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DETERMINATION OF INSULATING PROPERTIES OF HALF-MASKS OF RESPIRATORS IN TERMS OF PRESSURE DIFFERENCE

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ВИЗНАЧЕННЯ ІЗОЛЮВАЛЬНИХ ВЛАСТИВОСТЕЙ ПІВМАСОК РЕСПІРАТОРІВ ЗА ПЕРЕПАДОМ ТИСКУ

Purpose. Improvement of the half-face respirator insulating properties testing procedure according to EN 140 standard.

Methodology. The filtering half-masks have been tested on ten testees with the mounted simulators of filters on sodium chlorine and paraffin oil test-aerosols. During the test, it was required to perform seven 2-minute exercises.

Findings. The technique for testing the insulating properties of half-face respirator taking into account air inflow along the obturation line has been developed. It is based on the comparison of the values of aspiration resistance of the respirators on a tightly sealed half-face respirator with a half-face respirator having small tubes of certain size and diameter inserted into the obturation line to simulate gaps. The difference between these aspiration resistances allows determining the value of the gap between the respirator and testee's face. Moreover, the results indicating the dependence of the protective efficiency on the location of the air inflows along the obturation line were presented.

Originality. The dependence of the coefficient of test-aerosol penetration upon the value of airflow resistance of the filter and the location of the air inflow gap has been determined. Various dynamics of flows can be observed under the respirator and the location of the gaps near cheeks markedly affects the penetration coefficient.

Practical value. The technique for measuring insulating properties of half-face respirators has been developed. It has been determined that the gaps to a maximum of 1 mm along the obturator do not affect the protective efficiency of the respirator.

Keywords: *respirator, airflow resistance, penetration coefficient, filter*

The problem statement. Possible dust ethiology diseases of workers depend upon filtering efficiency of the means of individual protection of respiratory organs (MIPRO). At the same time, experimental research shows that this basic parameter of respirators is not constant in its nature depending mostly on the quality of an obturator. Most researchers consider it to be the 'weak point' of half-masks. Thus, everybody has their own anthropometric face features being quite difficult to take into account in terms of mass production of protective half-masks. That is why manufacturers try to find optimal solution for this problem. For example, some producers insert rubber cord into obturators of their disposable respirators to have consistent contact with a wearer's face [1] or special-purpose sealants made of porous materials are added. In case of elastomeric half-masks the task is solved by developing several standard sizes as well as with the help of corrugated obturators and air ones [2]. Search for rational obturator design requires constant assessment of its insulation properties performed according to EN140 standard. This quite complex and long-term procedure requiring significant costs makes it impossible to test the offered solutions constantly. That is why simplification of the procedure to test insulation properties of respirators is the topical problem to be solved as soon as possible.

Unsolved aspects of the problem. The procedure to test the quality of filtering masks according to EN 140 standard requires selecting ten testees with certain anthropometric characteristics coinciding with the sizes of half-masks; to replace filters with simulators and to determine coefficient of air inflow along the obturation line in terms of sodium chlorine and paraffin oil test-aerosols. During the test, it is required to perform seven 2-minute exercises. There are instructions as for determination of the value of contaminated air inflow of ready-made items. In terms of high-quality half-mask, it should not be more than 5 %. However, in the context of such approach there are possible difficulties in comparing the data obtained from different testees and half-masks owing to design peculiarities as well as impossibility to determine values of outflows and their effect on a protective coefficient of respirator in general. Besides, we can see in practice that even tested respirators show difference in the value of air inflow compared to laboratory values; it influences significantly the evaluation of dust load on a worker. Consequently, there is a task to develop a new simplified procedure to determine the coefficient of unfiltered air inflow along the obturation line or insulating properties.

Analysis of the recent research. There are some publications indicating the disadvantages of the laboratory research having been carried out, in particular, the value of inflows being determined on ten volunteers is possible to be reconstructed in terms of the workers with the same parameters as testees' ones [3, 4]. Besides, some researchers point out the possibility of significant errors in measuring insulating properties due to vague dynamics of flows under a mask [5], a place of sampling probe location [6], concentration of test substance in a chamber [7]. Moreover, the structure of sampling probe itself has great effect upon the obtained result [8]. However, a technique for determining the inflow coefficient has been offered recently; the technique is based on the change of rarefaction under a mask [9]. The authors claim that it is an inexpensive and simple technique. Its essence is in the fact that filters are removed from the respirators for some time and a pressure sensor is attached to it. When a testee holds his/her breathe, rarefaction reduction is measured under the mask indicating the available inflows. However, the offered technique does not take into account the effect of undermask volume and half-mask elasticity, which can influence greatly the value of air inflow.

