UDC 501,66.081

ITERATIVE SIMULATION PROCEDURE ISOLATING RESPIRATORY APPARATUS

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In the simulation of dynamic sorption activity, the equations of mathematical physics are used and the skipping expressions are written in the form of double series in powers of time and coordinates. For a multiple increase in the rate of numerical experimentation, this article proposes an alternative approach to the description of dynamic sorption activity that is not based on the ideology of equations of mathematical physics.

The simulation of the air regeneration process is a classic task of the dynamics of sorption [1], within which the evolution of impurity penetration through the absorber layer is tracked. It is usually solved by methods of mathematical physics in the presence of stationary boundary conditions at the entrance to the filter [2]. However, in an insulating breathing apparatus, a leakage of carbon dioxide is added to the constant component of the concentration of carbon dioxide molecules given by the mode of operation of the apparatus, monotonously increasing as the regenerative cartridge resource is exhausted. In other words, there is a variable concentration of sorbtiv at the entrance to the layer of the absorber. The corresponding formalism analytically describing the dynamic sorption activity in the presence of a variable concentration of the sorbent at the filter inlet is proposed in [3] and reduces to a system of equations:

$$-\omega_{\xi}'(\xi,\tau) = e^{-\tau}\left[e^{-\xi}\omega_0(0) + \int_0^{\tau} e^{\tau} d_{\tau}\,\omega(\xi,\tau)\right], \qquad \tau > 0, \tag{1}$$

$$u(\xi,\tau) = e^{-\tau}\int_0^{\tau} e^{\tau}\omega(\xi,\tau)\,d\tau, \qquad \tau > 0, \tag{2}$$

where τ and ξ – dimensionless time and, respectively, the coordinate (depth of penetration into the layer of the absorber), $\omega(\xi,\tau)$ – reduced concentration of CO_2, $\omega_0(0)$ – its initial value at the filter inlet, $u(\xi,\tau)$ – the proportion of waste product.

Solution (1) can be written as a series

$$\omega(\xi,\tau) = e^{-\xi-\tau}\sum_{n=0}^{\infty}\frac{f_n(\tau)}{n!}\xi^n, \tag{3}$$

which coefficients are connected by a recurrence relation

$$f_{n+1}(\tau) = \int_0^{\tau} f_n(\tau)\,d\tau, \tag{4}$$

allowing by known

$$f_0(\tau) = e^{\tau}\omega_0(\tau) \tag{5}$$

consistently calculate all $f_n(\tau)$ to any number. Expression (5) for $f_0(\tau)$ follows from the form of the series (3) and the boundary condition

$$\omega(0,\tau) = \omega_0(\tau). \tag{6}$$

Relations (1) - (6), involving computer calculations, allow one to quantitatively describe the CO_2 chemisorption in regenerative cartridges of breathing apparatus with a circular scheme of the airway part. For this in (6) instead of $\omega_0(\tau)$ as previously outlined, substitute

$$\omega_0(\tau) = 1 + \omega(\eta,\tau), \tag{7}$$

where η – dimensionless length of the cartridge.

The result is a self-consistent task of determining the desired function $\omega(\xi,\tau)$. To solve it, an iterative procedure with a small parameter is used $\omega(\eta,\tau)$. To obtain a zero approximation in (7), slip should be completely neglected $\omega(\eta,\tau)=0$. In this case, we return to the stationary boundary condition $\omega(0,\tau)=1$, for which the solution of the recurrence relation (4) can be written in an analytical form

$$f_n(\tau)=e^{\tau}-\sum_{k=0}^{n-1}\frac{\tau^k}{k!} \qquad (n=1,\,2,\,\dots)\cdot \tag{8}$$

Substituting (8) into (3), we get

$$\omega 0(\xi,\tau)=e^{-\xi}\left[1+\sum_{n=1}^{\infty}\frac{\xi^n}{n!}\left(1-e^{-\tau}\sum_{k=0}^{n-1}\frac{\tau^k}{k!}\right)\right]. \tag{9}$$

The next step of the iterative procedure, corresponding to the first approximation $\omega 1(\xi,\tau)$, is the substitution of (9) into (7) and the numerical implementation of the recurrent procedure (4). To this end, a special program was written in the MathCAD package environment (figure).

