SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2026
ORGANIZATION AND MANAGEMENT SERIES NO. 249

DEVICE FOR TESTING PARTICLE FILTERS, PARTICULARLY REUSABLE PARTICLE FILTERS FOR HALF-MASKS AND MASKS

Przemysław KĘDZIERSKI

Central Mining Institute – National Research Institute, Katowice; pkedzierski@gig.eu,
ORCID: 0000-0003-0049-2327

Purpose: there are a large number of dust masks and half-masks with replaceable filters available on the market. Dust filters are classified as new and clean breathing filters. There is no method for classifying these filters based on their service life and duration. The device guarantees that this test is performed objectively. To date, masks have been tested in real-world conditions by miners, who subjectively assess comfort.
Design/methodology/approach: a device was constructed to simulate human breathing. This device measures the amount of energy used for breathing. This amount of energy is proportional to the breathing resistance and serves as a substitute for it.
Findings: the device is used to determine the amount of energy used for breathing in used (clogged) filters. The difference in the energy used for breathing in a used filter compared to the energy used for breathing in a new filter indicates increased breathing difficulty.
Practical implications: the device described in this publication allows you to determine the maximum service life of dust filters. Using this device, you can differentiate filters based on their wear time and dust clogging.
Social implications: the device will allow for the identification of dust filter usage times and the differentiation of filters. This will impact the economics of filter purchase costs and the quality of miners' work.
Originality/value: a new device for carrying out a new type of research needed to optimize the use of reusable filters for masks.
Keywords: masks, halfmasks, breathing resistance, dust, mining.
Category of the paper: research paper, technical paper.

1. Introduction

Reusable half-masks and masks are equipped with dedicated filters, including particle filters. Particle filters are designed to filter the air breathed by humans.

The minimum requirements concerning half- and quarter-masks used as respiratory protective equipment, excluding escape and diving apparatus, as well as the laboratory and field tests enabling the conformity assessment of the half- and quarter-masks with the requirements, are described in standards PN EN 140:2001 Respiratory protective devices – Half masks and quarter masks – Requirements, testing, marking, and PN EN 149:2010 Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking.

The problem affects tens of thousands of miners, and the cost of purchasing dust filters is enormous. Optimizing the filter purchasing process based on reliable and objective research seems justified. To illustrate the scale of costs, one coal company uses approximately 530,000 filters per year. Knowledge of filter performance parameters is one element of cost management and optimization, as some filters have a lifespan of one day or several days.

Methods for assessing the practical usability of particle filters for reusable half-masks and masks are an established concept in the current state of knowledge, though not all of them guarantee conformity with the requirements of the above standards.

Current control practices concerning the practical usability of particle filters for reusable half-masks and masks are based on breathing resistance tests. The breathing resistance measurement consists in forcing an airflow through a half-mask placed on a head model at a constant volumetric flow rate and determining the pressure drop inside the half-mask relative to atmospheric pressure. The tests are described in standard EN 13274-3:2005 and performed at airflow rates of 30 l/min and 95 l/min, which correspond to minute ventilation during rest and heavy labour. The pressure readings are performed on a digital differential micromanometer.

The use of the device and filter testing will be useful in the decision-making process and in managing the purchasing process of personal protective equipment.

Given its low precision, such a procedure does not make it possible to identify certain faults or the wear level of the filters.

The device was designed to solve the key problem of distinguishing between different dust filters. Miners use respirators with dust filters daily. To date, there is no method or device for distinguishing between filters and identifying their characteristics, including cost. It is necessary to consider whether it is advisable to use cheaper disposable filters or more expensive, longer-lasting filters, and to establish a correlation between these parameters.

2. State of knowledge

Devices for inspecting industrial filters, such as filtering separators, are also an established concept in the current state of knowledge. The description of invention PL188632 (fig. 1) provides a device for testing filters, intended for inspecting filtering separators, particularly with bag-, pouch-, or cartridge-shaped filters, characterised in that it has a hose- or tube-shaped air conveyance section comprising a surface contact fitting at one end, wherein an air conveyor is installed in the air conveyance section for generating an airflow in at least one direction, and furthermore the air conveyance section comprises a pressure gauge for sensing and displaying the airflow pressure and is further equipped with an airflow meter and/or an air volume meter with a display, wherein the device is designed as a portable unit.