Objective of the research. The objective of the research is to develop a technique, which is not affected either by the volume of undermask space or by half-mask elasticity while determining inflows being the result of pressure difference.

Presentation of the main material. Imagine that there are two channels for air to come into undermask respiratory space: either through filters or through leakage points between face and half-mask. It is clear that in terms of a constant general air loss, decrease in the air intake within one channel will result in the increase in the other. The penetration coefficient of a respirator will depend upon the degree of air purification by means of a filter as well as upon the amount of aerosol particle penetration through leaking obturation lines [1]

$$K_n^p = \frac{Q_ф}{Q_з} K_n^Ф + \frac{Q_в}{Q_з} K_n^в = (1-q)K_n^Ф + qK_n,$$

where $Q_з$ is general air loss through a respirator, m^3/sec; $Q_ф$ is an air loss through a filtering element, m^3/sec; $Q_в$ is an air loss through gaps in the obturation line, m^3/sec; $K_n^Ф$ is the coefficient of penetration through a filtering element; $K_n^в$ is the coefficient of penetration through leakage points along the obturation line; $q = \frac{Q_в}{Q_з}$ is relative air leak.

Then the real protective coefficient of respirators taking into account values of inflows through the obturation line of half-masks can be evaluated using the following formula

$$K_з = \left[K_П^Ф + \frac{Q_в}{Q_з}\left(K_{ПВ} - K_П^Ф\right)\right]^{-1}.$$

As a first approximation, dust particles aspiration along the obturation line can be compared with aerosol aspiration into a sampling tube or a gap. In this case, the formula for coefficient of particle deposition proposed by Hinds is used.

$$K_n^{c.o.} = 1 - 5.5k^{2/3} + 3.77k, \quad \text{if } k < 0.009;$$

$$K_n^{c.o.} = 0.819\exp(-11.5k) + 0.0975\exp(-70.1k), \quad \text{if } k > 0.009,$$

where $k = \frac{DL}{Q_в}$; L is a gap or a tube length, m; $Q_{c.o.}$ is an air loss due to the leaking obturation line, m^3/sec; D is the diffusion coefficient.

To determine air losses through gaps of the obturation line the well-known formula [8] can be used

$$Q_B = k_B(\Delta p)^{a_0}(d_B)^{b_0}.$$

Where $k_в$, a_o, b_o are constants determined experimentally for each half-mask type (for RDA respirators $k_в$ = = 0.05…0.1, a_o = 0.56…0.92, b_o = 0.5…1); $d_в$ is the size of an equivalent opening between a half-mask and a face, mm.

The real size of gaps along the obturation line of MI-PRO can be evaluated with the help of calibrated tubes (in terms of their diameter and length) placed in a tightly sealed obturator of a half-mask on a dummy head (Fig. 1). Comparison of values of respiratory resistance of a respirator worn by a person with the corresponding value of a half-mask with calibrated tubes shows the equivalent opening along the obturation line.

In this case, the value of inflow is calculated using the theory of aerodynamics. Taking into consideration the fact that parallel flows have similar pressure difference (Fig. 2) we have

$$R_p Q_з = R_в Q_в,$$

Fig. 1. A dummy head with tubes arranged along the obturation line

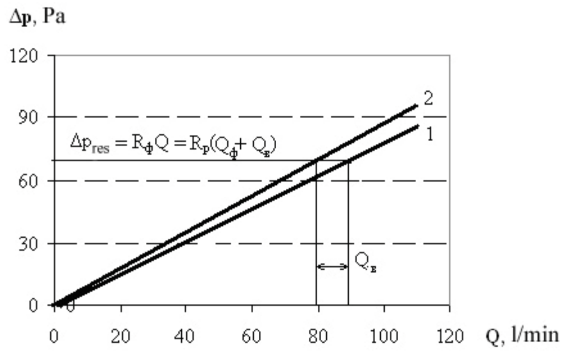

Fig. 2. Dependence of pressure difference (Δp) upon an air loss (Q) in unsealed (1) and sealed (2) fixed half-masks on a dummy head

hence

$$Q_в = \frac{Q_ф(R_ф - R_р)}{R_р} \quad \text{and} \quad q = \frac{Q_в}{Q_з} = 1 - \frac{R_р}{R_ф},$$

where $R_р$ is equivalent respirator resistance, $N \cdot s/m^5$; $R_ф$ is filter airflow resistance, $N \cdot s/m^5$; $R_в$ is airflow resistance of obturation line gaps, $N \cdot s/m^5$

Experimental part. Test techniques. Fig. 3 shows a stand to determine pressure difference on MIPRO. Respiratory resistance of elastomeric half-mask filters was determined according to EN 143. A respirator with filters was fixed on a dummy head. Calibrated tubes of 1, 2, 2.5 and 5 mm diameters and 5 mm length were mounted along the obturation line within nosolabial, chin, and cheek zones (Fig.1). The obturation line was siliconized to avoid leakage. A micromanometer was used to indicate pressure difference.

