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Mathematical simulation of the thermal processes in the heating networks insulation using thin-film covering

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Annotation. The necessity of application of computer technologies in the educational process with increasing requirements to the higher technical education quality is shown. The possibility of the program complex using of finite element modeling in the learning process, in the numerical study of the convection effect on heat exchange in the porous insulation of heat network pipelines using thin-film coatings, is considered.

Introduction

In the modern world, with growing demands on the quality of higher technical education, there is a rapid and widespread introduction of digital technologies into educational and research processes. The future engineer should be able to navigate in the modern software, to master the basic methods of working with programs for calculating various processes in their field in accordance with the training profile.

In the educational process, specialized mathematical complexes for scientific and engineering calculations, such as Mathcad, MatLab, Maple, MuPAD, GNU Octave, Scilab, Maxima, etc., can be used.

Along with theory teaching, calculation methods and techniques of heat transfer process experimental studies in the preparation of qualified engineering personnel in various specialties in the direction of heat power engineering, it is important to expand the possibility of heat exchange theory applying in engineering practice using the computer technology. At the same time, the student, the future engineer, must understand the physical features of the processes and be able to describe the phenomenon under investigation mathematically.

The introduction of computer technologies in all fields of science and technology led to the widespread use of numerical methods for solving problems in mathematical physics. One of the universal methods for solving boundary value problems is the finite element method (FEM). There is a large number of finite element modeling software packages, such as ANSYS, ELCUT, Femlab, FEMM, FlexPDE and others.

Description of finite element modeling program complex

From existing packages for solving differential equation systems, in the learning process, you can use the FlexPDE package [1]. Because, one of the advantages of this package is the availability of the student version, which is available for free distribution, when everyone can receive a key for its activation by e-mail, registering on the developer's site. This software product is designed to build scenario models, solving differential equations by the finite element method. The solution of the equations system is represented graphically. The system of differential equations can be stationary or non-stationary. In the framework of a single problem, stationary and nonstationary equations can be



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considered simultaneously. The equations can be nonlinear.

This program contains a complete set of functions necessary for solving the system of partial differential equations: - editing function for scenarios preparing; - generator of finite element grids; - function of finite elements selection for solution; - a graphical function to represent a graph of the results [2].

Advantages of this program is the ability to specify any number of geometric areas for a solution with various material properties, while it is fairly simple to use, and therefore it is of value for educational purposes.

In addition, it is designed to solve partial differential equations in an arbitrary form, which allows students to formulate a mathematical model independently.

The script for solving problems in the FlexPDE package is usually small in volume and easily compiled. It includes information about the desired functions, solved equations, the geometry of the domain boundary, the boundary conditions and the graphs of the required dependencies.

Application of the FlexPDE finite element simulation software package in the numerical study of thermal processes in the insulation of pipelines of heating networks using thin-film coatings

In work [3] results of experimental researches on application of a thin-film covering on a surface of a heat insulating design of heat network pipelines are presented. To theoretically the energy-saving effect from thin-film coating substantiate, a numerical study of thermal processes in thermal insulation was carried out. As an example of the FlexPDE package application, one can consider the results of solving the problem of complex heat transfer in the porous heat-insulating structure of the heat network pipeline taking into account natural convective processes (Figure 1a).

The convective phenomena in porous media study is of interest for solving both engineering and scientific problems. The most complete review of experimental and theoretical papers is presented in [4]. In [5], nonstationary regimes of natural convection in a closed porous cylindrical cavity were considered. Also, in a number of works, convective currents in annular layers of a saturated porous medium with an internal or external heat source under conditions of a closed shell have been studied [6, 7]. We note the paper [8], in which the effect of natural convection on heat exchange in porous annular layers under the condition of a closed outer shell was numerically investigated.

The heat exchange process in the pipeline insulation of heating networks has a stationary steady state, in view of the long-term regime throughout the entire heating season. The transition regime is insignificant during the periods of the heat supply system start-up and shutdown.

With a quasi-steady-state thermal state, the amount of heat flowing from the heat carrier to the concentric cylindrical heat insulation surface passing through any point of the field is equal to the amount of heat leaving this concentric surface to the external medium.

