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NUMERICAL MODELING OF PHYSIC-CHEMICAL PROCESSES OF MULTICORE CABLE IN THE POLYMERIZATION

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Abstract. There are developed mathematical model of physical and chemical processes of polymerization adhesive coating stranded cable.There are found time of full polymerization in the shell of the multicore cable product. There are compared with the single-core cable. Also the necessity of changing the speed of the cable pulling the multilayer product compared with single-core.

1. INTRODUCTION

Manufacture of cable products is one of the most energy and resource-intensive processes. In the process of manufacturing a variety of design elements are imposed on "Inside were" parts of a continuous motion product through the cable assembly equipment. It is necessary to minimize the cost to reduce the price of finished product [1].

The cable sheath may consist of several layers of reinforcing and sealing, as which may be used various materials: rubber, plastic, fabric, metal and so on. Cable for transmitting electrical signals may be provided with a metal screen coating [1].

Therefore, the simulation of the process of vulcanization cable products should be considered as a form of the products obtained, and the material and chemical processes occurring in it. It is necessary to determine whether the amount of influence on the process of living polymerization.

2. PROBLEM STATEMENT

Province of solving the problem is shown in Fig. 1. The cable consists of several layers: 7 twisted together and covered with a common living sheath. Product initial temperature T_0 is moving inside the oven, the surface of which is heated to a temperature T_v. As a result, the outer rubber layer is polymerized. There are solving the problem of the cylindrical coordinate system.

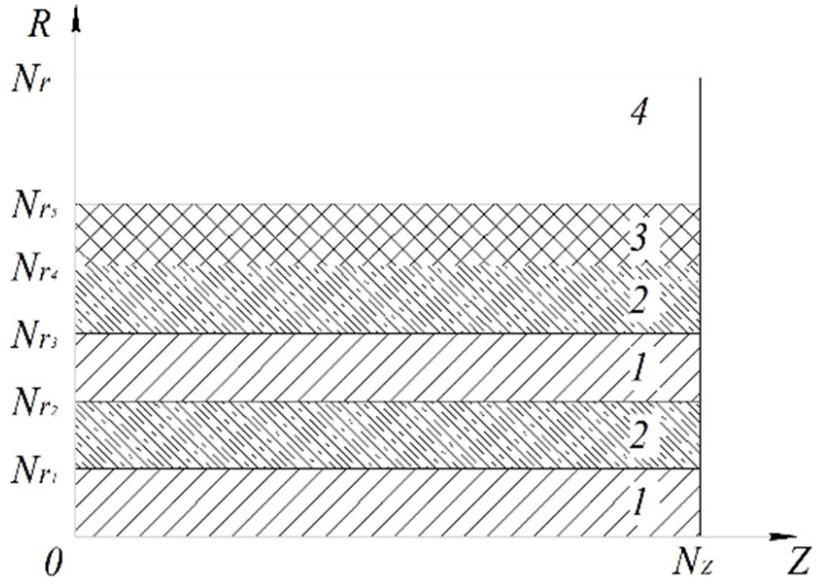

Figure 1. Scheme for solving the problem area:
1 – metal core,
2 – rubber sheath conductor,
3 – shell cable,
4 – hot air in furnace

The following assumptions were accepted:

1. Cable proper cylindrical shape is not limited in length.
2. Thermal characteristics of the metal (copper) and the rubber does not depend on the temperature.
3. Activation energy does not change within a given temperature [1].

3. MATHEMATICAL MODEL

The mathematical model of physical and chemical processes for cable products as a result of the vulcanization can be formulated in the form of non-stationary heat conduction equations "lived 7 - rubber sheath - air - oven" (Fig. 1) corresponding to formulate the problem is as follows [2, 3].

The heat equation for cores ($0<R<Nr_1$, $Nr_2<R<Nr_3$, $0<Z<Nz$):

$$\frac{\partial T_i}{\partial t} = a_i\left[\frac{\partial^2 T_i}{\partial R^2} + \frac{1}{R}\frac{\partial T_i}{\partial R} + \frac{\partial^2 T_i}{\partial Z^2}\right], \text{ i=1, 2.}$$

The energy equation for core insulations ($Nr_1<R<Nr_2$, $Nr_3<R<Nr_4$, $0<Z<Nz$):

$$\frac{\partial T_j}{\partial t} = a_j\left[\frac{\partial^2 T_j}{\partial R^2} + \frac{1}{R}\frac{\partial T_j}{\partial R} + \frac{\partial^2 T_j}{\partial Z^2}\right], \text{ j=1, 2.}$$