First, airflow resistance was determined on a sealed fixed half-mask; then to determine interrelation between pressure difference and air inflow, closed tubes were opened one by one. In this context an air loss was being increased through a half-mask up to the moment of such pressure difference which was fixed at sealed state; airflow value through the ob-turator was determined

$$Q_в = Q_1 - 95.$$

A specific stand (Fig. 4) was used to determine the effect of the known inflow value upon the penetration coefficient in terms of paraffin oil test-aerosol with particle distribution from 0.02 to 2 mcm. The test procedure was carried out according to EN 143 standard requirements.

Aerosol concentration in a test chamber was 20 mg/m^3. One test lasted for 3 minutes. This period was used to determine the penetration coefficient using an integral photometer. The effect of leakage upon the penetration coefficient along the obturation line was determined by comparing the parameters obtained with a completely leak-proof half-mask and with the opened tubes.

Fig. 3. A stand to determine half-mask resistance: 1 – sampling device from MIPRO undermask space; 2 – Sheffield dummy head; 3 – respiratory machine

Fig. 4. Overall view of a stand: 1 – aerosol generator; 2 – rotameters; 3 – liquid micromanometers; 4 – an aspirator; 5 – an integral photometer; 6 – a three-way valve; 7, 8 – adjustable valves; 9 – a test chamber; 10 – special mounting to fix half-mask or dummy head (filters require mounting only)

Penetration coefficient is determined according to the formula, %

$$K = \frac{I_2 - I_0}{I_1 - I_0} 100,$$

where I_2 stands for photometer indices after filtering; I_1 stands for photometer indices before filtering; I_0 stands for background photometer indices.

The results. Table represents the obtained results as for determining an air loss through the tubes mounted into the obturation line. We can see that pressure differential on a respirator decreases along with aspiration increase (Fig. 5).

Table

Air loss through the tubes mounted along the obturation line

Tube diameter, mm	Pressure difference on a respirator, Pa	Air loss, l/min		
		General loss through a respirator	Leaking through a tube (experiment)	Leaking through the tubes (according to the formula)
1	78.2	95	0.89	0.91
2	77.4		2.01	1.83
2.5	76.9		2.11	2.03
5	71.3		5.02	4.65

Thus, according to Fig. 6 it is possible to determine the value of the equivalent diameter of a gap along the obturation line in terms of the known pressure difference on RDA respirators being tested on a man.

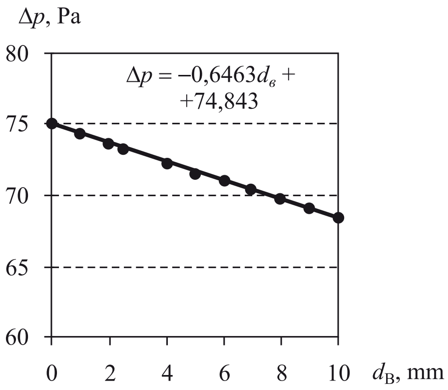

Fig. 5. Dependence of pressure difference on a half-mask of RDA respirator type (Δp) upon the equivalent opening ($d_в$) along the obturation line in terms of 95 dm³/min air loss

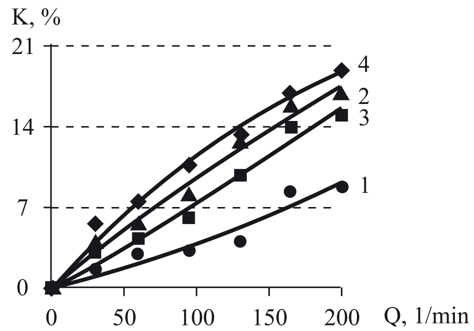

Fig. 6. Dependence of the penetration coefficient (K) upon the air loss (Q) on a respirator with a leakage diameter: 1 – 1 mm; 2 – 2 mm; 3 – 2.5 mm; 4 – 5 mm

