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MATHEMATICAL MODEL AND ANALYTICAL SOLUTIONS OF THE PROCESS OF PHYSICS-CHEMICAL HYDRODYNAMICS

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Abstract:

Objective. to describe mathematical models that calculate geo-technological indicators necessary for the management of physical-chemical hydrodynamic processes. Analyzing methods for solving these models and developing analytical solution methods.

Methods. methods of obtaining analytical solutions for the diffusion equation, Fourier and Laplace transformations, Green's function methods, Fourier integral, formula of cosines.

Results. Not all practical problems can always be solved analytically. Often, we only get solutions for special cases. In addition, the indicators considered in real conditions will be objective. For example, the area under consideration can be infinite, and the parameters involved in the model can be variable rather than constant. In this article, mathematical models of physical-chemical hydrodynamic processes suitable for mineral mixing, which is one of the geo-technological methods used in the extraction of minerals, were systematically analyzed. Compatible with these models, although there is little opportunity to find analytical solutions of the differential equation, these processes were studied because of its high efficiency and closeness to the exact solution. Analytical solutions corresponding to the obtained results were recommended.

Conclusion. The models chosen for the underground leaching processes correspond to its physical characteristics and they make it possible to obtain the necessary information in the process of appropriate management. Therefore, the issue of creating efficient algorithms suitable for the proposed mathematical model is considered based on numerical-approximate methods. There are several different finite-difference schemes for solving equations representing hydrodynamic processes by numerical calculation methods, and when it is necessary to choose the most effective method, obtained it will be possible to compare the results and the results obtained by the analytical method. As a result, it is possible to solve the set model in the most optimal way.

Keywords: physical-chemical processes, useful component, mathematical model, concentration quantity, optimization factors, Fourier integral, formula of cosines, analytical solutions, numerical-approximate methods.

Introduction. It is natural that the deterioration of the quality of minerals and the natural weakening of the land will lead to a rapid increase in the demand for their rational use and scientific research in the field of mineral enrichment. The complexity of the problem has led to the emergence of narrower scientific research and the inclusion of several disciplines in the field of mountain geology. They are such sciences as mathematics, mechanics, cybernetics, physics, physics-chemistry, radiation processes, microbiology.

In this regard, it is appropriate to emphasize the following tasks that must be solved:

- development of geologic-genetic models of useful component deposits and ore fields to create scientific bases for searching and forecasting high-grade ore concentrations;
- to create large-scale prediction maps in order to distinguish regions of promising mineral raw materials;
- creating a mathematical model of the production of ore deposits and making their software packages suitable for modern computers.

The models of these processes are simultaneously represented by a system of equations of hydrodynamics, diffusion and kinetics of substance exchange. By solving the underground mixing equations, it is possible to determine the amount of product in the ore-conducting boundary layer, the nature of mixing, and the consumption of product in the internal parts. There are various methods of solving the equation, which can be divided into analytical and numerical-approximate methods.

Methods. The analytical solution is important because it has no error except for the error present in the finite-difference approximation. All existing solutions are valid for some cases and differ from each other for different physical processes. It follows from the complexity of the mathematical model that it is not possible to obtain an analytical solution without any simplifications.

In the same sense, the diffusion equation also has an analytical solution only in some cases. To obtain analytical solutions, various mathematical methods are used, for example, Green's function method, Laplace or Foure substitutions.

Suppose the one-dimensional convective diffusion problem is expressed as follows [2].

$$C_t + U C_x = K C_{xx} \tag{1}$$

$c(t=0)=0,\quad c(x=0),\quad c(x=\infty)=0$ let the equation be given by the initial and boundary conditions $c(t=0)=0,\quad c(x=0),\quad c(x=\infty)=0$. Here, when K and U consist of constant coefficients, it is possible to create analytical solutions of a much simpler form for the given problem. It is known that the solution was found using the Fure substitution

$$C(x,t) = \Phi(x,t)\, e^{ax-bt} \tag{2}$$

is searched for in view [1]. Here, a and b are currently unknown coefficients, and to find their expression, we take special derivatives from equation (2) with respect to x and t:

$$C_x = \Phi_x e^{ax-bt} + \Phi\, a\, e^{ax-bt};$$
$$C_{xx} = \Phi_{xx} e^{ax-bt} + 2\Phi_x\, a\, e^{ax-bt} + \Phi_x\, a^2\, e^{ax-bt};$$
$$C_t = \Phi_t\, e^{ax-bt} - b\Phi\, e^{ax-bt}.$$

