UDC 622.85

DOI: 10.29202/nvngu/2019-3/13

Yu. I. Cheberiachko, Cand. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0001-7307-1553,
I. M. Cheberiachko, Cand. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0002-6193-5729,
M. M. Odnovol,
orcid.org/0000-0002-2022-7996,
L. S. Koriashkina, Cand. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0001-6423-092X

Dnipro University of Technology, Dnipro, Ukraine, e-mail: cheberiachkoyi@ukr.net

DEVELOPING A MATHEMATICAL MODEL OF LINKAGE PARAMETERS OF AIR FLOW IN A FILTER BOX

Purpose. Using the mathematical model, to study the air velocity flow in a filter box of a respirator taking into account its inluence on the geometric parameters and protective efficiency.

To define the influence of geometric parameters of a filter box on kinematic characteristics and its protective efficiency.

Methodology. To develop the mathematical model, the method of analysis and synthesis was applied. In the course of the analysis, the filter box was divided into a number of zones for estimation of the motion process of dust and gas flows. The synthesis method was used to describe the motion of a two-phase dust-laden flow in the cylindrical coordinate system r, z, θ in Eulerian variables.

Findings. Geometrical parameters of a filter box of a respirator have been optimised including the outlet port diameter; confusor height; outlet port shifting regarding the filter box centre.

Originality. A new technique for optimization of the geometrical parameters of a filter box of a respirator based on the mathematical model was presented. Dependencies of distribution of air flow velocities for filter boxes of different geometry have been obtained and dependencies between its aerodynamic and geometrical parameters have been established.

Practical value. The results allow defining the parameters of a filter box with minimum resistance to the air flow and improving protective efficiency of the respirator.

Keywords: *respirator, filter box, mathematical modelling, finite-element method, method of local variations, least square method*

Introduction. Protective properties of respirators are determined by insulating properties of a half-mask and parameters of a filter box with a filter. The latter ones influence the distribution of air flows in them considerably [1], which results in uneven flow distribution throughout the filter as well as in occurrence of dead zones which do not participate in the filtration process, thus, decreasing a service period of a dust respirator significantly. The air flow is influenced by the ratio of the sizes of the inlet and outlet ports inside the filter box along with their location regarding each other [2]. At the same time particles settle unevenly on some filter segments whereas others do not participate in dust collection [3, 4]. Therefore, design solutions contribute to uneven aerosol particle deposition over the filter, which results in decreasing its protective efficiency. Thus, research on dependence of linkage parameters of the air flow on changes in the filter box geometry is an urgent task.

Literature review. Regarding the issue under consideration, research works [5, 6] were reviewed. Most of them deal with choosing filtering material and determining the influence of their structure (the fibre diameter, packaging density and width) on the respirator protection coefficient. The latest research is directed at studying the issues of aerosol particle deposition on fibres of various sizes through computer modelling [7, 8]. They pay much attention to calculations of density of multilayer filter packaging. Studying of changes in filter resistance when polydisperse particles are settling is also of interest.

Work [9] considers issues of even distribution throughout the filter area for extensive corrugation. The purpose of the work is to estimate the filter configuration and, thus, increase its operational life. The authors in [10] established that optimization of a filter box and decrease in the value of pressure drop occur with structural changes in the back of a filter box in the form of a confusor, which reduces the number of dead zones and nonuniformity of the flow velocity distribution. That is why the major geometric parameters which influence the uniformity of the velocity distribution include the outlet port diameter of a filter box, confusor height and outlet port shifting regarding the filter box centre.

Statement of problem. Present-day respirators have filter boxes with a limited size due to design features of half-masks. It is considered that the decrease in the filtration rate occurs because of a sufficiently large area of the filtering material placed inside the filter box. However, the influence of the major geometric parameters of the filter box is not considered, whereas according to the

---

experimental studies [11] it can degrade filter operation significantly. Thus, a crucial task arises to analyse linkage parameters of the air flow inside the filter box in relation to the geometry changes.

The purpose of the article is to to study the air velocity flow in the filter box of a respirator using the mathematical model and taking into account its inluence on the geometric parameters and protective efficiency.

