IRSTI 27.41.19 https://doi.org/10.26577/jpcsit2024020105

Zh.D. Baishemirov[1], S.B. Rakhmetulayeva[2], A.B. Karakul [1*]

[1]Abai Kazakh Pedagogical University, Almaty, Kazakhstan
[2]International Information Technology University, Almaty, Kazakhstan
*e-mail: abzalkarakul@mail.ru

STUDY OF THE EFFICIENCY OF MATHEMATICAL MODELING FOR THE HEAT TRANSFER PROCESS

Abstract. This paper discusses mathematical methods and computational algorithms for the stationary process of heat transfer in artificial structures. We examined the temperature distribution inside the pipe depending on the radius, angle and length, which allowed us to conduct an in-depth analysis of the influence of various parameters on heat flows in the system. These results provide information to engineers and researchers working in the field of petroleum transportation, allowing them to better understand and optimize the thermal processes associated with this process. Modeling the thermal conductivity of pipelines is an integral part of the analysis of transportation processes, and the results of this study can be an important contribution to the design and control of technological processes in the energy and oil and gas industries. Due to the relevance of this topic, our work was carried out using the example of a literature review and control of the stationary oil heat transfer process. But the question of the relevance of the most effective and optimal methods for monitoring and controlling all heat transfer processes in various structures remains relevant.

Key words: mathematical model, heat transfer, liquid temperature, oil transport.

1 Introduction

All physical processes are described by mathematical means, and for its implementation effective methods specific to different heat transfers are used. There are many computational methods and simulators that need to be developed to address such engineering problems. But, in most cases, they need continuous updates in order to improve the considered processes. Among them, not only Kazakhstan, but also the leading producing countries in the field of oil and gas are increasing their production on the basis of various scientific studies, using rational and optimal methods for economic purposes without polluting nature from an environmental point of view. And there is no doubt that there will always be a search for increasing the optimality of production. An important factor in this sector is the transportation of oil through pipelines. Transportation of oil through pipelines is an important process in the oil and gas industry. It is the main means of distribution of oil from production sites to processing and distribution points. Ensuring the reliability and economy of this process requires careful understanding and control of the multifactorial phenomena occurring in the pipeline. In our research work, we focus on the significance of the mathematical model of oil transportation through an artificial pipeline and its implementation.

2 Literature review

Vasiliev G.G. In his work, it was shown that oil pipelines are designed for the transportation of oil products and that they have special names contingent upon the specific variety of... oil products (gasoline pipeline or fuel oil pipeline) [1]. The main pipeline is designed for transportation of oil and oil products from production sites to consumption sites, characterized by high capacity and large diameter. The main pipeline is characterized by the following features: length, diameter, capacity and number of pumping stations. Process oil pipelines are used within industrial enterprises to move various substances necessary for the production process. Modern main pipelines with a length of more than 1000 km are independent enterprises equipped with high-power, transfer stations, as well as stations with all necessary production and auxiliary facilities. Their throughput capacity reaches more than 50 million tons of oil per year. Such pipes are mainly made of steel pipes with a nominal diameter of 500, 700, 800, 1000, 1200 and 1400 mm. For pumping oil and oil products, pressure is usually 5.0 – 6.5 MPa.

Oil pipeline transportation is the process of transporting oil from production sites to disposal or processing sites using long lines of pipelines. Pipelines are designed to provide a continuous and controlled flow of oil along a specific route. This process control involves adjusting various parameters such as flow rate, pressure and temperature to ensure system efficiency and reliability. Pipeline transportation also includes phases such as re-injection (or injection phase), transmission and reception, each of which requires special installation and management. The equipment, technologies and methods used may vary depending on the properties of the oil, distances and terrain. The main component of the main pipeline is the pipeline itself. Kurochkin V.V. [2] and Tugunov P.I. Shcherbakov S.G. In works [3,4], the depth of the pipeline is determined depending on the climatic and geological conditions, as well as taking into account the specific conditions related to the need to maintain the temperature of the pumped product. In the event of an accident due to the terrain, line valves are installed along the route to shut off sections of the pipeline at intervals of 10-30 km. Intermediate pumping stations are placed along the pipeline route according to hydraulic calculations. The distance between the stations is 60 – 200 km.

