Determination of the design parameters of the simulator breathing apparatus for training complexes

Artem Obukhov*, Denis Dedov and Alexey Arkhipov
Tambov State Technical University, Tambov, Russian Federation

*obuhov.art@gmail.com

Abstract. The paper considers an approach of improving the quality of training for personnel of industrial and mining enterprises working in polluted atmosphere conditions through the use of training complexes. Within the framework of this problem, the choice of designs of heating units for gas breathing mixes and breathing resistance for the breathing apparatus simulator of the training complex is considered. A comparative analysis of possible designs and the choice of the optimal solution are implemented. The resulted simulator allows you to properly organize the learning process and increase its effectiveness by eliminating one-time and expensive self-rescuers. Practical studies of the simulator with selected designs of heating units and breathing resistance were carried out in order to verify that its functioning complies with the real-life insulating breathing apparatus.

1. Introduction
The topical problem in the engineering and mining industries, transport and other spheres of human activity is to train personnel to work correctly in normal and emergency situations. Proper organization of the process of employees’ training allows reducing the negative impact of the human factor, the possibility of errors in the performance of work operations, the risk to the health and lives of staff.

Within this study, the problem of imitating the use of breathing apparatus, which is relevant for the coal and mining sectors, as well as for engineering industries, where personnel have to work in a polluted atmosphere, is considered. This leads to the need to use various isolating breathing apparatus (IBA), for example, self-rescuers. Since this type of equipment is disposable, training on real IBA leads to large material costs. Therefore, the development of IBA simulation systems has a great practical importance, and the modeling of their design and operational parameters that ensure compliance with real self-rescuers obtains a high scientific importance due to the originality of this type of device.

The analysis of the sources showed that the training of personnel working in a polluted atmosphere is carried out on various types of IBA [1, 2]. The study of respiratory processes based on IBA simulator wasn’t conducted previously, which makes the task of mathematical modeling of its components original from a scientific point of view.

The developed IBA simulator should implement the breathing conditions corresponding to the breathing conditions in the self-rescuer during various physical activities. In order to realize the simulator, it is necessary to carry out mathematical modeling of its components, determine their design
and performance characteristics, under which the key indicators of the simulator (breathing resistance and gas breathing gas temperature) correspond to ones of a real self-rescuer.

2. Design of simulator breathing apparatus
At the first stage, the simulation of the general design of the simulator IBA was carried out [3]. The appearance of the simulator is similar to the self-rescuer, the placement of the actuators is implemented in the cartridge shell (figure 1).

![Figure 1. Scheme of actuators of the breathing apparatus simulator.](image)

The main actuators of the simulator include: 1 - external shell; 2 - shell cover; 3 - lower heater chamber; 4 – cover of heating bottom chamber; 5 - top chamber heater; 6 - heating chamber cover; 7 - heating tube; 8 - valve node chamber; 9 - valve inlet base; 10 - outlet valve base; 11 - flap valve; 12 - stepping motor; 13 - inlet flap; 14 - gate output; 15 - engine button; 16 - flow sensor; 17 - valve cover; 18 - stand; 19 - differential pressure sensor; 20 – circuit board; 21 - connector; 22 - temperature sensor; 23 - valve chamber nozzle.

For IBA simulator, it is necessary to calculate the resistance to breathing and the temperature of the gas breathing mixture (GBM) to match these indicators with a real self-rescuer. The complexity of the solved problem lies in the choice of the optimal design of the corresponding nodes of the simulator [3]. Within this study, two main nodes are considered: resistance to breathing and heating of GBM.

3. Selection of structures of breathing resistance node
During the study of the formation of resistance to breathing, several design solutions were proposed - the throttle, the floating valve on the helical axis and the diaphragm.

Practical studies on the modeling of breathing resistance processes for the proposed design solutions allowed us to carry out a comparative analysis and select the optimal option of the node design [4, 5]. The results of the simulation of the dependence of pressure on the value of the valve’s closure are presented in figure 2.
The advantage of the design of the throttle valve is the simplicity of the design, low energy costs to overlap the path. The disadvantage consists in the large size and the impossibility of fixing the valve in the boundary positions, the difficulty of installing the positioning mechanism.

![Figure 2](image)

**Figure 2.** Comparison of the results of tests of structures of the breathing resistance node

The design of the floating valve on the helical axis is characterized by the simplicity of the mechanism; however, its essential drawback is the need to create guides to reduce friction during movement and reduction of energy costs.