Basic theoretical part. To achieve the objective let us apply the mathematical model presented in [12] whose implementation resolves itself to solution of a boundary-value problem for the system of four partial nonlinear differential equations. It describes the motion of a two-phase dust-laden flow in the cylindrical coordinate system r, z, θ in Eulerian variables.

$$\begin{cases} V_r \dfrac{\partial V_r}{\partial r} + V_\theta \dfrac{\partial V_r}{r\partial\theta} + V_z \dfrac{\partial V_r}{\partial z} + \dfrac{V_\theta{}^2}{r} = -\dfrac{1}{\rho}\dfrac{\partial P}{\partial r} \\ V_r \dfrac{\partial V_\theta}{\partial r} + V_\theta \dfrac{\partial V_\theta}{r\partial\theta} + V_z \dfrac{\partial V_\theta}{\partial z} + \dfrac{V_r V_\theta}{r} = -\dfrac{1}{\rho}\dfrac{\partial P}{r\partial\theta} \\ V_r \dfrac{\partial Vz}{\partial r} + V_\theta \dfrac{\partial Vz}{r\partial\theta} + V_z \dfrac{\partial V_z}{\partial r} = -\dfrac{1}{\rho}\dfrac{\partial P}{\partial z} \\ \dfrac{1}{r}\dfrac{\partial\left(r\rho V_r\right)}{\partial r} + \dfrac{1}{r}\dfrac{\partial\left(\rho V_\theta\right)}{\partial\theta} + \dfrac{\partial\left(\rho V_z\right)}{\partial r} = 0 \end{cases}, \qquad (1)$$

where V_θ, V_r, V_z are tangential, radial and axial velocities in the filter box, m/s; r, z are the current radius and research field width, m; P, ρ are pressure and density of the flow in the filter box, pascal, kg/m^3.

For computer-aided solution of this system of equations, let us write the system of equations (1) as dimensionless form. This will allow obtaining characteristics of process behaviour mode by simple conversion calculation according to the transition coefficients obtained while solving this system.

Let us select the initial parameters: V_0 is the filter input velocity; ρ is the flow density at the filter input; R_K is the radius of the filter box.

Then

$$\begin{gathered} V'_\theta = \frac{V_\theta}{V_0};\ \ V'_z = \frac{V_z}{V_0};\ \ V'_r = \frac{V_r}{V_0};\ \ \rho' = \frac{\rho}{\rho_0};\ \ p' = \frac{p}{p_0}; \\ H' = \frac{H}{R_b};\ \ R'_0 = \frac{R_0}{R_b};\ \ r' = \frac{r}{R_b};\ \ z' = \frac{z}{R_b}. \end{gathered} \qquad (2)$$

Conducting rearrangements of the system of equations (1, 2), we will obtain equations of the dust and gas flow motion and continuity in filter zones in dimensionless form

$$\begin{cases} \dfrac{1}{r}\rho V_r + \dfrac{\partial\rho}{\partial r}V_r + \dfrac{\partial V_r}{\partial r}\rho + V_z\dfrac{\partial\rho}{\partial z} + \dfrac{\partial V_z}{\partial z}\rho = 0 \\ V_r\dfrac{\partial V_r}{\partial r} + V_z\dfrac{\partial V_r}{\partial z} - \dfrac{\left(V_\theta\right)^2}{r} = -\dfrac{RT}{V_0^2}\dfrac{1}{\rho}\dfrac{\partial\rho}{\partial r} + k_f V_r \dfrac{R_b}{V_0^2} \\ V_r\dfrac{\partial V_\theta}{\partial r} + V_z\dfrac{\partial V_\theta}{\partial z} + \dfrac{V_r V_\theta}{r} = k_f V_\theta \dfrac{R_b}{V_0^2} \\ V_r\dfrac{\partial V_z}{\partial r} + V_z\dfrac{\partial V_z}{\partial z} = -\dfrac{RT}{V_0^2}\dfrac{1}{\rho}\dfrac{\partial\rho}{\partial z} + k_f V_z \dfrac{R_b}{V_0^2} \end{cases}, \qquad (3)$$

where k_f is the frequency factor of collision of particles with the filter; R is the gas constant; T is the temperature of the dust-laden flow.

To solve the system of equations (3) under specified boundary conditions let us apply the least square method [8, 13]. Let us consider the algebraic and differential form of simultaneous equations

$$f_1(u_1(x, y, z), \ldots, u_n(x, y, z)) = 0, \quad j = 1, 2, 3, \ldots, n, \qquad (4)$$

where x, y, z are points of a certain domain Ω.

