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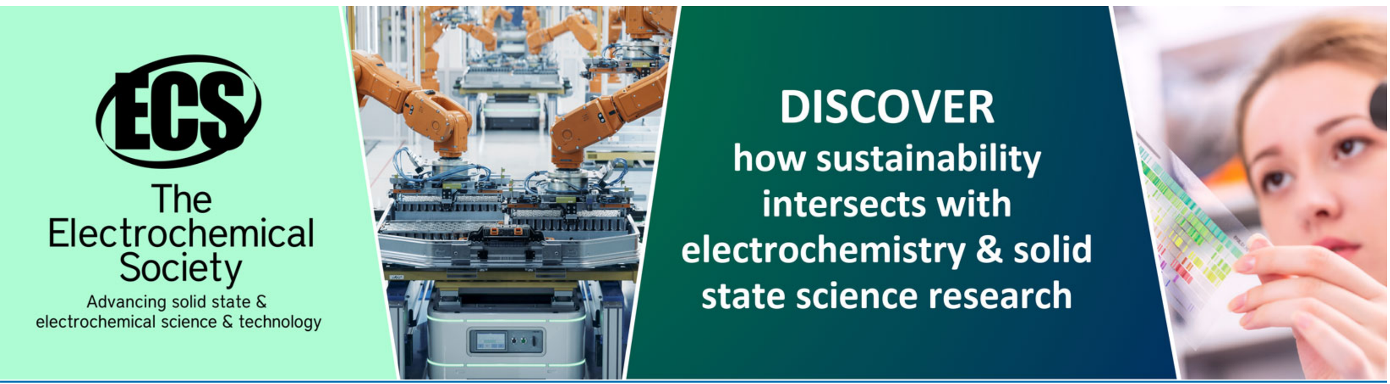

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Mathematical modeling of the fuel element of a nuclear reactor taking into account the temperature dependence of the thermal conductivity of the fuel element made of uranium oxide

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Abstract. The work is devoted to the thermal calculation of the fuel element of a nuclear reactor. Attention was paid to the mathematical modeling of the temperature field under boundary conditions of the first kind. Approximations of the dependence of the thermal conductivity of uranium oxide on temperature in the form of a quadratic function were used for numerical modeling.

1. Introduction

As is known, the fuel element is the main structural element of the core of a nuclear reactor containing nuclear fuel. It is the main structural element of the zone containing nuclear fuel. In it, the fission of heavy uranium 235 or plutonium 239 nuclei occurs, accompanied by the release of thermal energy, which is then transferred to the coolant. Therefore, the fuel element must ensure the removal of heat from the fuel to the coolant and prevent the spread of radioactive products from the fuel into the coolant. Therefore, thermal and strength calculations of fuel elements are an important task of designing structural elements of nuclear technology.

Numerical modeling is used in many fields of science and technology, including in areas related to nuclear energy. There are many computer programs for modeling the processes of the core of a nuclear reactor [1-6]. From the point of view of a mathematical model, a nuclear reactor can be considered as a complex conglomerate of interacting processes. To describe its properties, simpler models are often used today. Many works have been devoted to the calculation of fuel elements, where uranium oxide serves as nuclear fuel [7-9], but the temperature dependence of thermal conductivity is not always taken into account.

The article considers numerical modeling of the temperature field of a heat-generating element, taking into account the dependence of the thermal conductivity of uranium oxide on temperature.

2. Materials and methods

The method of mathematical modeling is used in the work.

3. Results

There is a gap between the fuel rod and the shell – a thin gas layer filled with chemically neutral and highly conductive helium (figure 1).

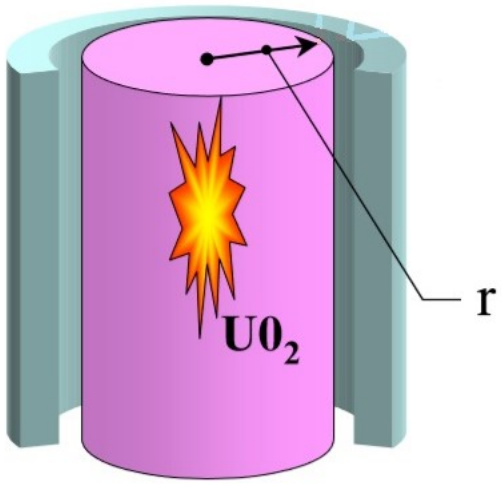

Figure 1. Construction of an axisymmetric heat-generating element.

