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Improving efficiency of dust mask use in mining

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П32 **Improving** efficiency of dust mask use in mining: monograph/ V.I. Golinko, S.I. Cheberyachko, Y.I. Cheberyachko, O.O. Yavorska, V.V. Tykhonenko; Ministry of Education and Science of Ukraine; National mining university. – D.: NMU, 2014. – 100 p.

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Working conditions of miners according to dust factor are characterized. Highest dustiness of separate working areas is shown. Peculiarities of respiratory protective devices selection to resist dust aerosol are highlighted. Data concerning structure of dust respirators, their effect on human working ability, peculiarities of their use, and role in occupation disease prevention are given.

The edition is meant for specialists in the sphere of manufacturing and use of respiratory protective devices. It can also be useful for scientific and engineer-technician workers participating in the development of respiratory devices.

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INTRODUCTION

Current situation with occupational incidence rate in Ukraine is not just threatening but critical one: its rate has grown by almost five times for the last five years. Data of State Department of Industrial Safety, Labour Safety, and Mining Inspectorate show that more than a half of occupational diseases are related to dust etiology. High dust concentration within working areas of mines and pits as well as difficulties in standardization of working conditions according to dust factor makes the problem of pneumonoconiosis to be among the most burning ones. According to Donetsk Research Institute of labour and occupational diseases hygiene, number of diseased is more than 57 thousand; consequently, each year coal industry loses more than 200 mln hryvnas to compensate miners for losses [1]. Moreover, one should also remember about considerable social losses: growth of disablement and mortality; general length of life reduces.

According to sad statistics, dust etiology occupational diseases rank first among other occupational diseases, that is why their reduction is quite an important problem today. One of ways to solve this problem is to improve performance of respiratory protective devices (RPD) that will help save health and even life under working conditions. Here it is necessary to select RPD correctly taking into account definite working conditions, type and duration of harmful industrial factors as well as physiological peculiarities of each worker.

Recently there have been a number of experimental and theoretical studies: interrelations of main respirator parameters with their structure as well as with filtering materials quality, environmental influence, human physiological data etc. have been established. Nowadays various home means to prevent occupational diseases using new materials are being implemented and developed. That is why there is a necessity to generalize the obtained results or intensify structural developments in RPD sphere to eliminate its further doubling.

Monograph consists of three divisions. First division contains evaluation of dust conditions in coal mines, in particular professions are enumerated and working areas with the highest dustiness are singled out. Second division represents main types of dust respirators used at mining enterprises. Their properties and specific use under underground conditions are characterized. Innovations in structural solutions of respiratory protective devices are studied. Third division discusses issues concerning decrease of dust etiology diseases. Protective efficiency of the mentioned devices according to coal dust concentration is evaluated. Pneumonoconiosis risks at available respirator are calculated.

The book contains appendices and references.

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DIVISION 1

Air dustiness and dust load level in mine workings

Working conditions are characterized according to dust factor of coal mines. Dust conditions are evaluated. Professions and operating areas with the highest dust content are studied.

1.1. Evaluation of dust etiology incidence rate

Nowadays situation with occupational diseases in Ukraine is extremely problematic. (Fig. 1.1).