The energy equation for cable insulation shell ($Nr_4<R<Nr_5$, $0<Z<Nz$):

$$\rho_3 C_3 \frac{\partial T_3}{\partial t} = \lambda_3\left[\frac{\partial^2 T_3}{\partial R^2} + \frac{1}{R}\frac{\partial T_3}{\partial R} + \frac{\partial^2 T_3}{\partial Z^2}\right] + q_3\rho_3\frac{d\varphi_3}{dt},$$

$$\frac{d\varphi_3}{dt} = (1-\varphi_3)k_0 \exp\left[-\frac{E}{R_t T_3}\right].$$

The energy, motion and continuity equations for air in camera ($Nr_5<R<Nr_7$, $0<Z<Nz$):

$$\frac{\partial T_4}{\partial t} + u\frac{\partial T_4}{\partial R} + w\frac{\partial T_4}{\partial Z} = a_4\left[\frac{\partial^2 T_4}{\partial R^2} + \frac{1}{R}\frac{\partial T_4}{\partial R} + \frac{\partial^2 T_4}{\partial Z^2}\right],$$

$$\frac{\partial \omega}{\partial \tau} + u\frac{\partial \omega}{\partial R} + w\frac{\partial \omega}{\partial Z} = v_4\left[\frac{\partial^2 \omega}{\partial R^2} + \frac{1}{R}\frac{\partial \omega}{\partial R} + \frac{\partial^2 \omega}{\partial Z^2}\right] + \beta g\frac{\partial T_4}{\partial Z},$$

$$\frac{\partial^2 \psi}{\partial Z^2} + \frac{1}{R}\frac{\partial \psi}{\partial R} + \frac{\partial^2 \psi}{\partial R^2} = \omega.$$

Initial ($\tau=0$) conditions: $T_i=T_0$ by $0<R<Nr_1$, $Nr_2<R<Nr_3$, $0<Z<Nz$; $T_j=T_0$ by $Nr_1<R<Nr_2$, $Nr_3<R<Nr_4$, $0<Z<Nz$; $T_3=T_0$ by $Nr_4<R<Nr_5$, $0<Z<Nz$; $T_4=T_v$ by $Nr_5<R<Nr_7$, $0<Z<Nz$; $\varphi=0{,}99$ by $Nr_1<R<Nr_2$, $Nr_3<R<Nr_4$, $0<Z<Nz$; $\varphi=\varphi_0$ by $Nr_4<R<Nr_5$, $0<Z<Nz$.

Boundary conditions ($0<\tau<t_p$):

$Z=0$, $0<R<Nr_1$, $Nr_2<R<Nr_3$ $\frac{\partial T_i}{\partial Z} = 0$;

$Z=0$, $Nr_1<R<Nr_2$, $Nr_3<R<Nr_4$ $\frac{\partial T_j}{\partial Z} = 0$;

$Z=0$, $Nr_4<R<Nr_5$ $\frac{\partial T_3}{\partial Z} = 0$;

$Z=0$, $Nr_5<R<Nr_6$ $T_4=T_v$, $\frac{\partial \psi}{\partial Z} = 0$, $\frac{\partial \psi}{\partial R} = -w_c R$;

$Z=0$, $Nr_6<R<Nr_7$ $\frac{\partial T_4}{\partial Z} = 0$, $\psi=0$, $\frac{\partial \psi}{\partial R} = 0$;

$Z=Nz$, $0<R<Nr_1$, $Nr_2<R<Nr_3$ $\frac{\partial T_i}{\partial Z} = 0$;

Z= Nz, $Nr_1<R<Nr_2$, $Nr_3<R<Nr_4$ $\frac{\partial T_j}{\partial Z}=0$;

Z=Nz, $Nr_4<R<Nr_5$ $\frac{\partial T_3}{\partial Z}=0$;

Z=Nz, $Nr_5<R<Nr_6$ $T_4=T_v$, $\frac{\partial \psi}{\partial Z}=0$, $\frac{\partial \psi}{\partial R}=-w_c R$;

Z=Nz, $Nr_6<R<Nr_7$ $\frac{\partial T_4}{\partial Z}=0$, $\psi=0$, $\frac{\partial \psi}{\partial R}=0$;

R=0, 0<Z<Nz $\frac{\partial T_i}{\partial R}=0$;

R=Nr_1, 0<Z<Nz $-\lambda_i \frac{\partial T_i}{\partial R}=-\lambda_j \frac{\partial T_j}{\partial R}$, $T_i=T_j$;

R=Nr_2, 0<Z<Nz $-\lambda_i \frac{\partial T_i}{\partial R}=-\lambda_j \frac{\partial T_j}{\partial R}$, $T_i=T_j$;