The construction of the diaphragm with petals has the following advantages: small sizes, possibility of upgrading the structure with manual control, low energy costs for tract overlap, fixed boundary positions of the petals. The disadvantages include the high complexity of manufacturing the orbital transmission mechanism.

Based on the analysis of tests of various designs, it was concluded that the throttle valve allows the regulation of the resistance of breathing more smoothly, has several advantages over analogues.

4. **Selection of node structures for gas breathing mixture heating**

It was necessary to make a selection of four types of heaters [2] to implement GBM heating node: a nichrome spiral, a halogen lamp, a flat ceramic heater and a cartridge heater. The results of modeling the dependence of GBM temperature on the heater operation time are presented in figure 3. On the basis of this study, a comparative analysis of all types of heaters and their applicability for solving the problem can be carried out.

The advantage of the implementation of heating with the help of a nichrome spiral is the ease of manufacturing of the node, however, it has a high cost, since the support to which the spiral is attached must be a dielectric, be durable and comply with hygienic requirements. Ceramics are suitable for this requirement, which leads to a significant increase in the cost of the heater frame.

Heating with halogen lamps is cost-effective due to the low cost of the lamps themselves and their availability, but the risk of rupture of the lamp due to moisture and insufficient heating temperatures are serious drawbacks.

The use of a flat ceramic heater allows a high heating power, as well as to increase the heat transfer area with radiators.
The cartridge heater has the same advantages as the previous one, but its design is better suited for use in IBA simulator.

According to the results of the experiments, it was determined that most of the heaters work in the same range, except for halogen lamps, and since the halogen lamps and the nichrome filament turned out to be a non-optimal choice due to the above disadvantages, the decision was made based on the convenience of installing the heating element. Thus, the method of heating using a cartridge heater is selected.

5. Test of selected structure of simulator

Forming the design of the nodes of resistance to breathing and heating GBM on the basis of the results of their comparative analysis, we proceed to testing the structure of the simulator for compliance with its requirements. The developed breathing apparatus simulator should simulate the filling of the breathing bag and breathing resistance under a moderate load of up to 1000 Pa, as well as a change in the temperature of the inhaled gas mixture. The results of studies of the resulted structure for compliance with the requirements for resistance to breathing are presented in figure 4.

![Figure 3. Comparison of structures of heating elements](image)

![Figure 4. Results of studies of obtained simulator structure for modeling the processes of breathing resistance](image)
The developed simulator provides resistance to breathing within the prescribed limits (up to 1000 Pa), due to the presence of a heating unit, it allows you to adjust the temperature of GBM, and its structure outwardly corresponds to the existing self-rescuers. Thus, on the basis of the implemented tests and the obtained experimental values, it can be concluded that the simulator design meets the stated requirements and the task of selecting the optimal design of the breathing apparatus simulator assemblies is solved.

6. Conclusion
In this study, an approach for the improvement of the quality of training of personnel of industrial and mining enterprises working in polluted atmosphere conditions through the use of training complexes is considered. A key component of such training complexes is the proposed simulator of breathing apparatus, which allows significantly reducing the cost and effectiveness of training due to repeated use and the possibility of collecting data on the training process.

However, it is necessary to select the optimal design parameters to implement a breathing apparatus simulator. Within this article, various options of the nodes of breathing resistance and heating of GBM, which are the main elements of the simulator, are considered in detail. Based on the conducted mathematical modeling and experimental studies, a comparative analysis of various designs of these nodes was carried out, which made it possible to choose the optimal solution.

Further, practical studies of the simulator with selected designs of GBM heating units and breathing resistance were carried out in order to verify the compliance of its functioning with the actual self-rescuers.

The application of the proposed design of a breathing simulator allows personnel to be prepared for breathing with the use of great efforts, to develop all the muscle groups involved in breathing, the diaphragm and intercostal muscles. The learner will learn to breathe regularly and correctly even during exercise after training with the use of the simulator.

The scientific novelty of the research consists in the analysis of the components of the original design of the breathing apparatus simulator and the selection of the optimal design of the nodes, taking into account the specified requirements based on the simulation results and experiments.

Further research in this direction will be associated with the improvement of the simulator design, optimization of energy consumption, tight integration of the simulator with the training complex to obtain a more complete estimation of the physical condition of a person in the learning process.

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