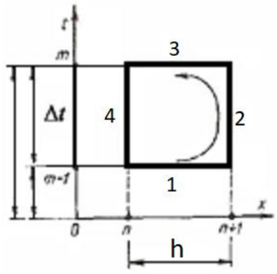


Fig. 2. Computational cell of a planar grid:
where Δt is the time step; h is the spatial step

When transitioning to a new time step, numerical discontinuities and jumps in model parameters may occur at the nodes of a staggered computational grid. To eliminate such instabilities and correctly determine gas-dynamic quantities at intermediate points $h/2$, an algorithm for solving the arbitrary discontinuity breakdown problem is applied [11, 12]. The use of this approach within the software implementation ensures the numerical stability of the computational process and improves the accuracy of reproducing gas flow dynamics in the simulation software package:

– density at the new time step

$$\rho_{i+1/2}^{j}=\rho_{i+1/2}^{j-1}-\frac{\Delta t}{h}\left[\left(\rho\omega\right)_{i+1}^{j}-\left(\rho\omega\right)_{i}^{j-1}\right]\ ; \quad (11)$$

– velocity at the new time step

$$\omega_{i+1/2}^{j}=\left(\left(\rho\omega\right)_{i+1/2}^{j-1}-\frac{\Delta t}{h}\left[\left(p+\rho\omega^2\right)_{i+1}^{j}-\left(p+\rho\omega^2\right)_{i}^{j-1}\right]+\frac{\Delta t}{2d}\left(\xi\rho\omega^2\right)_{i+1/2}^{j-1}\right)\Big/\rho_{i+1/2}^{j}\ ; \quad (12)$$

– pressure on the new time layer

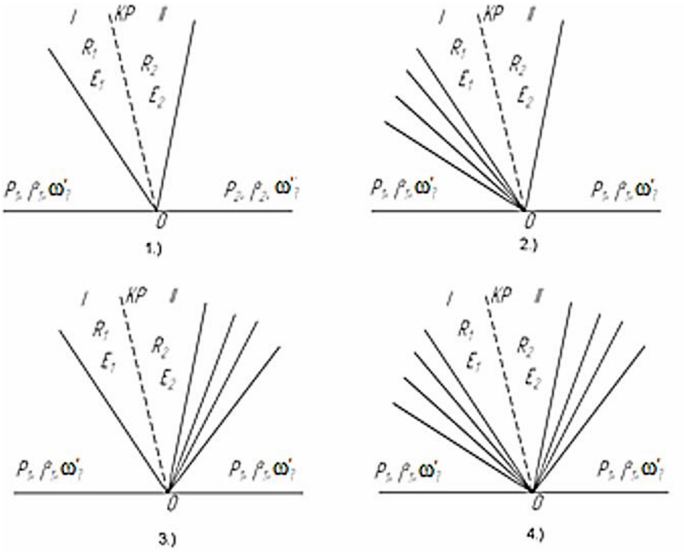
$$p_{i+1/2}^{j}=\left(k-1\right)\left\{\begin{matrix}\left[\dfrac{p}{k-1}+\dfrac{\rho\omega^2}{2}\right]_{i+1/2}^{j-1}-\dfrac{\Delta t}{h}\left[\left[\omega\left(\dfrac{p}{k-1}+\dfrac{\rho\omega^2}{2}\right)\right]_{i+1}^{j}-\left[\omega\left(\dfrac{p}{k-1}+\dfrac{\rho\omega^2}{2}\right)\right]_{i}^{j-1}\right]\\ -\left[\dfrac{\rho\omega^2}{2}\right]_{i+1/2}^{j}+\dfrac{4\alpha}{d}\Delta t\left(T_{i+1/2}^{j-1}-T_{i}^{j-1}\right)\end{matrix}\right\}. \quad (13)$$

Gas parameter jumps may occur between nodes in the computational grid within a pipe, leading to calculation errors and potential failure of the finite difference scheme.