Hydraulic calculations of main pipelines are usually based on the condition of stationary fluid movement. Ahatov I.Sh. In [5], it is shown that the movement of the product in various pipelines is unstable in most cases, that is, variable over time. The pressure and flow vary both along the length and over time. There can be various reasons for the unstable movement of products in pipelines. These include variable consumption, switching on and off of pumping units, closing shut-off devices, occurrence of emergency leakage from the pipeline. The real environment inside the pipeline is considered as a dynamic system where the laws of conservation of momentum and energy apply.

Perun I.V. [6] and Mirzajanzade A.H. [7] in the works of scientists, it is shown that the requirements for the reliability of pipeline systems play a very important role, since the transportation of oil products is carried out not only over long distances, but also on a large scale. In addition to the loss of a significant amount of oil, failures will inevitably lead to a change in their operating mode. The injection of oil at the initial sections of the main pipelines and the reception of customers along the route and at the end sections are another reason for the pressure and flow changes along the entire length of the pipelines and with time.

A long-distance pipeline system is a complex dynamic system consisting of many elements that are variously involved in the pumping process. Some of them have non-linear characteristics that significantly affect the monitoring and control of the main pump parameters. Hence, it's crucial to consider their dynamic characteristics when formulating a mathematical model and devising an oil transportation management system grounded on it.

The choice of a particular numerical method depends on the problem to be solved and may take into account position, oil characteristics, pipeline conditions, and required accuracy. The effectiveness of the numerical method is mainly determined by its ability to provide fast and accurate solutions when solving the equations that describe the transportation of oil through pipelines.

According to numerous studies, mathematical modeling of fluid flow is the main method of studying processes, particularly when direct observation or examination of object or process is not possible. Nikolaev D.A. [8] and Prokopov A.A. [9] in the works of scientists, it is shown that mathematical models are an effective tool for the development and research of complex objects and are used to determine the rational modes of experimental research and work. Many works are devoted to the modeling of fluid flows and related processes in pipeline transport systems, dealing with various aspects of model construction.

The assessment standard for the simulation involves verifying if the outcome aligns with experimental findings and if certain criteria are fulfilled: congruence – the result aligns with available data without rejection; significance – the decision quality metric with test cases suggests causal relationships; coherence – the outcome can be reasoned and supported by existing information. Each element of the model remains subject to alteration throughout problem-solving tasks. The model progresses as additional data is gathered and fresh hypotheses on causality arise.

The thermal efficiency of hot oil affecting the surrounding soil is the main problem of Hanyu Xie and Changjun Li [10]. A hexahedral structural mesh of the models was created using ICEM software. Based on the results of the research, it is recommended to install the thermally affected zone with a width of 16 m and a height of 9 m in normal conditions. It shows that a rectangular thermal effect zone is a more suitable approach than a circular thermal zone when modeling an underground oil pipeline system.

Kurasov D. [11] shows that MatLab offers extensive tools for visualizing mathematical solutions, including graphical representations of results, animations, and symbolic mathematics. This emphasis on clear visualization is beneficial to both problem solvers and those who study or visualize results. MatLab is faster at creating 3D shapes than Mathcad with advanced algorithms for rendering 3D surfaces and shapes. It is widely taught in US universities and used in leading Russian universities, making it a standard tool for engineering development. This widespread adoption reflects its importance in both education and industry. Over the past three decades, it has evolved into a comprehensive system of modern numerical techniques that integrate centuries of mathematical knowledge and provide powerful graphical visualization tools. The system's extensive documentation makes it a fundamental electronic reference for computer mathematics support. Mathematical modeling systems are characterized by advanced visualization capabilities, speed of 3D modeling, widespread use in education and industry, continuous evolution, and successful real-world applications.

In [12], the article presents the development of a dynamic mathematical model of heat exchange for a two-phase flow through the absorber pipe of a linear solar collector. The model takes into account changes in thermophysical properties depending on temperature and provides a better fit to the temperature profile in the solar collector. The findings indicate a decline in the solar collector's effectiveness as water transitions to vapor, attributed to a reduction in the convective heat transfer coefficient stemming from alterations in the thermophysical characteristics of the liquid-vapor blend.