To determine the temperature field of a cylindrical heat-generating element, we solve the equation of thermal conductivity under the boundary condition. The same heat source with a specific power of q_v operates inside. At the same time, we will consider the process stationary. To find the distribution of the temperature field, it is necessary to solve the Poisson equation [10]

$$\Delta T + \frac{q_v}{\lambda} = 0 \tag{1}$$

expression (2) in the cylindrical coordinate system will take the form

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dt}{dr}\right) = -\frac{q_v}{\lambda} \tag{2}$$

let's separate the variables

$$\frac{d}{dr}\left(r\frac{dt}{dr}\right) = -\frac{q_v}{\lambda}r \tag{3}$$

let 's integrate both parts of the equation

$$r\frac{dt}{dr} = -\frac{q_v r^2}{2\lambda} + C_1 \tag{4}$$

let's separate the variables again

$$\frac{dt}{dr} = -\frac{q_v r}{2\lambda} + \frac{C_1}{r} \tag{5}$$

Due to the finite temperature value in the center, the constant $C_1 = 0$. Then

$$\frac{dt}{dr} = -\frac{q_v r}{2\lambda} \tag{6}$$

In fact, the thermal conductivity of uranium oxide strongly depends on temperature (figure 2) and this dependence must be taken into account in practical calculations.

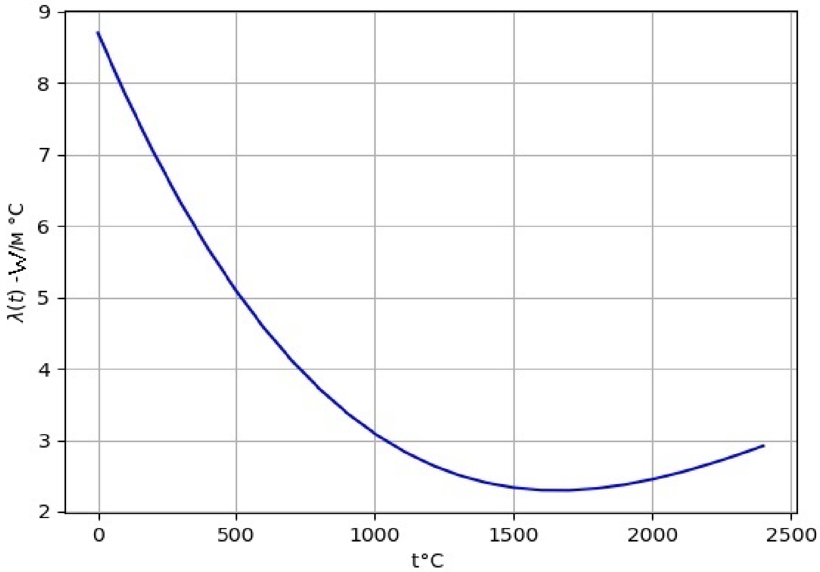

Figure 2. Thermal conductivity of uranium oxide depending on temperature.

The above dependence is well described in the form of a polynomial of the fourth degree. To simplify the calculations, we will approximate the temperature dependence of the thermal conductivity not over the entire interval, but only in the operating temperature range (500-1700 ^{0}C). At this interval, the approximation can be represented as a quadratic function

$$\lambda = (0,00068t - 2,58)^2 \tag{7}$$

Substitute expression (7) in (6)

$$(0,00068t - 2,58)^2 dt = -\frac{q_v r}{2} dr \tag{8}$$

Let's integrate both parts of the equation. Then

$$490(0,00068t - 2,58)^3 = -\frac{q_v r^2}{4} + C_2 \tag{9}$$

From where the desired temperature is equal to

$$t = 3800 + \sqrt[3]{C_3 - 1,62 \cdot 10^6 q_v r^2} \tag{10}$$

We will find the constant C_3 from the boundary condition: the temperature t_0 is set on the surface of the rod, which we will describe by a boundary condition of the first kind