The structure of the insulated pipeline of the heat network consists of several layers in the thickness of the concentric arrangement (Figure 1a), in this case consisting of mineral wool (3) as an insulating layer and a covering layer consisting of glass-reinforced plastic (GRP) with a thin-film coating applied on its surface (4). Hot water (1) is used as the coolant. The temperature of the coolant throughout the entire model area under consideration remains unchanged. The layer adjacent to the heat carrier is the steel pipe wall (2).

The simulation area is a porous medium between two horizontal coaxial cylinders and consists of the following zones (Figure 1b):

I - is the basic insulating layer having a porous character and consisting of mineral wool, where R_0 is the inner radius of the main insulation layer corresponding to the outer diameter of the steel pipe outer wall, R_1 is the main insulation layer outer radius, with permeability κ_1 , thermal conductivity λ_1 and layer thickness $\Delta R_1 = R_1 - R_0$;

II - a covering layer consisting of GRP and a thin-film rubber coating applied on its surface, where R_2 is the outer radius of the thermal insulation structure, with permeability K_2 , thermal conductivity λ_2 and layer thickness $\Delta R_2 = R_2 - R_1$;

III - the air environment, where T_3 is the average ambient temperature, α_3 is the heat transfer

coefficient between the surface of the thin-film coating and the surrounding air.

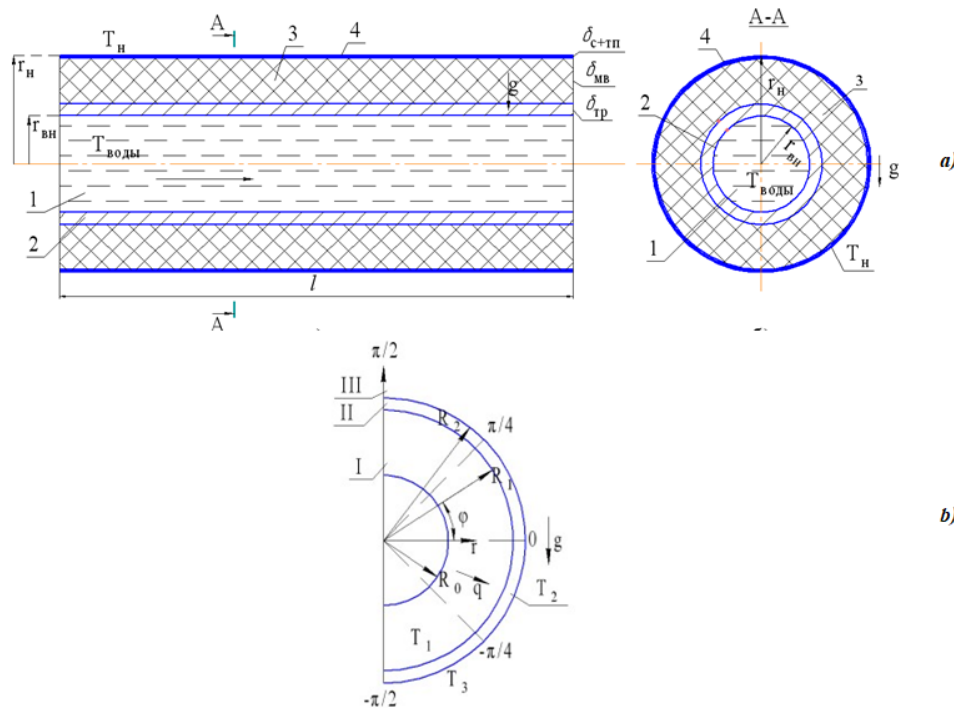


Figure 1. Pipeline model of the: a) physical model of the pipeline; b) a two-dimensional model of a pipeline thermal insulation design

To calculate the flow field and heat transfer under steady-state conditions, the convection equation was used in the Boussinesq approximation, where the surface force was replaced by an equivalent volume resistance force in accordance with Darcy's law [9].

$$\mu \bar{v}/k = -\nabla p + \rho g \beta \Delta T, \quad \text{div } v = 0, \quad \sigma(\bar{v} \nabla) T = \lambda \nabla^2 T$$

The heat exchange in the pipeline insulation proceeds identically along the length in the radial direction and the main change in the heat flux occurs in the plane of the cross section, so the heat exchange simulation can be carried out in two-dimensional coordinates.

Because of the symmetry with respect to the vertical axis passing through the center of the annular layer [9], which represents the heat-insulating construction of the pipeline (Fig. 1b), the mathematical model can be applied for half the annular region.