Let us introduce the functional related to this system (4)

$$I\left[u_1, u_2, \ldots, u_n\right] = \int_\Omega \sum_{j=1}^{n} f_j^2\left(u_1\left(x,y,z\right), \ldots, u_n\left(x,y,z\right)\right) d\Omega. \qquad (5)$$

It is easy to show that providing the functions $u_1^*(x,y,z), \ldots, u_n^*(x,y,z)$ satisfy the system of nonlinear equations for all x, y, z from the domain Ω, the functional (5) becomes zero. On the other hand, it is evident that providing $f(u_1, u_2, \ldots, u_n) \geq 0$, whereby the equality sign is attained only at the functions $u_1^*(x,y,z), \ldots,$ $u_n^*(x,y,z)$ satisfying the system of equations (3), the solution of the system (3) provides the functional (5) with the least value. Therefore, the task of solving the system of nonlinear equations (3) can be replaced by the task of minimizing the functional (5). Such substitution of one task with another allows developing simple and efficient numerical algorithms.

Taking into account the axial symmetry, the integral (5) is decomposed into a double integral of the following form

$$I\left[V_\theta, V_z, V_r, \rho\right] = \int_0^R \int_0^H \left\{ \begin{aligned} & \left[\frac{1}{r}\rho V_r + \frac{\partial\rho}{\partial r}V_r + \frac{\partial V_r}{\partial r}\rho + V_z\frac{\partial\rho}{\partial z} + \frac{\partial V_z}{\partial z}\rho\right]^2 + \\ & + \left[V_r\frac{\partial V_r}{\partial r} + V_z\frac{\partial V_r}{\partial z} - \frac{\left(V_\theta\right)^2}{r} + \frac{RT}{V_0^2}\frac{1}{\rho}\frac{\partial\rho}{\partial r} - k_f V_r\frac{R_b}{V_0^2}\right]^2 + \\ & + \left[V_r\frac{\partial V_\theta}{\partial r} + V_z\frac{\partial V_\theta}{\partial z} + \frac{V_r V_\theta}{r} - k_f V_\theta\frac{R_b}{V_0^2}\right]^2 + \left[V_r\frac{\partial V_z}{\partial r} + V_z\frac{\partial V_z}{\partial z} + \frac{RT}{V_0^2}\frac{1}{\rho}\frac{\partial\rho}{\partial z} - k_f V_z\frac{R_b^2}{V_0^2}\right]^2 \end{aligned} \right\} drdz. \qquad (6)$$

Since the motion of the dust-laden flow in the filter box is asymmetrical, only coordinates r, z will be its significant arguments of the required functions.

The next step of numerical solution of the task involves discretisation of the extremum problem for the functional (5). For discretisation, the finite-element method is used [14–16]. Based on the finite-element method it is necessary to divide the area of study into triangular elements as is shown in Fig. 1.

Within the limits of a finite element each of the the required functions $V_\theta(r, z)$, $V_z(r, z)$, $V_r(r, z)$, $\rho(r, z)$ is approximated using the linear expression according to the variables r, z

$$\begin{cases} V_\theta(r,z) = a_0 + a_1 r + a_2 z \\ V_r(r,z) = b_0 + b_1 r + b_2 z \\ V_z(r,z) = c_0 + c_1 r + c_2 z \\ \rho(r,z) = d_0 + d_1 r + d_2 z \end{cases}. \qquad (7)$$

Invariables $a_0, a_1, \ldots, d_0, d_1, d_2$ are expressed in terms of the function values at mesh nodes belonging to the given triangle. Within the introduced approximation, we obtain the partial differential coefficients

$$\frac{\partial V_\theta}{\partial r} = a_1; \quad \frac{\partial V_\theta}{\partial z} = a_2; \quad \ldots; \quad \frac{\partial \rho}{\partial r} = d_1; \quad \ldots. \qquad (8)$$

Let us substitute expression (7) for V_θ, V_z, V_r, ρ and for their partial differential coefficients to the functional (5). Further we evaluate the integral (6) using the simplest investigations [17–19] according to which the integral is substituted with the sum of the product of finite element areas by the value of the subintegral function in the centres of these elements.

Let us satisfy boundary conditions assuming that the required functions at the nodes belonging to the border take up specified values. Then, the task resolves itself to defining the values of the required functions V_θ, V_z, V_r, ρ at the mesh nodes of the finite elements based on the condition for minimum of the multivariable functional occurring with integral approximation.