We put the expression of the special derivatives into the equation in problem (1), for convenience we write e in the form without temporary degrees:

$$\Phi_t e - b\Phi e + U\Phi_x e + U a \Phi e = K(\Phi_{xx} e + 2a\Phi_x e + a^2\,\Phi e).$$

We group the resulting expression with respect to the function *Φ*:

$$\Phi_t = K\Phi_{xx} + (2Ka - U)\Phi_x + (Ka^2 - Ua + b)\Phi.$$

To convert the generated expression into a homogeneous parabolic type equation and to find the value of unknowns a and b, we set the coefficients in front of Φ_x and *Φ* to 0.

Then $2Ka - U = 0$ is equal to $a = \dfrac{U}{2K}$.

On the other hand, if we consider $Ka^2 - Ua + b = 0$, from $K\dfrac{U^2}{4K^2} - U\dfrac{U}{2K} + b = 0$ this expression $b = \dfrac{U^2}{4K}$ comes out.

We put the values of the coefficients a and b found in equation (2):

$$\Phi(x,t) = C(x,t)\, e^{-\frac{U}{2K}x - \frac{U^2}{4K}t} \tag{3}$$

In that case,

$$\Phi_t = K\Phi_{xx} \tag{4}$$

Equation's solution will be the formula 3.

$C(x,0) = f(x)$

For this case, the solution of equation (4) when the initial distribution occurs is as follows.

$$\Phi(x,0) = f(x)\, e^{-\frac{U}{2K}x} \tag{5}$$

Now we look for a general solution to equation (4).

For this, the function Φ (x,t). We will write as follows

$$\Phi(x,t) = X(x)T(t)$$

In that case the equation $XT^{'} = KX^{''}T$ or $\frac{T^{'}}{KT} = \frac{X^{''}}{X} = -\lambda^2$ will be formed.

Since each ratio depends on and is equal to different variables, they must necessarily be equal to some constant.

We create two equations from it and solve each one separately.

1) $T^{'} + \lambda^2 KT = 0, \quad \frac{dT}{dt} = -\lambda^2 KT, \quad \frac{dT}{T} = -\lambda^2 Kdt, \quad \ln T = -\lambda^2 Kt + c, \quad T = c\, e^{-\lambda^2 Kt}$

2) $X^{''} + X\lambda^2 = 0$ since the equation is a linear differential equation, its solution will be as follows $X = A\cos\lambda x + B\sin\lambda x$

Then Φ is a function which will be expressed

$$\Phi_{\lambda} = e^{-k\lambda^2 t}(A\cos\lambda x + B\sin\lambda x)$$

Here C is included in the constants $A(\lambda), \quad B(\lambda)$.

Since A and B have different values at different values of the argument, we express the solution of the linear differential equation in summation form.

$$\sum_{\lambda} e^{-k\lambda^2 t}(A\cos\lambda x + B\sin\lambda x)\, d\lambda\,.$$

The sum, in turn, is expressed as an integral from 0 to infinity:

$$\Phi(x,t) = \int_0^{\infty} e^{-k\lambda^2 t}(A\cos\lambda x + B\sin\lambda x)\, d\lambda \tag{6}$$

(5) according to the initial condition:

$$\Phi(x,0) = f(x)\, e^{-\frac{U}{2K}x}$$

(6) according to $\Phi(x,0) = \int_0^{\infty}(A\cos\lambda x + B\sin\lambda x)\, d\lambda$

If we find f(x) from equation (5) and replace F with the above value, we can see that it is equal to $f(x) = \int_0^{\infty}(A\cos\lambda x + B\sin\lambda x)e^{\frac{UX}{2K}}\, d\lambda$

Here we assume that the function f(x) is represented by the Fourier integral, i.e

$$f(x) = \frac{1}{\pi}\int_0^{\infty}\Big(\int_{-\infty}^{\infty} f(\xi)\cos\lambda(\xi - x)d\xi\Big)e^{\frac{U\xi}{2k}}\, d\lambda \tag{7}$$

Or if we use the formula of the cosine of the sum:

$$f(x) = \frac{1}{\pi}\int_0^{\infty}\Big(\Big(\int_{-\infty}^{\infty} f(\xi)\cos\lambda\xi d\xi\Big)\cos\lambda x + \Big(\int_{-\infty}^{\infty} f(\xi)\sin\lambda\xi d\xi\Big)\sin\lambda x\Big)e^{\frac{U\xi}{2k}}\, d\lambda \tag{8}$$