A study of the mathematical model and their conditions shows that using a mixture of oil, gas and water as the working fluid in a folded heat exchanger promotes efficient heat transfer and improves energy efficiency [13]. The results of numerical modeling show that gas accumulation on the walls reduces the local efficiency of heat exchange in the heat exchanger channels, and an increase in the gas content in the flow leads to a deterioration in this efficiency. The effect of the fold height on heat transfer is also significant, and at low values of the Reynolds number, the best heat transfer efficiency is shown by channels with a higher fold, but with the increase in the Reynolds number, the heat transfer efficiency decreases.

The work is devoted to the study of the characteristics of oil diffusion in particles of an oil sludge mixture under supercritical water conditions [14]. Experimental data showed significant improvement in oil removal efficiency with treatment times ranging from 5 to 60 minutes and temperatures ranging from 375 to 425 degrees Celsius. Based on this, a mechanism for the diffusion of oil in oil sludge particles under the influence of supercritical water was proposed, and a mathematical model of oil diffusion was developed that takes into account heat transfer and mass transfer, which can help improve the efficiency of oil sludge treatment.

Mathematical modeling has been developed to predict temperature profiles in flows of Newtonian and non-Newtonian fluids in curved pipes intended for petroleum industry operations [15]. The model has been successfully validated against data from real maritime operations, allowing highly accurate process simulations to save time and resources. Based on theoretical analysis and industrial data, the study demonstrates the significance of developing robust mathematical models for process optimization in the petroleum industry.

This research conducted a computational simulation of the consecutive stages involved in heating waxy crude oil within pipelines, transitioning from cooling to heating [16]. Physical and mathematical frameworks were developed to depict the heat transfer and fluid flow of waxy crude oil throughout the tube heating procedure. Insights are gained into the thermal and flow characteristics during the process from cooling to heating, which is a key aspect for optimizing the strategy of this heating technology to reduce costs. The results show that the thermal process during tube heating can be divided into four phases: local thermal response, thermal diffusion, global thermal response, solidified oil elimination.

This study investigates the combined effect of the volume fraction of carbon nanotubes and electric field on improving the heat transfer of a dielectric oil-conducting fluid [17]. The geometry considered in the work is an annular layer filled with dielectric oil and bounded by two eccentric or concentric cylinders. The goal is to analyze flow behavior and improve heat transfer using a dual enhancement technique by combining active (electric field) and passive (nanoparticle) approaches. To solve the established set of equations describing the laws of conservation of electro-thermo-hydrodynamic flow, a numerical finite volume method was used. A parametric study was carried out to reveal the influence of various relevant variables on heat transfer enhancement. Significant heat transfer improvements ranging from 3% to 77% have been obtained, especially when applying an electric field. Adding 0.5% volume fraction of carbon nanotubes provides approximately 27% improvement in heat transfer. Declaration of Competing Interest None.

The study [18] examines the fluid flow and heat transfer characteristics of an oil-containing wastewater outer film flowing around an elliptical tube. Using numerical models, the processes of heat exchange and fluid flow around a pipe are analyzed. The effect of oil concentration on heat transfer is discussed, and the effect of contact angle on heat transfer performance is analyzed. The obtained computational results allow us to establish that increasing the fluid flow rate significantly affects the movement speed, and increasing the oil concentration has a complex effect on heat transfer due to changes in forces around the pipe structure.

A review of the study on three-dimensional numerical modeling of the heat transfer process in horizontal oil pipelines considering shutdown shows [19] that using the additional specific heat method and the torque source method, a mathematical model was built to numerically simulate heat transfer and flow characteristics. The results show that the effect of an anomalous temperature drop during shutdown leads to differences in the temperature, velocity and gelation fields along the oil pipeline axis during the early stages of shutdown. However, over time, these differences gradually decrease. The study also shows that the process of cooling waxy crude oil in three dimensions is accompanied by changes in heat transfer patterns and gel formation, this has significant ramifications for the safety and effectiveness of oil pipeline operations.

3 Materials and methods

The conveyance of oil via pipelines has emerged as a crucial sector within the oil and gas domain. Ensuring proficient oversight of this operation stands as a pivotal element in guaranteeing the dependability and peak performance of the infrastructure. In this context, the thermal processes taking place inside the pipeline play an important role in ensuring the safety of transportation, as well as in the efficient use of energy resources. The basis of this study is the consideration of a mathematical model that considers the distribution of temperature inside the pipeline during oil transportation. This facilitates a complete understanding of the thermal processes in the system. We emphasize the importance of understanding the thermal aspects of oil transport and use Matlab for the numerical solution of thermal conductivity in pipelines. Presentation of quantitative results of influence of various parameters on temperature distribution can be a basis for more effective design, management of oil transportation system and optimization of technological processes in oil and gas industry.