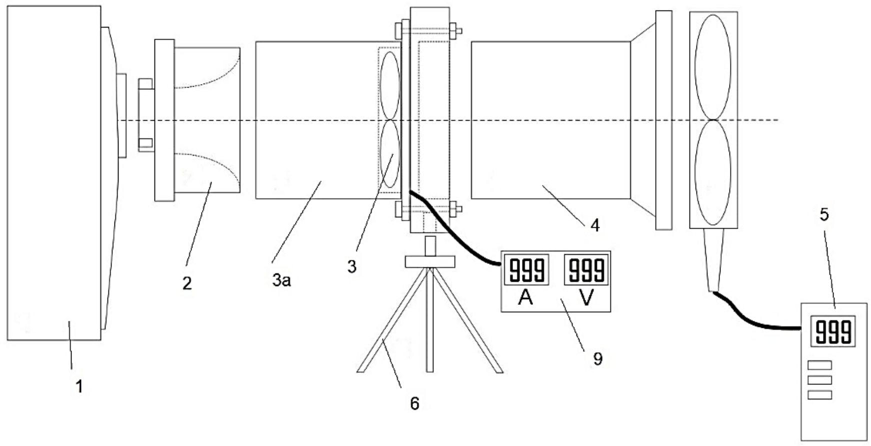

Figure 1. The device for testing power needed to breathing through filters, (1 – testing filter, 2 – original connection from mask, 3 – fan, 3a, 4 – tube, 5 – anemometr, 6 – stand, 9 – power supply of fan).

Source: own elaboration.

The invention PL188632 was made by GIG-PIB.

In this invention preferably is:

- the pressure gauge is installed in the surface contact fitting section,
- the air conveyance section comprises a controller for setting a specific pressure or volumetric flow rate,
- the device comprises multiple pressure gauges,
- the air conveyor is in the form of a fan, alternatively an air ejector,
- the air conveyor is adapted to generate an airflow from the air conveyor to the surface contact fitting,
- the air conveyor is adapted to generate an airflow from the surface contact fitting to the air conveyor,
- the air conveyor is adapted to generate an airflow in both directions,
- a dust detector with a display is installed in the air conveyance section,
- the device comprises a hose- or tube-shaped air conveyance duct, wherein the air conveyance duct comprises a surface contact fitting at one end, and furthermore a valve is installed in the air conveyance duct, wherein the air conveyance duct has a compressed air connection on the side of the valve facing away from the surface contact fitting,
- an auxiliary compressed air tank is installed between the compressed air connection and the valve,
- the auxiliary compressed air tank can be closed from the side of the compressed air connection,

- the auxiliary compressed air tank is surrounded by the air conveyance duct between the valve and the surface contact fitting,
- the valve is a diaphragm valve,
- the valve comprises an electromagnetic controller with a controlled opening time,
- the surface contact fitting is bell-shaped,
- the surface contact fitting comprises sealing elements on the front side,
- the air conveyance duct and the air conveyance section are mutually connected,
- the air conveyance duct and the air conveyance section converge in the area of the surface contact fitting,
- the air conveyance section comprises a closing valve.

Testing particle filters, particularly reusable particle filters for half-masks and masks, which would enable inspecting the filters and their wear level, particularly from the perspective of their flow capacity (degree of clogging), is a technical problem. This led to the need to develop a solution enabling the testing of particle filters, particularly reusable particle filters for half-masks and masks, from the perspective of inspecting their wear level according to standards PN EN 140:2001 and PN EN 149:2010. There was a need to develop a solution that would eliminate or at least minimise the inconveniences of methods established in the current state of knowledge. There was a need to develop a solution that would enable the comprehensive determination of the quantity of energy necessary to obtain a given airflow through the tested filters. There was a need to develop a solution that would enable the simple determination of the level of airflow obstruction in the tested filters (e.g. due to contamination). There was a need to develop a solution that would complement an existing market gap – the demand for a simple method of conducting filter testing in such a manner (currently there are no such methods on the market).

The above goal is fulfilled by the solution according to this invention, in the form of a method for testing particle filters, particularly the wear level testing of reusable particle filters for half-masks and masks, the nature of which is that a tested filter is connected to a sealed measuring system comprising at least a fan and an anemometer, after which an airflow is forced by means of the fan installed in the system, drawing air from outside the measuring system through the filter, and the airflow passing through the tested filter and measuring system is measured by the anemometer, wherein the fan is supplied by a direct current power supply unit with a display and smooth intensity [A] and voltage [V] control, which is used to conduct the testing and measuring procedures, consisting in that the intensity and voltage of the fan power supply unit are set to a value ensuring the adopted airflow in the measuring system, after which the intensity [A] and voltage [V] are measured and the fan power is calculated, whereas the obtained results, i.e. the airflow through the measuring system and the fan power required to obtain the adopted airflow through the measuring system, in measuring series simulating the energy required for standard ventilation during respiration and labour, particularly 30 l/min and

95 l/min, are collected, systematised and analysed by known methods, wherein the described method involves the use of a fan and an anemometer in a sealed installation in a sealed air conveyance section, wherein the testing and measuring procedures are performed in a measuring system with an air conveyance section located on an axis shared with the fan and the anemometer, thereby forming a measuring circuit with the same internal diameter, wherein the above procedures are carried out for new filters and filters of various wear level.

