https://doi.org/10.33271/nvngu/2022-1/102

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DETERMINATION OF TIGHTNESS OF THE FILTERING HALF-MASK ADHESION TO A USER'S FACE

Purpose. To determine the correlation between adhesion tightness of filtering half-masks and anthropometric indices of employees' faces.

Methodology. To study tightness of the half-mask adhesion to a user's face, a coefficient of NaCl aerosol test was determined in accordance with the requirements by DSTU EN 149:2017 (EN 149:2001+A1:2009, IDT). Volunteers took part in the testing selected in keeping with the parametric table divided into 12 settings along the face length and across its width. The tests were carried out using *Respi* and *Standart* respirators produced in lots by SPE *Standart* ltd.

Findings. It has been identified that the tested filtering half-masks correspond to the standards by DSTU EN 149:2017 (EN 149:2001+A1:2009, IDT) and provide adequate protection of respiratory organs of users against harmful aerosols. It has been demonstrated that the required half-mask adhesion to a face depends upon the obturator design, half-mask geometry, and stretching force of a headband. It has been proved that employees with small faces require the instrumental verification of the preferred half-mask while selecting respiratory protective equipment. In turn, for users with large faces quality control is quite sufficient by means of any suitable method described by DSTU EN 529:2006 (EN 529:2005, IDT). Individuals with large faces have demonstrated the greatest values of the tightness coefficient of filtering half-mask adhesion.

Originality. It is represented by the scientific substantiation of the tightness coefficient of filtering half-mask adhesion upon the length and width of users' faces.

Practical value. Mathematical expressions have been derived making it possible to calculate the tightness coefficient of the half-mask adhesion relying upon the face size. The abovementioned will help assess preliminarily protective characteristics of respirators without specific laboratory equipment.

Keywords: *penetration coefficient, inflow coefficient, half-mask, obturator*

Originality. According to the requirements of Technical Regulations '2016/425, usability and efficiency of respiratory protection equipment (RPE)' are evaluated by test as for the adhesion to a user's face. Design of a filtering respirator should provide its tight comfortable adhesion to a face during the whole operational period. For the purpose, any half-mask involves adaptive capacity for the anthropometric face parameters through the headband control, changes in its fixation points at the half-mask surface, production of several standard sizes, and additional obturator tightness. However, the listed measures are not sufficient. Due to the required movements, talks, and unmasking, some gaps arise behind obturation line deteriorating protection of employees against harmful matters getting into their respiratory organs [1]. Within the last, year respiratory protection became a very important and necessary condition of health care of users, thus tightness test of filtering half-masks of respirators moves to the forefront [2, 3].

American Standard [4] as well as European one [5] involves the requirement to identify a tightness coefficient of half-mask adhesion before the respirator starts its operation to know positively that the protective device is reliable. The tightness coefficient shows how well the half-mask is placed on a user's face. Unfortunately, the process of DSTU EN 529 development did not involve the expected protection coefficients for each RPE type; hence, there is a high risk of inefficient employee protection. Meanwhile, at many mining enterprises the problem of protection of respiratory organs from dust is very actual [6, 7].

Besides, lack of instrumental test of half-mask adhesion to a face while selecting respirators for employees results in such a situation that a certain number of them will obtain inadequate protection. Nonavailability of the procedure favours irresponsible attitude toward RPE use and loss of confidence for its protective properties. The problem may be solved if the USA Standard 29 CFR 1910.134 is implemented and the available EN 529 is amended. In the meantime, reliable protection of employees with the help of correct RPE may turn out to be insufficient. Thus, it is required to develop rapid understandable evaluation of respiration adhesion to a face. Currently, two basic techniques are known – qualitative and quantitative. The former uses various safe aerosols with aggressive odour or strong taste (i.e. bitrex or saccharine) spraying them near a user in a half-mask. If correct RPE is selected, then neither odour nor taste is experienced. It is believed that the technique helps select a qualitative filtering respirator. However, use of medium- or high-efficiency filters prevents from obtaining acceptable results. In such cases, quantitative methods are applied requiring availability of relevant devices. They help determine rapidly a coefficient of aerosol test penetration into undermask space. *Fit-test* and *qualitest* are the most popular ones. It is thought that ideal half-mask adhesion prevents completely from penetration of harmful matters through the potential gaps between a face and a half-mask. Otherwise, the adhesion coefficient is quite small.