To eliminate numerical instabilities at the nodes of the computational grid, an approach based on solving the problem of the decay of an arbitrary discontinuity is employed. Within this framework, the model considers two semi-infinite regions of the working medium, in each of which the gas parameters are constant at the initial time but may differ from one another. This formalization allows for a correct description of the evolution of the distribution of physical properties after the occurrence of a discontinuity and ensures the stability and consistency of the numerical algorithm during the computer simulation process.

The problem of an arbitrary discontinuity

When two gas media come into contact, the nature of their interaction is determined by the values of the main parameters, which can result in the formation of various flow patterns (see Fig. 3). On both sides of the initial separation point (point 0), the gases are in states with constant parameters: on the left – $p_1\ \rho_1\ \omega_1$, on the right – $p_2\ \rho_2\ \omega_2$.



1 – shock waves propagate to the left and right;
2 – a rarefaction wave propagates to the left, a shock wave to the right;
3 – a shock wave propagates to the left, a discharge wave to the right;
4 – a discharge wave propagates to the left and right

Fig. 3. Diagram of the location of the discontinuity: where
I – is the space on the left; I – is the space on the right; KP – is the contact gap;
ρ is the density of the working fluid; ω is the flow velocity; p is the pressure

At the boundary of the flow, which may manifest as a shock wave or a rarefaction wave, a change in flow parameters occurs. In this region, a redistribution of physical quantities takes place; in particular, the values of gas pressure and velocity change to new, consistent values that ensure compliance with the laws of conservation of mass, momentum, and energy [13, 14].

The calculation is performed in the following sequence:

$$a = \sqrt{k\,\frac{p_i + p_{i+1}}{2}\,\frac{\rho_i + \rho_{i+1}}{2}} \qquad (14)$$

$$P_k = \frac{p_i + p_{i+1}}{2} - a\,\frac{\omega_i + \omega_{i+1}}{2} \qquad (15)$$

$$U_k = \frac{\omega_i + \omega_{i+1}}{2} - \frac{p_i - p_{i+1}}{2a} \qquad (16)$$

where a – is the mass velocity of sound; U_k is the contact discontinuity velocity; P_k is the contact discontinuity pressure.

The wave velocity propagating to the left and right of the discontinuity (see Equations 17, 18):

$$D_I = \omega_i - a/\rho_i \qquad (17)$$

$$D_{II} = \omega_{i+1} + a/\rho_{i+1} \qquad (18)$$

Depending on the sign of the speeds D_I and D_{II}, the following options are possible:

$$D_I > 0,\ D_{II} > 0,\ \text{then } U = \omega_i,\ P = p_i,\ R = \rho_i \qquad (19)$$

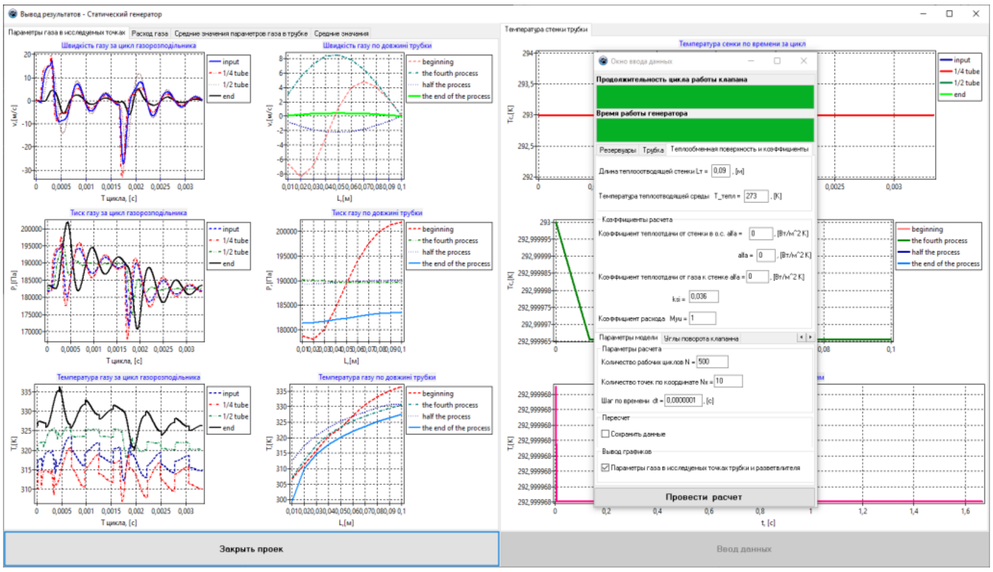
$$D_I < 0,\ D_{II} < 0,\ \text{then } U = \omega_{i+1},\ P = p_{i+1},\ R = \rho_{i+1} \qquad (20)$$