$$\eta := 4 \qquad \xi := 0, 0.1 .. \eta \qquad N := 30 \qquad \beta := 1 \qquad \tau := 0, 0.05 .. \eta + 5$$

$$\omega 0(\xi,\tau) := e^{-\xi}\cdot\left[1+\sum_{n=1}^{N}\left[\frac{\xi^n}{n!}\cdot\left(1-e^{-\tau}\cdot\sum_{k=0}^{n-1}\frac{\tau^k}{k!}\right)\right]\right]$$

$$f0(\tau) := (1+\omega 0(\eta,\tau))\cdot e^{\beta\cdot\tau} \qquad N1 := 80 \qquad k := 0 .. N1 \qquad x_k := 0.05\cdot k$$

$$y1_k := \beta\cdot\int_0^{x_k} f0(\tau)\,d\tau \qquad S1 := \mathrm{cspline}(x,y1) \qquad f1(\tau) := \mathrm{interp}(S1,x,y1,\tau)$$

$$y2_k := \beta\cdot\int_0^{x_k} f1(\tau)\,d\tau \qquad S2 := \mathrm{cspline}(x,y2) \qquad f2(\tau) := \mathrm{interp}(S2,x,y2,\tau)$$

$$y3_k := \beta\cdot\int_0^{x_k} f2(\tau)\,d\tau \qquad S3 := \mathrm{cspline}(x,y3) \qquad f3(\tau) := \mathrm{interp}(S3,x,y3,\tau)$$

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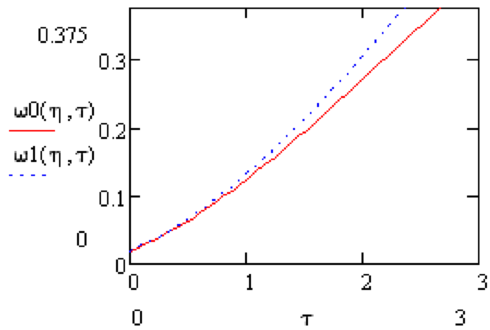
$$y35_k := \beta\cdot\int_0^{x_k} f34(\tau)\,d\tau \qquad S35 := \mathrm{cspline}(x,y35) \qquad f35(\tau) := \mathrm{interp}(S35,x,y35,\tau)$$

$$\omega 1(\xi,\tau) := e^{-\beta\cdot(\xi+\tau)}\cdot\left[f0(\tau)+f1(\tau)\cdot\beta\cdot\xi+f2(\tau)\cdot\frac{(\beta\cdot\xi)^2}{2!}+f3(\tau)\cdot\frac{(\beta\cdot\xi)^3}{3!}+\dots+f35(\tau)\cdot\frac{(\beta\cdot\xi)^{35}}{35!}\right]$$



$$\tau := \eta \qquad \tau(\eta) := \mathrm{root}(\omega 0(\eta,\tau)-0.375,\tau)$$

$$\tau 1 := \eta \qquad \tau 1(\eta) := \mathrm{root}(\omega 1(\eta,\tau 1)-0.375,\tau 1)$$

$$\tau(\eta) = 2.666 \qquad \frac{\tau 1(\eta)}{\tau(\eta)} = 0.884$$

$$\tau 1(\eta) = 2.358$$

Figure. – Program for calculating the evolution of CO_2 leakage through a regenerative cartridge of a breathing apparatus on chemically bound oxygen with a circular pattern of the airway part

Built for $\eta = 4$ using this program, the time dependence of the leakage permits reasonable interpretation. At the beginning, when the CO_2 leakage is insignificant, the dependences constructed for the open (solid) and circular schemes (dashed lines) of the airway part are almost the same. However, as the cartridge's resource is exhausted, the breakthrough in the circular pattern grows faster, as it should be, because the CO_2 molecules that have avoided chemisorption return to inhale, increasing the carbon dioxide content in the exhale. Developing in the specified direction, the process is increasingly moving away from having a place in the open circuit. As a result, the time $\tau_{кр}$ of the onset of the critical CO_2 $\omega_{kp} = 0,375$ leakage decreases by 11,6%.

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