Preferably, in this method the tested filter is connected to the sealed measuring system by a ring with a sealed bayonet coupling, which is located between the tested filter and the measuring system, before the fan.

Preferably, in this method the applied ring is formed from moisture-resistant plastic.

Preferably, in this method the applied fan has an airflow measurement capacity ranging from 30 l/min to 100 l/min, most preferably 30 l/min and 95 l/min.

Preferably, in this method the applied fan has a power rating of 0.8 W to 2 W.

Preferably, in this method the applied fan is supplied by a direct current power supply unit with a display and smooth intensity A and voltage V control enabling the setting and reading of the fan power through intensity A and voltage V readouts.

Preferably, in this method the applied anemometer has an airflow measurement capacity ranging from 20 l/min to 100 l/min.

Preferably, in this method the applied anemometer is a vane anemometer.

Preferably, in this method the applied anemometer is adapted to the measuring circuit diameter in a sealed manner.

Preferably, the method as described above utilises a device comprising a ring with a sealed bayonet coupling for mounting a tested filter, with a fan and a tube installed after it, and an anemometer installed further after them, wherein the ring, the fan and the anemometer are installed in a sealed manner on the sealed air conveyance section, wherein the central points of the air conveyance section, the ring, the fan, the tube and the anemometer are located on a shared axis and form a measuring circuit with the same internal diameter.

Preferably, the method as described above can be applied in an enclosed climatic chamber under controlled climatic conditions corresponding to the ultimate operating conditions of the filters, preferably corresponding to the conditions present in a mining plant, preferably in an enclosed climatic chamber with controlled air temperature and relative air humidity.

The advantage of the solution in the form of the method for testing particle filters, particularly reusable particle filters for half-masks and masks, per this invention is that it enables the determination of the energy necessary to obtain a given airflow through tested filters in a simple manner. The method makes it possible to examine filters and draw conclusions regarding the filter wear level (the more clogged a filter, the higher the fan energy required to obtain the given airflow). The method is simple and inexpensive, and it complements an existing market gap.

The subject of the invention is described in examples of execution below and depicted in drawings, where Fig. 1 presents the device and the tested filter as a block diagram, Fig. 2 displays the individual elements of the device and the tested filter, and Fig. 3 depicts charts with results obtained using the method by means of the device.

3. Design of a new device for testing particle filters

The device for testing particle filters (fig. 2), particularly reusable particle filters for half-masks and masks, comprises: an anemometer 5 with a connecting tube 4, before which is a fan module (stand, connectors, fan power supply) with a fan 3 and a ring 2 with a bayonet coupling dedicated for a specific filter 1, enabling the establishment of a precise and sealed connection of the tested filter 1 with the measuring system.

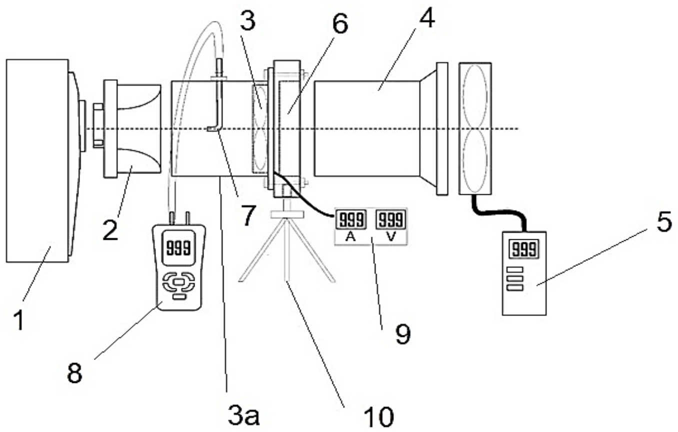

Figure 2. The device for testing power needed to breathing through filters with module of testing breathing resistance, (1 – testing filter, 2 – original connection from mask, 3 – fan, 3a, 4 – tube, 5 – anemometr, 6 – seal, 7 - pressure measurement probe , 9 - pressure instrument, 9 – power supply of fan, 10 – stand).

