needs to solve the task by having chosen earlier algorithm. Also in the program, there is a test mode with disabled tips, but there is a time limit for the solution of the task, and by the end of solving the task the number of errors and the full course of solutions are shown.

In the program includes both the generation of a task with a certain level of complexity and the loading of a previously created task.

The screenshot of the program is shown in Figure.

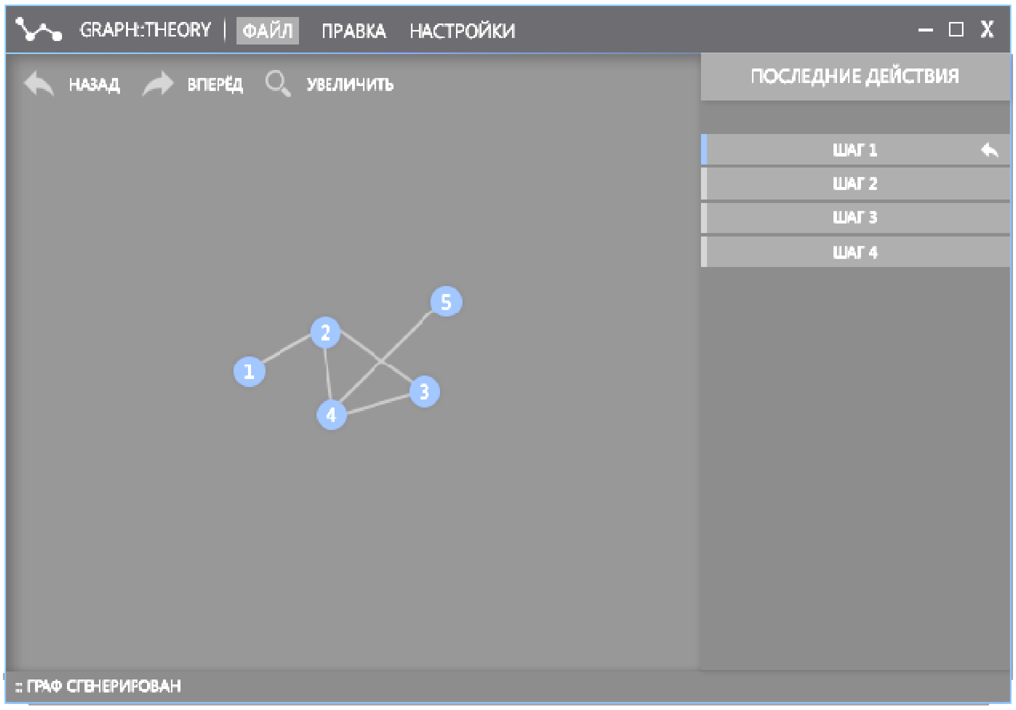

Fig. Screenshot of program

REFERENCES

1. Graph_theory [Electronic Resourse] / Wikipedia.org. – Mode of Access: https://en.wikipedia.org/wiki/Graph_theory. – Date of Access: 01.01.2015.
2. Graph Theory [Electronic Resourse] / Primes.utm.edu. – Mode of Access: http://primes.utm.edu/graph/. – Date of Access: 27.12.2014.
3. Johnsonbaugh, Richard. Discrete Mathematics / Richard Johnsonbaugh. – 7th edition. – Prentice Hall, 2008.
4. Конечная математика // Большая Сов. энциклопедия: в 30 т. / гл. ред. А.М. Прохоров. – 3-е изд. – М. : Сов. энциклопедия, 1969 – 1978.

UDC 622.867.322;614.894

IMITATION OF THE BREATHING APPARATUS OPERATION ON CHEMICALLY BONDED OXYGEN AFTER THE CHANGES IN ITS OPERATION MODE

E. POTAPENKO, S. ALSHANIKAU, SERGEI EKHILEVSKIY
Polotsk State University, Belarus

Recordkeeping of the initial clogging of the regenerative cartridge [1, 2] is necessary to imitate real situations that arise at the exploitation of the mine rebreather. Among them are the following items: the change of the air filtration rate at the variation of work load, reverse of the air flow if there are pendulum or combined junctions of the airway, and so on.