Comparing formulas (7) and (8).

$$A(\lambda)=\frac{1}{\pi}\int_{-\infty}^{\infty} f(\xi)\cos\lambda\xi d\xi$$

$$B(\lambda)=\frac{1}{\pi}\int_{-\infty}^{\infty} f(\xi)\sin\lambda\xi d\xi \qquad (9)$$

Putting the values of (9) into expression (6), we make the necessary substitutions:

$$\Phi(x,t)=\frac{1}{\pi}\int_{0}^{\infty} e^{-k\lambda^2 t}[(\int_{-\infty}^{\infty} f(\xi)\cos\lambda\xi d\xi)\cos\lambda x+(\int_{-\infty}^{\infty} f(\xi)\sin\lambda\xi d\xi)\sin\lambda x))]e^{\frac{U\xi}{2k}}d\lambda=$$

$$=\frac{1}{\pi}\int_{0}^{\infty} e^{-k\lambda^2 t}[\int_{-\infty}^{\infty} f(\xi)(\cos\lambda\xi\cos\lambda x+\sin\lambda\xi\sin\lambda x)d\xi]e^{\frac{U\xi}{2k}}d\lambda=$$

$$=\frac{1}{\pi}\int_{0}^{\infty} e^{-k\lambda^2 t}(\int_{-\infty}^{\infty} f(\xi)\cos\lambda(\xi-x)d\xi)e^{\frac{U\xi}{2k}}d\lambda$$

Results.

By changing the sign of the integral, we create the resulting formula:

$$\Phi(x,t)=\frac{1}{\pi}\int_{-\infty}^{\infty}[f(\xi)(\int_{0}^{\infty} e^{-k\lambda^2 t}\cos\lambda(\xi-x)d\lambda)]e^{\frac{U\xi}{2k}}d\xi \qquad (10)$$

Now we calculate the integral expression in small brackets.

$$\int_{-\infty}^{\infty} e^{-k\lambda^2 t}\cos\lambda(\xi-x)d\lambda=\left[z=\lambda\sqrt{kt},\ dz=\sqrt{kt}d\lambda,\ \beta=\frac{\xi-x}{\sqrt{kt}}\right]=\frac{1}{\sqrt{kt}}\int_{0}^{\infty} e^{-z^2}\cos\beta z dz \qquad (11)$$

We define the integral expression:

$$p(\beta)=\int_{0}^{\infty} e^{-z^2}\cos\beta z dz \qquad (12)$$

and we differentiate:

$$p'(\beta)=-\int_{0}^{\infty} e^{-z^2} z\sin\beta z dz$$

we use the method of integration by pieces:

$$u=\sin\beta z,\quad du=\beta\cos\beta z dz,\quad dv=-ze^{-z^2}dz,\quad v=\frac{1}{2}e^{-z^2}$$

In that case,

$$p'(\beta)=\frac{1}{2}(e^{-z^2}\sin\beta z)\Big|_0^{\infty}-\frac{\beta}{2}\int_{0}^{\infty} e^{-z^2}\cos\beta z dz$$

The first addendum in the expression is equal to zero when setting the threshold values, and if we replace the second addendum with the expression from the original definition

$$p'(\beta)=-\frac{\beta}{2}p(\beta)$$

only the expression remains. We solve the resulting ordinary differential equation:

$$\frac{dp}{d\beta}=-\frac{\beta}{2}p;$$

$$\frac{dp}{p}=-\frac{\beta}{2}d\beta.$$

Integrating both sides:

$$\ln p=-\frac{\beta^2}{4}+c,\quad p=ce^{-\frac{\beta^2}{4}}. \tag{13}$$

Now we determine the value of the constant C. (12) from the formula

$$p(0)=\int_0^\infty e^{-z^2}dz=\frac{\sqrt{\pi}}{2}.$$

and from (13) $p(0)=c=\frac{\sqrt{\pi}}{2}$ is obtained. So, according to formula (13), we can write the solution as follows:

$$p(\beta)=\frac{\sqrt{\pi}}{2}e^{\frac{-\beta^2}{4}}. \tag{14}$$

We put the expression (14) into (11):

$$\int_0^\infty e^{-k\lambda^2 t}\cos\lambda(\xi-x)d\lambda=-\frac{1}{\sqrt{kt}}\frac{\sqrt{\pi}}{2}e^{-\frac{\beta^2}{4}}=\left[\beta=\frac{\xi-x}{\sqrt{kt}}\right]=\frac{1}{2\sqrt{k}}\sqrt{\frac{\pi}{t}}e^{-\frac{(\xi-x)^2}{4kt}}.$$