$$t\big|_{r=R} = t_0 \tag{11}$$

substituting (11) into (10), we get

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$$t = 3800 + \sqrt[3]{(t_0 - 3800)^3 + 1,62 \cdot 10^6 q_v (R^2 - r^2)} \tag{12}$$

for a graphical representation of the temperature field, we introduce the variable x

$$x = \frac{r^2}{R^2} \tag{13}$$

then the expression (12) will take the form

$$t = 3800 + \sqrt[3]{(t_0 - 3800)^3 + 1,62 \cdot 10^6 q_v R^2 \left(1 - x^2\right)} \tag{14}$$

where x takes values from 0 to 1. Figure 3 shows a graph of the temperature dependence on the radius.

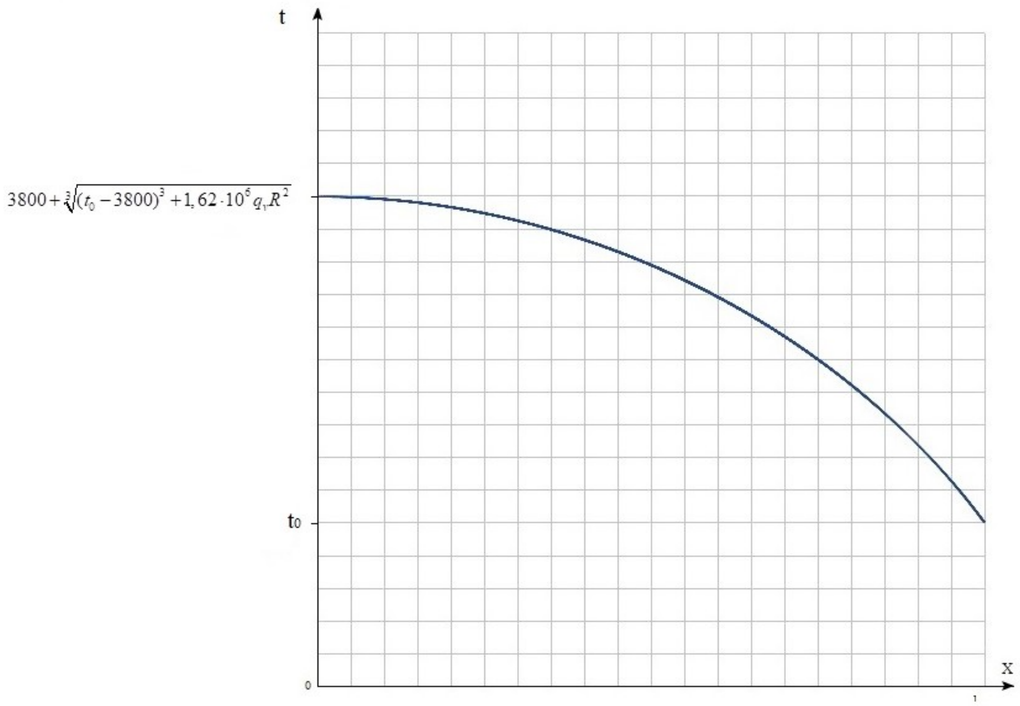

Figure 3. Graph of the dependence of the rod temperature on the radius.

4. Discussion

As follows from figure 3, the temperature decreases during the transition from the center to the edge. Which is to be expected, since the process of heat transfer to the environment is more intense at the edge?

5. Conclusion

In this paper, the solution of the stationary problem of the distribution of the temperature field of the fuel element of a nuclear reactor is considered. Using quadratic approximation, a mathematical model for an axisymmetric rod has been developed. This model takes into account the dependence of the thermal conductivity of uranium oxide on temperature. The solution is obtained for the stationary case in a system of cylindrical coordinates under boundary conditions of the first kind.

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