In this paper we will consider the operation of the breathing apparatus after the change in its operation mode due to the decrease in the filtration rate of the air recovered. Since in the problems considered a new structure of the working sorbent layer is formed if there is its initial contamination, we will use the formalism offered in [2]:

$$-\omega'_{\xi}(\xi,\tau) = \omega(\xi,\tau) - e^{-\tau}\left[u(\xi,0) + \int_0^{\tau} e^{\tau}\omega(\xi,\tau)d\tau\right],\ \tau \geq 0 \tag{1}$$

$$u(\xi,\tau) = e^{-\tau}\left(u(\xi,0) + \int_0^{\tau} e^{\tau}\omega(\xi,\tau)d\tau\right),\ \tau \geq 0 \tag{2}$$

where $\omega(\xi,\tau)$ and $u(\xi,\tau)$ are the reduced volume concentrations of CO_2 molecules and fixed carbon respectively, ξ and τ are the dimensionless coordinate and time connected with the depth of penetration into the filter x and the operating period of the apparatus t through the ratios

$$\xi = \beta x / v,\ \tau = \beta\gamma t, \tag{3}$$

where v is the rate of filtration, β and γ are phenomenological constants characterizing the rate and resource of the reaction of CO_2 fixation

In the offered arrangement $u(\xi,0)$ is the known initial clogging of the cartridge, which influence on the sorption dynamics is the purpose of the present study.

According to [2], the solution of (1) can be represented as a series in powers of ξ

$$\omega(\xi,\tau) = e^{-\tau}\sum_{n=0}^{\infty}\frac{f_n(\tau)}{n!}\xi^n, \tag{4}$$

which variables coefficients are determined by a recursive procedure

$$f_{n+1}(\tau) = u_{\xi}^{(n)}(0,0) + \int_0^{\tau} f_n(\tau)\,d\tau - f_n(\tau),\ n = 0, 1, 2\ ... \tag{5}$$

which start is provided by the relation which follows from (4) with $\xi = 0$

$$f_0(\tau) = e^{\tau}\omega(0,\tau), \tag{6}$$

providing the influence of a variable boundary condition on the dynamics of sorption activity. The dependence of $\omega(\xi,\tau)$ on the initial clogging $u(\xi,0)$, in accordance with the Maclaurin's formula, was included in (5) through its derivatives at the filter inlet

$$u(\xi,0) = \sum_{n=0}^{\infty}\frac{u_{\xi}^{(n)}(0,0)}{n!}\xi^n. \tag{7}$$

Relations (4) - (6) allow to find $\omega(\xi,\tau)$ by the known $\omega(0,\tau)$ and $u(\xi,0)$, when we substitute the result in (2) we can calculate $u(\xi,\tau)$, thus completing the solution of the heterogeneous and non-stationary problem of sorption dynamics.

In particular, if there is no initial clogging ($u(\xi,0) = 0$) the relations (1), (2) will take the form

$$-\omega'_{\xi}(\xi,\tau) = \omega(\xi,\tau) - e^{-\tau}\int_0^{\tau} e^{\tau}\omega(\xi,\tau)d\tau, \tag{8}$$

$$u(\xi,\tau) = e^{-\tau}\int_0^{\tau} e^{\tau}\omega(\xi,\tau)d\tau. \tag{9}$$

Performing integration by parts in (8) we obtain

$$-\omega'_{\xi}(\xi,\tau) = e^{-\tau}\left[\omega(\xi,0) + \int_0^{\tau} e^{\tau}d_{\tau}\omega(\xi,\tau)\right]. \tag{10}$$

It follows from (10) where $\tau = 0$

$$\omega(\xi,0) = \omega(0,0)e^{-\xi}. \tag{11}$$

Considering this, it is convenient to look for the solution of (10) in the form

$$\omega(\xi,\tau)=e^{-\xi-\tau}\sum_{n=0}^{\infty}\frac{f_n(\tau)}{n!}\xi^n\ , \tag{12}$$