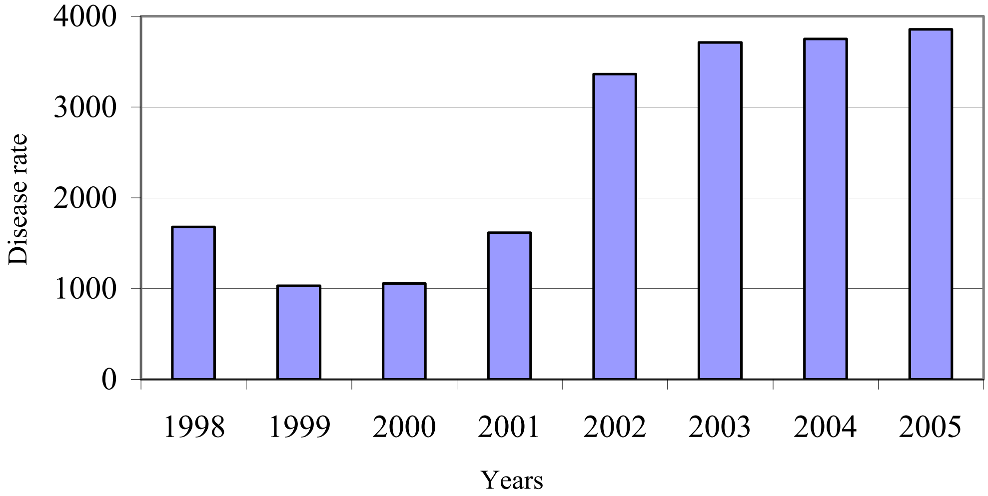


Fig.1.1. Rate of occupational diseases recorded in Ukraine within 1998 – 2005

Coal dust, noise, vibration, unfavourable microclimate are the most harmful occupational factors at miners’ working places. About 70 % of miners work under conditions that does not meet sanitary standards. According to the State Department of Industrial Safety, Labour Safety and Mines Inspectorate dust etiology diseases heads the list of occupational diseases (Fig. 1.2) [1 – 2].

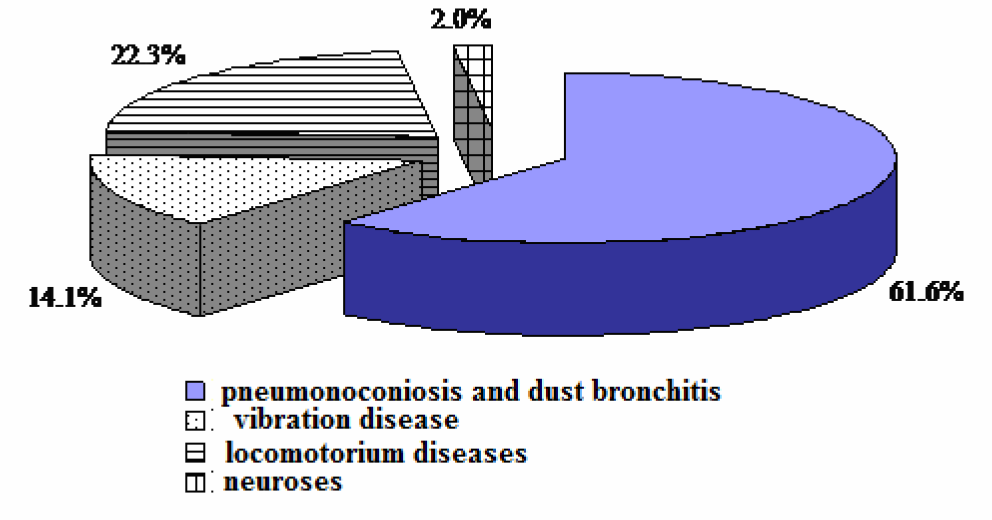


Fig. 1.2. Structure of occupational incidence rate per 2005

Elevated dust concentrations within working areas as well as problems of normalization of working conditions according to dust factor have become topical issue due to pneumonoconiosis and dust bronchitis incidences. Incidence rate of miners' bronchopulmonary system is still high all over the world reaching 15 – 30 % of all occupational diseases. For example, pneumonoconiosis rate in Poland ranks third. According to the data of incidence rate of dust etiology diseases, German shows 20 %, the USA shows 25 % of total number of underground workers [3].

Every year there is a growing tendency for total pneumonoconiosis rate among coal miners (Fig. 1.3).

According to professional division miners who are the closest to dust generation sources, first of all, miners of stoping faces and shaftmen suffer from the disease most of all; then goes cutters, overmen, underground electrical fitters, timbermen, and others (Table 1.1) [1].

Division of diseased miners according to professional experience has shown increment of disease frequency along with its growth but after 30 years of working at coal enterprises their decrease can be observed (Fig. 1.4). It is also established that miners working on deep levels (more than 700 m) at air temperature of about 28^0C and more suffer from pneumonoconiosis earlier comparing to the miners doing the same work on shallow depths. It proves that unfavourable microclimate accelerates pathological processes [2].