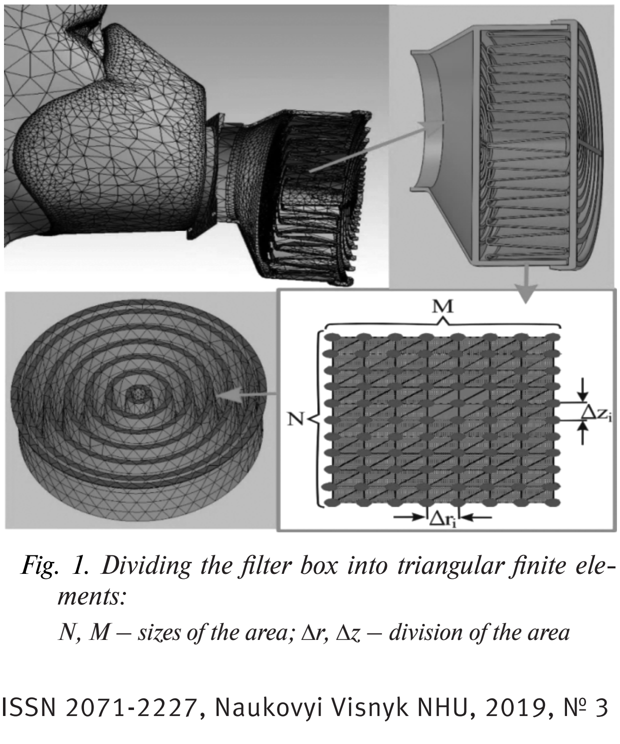

Fig. 1. Dividing the filter box into triangular finite elements:

N, M – sizes of the area; Δr, Δz – division of the area

Using the method of local variations the solution of minimisation problem is defined as a result of successive approximations – iterations. During one iteration, successive single-fold "improvement" of nodal values occurs in such a way that the minimised function decreases at every step. Let us assume that iterations of the method of local variations have been completed; as a result, values $V_i^{(k)}, V_{zi}^{(k)}, V_{ri}^{(k)}, \rho_i^{(k)}$ are obtained. The superscript within the brackets shows an iteration number, while the subscript indicates a mesh node number. Then, let the first nodal values V_θ, V_z, V_r, ρ, on the $(K + 1)^{th}$ iteration have been revised and they are equal to

$$V_{\theta i}^{(k+1)}, V_{zi}^{(k+1)}, V_{ri}^{(k+1)}, \rho_i^{(k+1)} \quad \text{with} \quad i \le m. \qquad (9)$$

Let us calculate the values $V_{\theta(m+1)}^{(k+1)}, V_{z(m+1)}^{(k+1)}, V_{r(m+1)}^{(k+1)}, \rho_{(m+1)}^{(k+1)}$ according to the method of local variations. Let us choose certain $\delta > 0$ called a variability step. As value $V_{(m+1)}^{(k+1)}$ we take one of the variables

$$V_{(m+1)}^{(k)} - \delta, V_{(m+1)}^{(k)}, V_{(m+1)}^{(k)} + \delta. \qquad (10)$$

The choice is made based on the condition for minimum of the multivariable function with fixed values of other variables which are eqaul to

$$\begin{gathered} V_{\theta 1} = \begin{cases} V_{\theta i}^{(k+1)}, & i \le m \\ V_{\theta i}^{(k)}, & i > m+1 \end{cases}; \\ V_{r1} = \begin{cases} V_{ri}^{(k+1)}, & i \le m \\ V_{ri}^{(k)}, & i > m+1 \end{cases}; \\ V_{z1} = \begin{cases} V_{zi}^{(k+1)}, & i \le m \\ V_{zi}^{(k)}, & i > m+1 \end{cases}; \\ \rho_1 = \begin{cases} \rho_i^{(k+1)}, & i \le m \\ \rho_i^{(k)}, & i > m+1 \end{cases}. \end{gathered} \qquad (11)$$

Having obtained $V_{\theta(m+1)}^{(k+1)}$, we define $V_{r(m+1)}^{(k+1)}$ in a similar way, then $V_{z(m+1)}^{(k+1)}$ and proceed to the node $m + 2$.