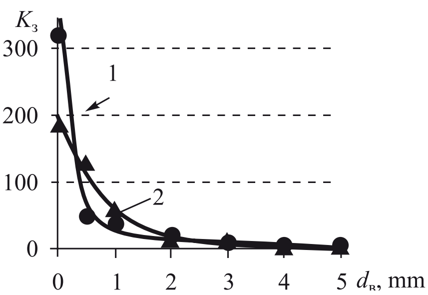

Fig. 7. Dependence of the protective coefficient ($K_з$) of RDA type respirator with filters of the third FD-310 (1) and second FD -210 (2) classes upon the opening value ($d_в$) along the obturation line at general 95 dm³/min air loss

The second stage helped determine effect of the value of unfiltered air aspiration upon the penetration coefficient of respirators (Fig. 6). The research has shown that in terms of the equivalent opening of more than 1 mm protective efficiency of a respirator does not depend on the quality of filters (Fig. 7). For example, an elastomeric RDA half-mask with a calibrated tube having a 2 mm diameter the aspiration coefficient increases from 2 up to 12 % with the decrease in pressure difference from 40 down to 22 Pa at 30 dm³/min air loss.

The third stage of the research involved determining the effect of leakage points along obturation lines upon protective efficiency of a respirator in terms of various filtering rate (60, 95 and 110 l/min). The obtained results show the following facts:

- the highest penetration coefficient was recorded in terms of aspiration from the cheek side; the lowest one was recorded within a chin zone;
- difference between the penetration coefficient through the tubes decreased along with the increase in leakage points diameter;
- the effect of aspiration point upon the value of the penetration coefficient decreases along with the increase in filtering rate.

Conclusions. As a result of the performed theoretical and experimental studies the following facts have been determined:

- dependence of the penetration coefficient of a respirator upon the value of unfiltered air aspiration along the obturation line;
- a mechanism to determine leakage values by means of determining difference between pressure differential of half-masks with either leak-proof or leakage fixation;
- air volume flowing through the known tube dimensions arranged along the obturation line;
- dependence of relative pressure differential upon leakage point sizes to characterize obturator quality;
- the highest penetration effect was recorded in terms of inflow from the cheek side; the lowest one was recorded within a chin zone;
- difference between the penetration coefficients through the tubes decreased along with the increase in leakage points diameter;
- the effect of an aspiration point upon the value of the penetration coefficient decreases along with the increase in filtering rate.
- dependence of the penetration coefficient upon an air loss of a respirator with various diameters of leakage points.

References / Список літератури

1. Kaminskiy, S. L., 2007. *Osnovy ratsyonalnoy zashchity organov dykhaniya na proizvodstve* [Fundamentals of rational protection of respiratory organs at production site]. Saint Petersburg: Prospekt Nauki.

Каминский С. Л. Основы рациональной защиты органов дыхания на производстве / Каминский С. Л. – СПб.: „Проспект Науки“, 2007. – 208 с.

2. Cheberiachko, S. I., Yavorskaia, Ye. A. and Chirkin, A. V., 2015. Respirator as the protective means for miners. *Ugol Ukrainy*, no. 1, 2, pp. 67–70.

Чеберячко С. И. Респиратор как средство защиты шахтерев / С. И. Чеберячко, Е. А. Яворская, А. В. Чиркин // Уголь Украины. – 2015. – № 1, 2. – С. 67–70.

3. Kirillov, V. F., Bunchev, A. A. and Chirkin, A. V., 2013. On means of individual protection of respiratory organs of the workers (literature review). *Meditsyna Truda i Promyshlennaya Ekologiya*, no. 4, pp. 25–31.

Кириллов В. Ф. О средствах индивидуальной защиты органов дыхания работающих (обзор литературы) / В. Ф. Кириллов, А. А. Бунчев, А. В. Чиркин // ФГБУ „НИИ Медицины труда" Российской академии медицинских наук Медицина труда и промышленная экология. – 2013. – № 4. – С. 25–31.

4. Brochocka, A. and Makowski, K., 2014. Filtering half masks for respiratory protection against nanoparticles-containing aerosols. *Przemysł Chemiczny*, no. 1, pp. 1000–1005. DOI: 10.12916/przemchem.2014.93

Brochocka, A. and Makowski, K., 2014. Półmaski filtrujące do ochrony układu oddechowego przed aerozolami zawierającymi nanocząstki. *Przemysł Chemiczny*, no. 1, pp. 1000–1005. DOI: 10.12916 / przemchem. 2014.93

5. Plebani, C., Listrani, S. and Luigi, M. Di., 2010. Filtering facepieces: Effect of oily aerosol load on penetration through the filtering material. *Ergonomics*, no. 101(4), pp. 293.