Nevertheless, such a test gives no way to identify correlation between protective efficiency of RPE and anthropometric parameters of individuals. The problem is quite topical and its solution will facilitate design process of new half-mask types.

Literature review. More emphasis is put on the problem of influence of face parameters on the protection coefficient of respirators. First, it is necessary to tabulate parameters for the selection of RPE testers [8]. Since the obtained data get out of date constantly and may vary depending upon age, gender, and nationality, a problem arises to develop a relevant mathematical model for rapid introduction of the required changes. Moreover, such tests are necessary to identify the most important anthropologic sizes for 3D-development of a user's head

[9] applied for the design of half-masks as well as panoramic RPE masks. Much attention is paid to determine dependencies between a protective degree of a respirator and different operations [10] making it possible to evaluate the gap geometry along the obturation line, causes of their origination, and elimination measures [11]. Virtual design of a head and a respirator to calculate both protective and ergonomic parameters of the latter during design stages is the important problem being solved [12, 13]. Hence, relying upon the analysis, the essential stage to improve the efficiency of human protection involves determination of interrelation between adhesion tightness of a half-mask and geometry of users' faces, helping evaluate new designs of respirators as well.

Purpose. High protection degree of users of filtering respirators should involve assurance of tight half-mask adhesion to a face, which needs qualitative selection of the available types. Moreover, the necessity arises to define correlation between adhesion coefficient and geometry of users' faces making it possible to evaluate preliminarily protective properties of a respirator while selecting it and while testing new designs.

Methods. Twelve individuals (five women and seven men) with different face sizes corresponding to the parametric table were chosen to identify the adhesion coefficient of half-masks of respirators (Fig. 1). The length of the testers' faces was 93.5 to 133.5 mm; width of their faces was 114.5 to 161.5 mm. The study used 2 types of filtering respirators (i.e. *Standart* and *Respi* types) manufactured by SPE *Standart* ltd (Dnipro, Ukraine) (Fig. 2). Table 1 demonstrates their basic specifications.

The adhesion coefficient was determined according to aerosol test using a specific testing device in accordance with the requirements by DSTU EN 149:2017 (EN 149:2001 + A1:2009 IDT); NaCl aerosol test generator; laser particle counter MetOne 227A with a built-in aspirator for sampling; a sampling device with switching to selection from the test chamber and from undermask space; and the test chamber within which the tester housed. Dry 2 % NaCl solution was used as an aerosol test. It was supplied into the test chamber with 2 dm^3/min air consumption. Concentration, set up by the aerosol generator in the test chamber, is not less than 8 mg/m^3; average mass aerodynamic particle diameter is 0.6 ± 0.05 mcM. Its spraying uniformity within the test chamber was provided by a supply system, availability of four fans along the chamber perimeter, and nonavailability of external sources of clean or contaminated air.

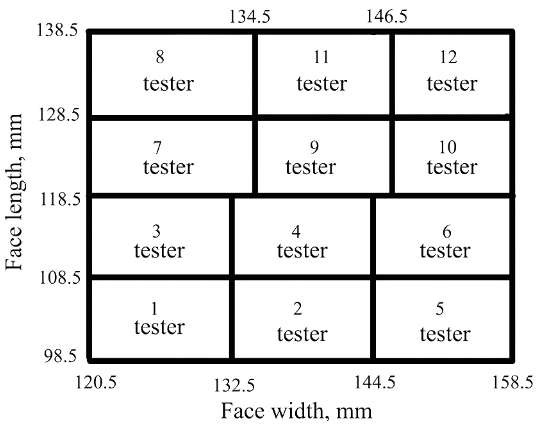

Fig. 1. Distribution of the testers on the cells of the parametric table

a *b*

Fig. 2. Filtering half-masks:
a – Respi; b – Standart

Table 1

Parameters of respirators used by the study

	Type	Respiratory resistance in terms of 95 dm^3/min	Penetration coefficient* in terms of 95 dm^3/min	Protection index	Shape of half-mask
1	*Standart*	35	up to 12 TLV	P2	cup-shaped
2	*Respi*	45	up to 12 TLV	P2	envelope

A laser particle counter measured aerosol test concentration outside a half-mask and determined quantity of the determined size of NaCl particles in air. The overall penetration coefficient was calculated as follows: the penetration coefficient = aerosol concentration in front of the half-mask/aerosol concentration within the undermask space [14].