And finally, if we put the generated expression into the formula (10), the solution of the differential equation (4) is obtained:

$$\Phi(x,t)=\frac{1}{2\sqrt{k\pi t}}\int_{-\infty}^{\infty}f(\xi)e^{-\frac{(\xi-x)^2}{4kt}+\frac{U\xi}{2k}}d\xi. \tag{15}$$

Then the value of $C(x,t)$ in expression (3) is equal to the following.

$$C(x,t)=e^{\frac{U}{2K}x+\frac{U^2}{4K}t}\frac{1}{2\sqrt{\pi Kt}}\int_{-\infty}^{\infty}e^{-\frac{(x-\xi)^2}{4Kt}+\frac{U\xi}{2K}}f(\xi)d\xi.$$

We make the necessary substitutions in the expression:

$$C(x,t)=\frac{1}{2\sqrt{\pi Kt}}\int_{-\infty}^{\infty}e^{\frac{U}{2K}x-\frac{U^2}{4K}t-\frac{(x-\xi)^2}{4Kt}+\frac{U\xi}{2K}}=\frac{1}{2\sqrt{\pi Kt}}\int_{-\infty}^{\infty}e^{-\frac{(x-\xi)^2-2Ut(x-\xi)+U^2t}{4Kt}}f(\xi)d\xi=$$

$$=\frac{1}{2\sqrt{\pi Kt}}\int_{-\infty}^{\infty}e^{-\frac{(x-\xi-Ut)^2}{4Kt}}f(\xi)\,d\xi.$$

Discussion. So, the solution for problem (1) is found using Fourier transformation formula.

$$C(x,t)=\frac{1}{2\sqrt{\pi Kt}}\int_{-\infty}^{\infty}e^{-\frac{(x-\xi-Ut)^2}{4Kt}}f(\xi)d\xi. \tag{16}$$

will appear. Suppose that the field under consideration is bounded and satisfies the following conditions. Let f(x)=1 if the domain $|x| \le g$ is bounded by g, and f(x)=0 if the domain g is outside the domain $|x| \ge g$. Then expression (16)

$$C(x,t) = \frac{1}{2\sqrt{\pi K t}} \int_{-g}^{g} e^{-\frac{(\xi - y)^2}{4Kt}} d\xi \,. \qquad (17)$$

appears [3]. Marking is used here $y = x - Ut$. To make the integral expression more precise, we replace it with variable assignment $z = \frac{\xi - y}{2\sqrt{Kt}}$.

Then the differential will be appropriate $\xi = 2\sqrt{Kt}\,z + y, \quad d\xi = 2\sqrt{Kt}\,dz$.

And for the new variable $\xi = g$, when there are threshold values

$z = \frac{g - y}{2\sqrt{Kt}}$, $\xi = -g$ when $z = -\frac{g + y}{2\sqrt{Kt}}$ comes out.

We put all the generated values in the expression (17):

$$C(x,t) = \frac{1}{2\sqrt{\pi K t}} \int_{-\frac{g+y}{2\sqrt{Kt}}}^{\frac{g+y}{2\sqrt{Kt}}} e^{-z^2}\, 2\sqrt{Kt}\,dz \,.$$

It is known that the expression of the probability integral, which is one of the special functions:

$$erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2} dt \,.$$

and in order to replace the above integral with these expressions, we divide it into two parts.

$$C(x,t) = \frac{1}{2}\left(\frac{2}{\sqrt{\pi}} \int_{-\frac{g+y}{2\sqrt{Kt}}}^{0} e^{-z^2} dz + \frac{2}{\sqrt{\pi}} \int_{0}^{\frac{g-y}{2\sqrt{Kt}}} e^{-z^2} dz\right).$$