R=Nr_3, 0<Z<Nz $-\lambda_i \frac{\partial T_i}{\partial R}=-\lambda_j \frac{\partial T_j}{\partial R}$, $T_i=T_j$;

R=Nr_4, 0<Z<Nz $-\lambda_j \frac{\partial T_j}{\partial R}=-\lambda_3 \frac{\partial T_3}{\partial R}$, $T_j=T_3$;

R=Nr_5, 0<Z<Nz $-\lambda_3 \frac{\partial T_3}{\partial R}=-\lambda_4 \frac{\partial T_4}{\partial R}$, $T_3=T_4$, $\psi=0$, $\frac{\partial \psi}{\partial Z}=w_c R$;

R=Nr_7, 0<Z<Nz $T_4=T_v$, $\psi=0$, $\frac{\partial \psi}{\partial Z}=0$.

The system of time-dependent differential equations solved by finite difference method [4]. The difference analogues of differential equations solved by the locally one-dimensional method and alternating direction method [4]. There have applied sweep method by using a four-point implicit scheme for solving dimensional difference equations [4]. The approximation of boundary conditions for Poisson equations and vortices equation is performed analogically [5].

4. RESULTS AND DISCUSSION

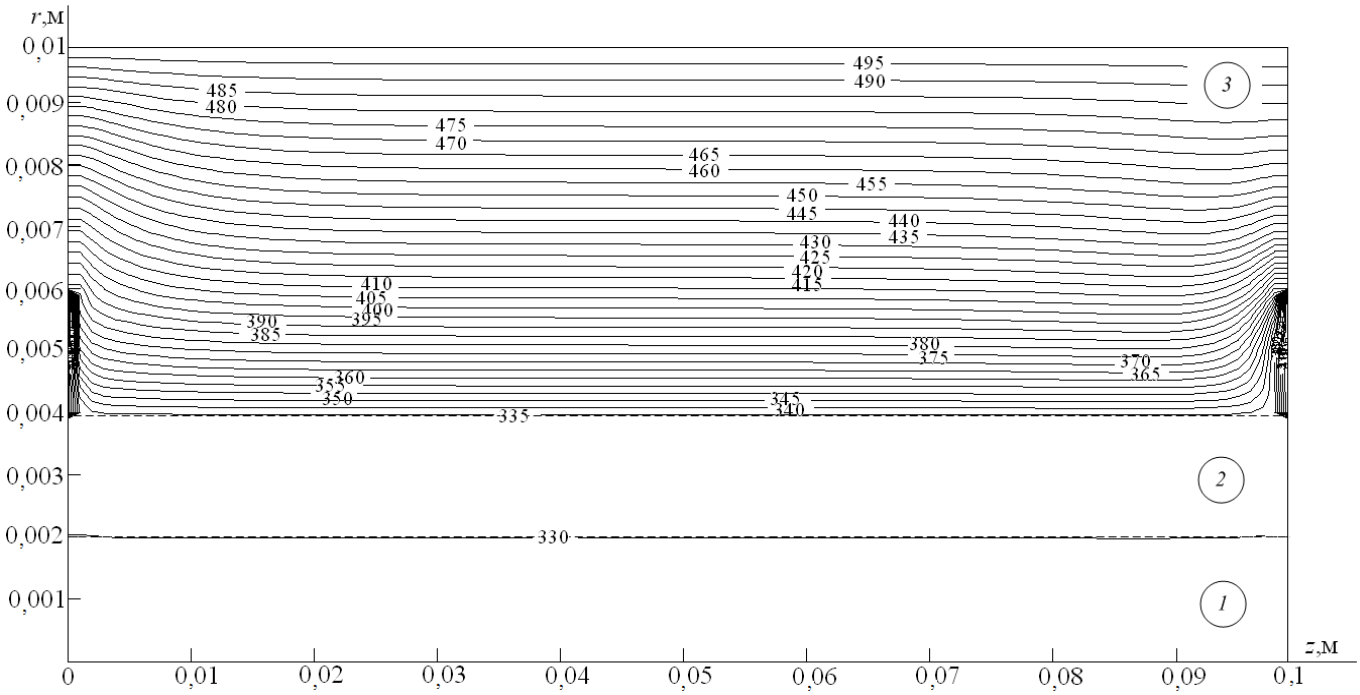

Figure 2. Isotherms by full polymerization shell of single-core cable (t_p=497 sec and φ≈0,99 by Nr_2<R<Nr_3)