Then, the adhesion coefficient was determined as an inverse between the determined total penetration coefficient of aerosol test of the respirator on a user and the coefficient of filter penetration determined similarly in terms of complete insulation of the obturation line owing to the obturator treatment with the help of Coloplast sealer. After the tests, the paste was removed from the tester's skin.

The experiment involved the following stages.

Stage 1: after the tester worn a respirator and the device operation was controlled, the person performed three exercises in the test chamber: normal respiration; up-down head turns; and right-left head turns. The exercises lasted 1 minute each. Right-left head turns as well as up-down ones may result in the respirator slip and origination of gaps. The number of aerosol particles in front of the half-mask and behind it was measured three times for each tester; then, the average value of the penetration coefficient was calculated.

Before the test started, a participant worn respirator in accordance with the instructions by the manufacturer; the former was given three minutes to accustom. The time was also required to develop uniform stable aerosol test concentration under the mask. Standard control of correct putting, proposed by the RPE manufacturer, was carried out (the requirements are in the operating instructions). After the exercises were performed, the tester removed the respirator and had a few minutes' break to be ready for the following test with the use of another design of a respirator.

Stage 2: the penetration coefficient through a filter was determined for each of the represented respirators. For the purpose, specific sealer was laid on the obturator to prevent from unfiltered air inflow from gaps between the half-mask and face. Then, the procedure, described within the previous stage, was performed. In the context of all the filtering respirators, the average value of the penetration coefficient was not more than 1.2 %. The abovementioned can be explained by uniform testing conditions and manufacturing of the respirators with the use of one filtering material (i.e. Eleflen).

Stage 3: to calculate the adhesion coefficient, the penetration coefficient through a filter was differenced from the overall coefficient. The results were tabulated. Three penetration coefficients were obtained for each combination of tester/respirator/model. The coefficients were averaged to compare with the allowable one (being no less than 0.5) to understand whether the test is successful. If the average value is less than 0.5, then the test is failed; and if it is more than 0.5, then the test is successful. To study connection between the values of the average penetration coefficient and human face geometry, a multiple linear regression model was applied. To derive the model, the testers were divided into three groups according to the sizes of their faces: cells 1–4 of the parametric table corresponded to a small size; cells 5–8 corresponded to a medium size; and cells 9–12 corresponded to a large size. For convenience, each cell had a central point to lock the obtained coefficients of tightness of half-masks, worn by participants, who suited for the specific cell. Table 2 explains coordinates of the central point.

Excel for Windows (SAS Institute Inc., Cary, N.C.) was applied to identify regression level. The final stage calculated share of successful tests for each group of participants (in terms of face sizes) as well as for each respirator size.

Results. A sliding calliper was used to determine geometry of the users' facies. Preliminarily, the testers were acquainted with the methods determining parameters of their faces; the agreement was obtained. Face length is a distance between the deepest point within a top nose part and the lowest one being a front part of the chin bone. Location of the points was determined manually before measurements. After their location was identified, testing tools were applied. The result was rounded off to the near millimetre value. Face width was determined as the maximum distance between the left and right face bones. Moreover, the places were also identified visually before measurements. The instrument hardly touched the skin in the process of the two measurements. To define which cell of the two-parametric table is suitable for the tester (Fig. 1) face length and width were used.

In the process of the calculations, the averaged values of half-mask adhesion, concerning each tester, were registered in the proper cell (1–12) of the two-parametric table. Fig. 3 shows the results. It has been defined that each penetration coefficient (PC) of the half-masks corresponded to the Standard requirements. In this context, the highest tightness coefficients were found in case of testers with medium face sizes (*Respi* type); as for the *Standart* type, the highest tightness coefficients were found in case of testers with the medium and large faces. Fig. 4 explains PC dependence upon the face width. It

Table 2

Coordinates of the central points

Face type	Cell number	Central points of all cells	
		Face width, mm	Face length, mm
small	1	121	101
	2	123	110
	3	135	103
	4	136	112
medium	5	146	105
	6	148	116
	7	124	124
	8	126	132
large	9	136	121
	10	146	125
	11	133	136
	12	148	137