$$D_I < 0,\ D_{II} > 0,\ U_k > 0,\ \text{then } U = U_k,\ R = \rho_i \frac{(k+1)P_k + (k-1)p_i}{((k-1)P_k + (k+1)p_i} \qquad (21)$$

$$D_I < 0,\ D_{II} > 0,\ U_k < 0,\ \text{then } U = U_k,\ R = \rho_i \frac{(k+1)P_k + (k-1)p_{i+1}}{(k-1)P_k + (k+1)p_{i+1}} \qquad (22)$$

6. Analysis and verification of modeling algorithms

The developed unified one-dimensional computational model was implemented using the Lazarus Free Pascal programming language [15] as a software package for the numerical calculation of the operating parameters of gas-jet acoustic generators (see Fig. 4). The chosen language ensures high computational speed, flexibility in implementing numerical algorithms, and the ability to create an intuitive graphical user interface.



Продолжительность цикла работы клапана

Время работы генератора

Резервуары | Трубка | Теплообменная поверхность и коэффициенты

Длина теплоотводящей стенки Lт = 0,09 , [м]

Температура теплоотводящей среды T_тепл = 273 , [K]

Коэффициенты расчета

Коэффициент теплоотдачи от стенки в о.с. alfa = 0 , [Вт/м^2 K]

alfa = 0 , [Вт/м^2 K]

Коэффициент теплоотдачи от газа к стенке alfa = 0 , [Вт/м^2 K]

ksi = 0,036

Коэффициент расхода Myu = 1

Параметры модели | Углы поворота клапана

Параметры расчета

Количество рабочих циклов N = 500

Количество точек по координате Nx = 10

Шаг по времени dt = 0,0000001 , [c]

Пересчет

☐ Сохранить данные

Вывод графиков

☑ Параметры газа в исследуемых точках трубки и разветвлителя

Провести расчет

Fig. 4. Software package for calculation

The developed software enables numerical simulation of the thermo-gasdynamic processes occurring in the system's working elements, specifically the study of wave processes associated with the propagation of shock waves and rarefaction waves, as well as thermal processes involving heat transfer between the working medium and the walls of the receiving tube. This approach enables the integration of the computational model into software packages for the analysis, optimization, and verification of gas-jet acoustic generators.

A key element of such a system is the data storage subsystem, implemented using modern database technologies. The use of a specialized data warehouse allows for the accumulation of information on geometric parameters, operating modes, performance characteristics, and numerical simulation results for a set of objects of the same type. Given the structure of the subject domain, it is advisable to use a relational data model, which ensures integrity, consistency, and efficient query execution. At the same time, for tasks involving complex relationships between objects, network or hybrid approaches to data organization may be used.

Integrating the computational model with the database enables the automated generation of input parameters for modeling based on accumulated operational data, as well as the storage of calculation results for further analysis. Periodic updates of equipment status data and the re-execution of numerical calculations allow for the implementation of mechanisms to predict changes in technical characteristics over time.

Based on this approach, it becomes possible to model equipment aging processes, assess parameter degradation, and predict remaining service life. This, in turn, creates the prerequisites for building decision support systems for maintenance and repair, including the optimization of preventive maintenance schedules. Thus, the computational model, combined with an information subsystem for data storage and processing, transforms into a tool for modeling the life cycle of technical objects.

To confirm the reliability of the results, the model was verified by comparing it with known literature data [16, 17] prior to conducting numerical experiments. A comparison of the simulation results with experimental and literature data showed that the relative error does not exceed 5% (see Fig. 5). This indicates a sufficient level of model adequacy for describing the physical processes under study in flow elements of technical systems.

