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INVESTIGATION OF THE STABILITY OF A CYLINDRICAL COATING MADE OF A POROUS MATERIAL

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Abstract- In nuclear power plants, an element made of uranium, which is mainly a radioactive substance, is used as a heat source. The heat-separating structure consists of a core of a uranium element, a steel cylinder holding it inside, and a liquid metal flowing through their intermediate space. Due to the fast neutrons coming out of the uranium nucleus, the cylindrical element receives a large dose of radiation, resulting in a huge amount of heat being released. Since the heat capacity of water vapor is not sufficient to transfer such a large amount of heat, the liquid metal is released from the intermediate gap of the coating. Despite the fact that the cylindrical shell is made of steel material, on the one hand, due to the heat released, it expands, and on the other hand, due to the collision of fast neutrons from the uranium nucleus with the atoms of the cylinder, the atoms leave their places. Atoms that have left their place shoot and displace other atoms from their places. After several collisions, the energy of the atom decreases, causing them to get stuck between other atoms. Leaving the atoms in their place leads to rarefaction in this place, and riveting leads to compaction. Thus, structural changes occur in the cylinder material, and the material behaves like a porous material. In space rockets and jet planes, the nozzles have a round cylindrical shape. It gets very hot when ignited fuel comes out of the nozzle. They make nozzles consisting of several layers so that the heat removed is not transferred to a rocket or an airplane. Some of these layers are made of porous material. A thin-walled cylindrical cover made of porous material, rigidly fixed at the ends, loses stability as a result of expansion from heat. It is required to find the crisis temperature value necessary for the loss of stability. The presented article is devoted to solving this issue.
Keywords: Nuclear power plant, The core, The neutrons, Porous material, Stability, Critical temperature.

PROBLEM STATEMENT

$$b_{11} = b_{12} = b_{21} = 0; b_{22} = \frac{1}{R}$$

$$w(x,T)\,|_{x=-\ell,\,\ell} = 0; \quad \frac{\partial w(x,T)}{\partial x}\,|_{x=-\ell,\,\ell} = 0.$$

$$w(x,T) = f(T)\cdot\left(cos\frac{\pi x}{\ell} + 1\right)$$

PROBLEM STATEMENT

$$b_{11} = b_{12} = b_{21} = 0; b_{22} = \frac{1}{R}. \quad (1)$$

$$w(x,T)|_{x=-\ell,\ \ell} = 0; \ \frac{\partial w(x,T)}{\partial x}|_{x=-\ell,\ \ell} = 0. \quad (2)$$

$$w(x,T) = f(T)\cdot\left(\cos\frac{\pi x}{\ell} + 1\right). \quad (3)$$

$$\varepsilon_{11} = \varepsilon_{xx} = \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 ; \varkappa_{11} = \varkappa_{xx} - \frac{\partial^2 w}{\partial x^2}$$

$$\varepsilon_{22} = \varepsilon_{\varphi\varphi} = \frac{w}{R} ; \varkappa_{22} = \varkappa_{\varphi\varphi} = 0 . \quad (4)$$

$$\dot{\tilde{\varepsilon}}^{e}_{xx} = \frac{1}{E}\left[\dot{\tilde{\sigma}}_{xx} - \nu\, \dot{\tilde{\sigma}}_{\varphi\varphi}\right]$$

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$$\dot{\tilde{\varepsilon}}^{v}_{xx} = \frac{1}{3}\dot{S} , \qquad \dot{\tilde{\varepsilon}}^{v}_{\varphi\varphi} = \frac{1}{3}\dot{S}$$

$$\dot{\tilde{\varepsilon}}_{xx} = \dot{\tilde{\varepsilon}}^{e}_{xx} + \dot{\tilde{\varepsilon}}^{v}_{xx} = \frac{1}{E}\left[\dot{\tilde{\sigma}}_{xx} - \nu\,\dot{\tilde{\sigma}}_{\varphi\varphi}\right] + \frac{1}{3}\dot{S};$$

$$\dot{\tilde{\varepsilon}}_{\varphi\varphi} = \dot{\tilde{\varepsilon}}^{e}_{\varphi\varphi} + \dot{\tilde{\varepsilon}}^{v}_{\varphi\varphi} = \frac{1}{E}\left[\dot{\tilde{\sigma}}_{\varphi\varphi} - \nu\,\dot{\tilde{\sigma}}_{xx}\right] + \frac{1}{3}\dot{S}; \qquad (5)$$