For the numerical solution of the heat equation, the Matlab program is used for cylindrical coordinates and discretization of space and time to numerically approximate the solution of the equation.

The stationary process of heat transfer in artificial structures (pipes) is described by the second-order independent differential equation in the cylindrical coordinate system:

$$\phi(r)\frac{\partial\theta}{\partial x}=\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\theta}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial\varphi}\left(\lambda\frac{\partial\theta}{\partial\varphi}\right),\qquad(1)$$

where

$$\phi(r)=C_p\cdot r\left(1-\left(\frac{r}{R}\right)^2\right)\cdot V\cdot\cos\left(\frac{\varphi}{3}\right),$$

V – velocity of fluid in the pipe (m/s), C_p – heat capacity coefficient of fluid (J/kg·K) λ – thermal conductivity coefficient; (W/m^2·K); R – radius of the pipe, $\theta(x,r,\varphi)$ – temperature of the fluid.

The boundary conditions for equation (1):

$$\theta|_{x=0}=T_0(r,\varphi)\qquad(2)$$

$$\left.\frac{\partial\theta}{\partial r}\right|_{r=0}=0,\ \lambda\left.\frac{\partial\theta}{\partial r}\right|_{r=R}=-h(\theta-T_a(x,\varphi))|_{r=R}, \quad (3)$$

$$\theta(x,r,\varphi)=\theta(x,r,\varphi+2\pi) \quad (4)$$

To solve the coefficient inverse problem, additional conditions are used. We will use the measured temperature values at the available boundary $x=R$:

$$T_g(x,\varphi).$$

In the future, we will study a one-dimensional model of oil transportation by pipeline. We believe that temperature does not depend on the polar angle φ:

$$\theta(x,r,\varphi)=\theta(x,r).$$

Due to the fact $\frac{\partial}{\partial\varphi}=0$ that system of equations (1)-(4) takes the following form:

$$\phi(r)\frac{\partial\theta}{\partial x}=\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\theta}{\partial r}\right), \quad (5)$$

$$\theta|_{x=0}=T_0 \quad (6)$$

$$\left.\frac{\partial\theta}{\partial r}\right|_{r=0}=0,\ \lambda\left.\frac{\partial\theta}{\partial r}\right|_{r=R}=-h(\theta-T_a(x))|_{r=R}. \quad (7)$$

Additional conditions on the pipe surface at $x=R$ are written in the form

$$T_g(x), \qquad x\in(0,l), \quad (8)$$

where l – length of a pipe.

4 Development of a method for calculating fluid velocity

The fluid velocity V is determined by the iterative method. At the beginning, the initial approximation is specified. The next approximation is determined from the monotonicity of the functional

$$J(V)=\int_0^l(\theta(x,R)-T_g(x))^2dx, \quad (9)$$

where n – iteration number.

For n iterations, the solution to problem (5)-(8) corresponds $\theta_n(x,r),$, and for iterations, it corresponds to $\theta_{n+1}(x,r)$, i.e.

$$V_{n+1}\phi(r)\frac{\partial\theta_{n+1}}{\partial x}=\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\theta_{n+1}}{\partial r}\right),$$

$$\phi(r)=r\left(1-\left(\frac{r}{R}\right)^2\right)\cdot C_p,$$

$$V_n\phi(r)\frac{\partial\theta_{n+1}}{\partial x}=\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\theta_n}{\partial r}\right).$$

Subtracting we get the equality

$$\phi(r)V_n\frac{\partial\Delta\theta}{\partial x}+\phi(r)\Delta V\frac{\partial\theta_{n+1}}{\partial x}=\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\Delta\theta}{\partial r}\right), \quad (10)$$

where $\Delta\theta=\theta_{n+1}(x,r)-\theta_n(x,r)$.