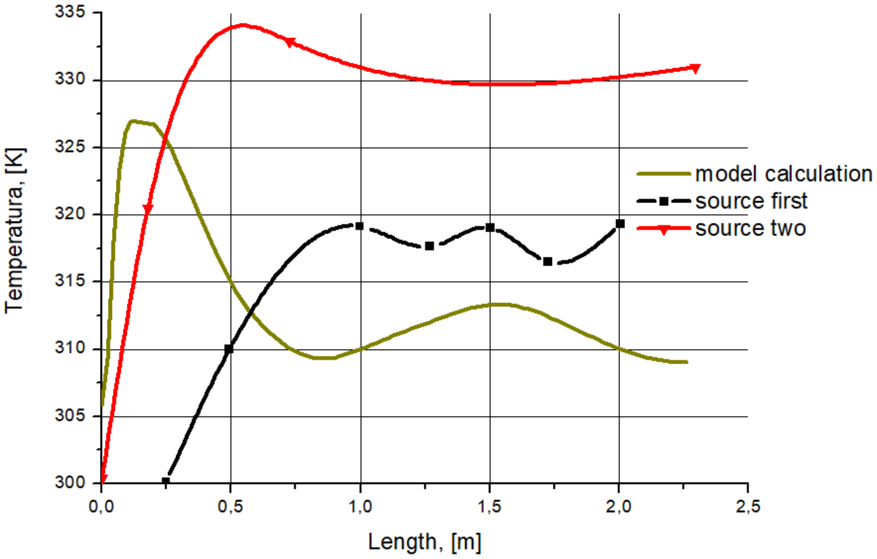


Fig. 5. Testing the model using existing results

Further development of the presented computational model should be directed not only toward improving its physical accuracy but also toward expanding the system's information component. In particular, the creation of an integrated software and information complex using distributed computing technologies, cloud services, and digital twin elements is promising, as it will enable real-time monitoring, modeling, and forecasting of operations.

7. Conclusions

As a result of the study, a unified one-dimensional computational model of gas-dynamic processes was developed, which accounts for key physical mechanisms, including gas flow, energy conversion, heat and mass transfer, turbulent effects, and local hydraulic losses, and enables the software implementation of numerical algorithms for engineering modeling. The model is based on the fundamental laws of conservation of mass, momentum, and energy, ensuring its physical validity and suitability for application to a wide class of gas-dynamic problems. During development, the structure of the computational model was defined, the selection of initial and boundary conditions was justified, and an approach to discretizing the computational domain was implemented, ensuring numerical stability, convergence, and computational efficiency.

The proposed model has been implemented as a software package that enables engineering calculations, analysis of operating modes, and parametric optimization of gas-dynamic systems. Verification of the model's adequacy through comparison with experimental and literature data confirmed a high degree of agreement between the results (the error does not exceed 5%), which indicates the correctness of the assumptions made and the practical applicability of the developed approach.

Further analysis showed that the effective use of the developed model should be considered not only in the context of numerical engineering modeling but also as part of information technology for supporting the life cycle of technical systems. In this case, the model is integrated into an information and analytical system that ensures the collection, storage, and processing of data on technical objects with individual parameters.

A key element of such information technology is a data management subsystem, implemented on the basis of databases or data warehouses. The choice of storage architecture (relational, hierarchical, or networked) is determined by the structure of the subject domain and the nature of the relationships between object parameters. The use of a centralized data warehouse enables the systematic updating of object parameters and their subsequent use in computational procedures.

Integrating the database with the computational model enables the implementation of a mechanism for recalculating operational characteristics based on current input data, which creates a foundation for predicting changes in the technical condition of equipment. This approach enables the modeling of aging processes, the assessment of parameter degradation, and the planning of maintenance interventions.

The results obtained confirm the feasibility of using one-dimensional computational models as a component of modern information technologies for engineering analysis and the management of the life cycle of technical systems. The developed approach can be used to create integrated software and information systems for decision support in the operation and optimization of gas-dynamic installations.

Conflict of Interest

The author declares that there is no conflict of interest regarding this study, including financial, personal, authorship, or other conflicts that could influence the study and its results presented in this article.