$$\dot{\tilde{\varepsilon}}_{xx} = \dot{\tilde{\varepsilon}}^{e}_{xx} + \dot{\tilde{\varepsilon}}^{v}_{xx} = \frac{1}{E}\left[\dot{\tilde{\sigma}}_{xx} - \nu\,\dot{\tilde{\sigma}}_{\varphi\varphi}\right] + \frac{1}{3}\dot{S}.$$

$$\dot{\tilde{\sigma}}_{xx} = \frac{E}{1-\nu^{2}}\left(\dot{\tilde{\varepsilon}}_{xx} + \nu\,\dot{\tilde{\varepsilon}}_{\varphi\varphi}\right) - \frac{ES}{3(1-\nu)}. \qquad (6a)$$

$$\dot{\tilde{\sigma}}_{\varphi\varphi} = \frac{E}{1-\nu^{2}}\left(\dot{\tilde{\varepsilon}}_{\varphi\varphi} + \nu\,\dot{\tilde{\varepsilon}}_{xx}\right) - \frac{ES}{3(1-\nu)}. \qquad (6b)$$

$$\begin{cases} \tilde{\sigma}_{xx} = \dfrac{1}{2h} N_{xx} + \dfrac{3z}{2h^3} M_{xx} \\ \tilde{\sigma}_{\varphi\varphi} = \dfrac{1}{2h} N_{\varphi\varphi} + \dfrac{3z}{2h^3} M_{xx} \end{cases} . \qquad (7)$$

$$N_{xx} = \int_{-h}^{h} \tilde{\sigma}_{xx} dz; \;\; N_{\varphi\varphi} = \int_{-h}^{h} \tilde{\sigma}_{\varphi\varphi} dz;$$

$$M_{xx} = \int_{-h}^{h} z\tilde{\sigma}_{xx} dz; \; M_{\varphi\varphi} = \int_{-h}^{h} z\tilde{\sigma}_{\varphi\varphi} dz.$$

$$N_{xx} = \frac{2hE}{1-\nu^2}\left(\varepsilon_{xx} + \nu\,\varepsilon_{\varphi\varphi}\right) - \frac{2hES}{3(1-\nu)}$$

$$N_{\varphi\varphi} = \frac{2hE}{1-\nu^2}\left(\varepsilon_{\varphi\varphi} + \nu\,\varepsilon_{xx} - \frac{2hES}{3(1-\nu)}\right). \qquad (8)$$

$$M_{xx} = \frac{2h^3E}{3(1-\nu^2)}\varkappa_{xx};\quad M_{\varphi\varphi} = \frac{2h^3\nu E}{3(1-\nu^2)}\varkappa_{xx}$$

$$\frac{\partial w}{\partial x} = -\frac{\pi f}{l}\sin\frac{\pi x}{l};\quad \frac{\partial^2 w}{\partial x^2} = -\left(\frac{\pi}{l}\right)^2 f\cos\frac{\pi x}{l}.$$

$$\varepsilon_{xx} = \frac{1}{2}\left(\frac{\pi}{l}\right)^2 f^2 sin^2 \frac{\pi x}{l};\ \varkappa_{xx} = \left(\frac{\pi}{l}\right)^2 f \cos\frac{\pi x}{l};$$

$$\varepsilon_{\varphi\varphi} = \frac{f}{R}\left(\cos\frac{\pi x}{l} + 1\right);\ \varkappa_{\varphi\varphi} = 0\,. \qquad (9)$$

$$N_{xx} = \frac{2hE}{1-\nu^2}\left[\frac{1}{2}\left(\frac{\pi}{l}\right)^2 f^2 sin^2\frac{\pi x}{l} + \frac{\nu f}{R}\left(\cos\frac{\pi x}{l} + 1\right)\right] - \frac{2hES}{3(1-\nu)}$$

$$N_{\varphi\varphi} = \frac{2hE}{1-\nu^2}\left[\frac{\nu}{2}\left(\frac{\pi}{l}\right)^2 f^2 sin^2\frac{\pi x}{l} + \frac{f}{R}\left(\cos\frac{\pi x}{l} + 1\right)\right] - \frac{2hES}{3(1-\nu)}$$