Source: own elaboration.

As regards the device described above:

- it constitutes an enclosed and sealed (i.e. all the drawn in air passes through the filter 1) isolated system,
- all the elements of the measuring system, together with the fan module with the fan 3, have the same internal diameter, making it possible to avoid air swirls that would disrupt the measurement,
- it is terminated with a ring 2 with a bayonet coupling for mounting filters 1 of various types on one end,

- it comprises a fan 3 that simulates human respiration and is intended to draw in air from the outside through a filter 1 – the efficiency of the fan 3 must be sufficient to obtain an airflow ranging from 30 l/min to 100 l/min, preferably 30 and 95 l/min, according to standards PN EN 140:2001 Respiratory protective devices – Half masks and quarter masks – Requirements, testing, marking, and PN EN 149:2010 Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking,
- it comprises an anemometer 5, preferably a vane anemometer with a display, which measures the airflow in the measuring system and must enable airflow measurements within a range of 20 l/min to 100 l/min,
- it is contained in a housing ensuring the air-tightness of the entire measuring circuit from the tested filter 1 to the anemometer 5.

Optionally, the housing of the fan 3 can comprise a thread for mounting the device on a stand, so that the tests may be performed on a stably fixed device.

Furthermore:

- anemometer 5 – has an internal diameter as close as possible to the internal diameter of the fan 3 and the entire measuring system,
- fan 3 – has a power rating of 0.8 W to 2 W,
- ring 2 – enables the mounting of the filter 1 on one end, and is tightly adapted to the measuring system on the other end. The ring 2 is formed from moisture-resistant plastic.

The device is characteristic in that all the above elements are installed on a shared axis and have the same internal diameters.

Device correlation was made using appropriate reference standards and instruments, including anemometers and power measuring instruments.

An example advantage of the solution described above is that:

- it constitutes a sealed measuring circuit – therefore the measured airflow corresponds only to the airflow through the tested filter 1,
- the airflow measurement concerns exclusively air drawn in through the filter 1 by means of the fan 3,
- it makes it possible to measure the amount of air flowing through the filter 1,
- it is relatively inexpensive and simple to construct,
- it makes it possible to measure the power of the fan 3 required to provide a sufficient airflow through the tested filter 1.

A number of procedures can be performed using the above system, consisting in:

1. grouping filters 1 according to the time of use / level of wear,
2. measuring the power of the fan 3 required to obtain the adopted airflow through an open measuring system (without the filter 1),

3. measuring the power of the fan 3 required to obtain the adopted airflow through a new / clean filter 1,
4. measuring the power of the fan 3 required to obtain the adopted airflow through filters 1 grouped according to the time of use / level of wear,
5. correlating the above data.

4. Testing procedure with device

The method as described in example execution I, using the device described in example execution I or example execution II, wherein the method is applied in a climatic chamber under controlled climatic conditions, preferably with controlled relative air humidity and temperature, corresponding to the ultimate operating conditions of the filters, preferably corresponding to the conditions present in a mining plant.

Thereby it is possible to conduct measurements of airflows through the filters under controlled atmospheric conditions (relative air humidity and temperature) that are identical to the ultimate operating conditions of the filters (e.g. as found in a mining plant).

This is intended to simulate the conditions in which the filters 1 were used. Additionally, it is possible to investigate whether the climatic conditions (dry or humid) affect the performance of the filters.

During stage I:

The tested filter 1 is classified according to its time of use / level of wear.

Afterwards:

- a new, unused filter 1 (reference filter) is mounted on the ring 2 of the device described above, and the power of the fan 3 required to obtain the adopted airflow through the measuring system is determined (the power of the fan 3 is determined by means of a power supply unit measuring the intensity A and voltage V, characterised by smooth intensity and voltage control, by which the power supplied to the fan 3 can be adapted freely),

afterwards:

- a used filter 1 (tested/evaluated filter) is mounted on the ring 2 of the device described above, and the power of the fan 3 required to obtain the adopted airflow through the measuring system is determined (in the same manner as above),

afterwards:

- the above procedure is repeated for filters 1 with different times of use / levels of wear.

During stage II:

The measurement results from stage I are compiled in the form of a chart (Fig. 3) or table.

The obtained results (fan power) are compared to the filter time of use / level of wear during measuring series involving the adopted airflow (30 and 95 l/min according to standards PN EN 140:2001 Respiratory protective devices – Half masks and quarter masks – Requirements, testing, marking, and PN EN 149:2010 Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking).

Fig. 3 presents an example chart with a compilation of two measuring series involving airflows of 30 l/min and 95 l/min for filters with three levels of wear (new, used for one day, used for three days).