Funding

The work was performed within the framework of the institution’s economic-contractual project No. 0126U001791.

Data Availability

The manuscript has no associated data.

Use of Artificial Intelligence

The author confirms that no artificial intelligence technologies were used in the creation of this work.

References

1. Потапов, В., Димерцов, Д. (2025), "Перспективи застосування газоструменевих акустичних генераторів у якості вторинних джерел енергії", Refrigeration Engineering and Technology, Vol.61, No 2, pp. 128–137, DOI: https://doi.org/10.15673/ret.v61i2.3178
2. Вислоух, С., Волошко, О., Тимчик, Г., Філіппова, М. (2021), "Комп’ютерне моделювання процесів та систем. Чисельні методи", Київ: КПІ ім. Ігоря Сікорського.
3. Dymertsov, D. (2025), "Modeling of Gas-Dynamic Processes of Wave Low-Temperature Heat Generators Dynamic Gas Distribution", In: Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G. (eds) Advanced Manufacturing Processes VI. Interpartner 2024. Lecture Notes in Mechanical Engineering. Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-82746-4_68
4. Zeidan, D., Hidalgo, A. (2025), "Computational Fluid Dynamics: Novel Numerical and Computational Approaches". Cham: Springer Nature. DOI: https://doi.org/10.1007/978-981-97-8152-2
5. Nadamani, M. N., Shadloo, M. S., Dbouk, T. (2025), "A Review Theoretical and Computational Fluid Dynamics Modeling of Coupled Heat and Mass Transfer", Energies, Vol. 18, No. 24. Article 6418, DOI: https://doi.org/10.3390/en18246418
6. Anderson, J. D. (2003), "Modern Compressible Flow with Historical Perspective", New York: McGraw-Hill, McGraw-Hill Series in Aeronautical and Aerospace Engineering.
7. Thompson, P. A. (1988), "Compressible Fluid Dynamics". New York: McGraw-Hill, p. 665.
8. Chaudhry, M. H. (2014), "Pipes and Flow Systems", Applied Hydraulic Transients. New York: Springer. DOI: https://doi.org/10.1007/978-1-4614-8538-4
9. Hirsch, C. (2007), "Numerical Computation of Internal and External Flows", Oxford: Butterworth-Heinemann.
10. Toro, E. F. (2009), "Riemann Solvers and Numerical Methods for Fluid Dynamics", Dordrecht: Springer. DOI: https://doi.org/10.1007/b79761
11. Chaudhry, M. H. (1987), "Fluid Transients in Systems", Englewood Cliffs: Prentice Hall.
12. Zucrow, M. J., Hoffman, J. D. (1976), "Gas Dynamics", New York: Wiley.
13. Hirsch, C. (2007), "Numerical Computation of Internal and External Flows", Butterworth-Heinemann.
14. Anderson, J. D. (2003), "Modern Compressible Flow: With Historical Perspective", McGraw-Hill.
15. Dymertsov, D. (2026), "Development of software for modeling gas-dynamic processes in wave cold generators", Simon Kuznets Kharkiv National University of Economics, №0126U001791, https://nrat.ukrintei.ua/en/searchdoc/0126U001791/#
16. Bauer, C., Hauser, M., Haidn, O. (2015), "Investigation of stabilization effects in Hartmann-Sprenger-Tubes", In Proceedings of the 30th International Symposium on Space Technology and Science, Kobe-Hyogo, Japan, 4–9 July.

17. Li, B., Hu, G., Zhou, Z. (2007), "Numerical simulation of flow in Hartmann resonance tube and flow in ultrasonic gas atomizer", Applied Mathematics and Mechanics (English Edition), Vol. 28.