$$M_{xx} = \frac{2h^3E}{3(1-\nu^2)}\left[\left(\frac{\pi}{l}\right)^2 f \cos\frac{\pi x}{l}\right]$$

$$M_{\varphi\varphi} = \frac{2h^3 \nu E}{3\left(1-\nu^2\right)}\left[\left(\frac{\pi}{l}\right)^2 f \cos\frac{\pi x}{l}\right]$$

$$N_1 = \frac{2hE}{1-\nu^2}\frac{1}{2}\left(\frac{\pi}{l}\right)^2 f^2; \; N_2 = \frac{2hE}{1-\nu^2}\frac{f}{R};$$

$$N_0 = \frac{2hE}{1-\nu^2} - \frac{2hES}{3\left(1-\nu\right)}; \; M = \frac{2h^3 E}{3(1-\nu^2)}\cdot\left(\frac{\pi}{l}\right)^2 f \,.$$

$$N_{xx} = N_1 sin^2 \frac{\pi x}{l} + \nu N_2 \cos \frac{\pi x}{l} + N_0,$$

$$N_{\varphi\varphi} = \nu N_1 sin^2 \frac{\pi x}{l} + N_2 \cos \frac{\pi x}{l} + N_0, \quad (10)$$

$$M_{xx} = M \cos \frac{\pi x}{l}; \; M_{\varphi\varphi} = \nu M \cos \frac{\pi x}{l}.$$

PROBLEM SOLUTION

$$\delta J = \int_{-l}^{-l} \Big\{ \dot{N}_{xx}\delta\dot{\varepsilon}_{xx} + \dot{N}_{\varphi\varphi}\delta\dot{\varepsilon}_{\varphi\varphi} + \dot{M}_{xx}\delta\dot{\varkappa}_{xx} + N_{xx}\frac{\partial\dot{w}}{\partial x}\delta\frac{\partial\dot{w}}{\partial x} +$$

$$+ \Big[\varepsilon_{\varphi\varphi} - \frac{p_0}{4h^2E}\left(N_{\varphi\varphi} - \nu N_{xx}\right)\Big]\delta\dot{N}_{\varphi\varphi} +$$

$$+\frac{d}{dT}\left[\varepsilon_{xx} - \frac{p_0}{4h^2E}\left(N_{xx} - \nu N_{\varphi\varphi}\right) - \frac{3p_1}{4h^4E}\left(M_{xx} - \nu M_{\varphi\varphi}\right)\right]\delta\dot{N}_{xx} +$$

$$-\frac{d}{dT}\left[\varepsilon_{\varphi\varphi} - \frac{p_0}{4h^2E}\left(N_{\varphi\varphi} - \nu N_{xx}\right)\right]\delta\dot{N}_{\varphi\varphi} +$$

$$+\frac{d}{dT}\left[\varkappa_{xx} - \frac{3p_1}{4h^4E}\left(N_{xx} - \nu N_{\varphi\varphi}\right)\right]\delta\dot{M}_{xx} -$$

$$-(\dot{S}_1\,\delta\dot{N}_{xx} + \dot{S}_1\delta\dot{N}_{\varphi\varphi})\Big\}\,dx\,. \qquad (11)$$

$$u_x = u_\varphi = 0; b_{11} = b_{12} = b_{21} = 0;$$

$$Q_1 = Q_2 = 0\ ;\ \psi_1 = \psi_2 = \psi_3 = 0; \varkappa_{\varphi\varphi} = 0;$$

$$E = const$$

$$p_1 = 0; q_0 = q_1 = q = 0; C_2 = S_2 = 0.$$

$$\begin{aligned}
&\left[\frac{f\pi^2}{8l}\left(2N_0+3N_1+N_2\right)\right]-\frac{l}{R}\left(2\dot{N}_0+\dot{N}_1+3\dot{N}_2\right)-\frac{\pi^2}{l}\dot{M}=0;\\
&\frac{3\pi^2\dot{f}f}{16l^2}-\frac{\dot{f}}{4R}-\frac{3}{16hE}\left(2N_0+3\dot{N}_1+\dot{N}_2\right)-\frac{\dot{S}_1}{2}=0;\\
&\frac{3\pi^2\dot{f}f}{16l^2}-\frac{3\dot{f}}{4R}-\frac{3}{16hE}\left(2N_0+\dot{N}_1+3\dot{N}_2\right)-\frac{\dot{S}_1}{2}=0;\\
&\frac{\pi^2\dot{f}}{2l^2}+\frac{9\dot{M}}{4h^3E}=0.
\end{aligned} \tag{12}$$