To sum up, the device for testing particle filters, particularly reusable particle filters for half-masks and masks, comprises a ring 2 with a sealed bayonet coupling for mounting a filter 1, with a fan 3 installed after it, and an anemometer 5 installed further after them, wherein the ring 2, the fan 3 and the anemometer 5 are installed in a sealed manner on a sealed air conveyance section, wherein the central points of the air conveyance section, the ring 2, the fan 3 and the anemometer 5 are located on a shared axis and form a measuring circuit with the same internal diameter.

Furthermore, in the device:

- the air conveyance section is a round section, preferably a tube or hose section,
- the air conveyance section, the ring 2, the fan 3 and the anemometer 5 have the same internal diameters,
- the ring 2 is a ring formed from moisture-resistant plastic,
- the fan 3 is a fan with an airflow measurement capacity ranging from 30 l/min to 100 l/min, preferably at a level of 30 l/min and 95 l/min,
- the fan 3 is a fan with a power rating of 0.8 W to 2 W,
- the anemometer 5 is an anemometer with an airflow measurement capacity ranging from 20 l/min to 100 l/min,
- the anemometer 5 is an anemometer adapted to the diameter of the measuring circuit in a sealed manner,
- the anemometer 5 is a vane anemometer,
- the ring 3 is a ring equipped with a bayonet coupling on one side, enabling the sealed mounting of a tested filter 1, and a sealed coupling with the measuring system on the other side.

It is permissible for the filter testing to be conducted in a climatic chamber under controlled climatic conditions, preferably with controlled relative air humidity and temperature, corresponding to the ultimate operating conditions of the filters, preferably corresponding to the conditions present in a mining plant.

To sum up, the method for testing particle filters, particularly reusable particle filters for half-masks and masks, is applied as follows:

A tested filter 1 is connected to a sealed measuring system, comprising at least a fan 3 and an anemometer 5, after which the fan 3 installed in the system is used to force an airflow by drawing in air from outside the measuring system through the filter 1, and the airflow through the tested filter 1 and measuring system is measured by means of the anemometer 5. The fan 3 is powered by a direct current power supply unit with a display and smooth intensity [A] and voltage [V] control, and it is used to conduct the testing and measuring procedures consisting in setting the intensity and voltage of the fan power supply unit to obtain the adopted airflow in the measuring system, after which the intensity [A] and voltage [V] are measured and the power of the fan 3 is calculated. The obtained results, i.e. the value of the airflow in the measuring system and the power of the fan 3 required to obtain the adopted airflow through the measuring system, from measuring series simulating the amount of energy required for standard ventilation during respiration and heavy labour, particularly 30 l/min and 95 l/min, are collected, systematised and analysed using known methods. The described method involves a fan 3 and an anemometer 5 installed in a sealed manner on a sealed air conveyance section. The testing and measuring procedures are carried out in a measuring system with the air conveyance section located on a shared axis with the fan 3 and the anemometer 5, thereby forming a measuring circuit with the same internal diameter. All the above procedures are performed for both new filters 1 and filters 1 with different levels of wear. The measurement method is intended to simulate the amount of energy required for standard ventilation during respiration, particularly 30 l/min corresponding to rest and 95 l/min corresponding to heavy labour. Respiration will be more difficult through a used filter 1, therefore the power required for respiration will be higher relative to respiration through a clean (unused) filter 1.

Furthermore, in the method:

- the applied air conveyance section is a round section, preferably a tube or hose section,
- the applied air conveyance section, the ring 2, the fan 3 and the anemometer 5 have the same internal diameters,
- the applied ring 2 is a ring formed from moisture-resistant plastic,
- the applied fan 3 has an airflow measurement capacity ranging from 30 l/min to 100 l/min, preferably at a level of 30 l/min and 95 l/min,
- the applied fan 3 has a power rating of 0.8 W to 2 W,
- the applied anemometer 5 has an airflow measurement capacity ranging from 20 l/min to 100 l/min,
- the applied anemometer 5 is a vane anemometer, preferably with a display,
- the applied anemometer 5 is adapted to the diameter of the measuring circuit in a sealed manner,

- the applied ring 3 is equipped with a bayonet coupling on one side, enabling the sealed mounting of the tested filter 1, and a sealed coupling with the measuring system on the other side,
- the results obtained by means of the anemometer 5, i.e. the airflow in the measuring system and the fan power required to obtain the adopted airflow through the measuring system, are subjected to further analysis – the obtained results (fan power) are compared with the time of use / level of wear of the filters 1 during measuring series involving the adopted airflow (30 and 95 l/min according to standards PN EN 140:2001 Respiratory protective devices – Half masks and quarter masks – Requirements, testing, marking, and PN EN 149:2010 Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking), after which charts and comparisons are made and conclusions are drawn from them.