выделив $e^{-\xi}$ в качестве множителя. Благодаря чему исчезает последнее слагаемое в (5)ю

having singled out $e^{-\xi}$ as a multiplier factor. Thereby the last summand disappears in (5)

$$f_{n+1}(\tau)=\int_0^{\tau} f_n(\tau)\,d\tau\,. \tag{13}$$

With $\xi=0$ condition (16) follows from (12), which at a constant concentration of the solute at the filter inlet ($\omega(0,\tau)=1$) will take the form

$$f_0(\tau)=e^{\tau}\,. \tag{14}$$

The solution of the recurrence relation (13), (14) is

$$f_n(\tau)=e^{\tau}-\sum_{k=0}^{n-1}\frac{\tau^k}{k!}\,,\ n=1,\,2\,... \tag{15}$$

Substituting (14), (15) into (12) we obtain the dependence of CO_2 breakthrough on time and coordinate with zero initial clogging of the cartridge and a constant concentration of CO_2 at the filter inlet

$$\omega 1(\xi,\tau)=e^{-\xi-\tau}\left[\,f_0(\tau)+\sum_{n=1}^{\infty}\frac{\xi^n}{n!}\,f_n(\tau)\right]=\,e^{-\xi}\left[1+\sum_{n=1}^{\infty}\frac{\xi^n}{n!}\left(1-e^{-\tau}\sum_{k=0}^{n-1}\frac{\tau^k}{k!}\right)\right]. \tag{16}$$

Using (9) we will find the corresponding (16) clogging of the cartridge

$$u1(\xi,\tau)=e^{-\xi}\sum_{n=0}^{\infty}\frac{\xi^n}{n!}g_n(\tau)\ \equiv 1-e^{-\tau}\left(1+e^{-\xi}\sum_{n=1}^{\infty}\frac{\xi^n}{n!}\sum_{k=1}^{n}\frac{\tau^k}{k!}\right), \tag{17}$$

wherein

$$g_n(\tau)=1-e^{-\tau}\sum_{k=0}^{n}\frac{\tau^k}{k!}\,. \tag{18}$$

We will assume that before the change in the operation mode of the apparatus the clogging of the cartridge evolved in accordance with the formulas (17) and (18). Then, at the point in time $\tau 1$ the filtration rate α has changed. At the same time, in accordance with (3), the dimensionless length of the cartridge will change at α^{-1}. That is, if we imply ξ as a dimensionless coordinate after the change in the mode of breathing, it is necessary to substitute $u1(\alpha\xi,\tau)$ as the initial clogging in (1), (2). For the recurrent procedure (5) the derivatives of this function by ξ will be required at the inlet of the cartridge

$$\frac{\partial^n u1(\alpha\xi,\tau)}{\partial\xi^n}\Big|_{\xi=0}=\alpha^n\,\frac{\partial^n u1(\xi,\tau)}{\partial\xi^n}\Big|_{\xi=0}\ . \tag{19}$$

According to (17) we have the equations

$$u1_{\xi}^{'}(\xi,\tau)=-e^{-\xi}\sum_{n=0}^{\infty}\frac{\xi^n}{n!}g_n(\tau)+e^{-\xi}\sum_{n=1}^{\infty}\frac{\xi^{n-1}}{(n-1)!}g_n(\tau)\ ,$$

$$u1_{\xi}^{'}(0,\tau)=-g_0(\tau)+g_1(\tau)\ ,$$

$$u1_{\xi}^{''}(\xi,\tau)=e^{-\xi}\sum_{n=0}^{\infty}\frac{\xi^n}{n!}g_n(\tau)-2e^{-\xi}\sum_{n=1}^{\infty}\frac{\xi^{n-1}}{(n-1)!}g_n(\tau)+e^{-\xi}\sum_{n=2}^{\infty}\frac{\xi^{n-2}}{(n-2)!}g_n(\tau)\,,$$

$$u1_{\xi}^{''}(0,\tau)=g_0(\tau)-2g_1(\tau)+g_2(\tau)\,.$$

By analogy,

$$u1_{\xi}^{'''}(0,\tau)=-g_0(\tau)+3g_1(\tau)-3g_2(\tau)+g_3(\tau)\,,$$

which allows to observe a common pattern

$$u1_{\xi}^{(n)}(0,\tau) = \sum_{k=0}^{n} (-1)^{n-k} C_n^k g_k(\tau) , \tag{20}$$

where C_n^k are the numbers of combinations from n of objects of k .