$$\bar{N}_1 = \frac{N_1}{hE};\ \bar{N}_2 = \frac{N_2}{hE};\ \bar{N}_0 = \frac{N_0}{hE};$$

$$\bar{M} = \frac{M}{h^2 E};\ \bar{f} = \frac{f}{l};\ \frac{h}{2l} = \eta;\ \frac{h}{R} = \lambda. \qquad (13)$$

$$
\begin{aligned}
&\pi^2\left(2\bar{N}_0+3\bar{N}_1+\bar{N}_2\right)\dot{\bar{f}}+\left(3\pi^2\bar{f}-\frac{\lambda}{\eta}\right)\dot{\bar{N}}_1+\\
&+\left(\pi^2\bar{f}-\frac{\lambda}{\eta}\right)\dot{\bar{N}}_2-8\pi^2\eta\,\dot{\bar{M}}=c_1,\\
&\left(3\pi^2\bar{f}-\frac{\lambda}{\eta}\right)4\,\dot{\bar{f}}-9\,\dot{\bar{N}}_1-3\,\dot{\bar{N}}_2=c_2,\qquad (14)\\
&\left(\pi^2\bar{f}-3\frac{\lambda}{\eta}\right)4\,\dot{\bar{f}}-3\,\dot{\bar{N}}_1-9\,\dot{\bar{N}}_2=c_3,\\
&16\pi^2\eta\,\dot{\bar{f}}+18\,\dot{\bar{M}}=0.
\end{aligned}
$$

$$c_1 = 2\bar{N}_0\left(\frac{\lambda}{n} - \pi^2 \bar{f}\right); \; c_2 = c_3 = 6\bar{N}_0 . \qquad (15)$$

$$\frac{d\bar{f}}{dT} = \frac{\Delta_f}{\Delta}; \; \frac{d\overline{N_1}}{dT} = \frac{\Delta_{\bar{N}_1}}{\Delta};$$

$$\frac{d\overline{N_2}}{dT} = \frac{\Delta_{\bar{N}_2}}{\Delta}; \; \frac{d\bar{M}}{dT} = \frac{\Delta_{\bar{M}}}{\Delta} . \qquad (16)$$

$$T = 0 : N_1 = 0; N_2 = 0; M = 0; \bar{f} = \bar{f}_0 . \qquad (16)$$

$$\dot{y}_i = f_i\left(y_1, y_2, y_3, \cdots y_7, t\right), i = 1, 2, 3, 4. \qquad (17)$$