There is (Figure 2) the script element for solving this problem in the FlexPDE package describing the equations of the considered mathematical model:

```
EQUATIONS {PDE's, one for each variable}
p: DX(vx)+DY(vy)=0 !p=pinit
u: div(l1*grad(u))=roCp*(vx*DX(u)+vy*DY(u)) {one possibility} !u=uinit
phi: phi=(arctan((y-dR)/(x+0.00001))+Pi/2)*180/pi
then
psi: div(grad(psi)) + w = 0! solve streamline equation separately from velocities
```

Figure 2. The FlexPDE program script element (p is the pressure, u is the temperature

Finite element analysis begins with the discretization of the problem under investigation and divides it into mesh cells, called finite elements, interconnected at the node points, and a finite-element grid of the model design area is shown in Figure 3.

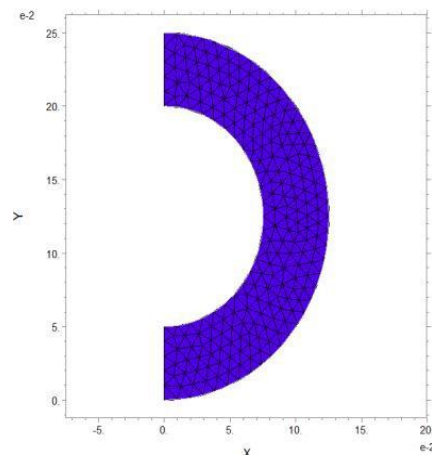


Figure 3. Two-dimensional finite element mesh of the model design area

The results of numerical analysis in the FlexPDE program in the insulation layer under natural convection conditions, for the pipeline with a diameter of 57 mm and a thickness of the insulating layer of 60 mm are shown in Figure 4.

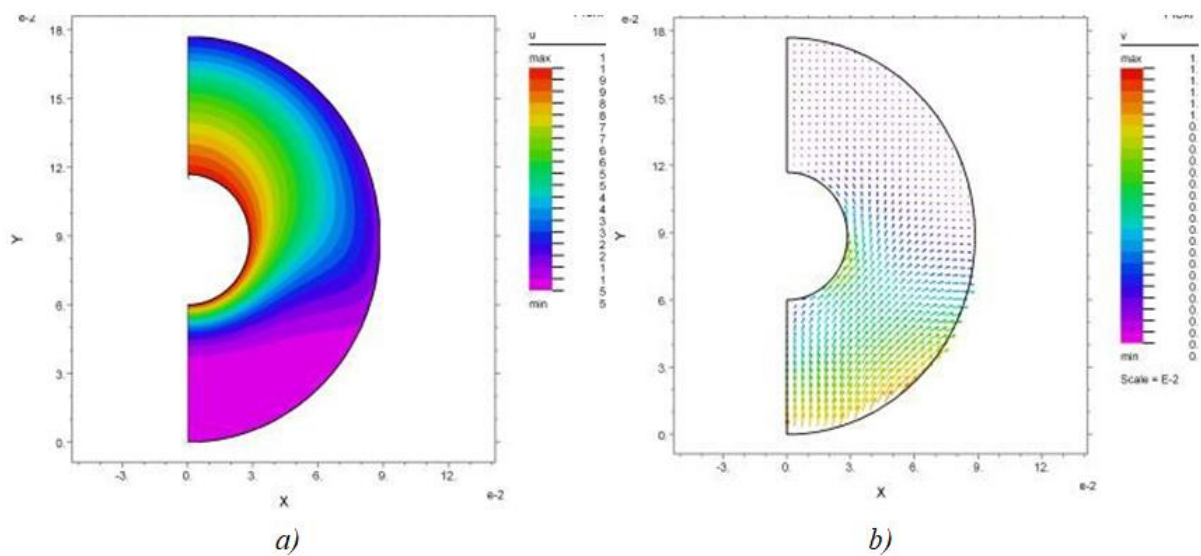


Figure 4. Results of numerical analysis a) distribution of temperature fields, °C; b) velocity distribution, m/s.

Conclusion

It should be noted that developed by the teachers mathematical model for the thermal processes calculation in the thickness of the heat insulation structure of the heating network pipelines for the FlexPDE package, which simulates physical processes, can be used for teaching students and graduate students. Thus, they will be able to compare the experimental data with the calculated ones. In

addition, the package will be very useful for students and graduate students in the performance of research and development.

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