Received (Надійшла) 05.03.2026
Accepted for publication (Прийнята до друку) 30.04.2026
Publication date (Дата публікації) 29.05.2026

Відомості про авторів / About the Authors

Димерцов Дмитро Олександрович – Харківський національний економічний університет ім. С. Кузнеця, старший викладач кафедри здорового способу життя, технологій і безпеки життєдіяльності, Харків, Україна;
Dmytro Dymertsov – Simon Kuznets Kharkiv National University of Economics, Senior Lecturer of the Department of Healthy Lifestyle, Technologies and Life Safety, Kharkiv, Ukraine;
e-mail: dmytro.dymertsov@hneu.net
ORCID ID: https://orcid.org/0009-0000-4894-3495

КОМП’ЮТЕРНЕ МОДЕЛЮВАННЯ СКЛАДНИХ ПРОЦЕСІВ НА ОСНОВІ ОДНОВИМІРНОГО ПІДХОДУ

Актуальність роботи зумовлена необхідністю в ефективних інформаційних технологіях і програмних засобах для моделювання газодинамічних процесів у технічних системах. Використання повномасштабних багатовимірних моделей обмежено значними обчислювальними витратами та складністю програмної реалізації, що знижує їх практичну ефективність. У цьому контексті одновимірні моделі є основою для побудови оптимізаційних обчислювальних алгоритмів, які забезпечують раціональний баланс між точністю, швидкодією та складністю реалізації. Додаткову актуальність визначає перехід до інтегрованих інформаційно-аналітичних систем для класів технічних об’єктів зі змінними параметрами, що потребує застосування баз даних і сховищ інформації для зберігання та оновлення експлуатаційних характеристик. **Об’єктом дослідження** є процеси чисельного моделювання газодинамічних явищ у проточних елементах технічних систем, а **предметом** – методи на основі узагальненої одновимірної математичної моделі розрахунку газодинамічних процесів у проточних елементах технічних систем. **Мета дослідження** – розроблення узагальненої математичної та обчислювальної моделі термогазодинамічних процесів у газоструменевих холодильно-нагрівальних акустичних генераторах із подальшою програмною реалізацією. **Завдання:** розроблення одновимірної математичної моделі та програмного комплексу для чисельного моделювання термогазодинамічних процесів у проточних елементах технічних систем, їх верифікація та аналіз точності; формування інформаційної технології підтримки життєвого циклу технічних об’єктів на основі інтеграції обчислювальної моделі з базами даних для зберігання, оброблення й оновлення параметрів із подальшим використанням для прогнозування технічного стану й аналізу експлуатаційних характеристик обладнання. Особливу увагу приділено формуванню ефективних обчислювальних алгоритмів, що беруть до уваги ключові фізичні процеси (рух газового середовища, тепло- й масообмін, енергетичні перетворення, турбулентність і гідравлічні втрати), а також забезпечують стійкість, збіжність і обчислювальну ефективність під час реалізації в програмному середовищі. **Результати дослідження** продемонстрували, що застосування методів підвищення чисельної стійкості та зменшення похибок обчислень забезпечує стабільну роботу програмних алгоритмів у моделюванні нестаціонарних газодинамічних процесів. Запропонована модель реалізована у вигляді програмного комплексу, як складник інформаційної технології чисельного моделювання й аналізу даних. Проведена верифікація на основі порівняння з аналітичними, чисельними й експериментальними показниками підтвердила коректність і високу точність запропонованих алгоритмів (похибка не перевищує 5%). **Висновки**. Підтверджено доцільність використання одновимірних обчислювальних моделей як базового елемента сучасних інформаційних технологій комп’ютерного моделювання складних фізичних процесів і створення програмно-інформаційних систем підтримки інженерного аналізу.

Ключові слова: моделювання; чисельні методи; математичне моделювання; програмна реалізація; обчислювальні системи; системний аналіз; технології; проєктування; бази даних.

Бібліографічні описи / Bibliographic descriptions

Димерцов Д. О. Комп’ютерне моделювання складних процесів на основі одновимірного підходу. *Автоматизовані системи управління та прилади автоматики.* 2026. № 2 (189). С. 267–275. DOI: https://doi.org/10.30837/0135-1710.2026.189.267

Dymertsov, D. (2026), "Computer simulation of gas-dynamic processes: a one-dimensional approach", *Management Information System and Devices*, No. 2 (189), P. 267–275. DOI: https://doi.org/10.30837/0135-1710.2026.189.267