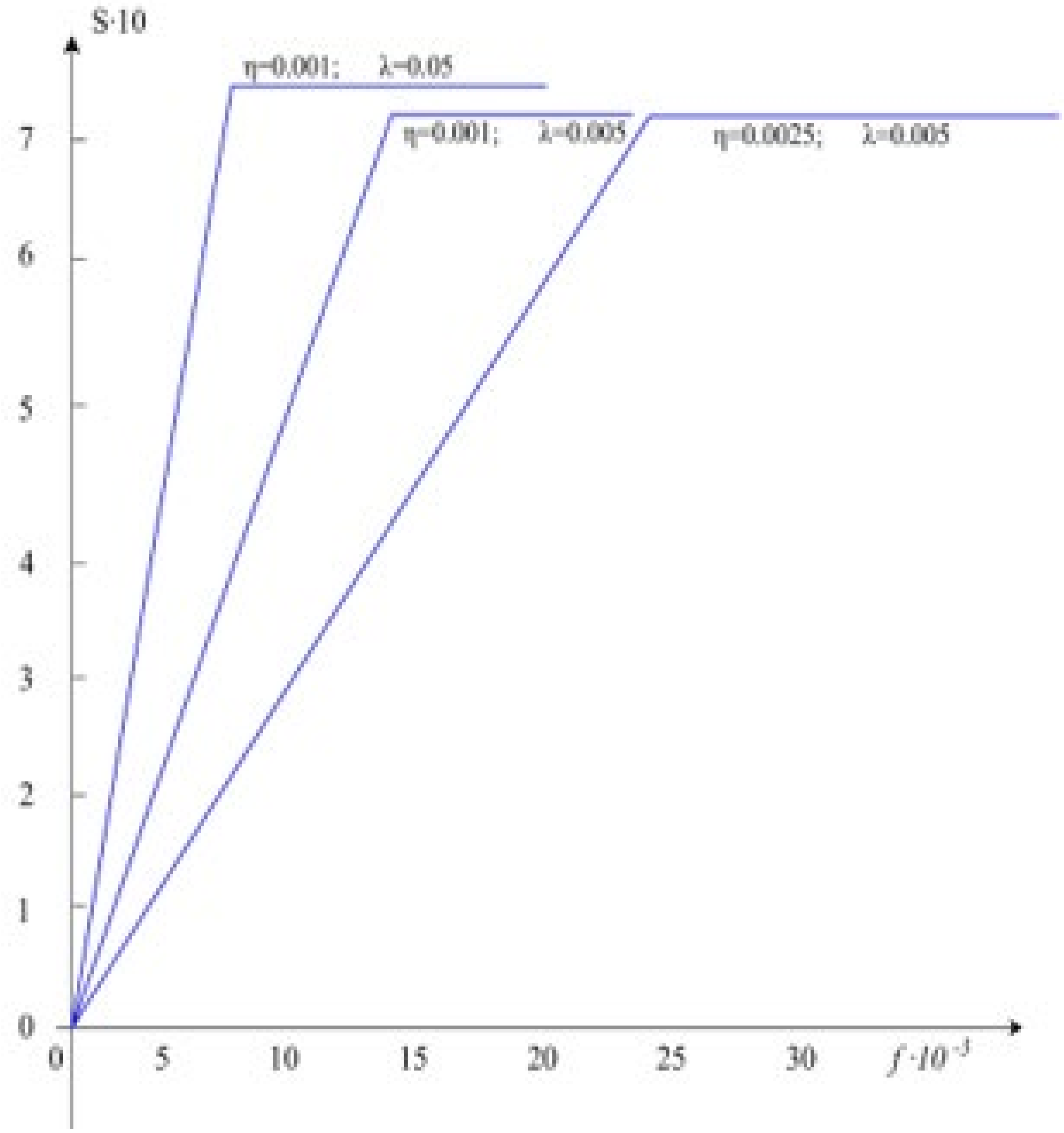
$$y_i^{n+1} = y_i^n + \frac{H}{6}\left(k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i}\right).$$