If, as a result of the iteration

$$\begin{gathered} V_{\theta i}^{(k+1)} = V_{\theta i}^{(k)}; \quad V_{ri}^{(k+1)} = V_{ri}^{(k)}; \quad V_{zi}^{(k+1)} = V_{zi}^{(k)}; \\ \rho_i^{(k+1)} = \rho_i^{(k)}, \end{gathered} \qquad (12)$$

the velocities and density (12) are equal for almost all the mesh nodes, the value of the variability step will halve, and will be repeated in the process of local variability.

Results of mathematical modelling. Research techniques include calculation of finite elements and local variations of linkage parameters of dust-laden air flow throughout the filter box with its present geometric parameters based on the mathematical model using the finite element method.

The initial data for the calculation based on the mathematical model are presented in Table.

Table

Estimated characteristics (Fig. 2)

Filter box parameters	Value	Filter parameters	Value
Box radius R_b, mm	45	Initial resistance to the air flow P, pascal	20
Inlet port radius r_b, mm	15–30	Filter area S, mm^2	460
Box height H, mm	30	Airflow rate l/min	30
Confusor height h, mm	5–20	Outlet port shifting, mm	0–20

The number of iterations and computational accuracy of the results obtained were predetermined. The iterations are terminated if the value of variability step grows smaller than the given permissible error. To make the algorithm operate, it is necessary to define the initial approximation – values $V_{\theta i}^{(0)}, V_{zi}^{(0)}, V_{ri}^{(0)}, \rho_i^{(0)}$ at the mesh nodes. Average rates were calculated according to the filter cross-section area and airflow rate in the filter box. The algorithm described converges without regard to choosing the initial approximation; however, to accelerate the iteration of the process it is desirable to choose the approximation which corresponds in nature to the proposed solution. The calculation was considered to be performed if the required computational accuracy was achieved or the predetermined number of iterations was valid.

As a result of modelling, there were obtained distribution diagrams for aerodynamic parameters of the specified calculation zone. The sizes of the study zone were presented by parameters z, r, as is shown in Fig. 1.

When calculated, distribution diagrams for air flow rates within the given zone were obtained. Ratio $V_{\max}/V_{\text{mim}}$, which was minimised in consequence of calculation, was an assessment criterion of uniformity of dust particle settlement on the filter surface. The most uniform velocity distribution occurred in three areas where this ratio was the smallest; in these circumstances no dead zones or non-uniform velocities throughout the studied area were observed.

The system of equations was solved within the Mathcad and allowed obtaining the distribution of air flow rate inside the filter considering the size and position of the outlet port as well as the confusor height.

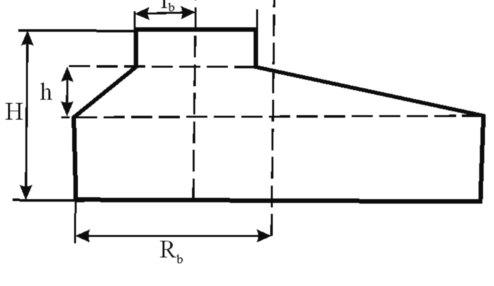

Fig. 2. The model of structure of the filter box

Linkage parameters of air flows in the filter box of different geometry were studied. Upon that, relations $V_{\max}/V_{\text{mim}}$, were compared; the results of comparison are given as diagrams in Figs. 3–5.

Discussion. As a result of modelling, interrelation between the geometric parameters of the filter box and filtration rate is obtained. The latter influences the non-uniformity of velocity distribution of a respirator. The

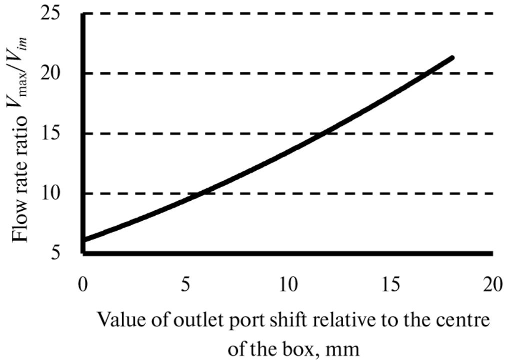

Fig. 3. Curve of dependence of distribution of relative velocity of the air flow on the value of the outlet port shift with a diameter of 50 mm from the centre of the filter box with a length of the confusor of 15 mm and airflow rate of 30 l/min