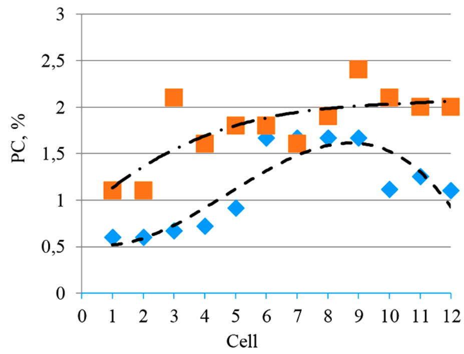

Fig. 3. The averaged PCs of a half-mask of each tester corresponding to cells:

■ – Standart respirator; ◆ – Respi respirator

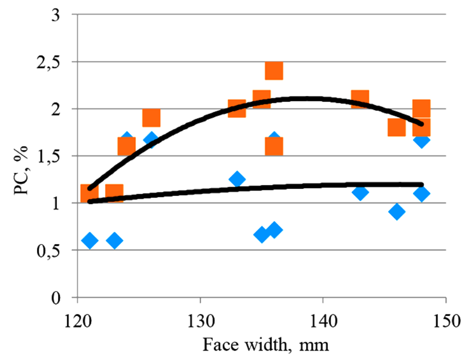

Fig. 4. The averaged PCs of each tester half-mask corresponding to the face width:

■ – Standart respirator; ◆ – Respi respirator

has been identified that PC increases along with the increase in face width from cell 1 to cell 12. Hence, there is correlation between insulation properties of a filtering respirator and cells of the parametric table ($p < 0.05$). Table 3 demonstrates results of correlation analysis and regression analysis. The most accurate regression model has been derived for *Standart* half-mask. Table 4 shows average geometric PC values for each cell groups of the two-parametric table. The testers, who were recorded in 9–12 cells, have demonstrated the highest results of adhesion coefficient; in turn, the testers from 1–4 cells (corresponding to small faces) had minimum PC values.

Table 3

Calculation results as for the correlation

Mask type	R^2	Number of participants	Linear regression *A	*p*-value
Standart	0.5437	12	$PC = -4.2 + 0.17 \times$ $\times LF + 0.026 \cdot WF$	<0.05
Respi	0.628	12	$PC = -6.8 + 0.034 \times$ $\times LF + 0.031 \cdot WF$	<0.05

Table 4

Geometric mean PC for different sizes of half-masks

Mask type	Geometric mean PC (Standard geometric deviation)		
	small 1–4 cells	medium 5–8 cells	large 9–12 cells
Standart	1.1743	1.336	1.692
Respi	0.835	1.536	1.912

The outcomes were expected; they support correspondence of the design half-mask sizes to proper anthropometric face parameters. Moreover, it has been identified that to test protective characteristics of respirators, testers should be selected in terms of the face length and width.

Discussion. The study shows interrelation between the adhesion coefficient of half-masks and face geometry of testers. It has been demonstrated that a half-mask size influences the measurement of PC results for different cells of the tables. If half-masks are worn on small faces, PC value decreases; if half-masks are worn on large faces, PC value increases. PC increase or decrease is of a practical value. For instance, in terms of large faces, PC is 1.6 up to 1.9; it is 0.8 up to 1.1 in terms of small ones. In this context, its minimum value cannot be less than 0.5 to provide sufficient protection since 0.5 is a boundary value while testing adhesion tightness. Hence, the abovementioned supports the idea of rather high insulating properties being tested. In this regard, *Standart* respirator is characterized by more stable indices; perhaps, it depends upon availability of a sealing tape along the obturator perimeter improving its adhesion to face [15]. Nevertheless, there is comparatively small share of people who cannot be adequately protected by half-masks (Table 5). The results support the necessity to select respirators individually in the workplace [16]. At the same time, employees with large faces do not need such testing since PC is more than 1 denoting high insulating properties of the half-masks. Similar conclusions may be drawn while analysing findings both for small and medium faces [17].