$$k_{1i} = f_i\left(y_1^n, y_2^n, y_3^n, y_4^n, t^n\right),$$

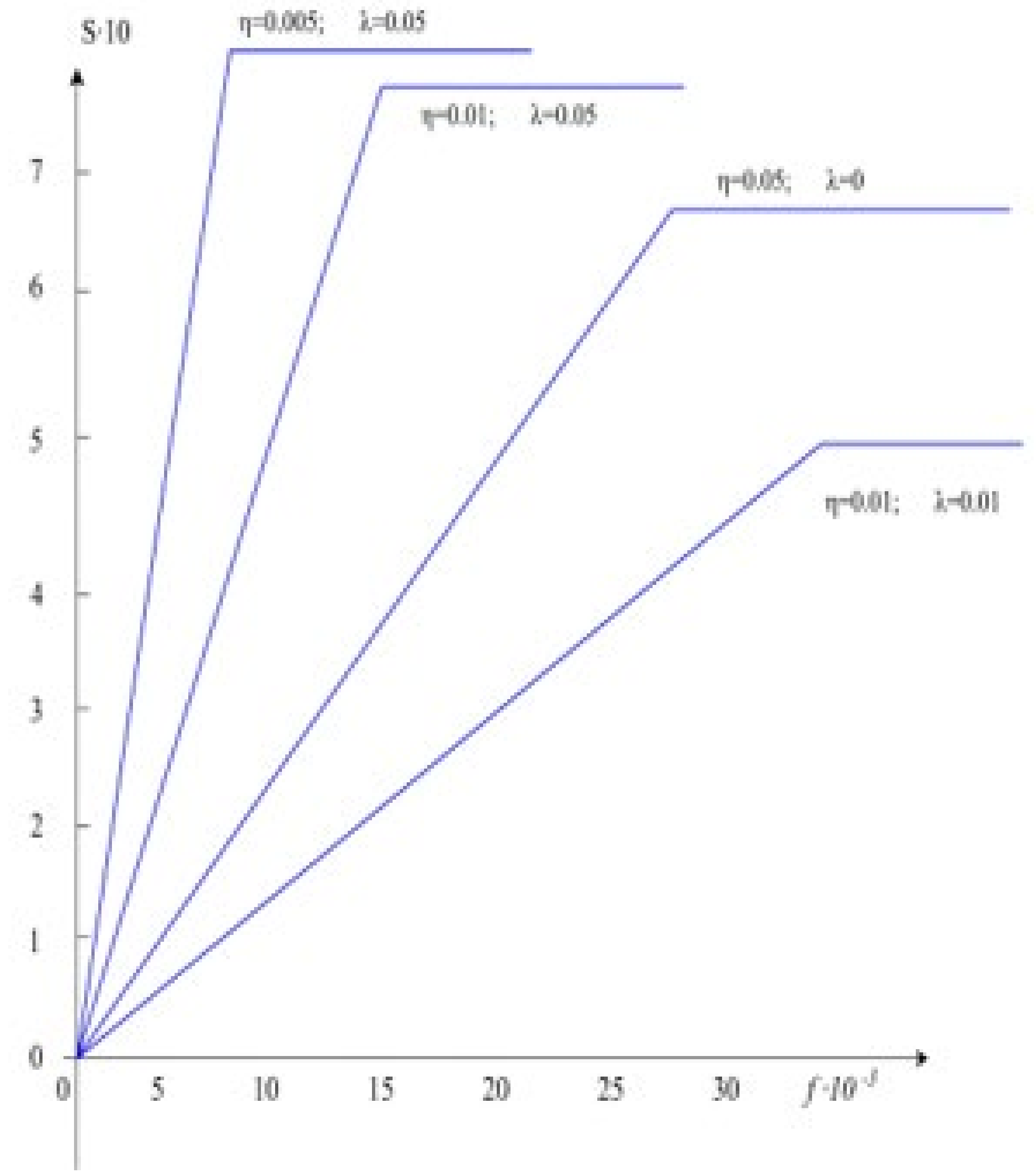
$$k_{2i} = f_i\left(\begin{array}{l} y_1^n + \frac{H}{2}k_{11}, y_2^n + \frac{H}{2}k_{12}, y_3^n + \\ + \frac{H}{2}k_{13}, y_4^n + \frac{H}{2}k_{14}, t^n + \frac{H}{2} \end{array}\right),$$

$$k_{3i} = f_i\left(\begin{array}{l} y_1^n + \frac{H}{2}k_{21}, y_2^n + \frac{H}{2}k_{22}, \\ y_3^n + \frac{H}{2}k_{13}, y_4^n + \frac{H}{2}k_{24}, t^n + \frac{H}{2} \end{array}\right),$$

$$k_{4i} = f_i\left(\begin{array}{l} y_1^n + Hk_{31}, y_2^n + Hk_{32}, \\ y_3^n + \frac{H}{2}k_{13}, y_4^n + Hk_{34}, t^n + H \end{array}\right).$$



S·10
η=0.001; λ=0.05
η=0.001; λ=0.005
η=0.0025; λ=0.005
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
f ·10⁻³



S·10
η=0.005; λ=0.05
η=0.01; λ=0.05
η=0.05; λ=0
η=0.01; λ=0.01
7
6
5
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3
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CONCLUSIONS

Approximations were chosen that satisfy the boundary conditions of displacement, while a thin-walled cylinder made of porous material, rigidly fixed at the ends, loses stability due to thermal expansion.

For a two - dimensional functional , Euler equations were obtained in the form of a system of linear differential equations for the problem under consideration and solved by the fourth - order Runge - Kutta numerical method

It is proved that with an increase in the ratio of λ - thickness to radius, the rate of increase in volume change increases, and with an increase in η - thickness to length, the growth rate decreases.

CONCLUSIONS

The generalized three-dimensional functional for porous bodies has been transformed into a two-dimensional one.

The influence of the environment on the mechanical properties of rods made of polypropylene material was studied experimentally.

The influence of the environment on the durability of rods made of polypropylene material was studied experimentally.

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