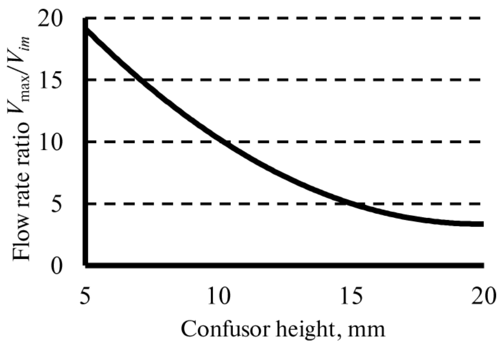

Fig. 4. Curve of dependence of distribution of relative velocity of the air flow on the height of the confusor with a 50 mm diameter of the outlet port arranged centrally with the airflow rate of 30 l/min

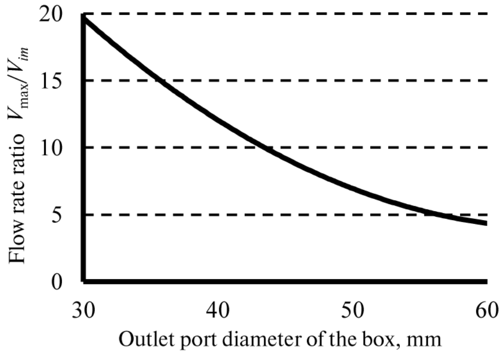

Fig. 5. Curve of dependence of distribution of relative velocity of the air flow on the diameter of the outlet port with a 90 mm diameter, confusor length of 15 mm and the airflow rate of 30 l/min

higher it is, the worse the process of capturing aerosol particles goes. About 80 % of all the dust in the filter is captured when using the electrostatic method. An increase in dust and gas flow rate will result in decreasing time of particles being in the electrostatic field created on the surface coating of the filter and, consequently, an increase in slippage of particles through it. The data obtained allow optimizing geometrical sizes of filter boxes which will contribute to even air flow velocity along the filter.

The suggested mathematical model features consideration of vortex flows, which can occur because of extreme growth of the airflow rate while performing hard work. In this case, the present-day models for estimating filter operation lead to significant errors.

The analysis of a particular calculated example of a filter box for the respirator RPA with a polypropylene filter shows that the 50 mm diameter is the most acceptable diameter of an outlet port. Further outlet port diameter increase requires production of a respirator inhaling valve of the proper size to protect the filter from moisture ingress when breathing out. Large size respirator inhaling valves feature less resistance and contribute to operation time increment and moist air impingement from underneath the mask to the filter, thus, decreasing their resource.

Confusor height increase is limited by respirator parameters. In particular, it can result in complicated fastening of a respirator to allow the mask to fit the face properly. A large size of a box will change the mass centre of a respirator and, therefore, cause headband load growth. Moreover, it can impair a user's visibility significantly, which is not allowed. As a result of mathematical modelling, 16–20 mm has proved to be the most appropriate confusor height.

Another element – outlet port shift with relation to the centre of a filter box – is conditioned by increase in service properties of respirators. However, the calculated data shows that outlet port shift with relation to the centre of a filter box results in considerable increase in air flow rate. If this construction of a filter box is required, the outlet port shift relative to the centre of a filter box should not exceed 5 mm.

As a result of performing mathematical modelling, a calculation procedure for designing filter boxes for various work conditions was obtained. Further research will be aimed at decreasing resistance of a filter box and increasing protective effect duration and protection coefficient of dust respirators. Since these characteristics are interrelated, a need arises to define the filtration coefficient [20]

$$\frac{\Delta P}{\mu v} = \frac{\ln K}{\gamma(a,\beta)},$$

where K is the penetration coefficient of the filter, v is the airflow rate; γ is the filtration coefficient.

Therefore, further studies are to be directed at reducing filter resistance and optimising the airflow rate in it using the mathematical model.

Conclusions. Thus, based on the issues considered we can draw the following conclusions:

- the new research technique based on the mathematical model is developed using the least square method, finite-element method and method of local variations; it allows obtaining linkage parameters of dust-laden air throughout the filter box with different geometry;
- geometric parameters of the filter box are optimised including the outlet port diameter, confusor height, and outlet port shift form its centre;
- the new technique for optimising geometric parameters of the filter box based on the mathematical model. Dependencies of distribution of air flow velocities for the filter box with different geometry are obtained and relationship between its aerodynamic and geometrical parameters is established.