Also, the fact that determination of boundaries between individuals with small, medium, and large sizes may also influence the results since use of criteria of the tables is rather random [18]. Especially, it concerns the sizes in the near-boundary cells (for instance, 4 and 5 or 8 and 9). It is quite possible that a tester whose face size is close to a medium one influenced the obtained results since he/she was in cell 4 neighbouring a boundary of the cell (medium size). A similar result was obtained for individuals from the parametric table having other sizes [19].

Consequently, inflow decrease is possible because of obturator 'skill' to match anthropogenic face parameters and provision of reliable half-mask fixing on a user's head with the uniform distribution of forces behind the obturation line. The latter is possible if action of equivalent force of the headband stretch coincides with the centre of a respirator mass. The abovementioned results in the necessity to develop a method determining geometry of gap values behind the obturation line, their placement, and pressing force influence.

Conclusions. The study has shown that filtering respirators have sufficient protective properties; in this context, a half-mask size influences tightness of its adhesion to a face. Conditional face geometry should correspond to a half-mask size. It is especially important for individuals with small dimensions since a necessity arises to control instrumentally a half-mask selection. The maximum values of the geometric tightness coefficient have been registered for individuals with large sizes. In this connection, availability of obturating rubber helps improve the tightness indices for each face type. The tested respirators have satisfactory ergonomic characteristics to provide reliable tightness of the half-mask adhesion to a face. The same is also true for a share of positive results of PC tests. The findings support correctness of the half-mask design, proposed by the manufacturers.

Table 5

Test results of the tightness coefficient of a half-mask

Face size	share (%) of positive testing
small 1–4 cells	2/8 = 25
medium 5–8 cells	7/8 = 88
large 9–12 cells	8/8 = 100*

* Note: the results are suitable only for the goods and the testers

Acknowledgements. This work was supported by the Ministry of Education and Science of Ukraine, "Geotechnological basics of the formation of energochemical complexes of coal-mining regions" (grant No. 0120U102084). Also this work was supported by the Ministry of Education and Science of Ukraine, "Substantiation of the newest technological solutions for the development of mineral deposits in the context of mining regions sustainable development" (grant No. 0120U102078).

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Визначення щільності прилягання фільтруючих півмасок до обличчя користувачів

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Мета. Встановити взаємозв'язок між щільністю прилягання фільтрувальних півмасок і антропометричними показниками обличчя працівників.

Методика. Для дослідження щільності прилягання півмаски до обличчя користувача визначали коефіцієнт підсмоктування тест-аерозолю хлориду натрію у відповідності до вимог ДСТУ EN 149:2017 (EN 149:2001 + A1:2009, IDT) на добровольцях, яких підбирали у відповідності до параметричної таблиці, розділеної на 12 позицій за довжиною й шириною обличчя. Дослідження проводились на респіраторах марок Респи і Стандарт, що серійно виготовляються компанією ТОВ НВП «Стандарт».

Результати. Встановлено, що перевірені фільтрувальні півмаски відповідають вимогам стандарту ДСТУ EN 149:2017 (EN 149:2001+A1:2009, IDT) і забезпечують відповідний рівень захисту органів дихання користувачів від потрапляння шкідливих аерозолів. Показано, що забезпечення щільності прилягання півмаски до обличчя залежить від конструкції обтюратора, розмірів півмаски та сили натягу наголів'я. Доведено, що у працівників з маленьким розміром обличчя виникає необхідність в інструментальній перевірці вибраної півмаски під час вибору засобів індивідуального захисту органів дихання, тоді як для користувачів із великими розмірами обличчя достатньо якісної перевірки будь-яким придатним методом, описаним у ДСТУ EN 529:2006 (EN 529:2005, IDT). Найбільші значення коефіцієнта щільності прилягання фільтрувальної півмаски зафіксовані в осіб з великим розміром обличчя.

Наукова новизна. Полягає в науковому обґрунтуванні залежності коефіцієнта щільності прилягання півмаски від довжини й ширини обличчя користувачів.

Практична значимість. Отримані математичні вирази, які дозволять розрахувати коефіцієнт щільності прилягання півмасок, виходячи з розмірів обличчя користувача, що дозволить проводити попередню оцінку захисних властивостей респіраторів без спеціального лабораторного обладнання.

Ключові слова: *коефіцієнт проникнення, коефіцієнт підсмоктування, півмаска, обтюратор*

The manuscript was submitted 18.06.21.