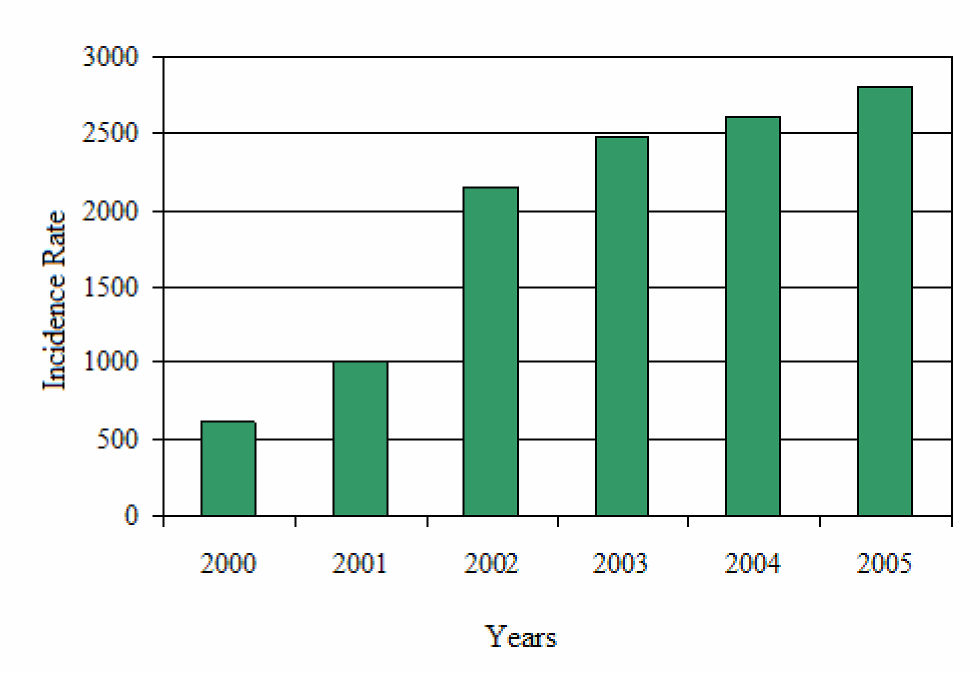


Fig. 1.3. Dynamics of occupational diseases of dust etiology

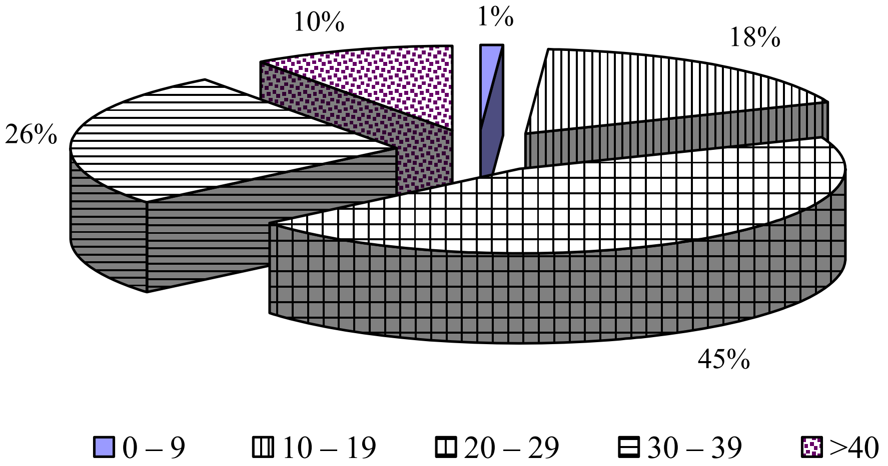


Fig. 1.4. Pneumonoconiosis rate of miners depending on their professional experience

Thus, irrespective of preventive measures, rate of dust etiology diseases growth year by year especially among the miners of main underground professions. That is why it is of high importance to know dust content level of mine workings.