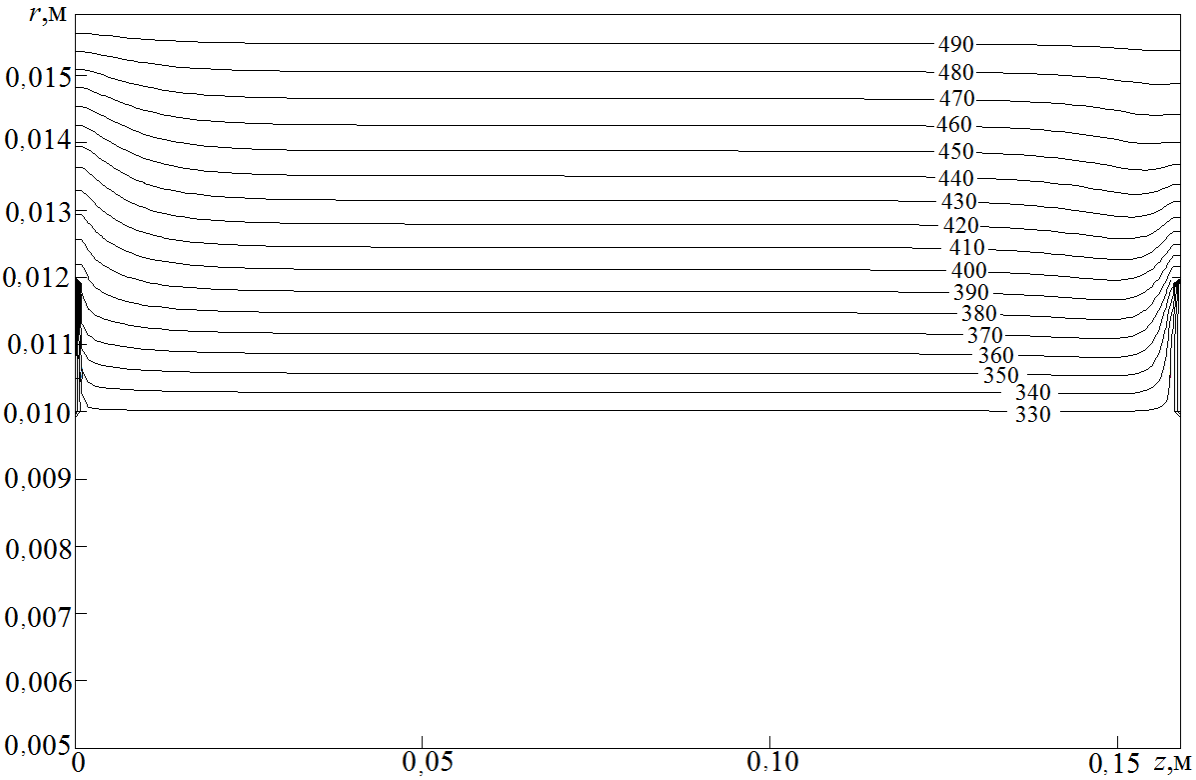

Figure 3. Isotherms by full polymerization shell of multilayer cable (t_p=774.6 sec and φ≈0,99 by Nr_4<R<Nr_5)

When setting objectives assumed that the cable passes through a specialized chamber at heating up to 480 K. It is considered [1], that the output of such a chamber characterized the product by a high degree of polymerization of the insulating shell over the entire thickness. [1] The term "full polymerization" [1] implies the completion of the chemical process in the insulating layer, rated to the condition φ≈1 (φ - the degree of completion of the main chemical reaction) [6].

Fig. 3 shows the isotherms in the system (Fig. 1) at the time (t = t_p) complete polymerization (φ≈0,99 at Nr_4 <R <Nr_5) shell stranded cable products. There are can mark up to a good-enough correlated with the distribution of isotherms temperatures obtained for single-core cables (Fig. 2). However, the typical curing times significantly exceed the value of t_p. So established that for considering multicore cable cured its rubber shell in the oven at a temperature T_v = 500 K is t_p≈775 sec. For a single-core cable under identical conditions (temperature in the furnace structural dimensions passage section, etc.) and parameters (thickness and material of the outer insulating layer), the process of vulcanization ends at t_p≈497 sec. When the temperature decreases to 450 K T_v deviation times t_p for solid and stranded cables up to 45%. By increasing T_v to 550 K, these deviations decrease somewhat (30%). It is possible to conclude a significant influence on the internal structure of the cable polymerization time its outer shell.

There are found, that polymerization time of multicore cable's rubber cover is exceeded Analogic parameters of the single - core product. Our result indicates about accounting internal structure of cable product in selecting the vulcanization mode. There is need to support more times for multicore cable (accordingly, less speed of broach) as compared with single-core.

5. CONCLUSION

The physical and mathematical models, numerical algorithms for solving problems of heat transfer can be used to analyze the quality of the insulation of cable products and energy efficiency of polymerization processes for their manufacture.

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