Boundary conditions for n and $n+1$:

$$\theta_{n+1}|_{x=0}=T_0, \qquad \theta_n|_{x=0}=T_0,$$

Hence

$$\Delta\theta|_{x=0}=0. \quad (11)$$

Boundary conditions for $r=0$:

$$\left.\frac{\partial\theta_{n+1}}{\partial r}\right|_{r=0}=0,\ \left.\frac{\partial\theta_n}{\partial r}\right|_{r=0}=0.$$

Consequently

$$\left.\frac{\partial\Delta\theta}{\partial r}\right|_{r=0}=0. \quad (12)$$

Similarly from Robin's condition

$$\lambda\left.\frac{\partial\theta_{n+1}}{\partial r}\right|_{r=R}=-h(\theta_{n+1}-T_a)|_{r=R},$$

$$\lambda\left.\frac{\partial\theta_n}{\partial r}\right|_{r=R}=-h(\theta_n-T_a)|_{r=R},$$

equality follows

$$\lambda\left.\frac{\partial\Delta\theta}{\partial r}\right|_{r=R}=-h\Delta\theta|_{r=R}. \quad (13)$$

5 Formulation of conjugate problem

In the domain $Q=(0,l)\times(0,R)$ we introduce the scalar product

$$\int_0^l dx\int_0^R f(x,r)g(x,r)dr=(f,g).$$

The formulas for integration by parts are written in the form

$$\int_0^l dx\int_0^R f(x,r)\frac{\partial g(x,r)}{\partial r}dr=\int_0^l\left[f(x,R)g(x,R)-f(x,0)g(x,0)\right]dx-\int_0^l dx\int_0^R g(x,r)\frac{\partial f(x,r)}{\partial r}dr,$$

or

$$\left(f,\frac{\partial g}{\partial r}\right)=(f,g)\Big|_{r=R}-(f,g)\big|_{r=0}-\left(\frac{\partial f}{\partial r},g\right),\quad(14)$$

where

$$(f,g)\big|_{r=R}=\int_0^l f(x,r)g(x,r)dx.$$

The formula for integration by parts over a variable x takes the following form

$$\left(f,\frac{\partial g}{\partial x}\right)=(f,g)\Big|_{x=l}-(f,g)\big|_{x=0}-\left(\frac{\partial f}{\partial x},g\right),\quad(15)$$

where

$$(f,g)\big|_{x=0}=\int_0^R f(x,r)g(x,r)dx.$$

We multiply equation (10) scalarly by an arbitrary function $\psi(x,r)$ in the domain $Q=(0,l)\times(0,R)$ and obtain

$$\left(\varphi(r)V_n\frac{\partial\Delta\theta}{\partial x},\psi\right)+\left(\varphi(r)\Delta V\frac{\partial\theta_{n+1}}{\partial x},\psi\right)=$$
$$=\left(\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\Delta\theta}{\partial r}\right),\psi\right).$$

We apply formulas (14) and (15), then

$$(\Delta\theta,\varphi\cdot V_n\psi)_{x=l}-(\Delta\theta,\varphi\cdot V_n\psi)_{x=0}-$$
$$-\left(\varphi\cdot V_n\cdot\Delta\theta,\frac{\partial\psi}{\partial x}\right)=\left(\lambda r\frac{\partial\Delta\theta}{\partial r},\psi\right)_{r=R}-$$
$$-\left(\lambda r\frac{\partial\Delta\theta}{\partial r},\psi\right)_{r=0}-\left(\frac{\partial\Delta\theta}{\partial r},\lambda r\frac{\partial\psi}{\partial r}\right).$$

Let is assume that $\psi|_{x=l}=0$ and take into account boundary conditions (11) and (13). Then

$$\left(\phi(r)\Delta V\frac{\partial\theta_{n+1}}{\partial x},\psi\right)-\left(\Delta\theta,\phi(r)\cdot V_n\frac{\partial\psi}{\partial x}\right)=$$
$$=-hR(\Delta\theta,\psi)\big|_{r=R}-\left(\frac{\partial\Delta\theta}{\partial r},\lambda r\frac{\partial\psi}{\partial r}\right).$$