Table 1.1

Air dustiness level within working areas of coal mines

Profession and working methods	Volume of average monthly air dustiness, mg/m^3	Volume of average shift volume of lung ventilation, m^3/min
Mines with low-dipping strata		
1. Blasting driving method		
1.1. Shaftman engaged in blasthole drilling with hand drills and perforators	90 -100	0.028
1.2. Shaftman engaged in blasthole drilling with drilling rig	65	0.026
1.3. Shaftman engaged in driving supports and material supply	70 – 80	0.027
1.4. Blaster	32	0.020
2. Shearer driving		
2.1. Shearer operator	600	0.023
2.2. Assistant operator	400	0.027
2.3. Shaftman engaged in a working supports	250	0.030
2.4. Miner engaged in material supply	200	0.027
3. Coal extraction with narrow-web shearer with individual support		
3.1. Shearer operator	300	0.018
3.2. Assistant operator	200	0.019
3.3.Miner engaged in a face support and conveyor movement	120	0.022
3.4. Miner engaged in a roof support	50	0.032
3.5. Miner engaged in stable holes development	335	0.032
3.6. Miner engaged in packing	160	0.031
4. Coal extraction with powered systems		
4.1. Shearer operator	300	0.018
4.2. Assistant operator	200	0.019
4.3. Operator of mechanized support	120	0.018
5. Coal extraction with plough plants		
5.1. Shearer operator	22	0.012
5.2. Assistant operator	39	0.015
5.3. Miner engaged in a face support	52	0.029
5.4. Miner engaged in stable holes development	75	0.032
5.5. Miner engaged in packing	53	0.031
Mines with steep bedding		
6. Coal extraction with narrow-web shearers having individual support		
6.1. Shearer operator	300	0.037
6.2. Assistant operator	200	0.037
6.3. Miner engaged in a face support	100	0.037

1.2. Evaluation of dust content in mine workings

Coal dust gets in mine workings air during various technological processes. Such operations as coal extraction, driving development workings and mined rock transportation result in the highest dust generation. Table 1.2 gives dust content rate of various operating processes.

Table 1.2

Dust condition at various operating processes

Operating process	Dust condition, %		
	In stoping face		In development heading
	On flat seams	On steep seams	
Shearer operation	100	100	100
Blasthole drilling	9 – 51	33 – 105	1 – 16.5
Stable holes development	9 – 28		
Face support	1 – 16	8 – 30	0.1 – 17
Coal loading	0.3 – 9.5	48 – 270	0.7 – 20

The most intensive dust generation is observed during shearer operation; it depends on the type of executing mechanism, seam thickness, and coal moisture content (Table 1.3). According to the research, dust content in the extracted coal can change twice (both towards increasing and decreasing) depending on the structure of executing mechanism. Along with the increase of seam thickness, dust content in working air will grow and vice versa: dust generation decreases along with the increase of coal moisture content.

Table 1.3

Specific dedusting during operation of shearers with different types of executing mechanism

Structure of executing mechanism	Shearer type	Seam thickness, m	Dust composition if the extracted coal, %		Specific dust extraction (g/t) At coal moisture content, %			
			Limit	Average on Середнє в усіх вибоях	До 2	2 – 3	3 – 6	More than 6
Screw	1К101	0.7 – 1.1	0,35 – 6.70	2.13	180 – 450	230 – 240	30 – 70	28 – 80
The same	2К52	1.1 – 1.8	0,5 – 5.25	2.25	1000 – 1800	310 – 1520	60 – 280	30
The same	1ГШ68	1.8 – 1.9	0,75 – 1.10	0.92	–	59 – 154	–	–
Drilling	БК52	1.2 – 1.6	1,10 – 6.60	3.22	110 – 430	110 – 315	40 – 85	–

Level of specific dedusting can be calculated according to the formula

$$q = 150ak_w k_H \text{, g/t,} \tag{1.1}$$

where a is dust content in the extracted coal [1];

k_W, k_H are coefficients taking into account value of seam thickness and moisture level (their values are given in Appendix A).

Taking into account specific dedusting, it is possible to forecast level of dust content in the air of working area as well as to determine dedusting methods that will make it possible to correct operating process to reduce dust concentration. Such collective methods of dust control are mostly used at mining enterprises as drop irrigation and premoistening.

The following formula is used to evaluate efficiency of air dedusting

$$\eta = \frac{C_n - C_з}{C_n} \text{, \%,}$$

where C_n, $C_з$ are levels of dust content in the air before and after use of dedusting methods correspondingly, mg/m^3.

However, even maximum efficient use of such methods does not reduce level of dust content up to boundary allowable concentrations (BAC). Consequently, it is necessary to specify so-called technically attainable levels of residual dust content meeting Makeyevka Research Institute that can be determined at the distance of 5 – 10 m from the site of shearer operation using the formula

$$C = 1000q\frac{P}{Q}k_в k_e k_n \text{, mg/m}^3\text{,} \tag{1.2}$$

where q is the degree of specific seam dedusting, g/t;

Q is the amount of air passing near dust source, m^3/min;

P is the level of process efficiency, t/min;

$k_в$, k_e, k_n are coefficients taking into account air speed in a face, efficiency of dedusting methods and technology of operating process correspondingly (their values are given in Appendix A).