It is permissible for the measurements to be conducted in a climatic chamber under controlled climatic conditions, preferably with controlled relative air humidity and temperature, corresponding to the ultimate operating conditions of the filters 1, preferably corresponding to the conditions present in a mining plant – see the device described in example execution III.

5. Testing of filters using in mine

A method for testing particle filters, particularly the wear level testing of reusable particle filters for half-masks and masks was used to test filters in one of the silesian mining.

Filters from half-masks used by miners were collected for the study. The filters were identified by their duration of use, as determined by the miners. The fan power required to achieve a given flow rate through each tested filter was tested. This flow rate corresponds to the standard flow rate and the actual airflow through the upper respiratory tract during breathing. For comparison, the same tests were performed for a new filter and without a filter, serving as reference values.

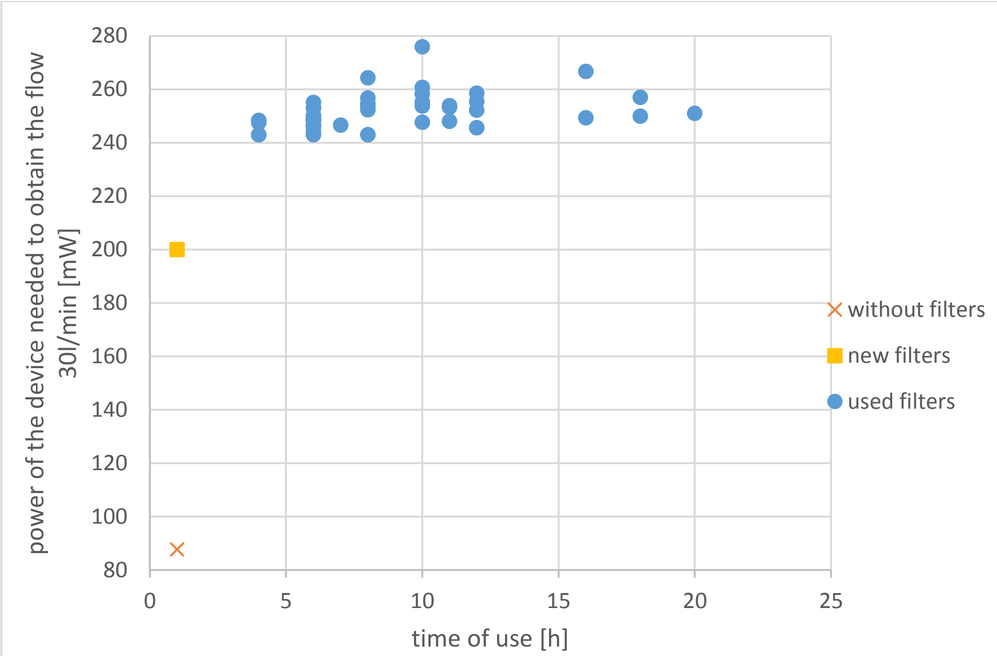

Figure 3. summary of the power of the device simulating breathing through used dust filters.

Source: own elaboration.

The power levels are presented in Figure 3.

The percentage increase in breathing difficulty was determined by the increase in power required to achieve the given flow rate through the tested used filter compared to the new filter. These values are presented in Figure 4.