6. Crutchfield, C. D., Fairbank, E. O. and Greenstein, S. L., 1999. Effect of test exercises and mask donning on measured respirator fit. *Applied Occupational and Environmental Hygiene*, vol. 14, pp. 827–837.

7. Grinshpun, S., Haruta, H. and Eninger, R.M., 2009. Performance of an N95 filtering facepiece particulate respirator and a surgical mask during human breathing: two pathways for particle penetration. *Journal of Occupational and Environmental Hygiene*, vol. 6, pp. 593–603.

8. Haruta, H., Honda, T. and Eninger, R.M., 2009. Experimental and theoretical investigation of the performance of N95 respirator filters against ultrafine aerosol particles tested at constant and cyclic flows. *Influenza and Other Respiratory Viruses*, vol. 25, pp. 75–88.

9. Richardson, A. W., Eshbough, J. P. and Hofacre, K. C., 2006. Respirator filter efficiency testing against particulate and biological aerosols under moderate to high flow rates. *Rapport d'etude du Chemical Biological Center d'Edgewood ECBC-CR- 085*.

10. Roberge, R. J., Monaghan, W. D., Palmiero, A. J., Shaffer, R. and Bergman, M. S. 2011. Infrared imaging for leak detection of N95 filtering facepiece respirators: A pilot study. *Am. J. Ind. Med*., no. 54(8), pp. 628–636.

Мета. Удосконалення процедури перевірки ізолювальних властивостей фільтрувальних півмасок відповідно до стандарту EN 140.

Методика. Проведення перевірки фільтрувальних півмасок проводиться на десяти дослідниках зі встановленими імітаторами фільтрів на тест-аерозолях натрій хлор і парафінова олива. При проведенні перевірки потрібно виконати 7 вправ тривалістю 2 хвилини.

Результати. Розроблено спосіб перевірки ізолювальних властивостей півмасок з урахуванням впливу підсмоктування повітря за смугою обтюрації. Він заснований на порівнянні величин опору диханню респіраторів на герметично закріпленій півмасці з півмаскою зі встановленими в смугу обтюрації трубочками певного розміру та діаметру, що моделюють щілини. Різниця між цими опорами диханню дозволяє визначити значення зазору між маскою й обличчям випробувача. Також наведені результати, що вказують на вплив місця розташування підсосу повітря по смузі обтюрації на захисну ефективність.

Наукова новизна. Встановлена залежність коефіцієнта проникання тест-аерозолю від величини опору повітряному потоку фільтра та місця розташування щілини підсмоктування повітря. Показано, що під маскою спостерігається різна динаміка потоків і найбільше впливають на коефіцієнт проникнення зазори біля щік.

Практична значимість. Розроблена методика проведення вимірювання ізолювальних властивостей фільтрувальних півмасок. Встановлено, що зазори до 1 міліметра за обтюратором не впливають на захисну ефективність респіраторів.

Ключові слова: *респіратор, опір повітряному потоку, коефіцієнт проникнення, фільтр*

Цель. Усовершенствование процедуры проверки изолирующих свойств фильтрующих полумасок в соответствии со стандартом EN 140.

Методика. Проведение проверки фильтровальных полумасок проводится на десяти исследователях с установленными имитаторами фильтров на тест-аэрозолях натрий хлор и парафиновое масло. При проведении проверки нужно выполнить 7 упражнений продолжительностью 2 минуты.

Результаты. Разработан способ проверки изолирующих свойств полумасок с учетом влияния подсоса воздуха по полосе обтюрации. Он основан на сравнении величин сопротивления дыханию респираторов на герметически закрепленной полумаске и полумаске с установленными в полосу обтюрации трубочками заданного размера и диаметра, которые моделируют щели. Разница между этими сопротивлениями дыханию позволяет определить значение зазора между маской и лицом испытателя. Также приведены результаты, которые указывают на влияние места расположения подсоса воздуха по полосе обтюрации на защитную эффективность.

Научная новизна. Установлена зависимость коэффициента проникновения тест-аэрозоля от величины сопротивления воздушному потоку фильтра и места расположения щели подсоса воздуха. Показано, что под маской наблюдается различная динамика потоков и наиболее влияют на коэффициент проникновения зазоры возле щек.

Практическая значимость. Разработана методика проведения измерения изолировочных свойств фильтрующих полумасок. Установлено, что зазоры до 1 миллиметра за обтюратором не влияют на защитную эффективность респираторов.

Ключевые слова: *респиратор, сопротивление воздушному потоку, коэффициент проникновения, фильтр*

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