Once again we apply the formula of integration by parts

$$\left(\phi(r)\Delta V\frac{\partial\theta_{n+1}}{\partial x},\psi\right)-\left(\Delta\theta,\phi(r)\cdot V_n\frac{\partial\psi}{\partial x}\right)=$$
$$=-hR(\Delta\theta,\psi)\big|_{r=R}-\left(\lambda r\Delta\theta,\frac{\partial\psi}{\partial r}\right)_{r=R}+$$
$$+\left(\Delta\theta,\lambda r\frac{\partial\psi}{\partial r}\right)_{r=0}+\left(\Delta\theta,\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\psi}{\partial r}\right)\right).$$

We accept the boundary condition $\left.\frac{\partial\psi}{\partial r}\right|_{r=0}$ and collect similar values

$$\left(\varphi(r)\Delta V\frac{\partial\theta_{n+1}}{\partial x},\psi\right)-\left(\Delta\theta,\varphi(r)\cdot V_n\frac{\partial\psi}{\partial x}+\frac{\partial}{\partial r}\left(\lambda r\frac{\partial\psi}{\partial r}\right)\right)+$$
$$+\left(\Delta\theta,h\psi+\lambda\frac{\partial\psi}{\partial r}\right)\Big|_{r=R}=0.$$

As a result of these transformations, a conjugate problem was created.

$$\phi \cdot V_n \frac{\partial \psi}{\partial x} + \frac{\partial}{\partial r}\left(\lambda r \frac{\partial \psi}{\partial r} \right) = 0. \quad (16)$$

$$\phi\big|_{x=L} = 0, \qquad \left.\frac{\partial \phi}{\partial r}\right|_{r=0} = 0, \quad (17)$$

$$\left(h\psi + \lambda \frac{\partial \psi}{\partial x} \right)_{r=R} = 2\left(\theta - T_g\right)\big|_{r=R}. \quad (18)$$

After this we obtain the integral relation

$$2\left(\Delta\theta, \theta_n - T_g\right)\big|_{r=R} = -\left(\Delta V \frac{\partial \theta_n}{\partial x} \varphi(r), \psi \right) - -\left(\Delta V \frac{\partial \Delta\theta}{\partial x} \varphi(r), \psi \right). \quad (19)$$

Let's consider functional (9) for iteration n and $n+1$:

$$J(V_{n+1}) = \int_0^l \left(\theta_{n+1}(x,R) - T_g(x)\right)^2 dx,$$

$$J(V_n) = \int_0^l \left(\theta_n(x,R) - T_g(x)\right)^2 dx.$$

Subtracting, we get the equality

$$J(V_{n+1}) - J(V_n) = = 2\int_0^l \Delta\theta(x,R)\left(\theta_n(x,R) - T_g(x)\right)dx + +\int_0^l \left(\Delta\theta(x,R)\right)^2 dx.$$

Substituting (19) we deduce that

$$J(V_{n+1}) - J(V_n) = -\left(\Delta V \frac{\partial \theta_n}{\partial x} \varphi, \psi \right) - -\left(\Delta V \frac{\partial \Delta\theta}{\partial x} \varphi, \psi \right) + \int_0^l \left(\Delta\theta(x,R)\right)^2 dx.$$

We are looking for a minimum of functionality $J(V)$. Therefore, the inequality must be satisfied $J(V_{n+1}) - J(V_n) < 0$. It follows that

$$\Delta V = \mu_n \left(\frac{\partial \theta_n}{\partial x} \phi, \psi \right),$$

or

$$V_{n+1} = V_n + \mu_n \left(\frac{\partial \theta_n}{\partial x} \phi, \psi \right),$$

$$V_{n+1} = V_n + \mu_n \int_0^l dx \int_0^R \frac{\partial \theta_n}{\partial x} \phi(r) \psi(x,r) dr. \quad (20)$$

6 Results and discussion

To numerically implement the solution to the inverse problem for this process, we rely on the following basic algorithms, which are described by the block diagram.

1st step. Input data: l, R, C_p, $\phi(r)$, $T_a(x)$, $T_g(x)$.

2nd step. Initial approximation is set V_n.

3rd step. Direct problem (5)-(8) is solved and determined $\theta(x,r)$, $\theta(x,R)$, $\frac{\partial \theta}{\partial x}$.

4th step. Inequality is checked $J(V_n) < \varepsilon$. If this step satisfied, then step 7. If not fulfilled, then step 5.

5th step. The conjugate problem (16)-(18) is solved and determined $\psi(x,r)$.