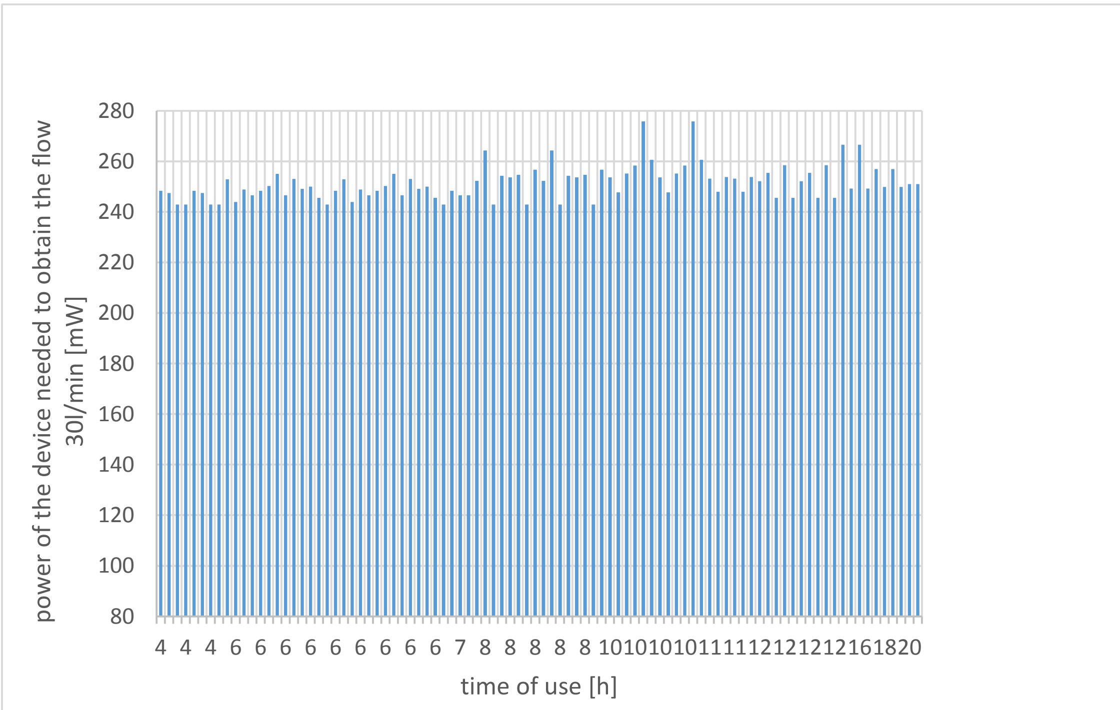

Figure 4. percentage increase in the power of the device simulating breathing through the used dust filters.

Source: own elaboration.

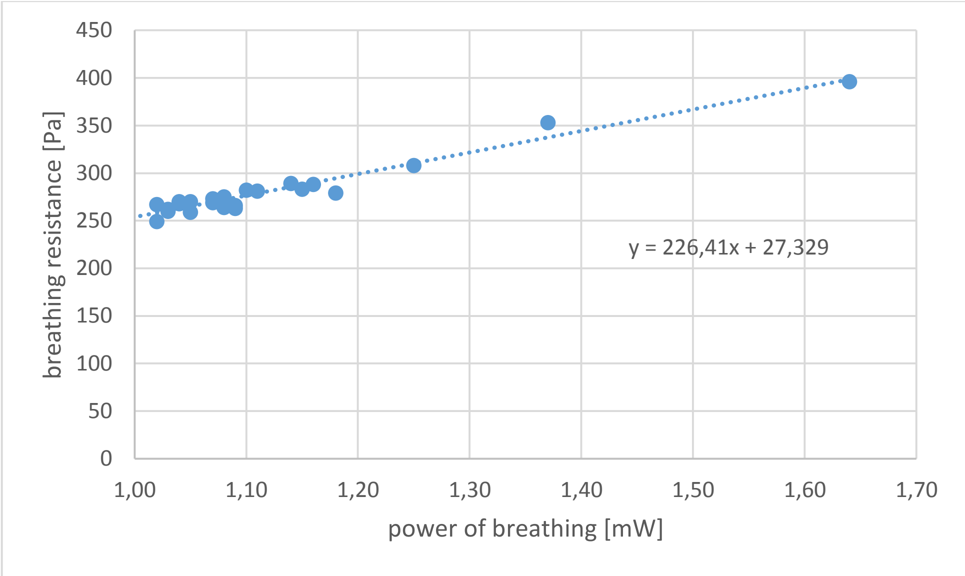

Figure 5. Correlation of breathing resistance and power needed to breathing.

Source: own elaboration.

Using the device in Figure 2 and the breathing resistance measurement functionality, the relationship in Figure 5 was created. Figure 5 shows the correlation between breathing resistance and the increase in power required for breathing. This graph clearly shows that breathing resistance increases in clogged filters.

6. Summary

The device design and measurement method have been registered with the Polish Patent Office. Commercialization plans include demonstrating the device's functionality to both dust filter manufacturers and customers. Implementation of the device assumes its use in filter differentiation, identifying their effectiveness and durability, which is crucial for production costs. Filter life is crucial for customers, who prioritize both economic considerations and disposal.

The costs of type testing for filters are negligible and provide a wealth of important information regarding their performance characteristics. The primary benefit of this test is the differentiation and identification of filter lifespan and usefulness. This testing can complement performance/in-service testing. To date, masks have been tested in real-world conditions by miners, who subjectively assess their comfort. The device guarantees that this test is performed objectively.