That is, in accordance with the above stated and the formulas (19), (20) and (18) we shall replace in (5)

$$u_{\xi}^{(n)}(0,0) = u1_{\xi}^{(n)}(\alpha\xi,\tau1)\Big|_{\xi=0} = \alpha^n \sum_{k=0}^{n} (-1)^{n-k} C_n^k \left(1 - e^{-\tau1} \sum_{m=0}^{k} \frac{\tau1^m}{m!}\right) . \tag{21}$$

At the same time, to start the iteration procedure it is necessary to use the formula (14) for a change in the filtration rate does not change the content of CO_2 at the expiration.

We have considered a situation where a three-fold deceleration of the air flow ($\alpha = 1/3$) increases the dimensionless length of the cartridge to $\eta = 10$. According to [3, 4], this corresponds to the self-rescuer with the mass of the oxygen containing product of 1 kg during the transition from the 10th breathing mode (close to the maximum load during the rapid evacuation of a miner from the accident area) to the 3rd (lower than the average load during a quiet exit of the miner from the accident area).

It can be seen (Fig. 1) that a deceleration in the rate of air filtration done at the moment $\tau1 = 2.077$ of CO_2 critical breakthrough ($\omega1(\eta,\tau1) = 0.375$) has led to a longer stay of carbon dioxide molecules in the layer of the chemisorbent and, as the result, dec;ine of their content in the regenerated air (curve 2). This occurs almost instantaneously ($\tau = 0$) (during the flow of the slow front through the filter). Then a gradual (evolutionary) growth in CO_2 concentration begins due to the further gradual exhaustion of the regenerative cartridge absorbing resource. Finally, at moment $\tau = \tau2 = 2.078$ a critical breakthrough of CO_2 is achieved again (curve 3) in the already weakened operation of the breathing apparatus. We shall note that thus the time of the protective action of the apparatus increases by 100% ($\tau2/\tau1 = 1$).

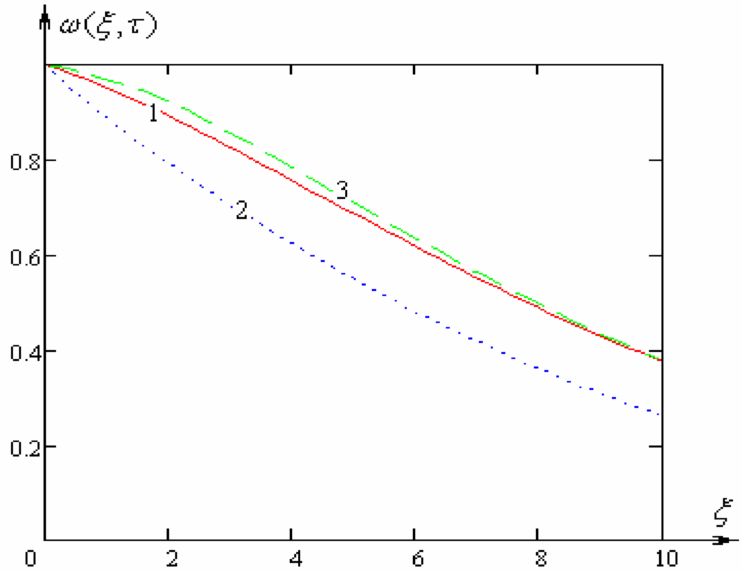

Fig. 1. The change of CO_2 critical breakthrough (curve 1)
after air deceleration: 2 – $\tau = 0$; 3 – $\tau = \tau2$

It is essential that curve 3 is more convex than curve 1 which describes the reduced concentration at the critical breakthrough, but before the flow deceleration. This means the formation of a new structure of the working layer of the sorbent after the change of breathing mode. Slower CO_2 molecules fix at the same time to a narrower layer of the absorbent. In the result the front part of the working sorbent is loaded and its resource is exhausted more quickly. For this reason, the decline of curve 3 in the front layer of the cartridge is slower than that of curve 1. At the end of the cartridge the curves intercross, the working sorbent layer became narrower after the filtration speed deceleration.