References.

1. Andrusyak, Z. V., Bolibrukh, B. V., Loik, V. B., & Krasutskaya, I. M. (2015). The problem of creating an effective individual protection of rescuers in case of accidents at hazardous chemical facilities. *Zeszyty Naukowe SGSP*, *56*(4), 111-134.

2. Zaripov, S. K. (2015). Numerical study of the efficiency of a facepiece filtering respirator using a model of an idealized spherical sampler with porous layer. In: *European Aerosol Conference. Milan: Digital Handbook. – 50ANT_O008,* 2015. Retrieved from https://kpfu.ru//staff_files/F727951931/50ANT_O008.pdf.

3. Holinko, V. I., Cheberiachko, S. I., Radchuk, D. I., & Cheberiachko, Y. I. (2014). Research on breathing resistance of a dust mask. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *6*(144), 131-136.

4. Srilec, V. M., & Vasiliev, M. V. (2010). Analysis of protective properties of personal protective equipment, which are intended for work in conditions of release of hazardous chemicals. *Collection of scientific works of Kharkiv University of Air Forces*, *1*(23), 197-200.

5. Zatonsky, A. P., Yasakov, A. I., & Sukhinin, V. E. (2013). Distribution of the velocities of the motion of the dusty air in the internal-combustion enginefilter with nonlinear resistance. *Bulletin of the Voronezh State Agrarian University*, *4*(39), 108-111.

6. Ostapenko, N. V., Lutsker, T. V., Rubanka, A. I., & Kolisnichenko, O. V. (2016). Generalized systematization of devices of special purpose. *Theory and practice of design*, *10*, 122-143.

7. Vinogradov, V. V., Zykova, Yu. A., & Samokhvalov, N. M. (2015). Method for calculating the slot filter. *Bulletin of Tomsk Polytechnic University. Engineering of georesources*, *326*(11), 67-74.

8. Michielsen, N., Lelandais, T., Brochot, C., & Bondiguel, S. (2011). Filtration of Nanoparticles: presentation of FANA Test Bench. *Filtration*, *11*, 114-117.

9. Newnum, J. D. (2010). *The effect sofrelative humidity on respirator performance*. (Master's thesis, University of Iowa, the USA). Retrieved from http://ir.uiowa.edu/etd/861.

10. Cheberyachko, S., Frundin, V., Cheberyachko, Y., & Stolbchenko, O. (2017). Studying the Influence of a Filter Box Design on Respirator Resistance to Breathing. *Journal of the International Society for Respiratory Protection*, *34*(1), Retrieved from https://www.isrp.com/the-isrp-journal/journal-public-abstracts/783-vol-34-no-1-2017.

11. Fabbro, L. D., Brun, PLaborde, J. C., Lacan, J., Renoux, A., & Ricciardi, L. (2012). Contribution to the modelling of industrial pleated filters by solid particles. American Journal of Environmental Science, *8*(4), 385-395.

12. Cheberiachko, Yu. I. (2017). Mathematical model of dust-laden flow motion in the filter of a respirator, *NTU "KhPI" Bulletin, series: "New solutions in modern technologies"*, *23*(1245), 194-199. DOI:10.20998/2413-4295.2017.23.31.

13. Taran, I. A., & Klymenko, I. Y. (2014). Innovative mathematical tools for benchmarking transmissions of transport vehicles. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *3*(141), 76-81.

14. Podgorny, S. A., Meretukov, Z. A., Koshevoi, E. P., & Kosachev, V. S. (2013). Finite Element Method for Solving Thermal Conductivity Problems. *Vestnik VGUIT*, *2*, 10-15.

15. Pivnyak, G., Samusia, V., Oksen, Y., & Radiuk, M. (2014). Parameters optimization of heat pump units in mining enterprises. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining,* 19-24.

16. Ilin, S. R., Samusya, V. I., Kolosov, D. L., Ilina, I. S., & Ilina, S. S. (2018). Risk-forming dynamic processes in units of mine hoists of vertical shafts. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *5*(167), 64-71. DOI: 10.29202/nvngu/2018-5/10.

17. Pivnyak, G., Dychkovskyi, R., Bobyliov, O., Cabana, C. E., & Smoliński, A. (2018). Mathematical and Geomechanical Model in Physical and Chemical Processes of Underground Coal Gasification. *Solid State Phenomena*, *277*, 1-16. DOI: 10.4028/www.scientific.net/SSP.277.1.