The use of the device and filter testing will be useful in the decision-making process and in managing the purchasing process of personal protective equipment.

Acknowledgements

This work was supported by the Polish Ministry of Science and Higher Education within the statutory activity in the year 2024 of the GIG-PIB, contract number 111840224-171.

References

1. Amendola, L., Saurini, M.T., Di Girolamo, F., Arduini, F. (2020). A rapid screening method for testing the efficiency of masks in breaking down aerosols. *Microchemical Journal, Vol. 157*, p. 104928, doi: 10.1016/j.microc.2020.104928
2. Cheberyachko, S., Cheberyachko, Y., Naumov, M., Deryugin, O. (2022). Development of an algorithm for effective design of respirator half-masks and encapsulated particle filters. *Int. J. Occup. Saf. Ergon., Vol. Jun;28(2),* pp. 1145-1159. doi: 10.1080/10803548.2020.1869429
3. Davies, A., Thompson, K.-A., Giri, K., Kafatos, G., Walker, J., Bennett, A. (2013). Testing the Efficacy of Homemade Masks: Would They Protect in an Influenza Pandemic? *Disaster Medicine and Public Health Preparedness, Vol. 7, Iss. 4*, pp. 413-418, doi:10.1017/dmp.2013.43
4. Frund, Z., Oh, S., Chalikonda, S., Angelilli, S., Waltenbaugh, H. (2022). Filtration Performance and Breathing Resistance of Elastomeric Half Mask Respirator P100 Filter Cartridges after Repeated and Extended Use in Healthcare Settings. *Journal of Occupational and Environmental Hygiene, Vol. 19,* pp. 1-11, doi: 10.1080/15459624.2022.2041649.
5. Hariri, A., Mohamad Noor, N., Paiman, N.A., Ahmad Zaidi, A.M., Zainal Bakri, S.F. (2018). Heavy metals found in the breathing zone, toenails and lung function of welders working in an air-conditioned welding workplace. *Int. J. Occup. Saf. Ergon., Vol. Dec. 24(4)*, pp. 646-651. doi: 10.1080/10803548.2017.1368950
6. Harmata, W. (2021). *Testing filter elements for gas masks*. Faculty of New Technologies and Chemistry, Military University of Technology, pp. 464-481, doi: 10.5604/01.3001.0015.3399
7. International Electrotechnical Comission (1998a). *EN 136:1998 Respiratory protective devices – Full face masks – Requirements, testing, marking.*
8. International Electrotechnical Comission (1998b). *EN 140:1998 Respiratory protective devices – Half masks and quarter masks – Requirements, testing, marking*.

9. International Electrotechnical Comission (2009). *EN 149:2001+A1:2009 Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking*.
10. International Electrotechnical Comission (2021a). *EN 143:2021 Respiratory protective devices – Particle filters – Requirements, testing, marking*.
11. International Electrotechnical Comission (2021b). *EN 14387:2021 Respiratory protective devices - Gas filter(s) and combined filter(s) - Requirements, testing, marking*.
12. Kędzierski, P., Bogucki, R. (2023). Device for testing dust filters, especially reusable dust filters for half-masks and full-face masks. *Application to the Polish Patent Office P.445408*. Central Mining Institute – National Research Institute.
13. Kędzierski, P., Bogucki, R. (2023). Method of testing dust filters, main dust-proof elements of home equipment for half-masks and masks. *Application to the Polish Patent Office P.445409.* Central Mining Institute – National Research Institute.
14. Wang, W., Chen, T., Li, Z., Tan, Q., Meng, Z., Qiu, H., Liu, X., Zheng, J. (2022). Comparison of filtration efficiency and respiratory resistance of COVID-19 protective masks by multi-national standards. *American Journal of Infection Control, Vol. 50, Iss. 5*, pp. 516-524, doi: 10.1016/j.ajic.2022.02.009
15. Yao, B.G., Wang, Y.X., Ye, X.Y., Zhang, F., Peng, Y.L. (2019). Impact of structural features on dynamic breathing resistance of healthcare face mask. *Science of The Total Environment, Vol. 689,* pp. 743-753, doi: 10.1016/j.scitotenv.2019.06.463
16. Zhuang, Z., Bergman, M., Lei, Z., Niezgoda, G., Shaffer, R. (2017). Recommended test methods and pass/fail criteria for a respirator fit capability test of half-mask air-purifying respirators. *Journal of Occupational and Environmental Hygiene, Vol. 14, Iss. 6*, pp. 473-481, https://doi.org/10.1080/15459624.2017.1296233