This can be seen by considering the evolution of the fixed carbon distribution in the cartridge (Fig. 2). In contrast to CO_2 breakthrough the change of clogging does not undergo a leap at the moment of the deceleration of the airflow ($u1(\alpha\xi,\tau1) = u(\xi,0)$). Both of these functions describe curve 1.

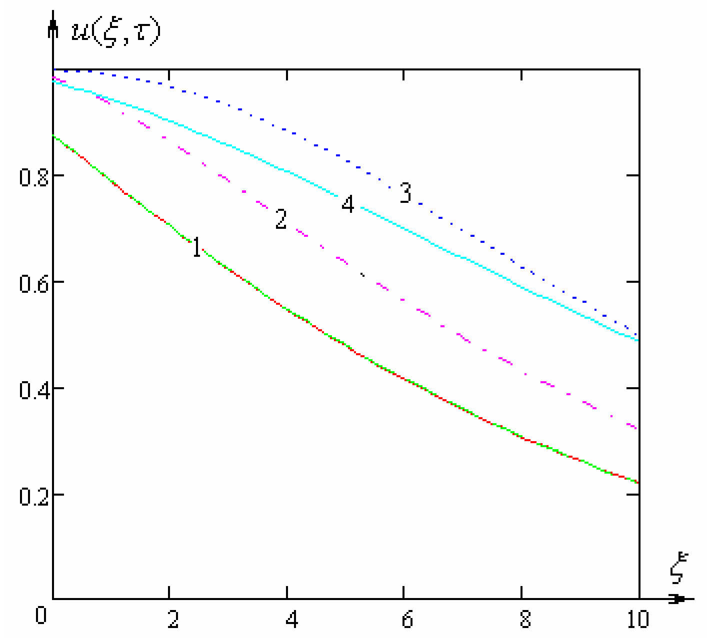

Fig. 2. The evolution of the cartridge workout after the critical CO_2 breakthrough (curve 1) with the deceleration of the airflow 2 – $\tau = \tau2$; 3 – $\tau = 5$ and without it (curve 4)

Curve 2 corresponds to the moment $\tau2$ when the second critical breakthrough is achieved. Obviously, when there is a change of the device mode the moment of the critical breakthrough (increase in lifetime) cannot be used to measure the protective action growth. According to [5] the average clogging of the cartridge should be used for that. In this case, its growth is 28.3%, which is equal to the relative difference of the areas under curves 1 and 2.

Curve 3 corresponds to the moment $\tau = 5$ after the change of the device mode. To compare that, Fig. 3 shows curve 4 which corresponds to the same number of CO_2 molecules, entered into the cartridge after $\tau1$ which works in the former mode $\omega1(\xi,\tau1+\alpha\cdot 5)$. Due to the higher speed of filtration the breakthrough is higher, and the degree of the oxygen containing product workout is lower. At this, curve 3 is more convex than curve 4, which confirms again the narrowing of the working layer of the sorbent.

Thus, we have developed a formalism which allows to imitate air regeneration in the rebreather after changing its mode of operation.

REFERENCES

1. Кримштейн, А.А. Решение задачи изотермической динамики сорбции при произвольных граничных и начальных условиях / А.А. Кримштейн // Тр. 1-й науч.-техн. конф. ТНИХИ «Динамика сорбции и ее практическое положение», Тамбов. – 1974. – С. 3 – 8.
2. Ехилевский, С.Г. Влияние начальной загрязненности регенеративного патрона на работу шахтного респиратора на химически связанном кислороде / С.Г. Ехилевский, Е.П. Потапенко, О.В. Голубева // Изв. вузов. Горный журнал. – 2014. – (в печати).
3. Значения феноменологических параметров модели хемосорбции в регенеративных патронах шахтных респираторов / В.В. Пак [и др.] // Изв. вузов. Горный журнал. – 1998. – № 11 – 12. – С. 108 – 112.
4. Диденко, Н.С. Регенеративные респираторы для горноспасательных работ / Н.С. Диденко. – М. : Недра, 1990. – 160 с.
5. Оценка повышения эффективности использования ресурса дыхательного аппарата на химически связанном кислороде / С.Г. Ехилевский [и др.] // Изв. Донецк. горного ин-та. – 2013. – № 2. – С. 113 – 120.