6th step. The next approximation V_{n+1}. is calculated by the formula (20).

7th step. Problem solved with precision ε. Arrays are output V_n, $J(V_n)$.

8th step. Analysis of calculated data.

The research result solves the heat equation in cylindrical coordinates using the Matlab program and visualizes the temperature distribution inside the cylinder. Heat transfer and boundary conditions are the basic conditions required for numerical calculations. The solution of the heat equation is based on the last differences for each point of the inner grid, and a new temperature value is calculated. Figure 1 shows the temperature distribution. A contour plot is created where the colors represent the temperature values inside the cylinder. The inclusion of a color bar provides an explanation of the temperature variations depicted by the colors.

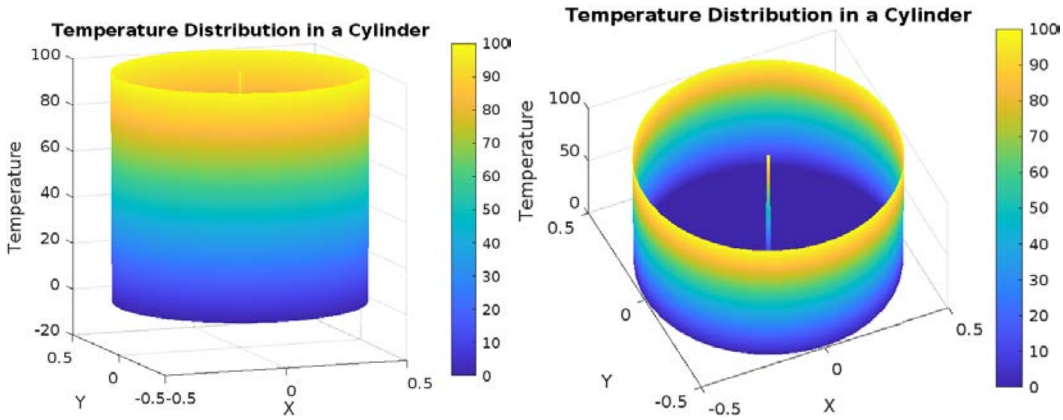

Figure 1 – Display of temperature distribution in different sections

7 Conclusion

According to the results, study successfully solves the heat equation, providing important information about the temperature distribution inside the pipeline for oil transportation conditions. The obtained results make it possible to understand the thermal processes taking place inside the system and to determine the influence of various parameters such as radius, angle and length on the temperature distribution. This heat transfer model can be an important tool in analyzing heat losses, optimizing oil transfer efficiency, or preventing problems related to pipeline temperature changes. The results of such simulations can be used to make decisions in the field of engineering and management of transport infrastructure. It should be noted that the heat transfer equation can be a key element in solving problems related to thermal aspects of oil transportation and allows understanding and optimization of technological processes in this context.

References

1. Vasiliev G.G. (2002) Pipeline oil transport: a textbook for universities. Nedra-Business Center LLC, 407 p.
2. Kurochkin V.V. (2001) Operational durability of oil pipelines: a textbook for universities: Nedra, 231 p.
3. Tugunov P.I., Nechval M.V., Novoselov V.F., Akhatov Sh.N. (1975) Operation of main pipelines. Ufa: Bashkir Book Publishing House, 160 p.
4. Shcherbakov S.G. (1982) Problems of pipeline transport of oil and gas: Nauka, 207 p.
5. Akhatov I.Sh. (2001) Developments of academic science to solve some problems of pipeline transport. Oil Pipeline Transport, no 3, pp.14 – 17
6. Perun I.V. (1987) Main pipelines in mountainous conditions: Nedra, 175 p.
7. Mirzajanzade A.Kh., Gallyamov A.K., Maron V.I., Yufin V.A. (1984) Hydrodynamics of pipeline transport of oil and petroleum products: Nedra, 287 p.
8. Nikolaev D.A. (2002) 3D modeling systems within the framework of monitoring and assessing the condition of the linear part of main pipelines.Ashirov Readings: International Scientific and Practical Conference, Samara, October 23-24, 2002: Abstracts of reports. Samara, 70 p.
9. Prokopov A.A., Tigist T.T.; St. Petersburg (2003) Mathematical models of complex heterogeneous distributed liquid pumping systems.State electrical engineering LETI University. St. Petersburg, 13 p.
10. Hanyu Xie, Changjun Li, Nan Wei, Caigong Zhang, and Jie He. Numerical Study on the Optimal Thermally Affected Region of a Buried Oil Pipeline.*ACS Omega* **2023**. https://doi.org/10.1021/acsomega.3c03945
11. D Kurasov. Mathematical modeling system MatLab To cite this article, (2020). https://doi.org/10.1088/1742-6596/1691/1/012123
12. Heriberto Sánchez-Mora, Sergio Quezada-García, Marco Antonio Polo-Labarrios, Ricardo Isaac Cázares-Ramírez, Alejandro Torres-Aldaco, Dynamic mathematical heat transfer model for two-phase flow in solar collectors, Case Studies in Thermal Engineering, Volume 40, 102594, ISSN 2214-157X, (2022). https://doi.org/10.1016/j.csite.2022.102594.
13. Xin-Yue Duan, Man-Rui Xu, Tian-Peng Zhang, Feng-Ming Li, Chuan-Yong Zhu, Liang Gong, Numerical analysis of the flow and heat transfer characteristics of oil-gas-water three-phase fluid in corrugated plate heat exchanger, Energy, Volume 281, 128260, (2023). https://doi.org/10.1016/j.energy.2023.128260.