18. Silaev, D. A. (2013). Cubature and quadrature formulas of high order. *Fundamental and Applied Mathematics*, *18*(5), 187-207.

19. Caceres, E., & Alca, J. J. (2016). Potential For Energy Recovery From A Wastewater Treatment Plant. *IEEE Latin America Transactions*, *14*(7), 3316-3321. DOI:10.1109/tla.2016.7587636.

20. Kirsch, V. A., & Stechkina, I. B. (2010). Kinetics of clogging and optimization of prefilters in a two-stage air purification system. *Theoretical Foundations of Chemical Technology, 44*(1), 78-87.

Розробка моделі кінематичних параметрів повітряного потоку всередині фільтруючої коробки респіратора

Ю. І. Чеберячко, І. М. Чеберячко, М. М. Одновол, Л. С. Коряшкіна

Національний технічний університет „Дніпровська політехніка“, м. Дніпро, Україна, , e-mail: cheberiachkoyi@ukr.net

Мета. Дослідження на математичній моделі течії швидкості повітря у фільтруючій коробці респіратора з урахуванням його впливу на геометричні параметри і захисну ефективність.

Визначити вплив геометричних параметрів фільтруючої коробки респіратора на кінематичні характеристики та її захисну ефективність.

Методика. Для побудови математичної моделі використовувався метод аналізу та синтезу. При проведенні аналізу фільтруюча коробка була розбита на кілька зон для оцінки процесу руху пилогазових потоків. Метод синтезу використовувався для опису руху двофазного запиленого потоку в циліндричній системі координат *r, z,* θ в Ейлерових змінних.

Результати. Оптимізовані геометричні параметри фільтруючої коробки респіратора: діаметр вихідного отвору; висота конфузору; зміщення вихідного отвору від її центру.

Наукова новизна. Представлена нова методика оптимізації геометричних параметрів фільтруючої коробки респіратора на математичній моделі. Отримані залежності розподілу швидкостей повітряного потоку для фільтруючої коробки з різною геометрією, а також встановлені залежності між аеродинамічними й геометричними її параметрами.

Практична значимість. Результати дозволяють визначити параметри фільтруючої коробки з мінімальним опором повітряному потоку та покращити захисну ефективність респіратора.

Ключові слова: *респіратор, фільтруюча коробка, математичне моделювання, метод кінцевих елементів, метод локальних варіацій, метод найменших квадратів*

Разработка математической модели кинематических параметров потока воздуха внутри фильтрующей коробки респиратора

Ю. И. Чеберячко, И. М. Чеберячко, Н. Н. Одновол, Л. С. Коряшкина

Национальный технический университет „Днепровская политехника“, г. Днепр, Украина, e-mail: cheberiachkoyi@ukr.net

Цель. Исследование на математической модели течения скорости воздуха в фильтрующей коробке респиратора с учетом его влияния на геометрические параметры и защитную эффективность.

Определить влияние геометрических параметров фильрующей коробки респиратора на кинематические характеристики и ее защитную эффективность.

Методика. Для построения математической модели использовался метод анализа и синтеза. При проведении анализа фильтрующая коробка была разбита на несколько зон для оценки процесса движения пылегазовых потоков. Метод синтеза использовался для описания движения двухфазного запыленного потока в цилиндрической системе координат *r*, *z*, θ в Эйлеровых переменных.

Результаты. Оптимизированные геометрические параметры фильтрующей коробки респиратора: диаметр выходного отверстия; высота конфузора; смещение выходного отверстиям от ее центра.

Научная новизна. Представлена новая методика оптимизации геометрических параметров фильтрующей коробки респиратора на математической модели. Получены зависимости распределения скоростей воздушного потока для фильтрующей коробки с разной геометрией, а также установлены зависимости между аэродинамическими и геометрическими ее параметрами.

Практическая значимость. Результаты позволяют определить параметры фильтрующей коробки с минимальным сопротивлением воздушному потоку и улучшить защитную эффективность респиратора.

Ключевые слова: *респиратор, фильтрующая коробка, математическое моделирование, метод конечных элементов, метод локальных вариаций, метод наименьших квадратов*

Рекомендовано до публікації докт. техн. наук В. Є. Колесником. Дата надходження рукопису 26.03.18.