Since the value of the integral of the probability exactly corresponds to the values under the integral and on the boundary of the integral in the expression we created, we can write the solution in the following form[2]:

$$C(x,t) = \frac{1}{2}\left(erf\left(\frac{g - y}{2\sqrt{Kt}}\right) + erf\left(\frac{g + y}{2\sqrt{Kt}}\right)\right). \qquad (18)$$

taking into account the definition $erfc(z) = 1 - erf(z)$, we can express the solution of the given problem in another way:

$$C(x,t) = \frac{1}{2}\left(erfc\left(\frac{x - Ut}{2\sqrt{Kt}}\right) + \exp\left(\frac{xU}{K}\right) erfc\left(\frac{x + Ut}{2\sqrt{Kt}}\right)\right). \qquad (19)$$

Fields of application of the obtained results. It is known that any practical problem does not always have analytical solutions. Most analytical solutions are obtained only for special cases. In practical processes, all indicators are objective. For example, the area under consideration may be infinite, and the coefficients involved in the equation may be variable rather than constant. In general, since it is very rare to find the solutions of all differential equations using an analytical method, in practice they are often approximated using numerical methods. Based on this, we come to the conclusion that it is necessary to find and apply numerical calculation methods that lead to effective results in order to solve any practical problem.

Conclusion. Thus, in this work, various methods of solving the equations representing the process and their possibilities are analyzed, specific advantages of approximate-analytical solutions and certain limitations imposed on them are presented. The approximate-analytical solution of the convective diffusion equation was derived using different substitutions: Laplace, Fourier, and Green substitutions, assuming a flat and constant filtration rate. Approximate-analytical solutions for the values corresponding to the estimated object were obtained on the basis of the working algorithms according to the Bubnov-Galerkin method, and parallel lines corresponding to the results were drawn, and the physico-chemical properties of the process were systematically analyzed. From the obtained results, it is possible to make such decisions that the models selected for the EQ process correspond to its physical characteristics and they provide the opportunity to obtain the necessary information in the appropriate control process. For this, it is necessary to develop computational algorithms for solving this two-dimensional mathematical model in all cases. Therefore, the problem of creating efficient algorithms suitable for the proposed mathematical model is considered based on numerical-approximate methods. There are several finite-difference schemes for solving equations representing hydrodynamic processes by numerical calculation methods, and when it is necessary to choose the most effective method from them, the obtained results and the analytical method it will be possible to compare the results obtained with As a result, it is possible to solve the set model in the most optimal way.

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MICROCONTROLLER-BASED MECHATRONIC SYSTEM WITH HEATING AND HUMIDITY SENSOR FOR SILKWORM EGGS INCUBATION

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Abstract:

Objective. Silkworms have been cultivated for centuries for their valuable silk production. To ensure a successful silkworm rearing process, it's crucial to maintain precise environmental conditions during the early stage of incubation. This article explores the development and implementation of a microcontroller-based mechatronic system equipped with heating and humidity sensors for improving silkworm eggs' incubation process.

Methods. In this study, we designed and built a mechatronic system powered by a microcontroller to control the environmental conditions required for silkworm egg incubation. The core components of the system include a microcontroller unit (MCU), a heating element, a humidity sensor, and a user interface for monitoring and control. The microcontroller serves as the brain of the system, executing a pre-programmed algorithm to maintain optimal temperature and humidity levels. The heating element is responsible for increasing the temperature when necessary, while the humidity sensor provides real-time feedback to adjust moisture levels.

Conclusion. The microcontroller-based mechatronic system with heating and humidity sensors has the potential to revolutionize the silkworm egg incubation process, leading to increased silk production efficiency. Its scalability and adaptability make it a valuable tool for silkworm farmers and researchers seeking to optimize their rearing practices. Further research and development in this area may unlock even more benefits for the sericulture industry, contributing to its sustainable growth and productivity.

Keywords: silkworm incubation, microcontroller-based system, mechatronic system, heating and humidity sensor, hatch rate improvement, sericulture, environmental control, incubation technology, silk production, rearing efficiency.

Introduction. Silk, a luxurious and highly sought-after fabric, has been cultivated for centuries through the art of sericulture. At the heart of this ancient practice lies the humble silkworm, whose life cycle begins with the incubation of eggs. This critical incubation stage sets the foundation for the successful rearing of silkworms and, consequently, the quality and quantity of silk produced. Traditionally, silkworm farmers have relied on manual methods to regulate the environmental conditions required for egg incubation. However, maintaining consistent temperature and humidity levels has always been a challenge, often resulting in suboptimal hatch rates. In recent years, the integration of advanced technology into

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