14. Gaoyun Wang, Le Wang, Linhu Li, Yunan Chen, Wen Cao, Hui Jin, Zhiwei Ge, Liejin Guo, Oil diffusion mathematical model in oily sludge particle under supercritical water environment, Journal of Hazardous Materials, Volume 443, Part B, 130348, (2023). https://doi.org/10.1016/j.jhazmat.2022.130348.

15. Beatriz R. Oliveira, Rodrigo F.O. Borges, Leônidas P. Filho, Pedro R. Villares, Eduardo C.H. Paraíso, Bruno F. Oechsler, José M.S. Rocha, LuísA. Calçada, Cláudia M. Scheid, Modeling and simulation of non-Newtonian fluid flows and heat transfer in a non-isothermal coiled tubing to oil well operations, Geoenergy Science and Engineering, Volume 228, 211980, (2023). https://doi.org/10.1016/j.geoen.2023.211980.

16. Jian Zhao, Junyang Liu, Hang Dong, Weiqiang Zhao, Lixin Wei, Numerical investigation on the flow and heat transfer characteristics of waxy crude oil during the tubular heating, International Journal of Heat and Mass Transfer, Volume 161, 120239, (2020). https://doi.org/10.1016/j.ijheatmasstransfer.2020.120239.

17. Sarra Rejeb, Walid Hassen, Lioua Kolsi, Patrice Estellé,Heat transfer by oil natural convection in an annular space under combined effects of carbon nanotubes and electric field,International Communications in Heat and Mass Transfer,Volume 138, 106345, (2022). https://doi.org/10.1016/j.icheatmasstransfer.2022.106345.

18. Zhu Zhang, Hao Lu, A numerical study on fluid flow and heat transfer characteristics of oily wastewater falling film outside an elliptical tube, International Communications in Heat and Mass Transfer, Volume 148, 107004, (2023). https://doi.org/10.1016/j.icheatmasstransfer.2023.107004.

19. Lixin Wei, Changshun Du, Jian Zhao, Yanpeng Li, A three – Dimensional numerical simulation of shut – Down heat transfer process in overhead waxy crude oil pipeline, Case Studies in Thermal Engineering, Volume 21, 100629, (2020). https://doi.org/10.1016/j.csite.2020.100629.

Information about authors:

Zharasbek Baishemirov – PhD, Acting Professor, Abai Kazakh National Pedagogical University (Almaty, Kazakhstan, e-mail: zbai.kz@gmail.com).

Sabina Rakhmetulayeva – PhD, Assosiate Professor, International Information Technology University (Almaty, Kazakhstan, e-mail: ssrakhmetulayeva@gmail.com).

Abzal Karakul (corresponding author) – Scientific Researcher, Abai Kazakh National Pedagogical University (Almaty, Kazakhstan, e-mail: abzalkarakul@mail.ru).

Submission received: 16 March, 2024.
Revised: 17 March, 2024.
Accepted: 17 March, 2024.