Value of dedusting efficiency coefficient k_e can be determined according to the formula

$$k_e = (1-\frac{E_1}{100})(1-\frac{E_2}{100})\times\ldots\times(1-\frac{E_n}{100}),$$

where E_n is the efficiency of separate dedusting methods, % (Table 1.4).

Table 1.4

Efficiency of dedusting methods

Dedusting method	Efficiency, %
Standard irrigation without covering	70 – 90
Standard irrigation with covering	85 – 96
High-pressure irrigation	85 – 96
Irrigation with water supply into cutting area	83 – 92
Pneumohydroirrigation	90 – 98
Premoistening of unworked coal with water	50 – 60

Possibilities to reduce degree of dust extraction by means of irrigation and premoistening were evaluated at some mines of Western Donbas. In particular, formula (1.2) was used to calculate expected levels of dust content in stoping faces represented in Table 1.5.

Table 1.5

Predicted levels of dust content of the air in stoping faces

Mine	Coal humidity, %	Specific dedusting, g/t	Efficiency, t/min	Air volume in a face, m^3/min	Air speed, m/s	Expected dust content, mg/m^3
“Stepova”	2.2	35.6	1.75	320	2.0	10 – 15
Stashkov mine	7.0	36.8	2.0	242	2.1	10 – 21
“Samarska”	4.0	80.8	1.2	285	2.0	11 – 23

Having analyzed calculated data, it has been established that air dustiness even under complex dedusting is several times higher than sanitary standards. The authors [1] who have calculated air dustiness level for different operating processes depending on specific dedusting (Table 1.6) make the same conclusions. They have established that dustiness level can be reduced down to boundary allowable concentration only on seams with specific dust extraction of about 50 mg/m^3 but Ukraine has only 7 % of such seams.

Table 1.6

Air dustiness during operating processes

Operating process	Coal grade	Residual level of air dustiness, mg/m^3, at different specific dust extraction, g/t						
		До 50	50 – 100	101 – 150	151 – 250	251 – 400	401 – 600	601 – 1000
Coal ploughing	Д, Г	1 – 14	7 – 20	5 – 64	16 – 24	–	–	–
	К, Ж	1 – 3	7 – 8	8 – 14	–	–	218 – 299	170 – 233
	ОС, Т	–	–	26 – 46	44 – 154	–	–	33 – 58
	А	3 – 5	15 – 20	34 – 73	12 – 64	55 – 90	–	–
Coal haulage	Д, Г	1 – 10	4 – 12	6 – 50	12 – 19	–	–	–
	К, Ж	1 – 3	4 – 5	6 – 11	–	–	168 – 230	130 – 180
	ОС, Т	–	–	20 – 35	33 – 118	–	–	25 – 45
	А	2 – 4	10 – 39	26 – 56	10 – 49	42 – 69	–	–
Coal cutting	Д, Г	1 – 16	8 – 23	9 – 74	18 – 28	–	–	–
	К, Ж	1 – 4	8 – 9	9 – 14	–	–	251 – 345	196 – 269
	ОС, Т	–	–	30 – 53	50 – 178	–	–	38 – 67
	А	3 – 5	14 – 58	40 – 84	14 – 74	64 – 104	–	–

It is clearly seen that residual level of air dustiness of mine workings is more than BAC by several times even with the use of dedusting methods.

1.3. Peculiarities of dust load evaluation

As the previous analysis shows level of dust etiology diseases remains high as dustiness level of operating areas of mine workings does not meet the standards. It has been already found out that collective protection methods do not allow reducing boundaries of dust accumulation to meet BAC. That is why constant individual dust load control of miners' lungs is of high importance. Long-term information storage as for the dynamics of received doses (for example, in electronic format) will allow predicting possible incidence rates of pneumonoconiosis and dust bronchitis and assessing level of everybody's health when reliable data for medical examinations and evaluations are required.

Dust volume entered miners' lungs can be determined both according to average shift dust concentration [2] and according to its single accumulation in the air [3] using the following formulas:

$$П = CQt, \tag{1.3}$$

where $П$ is the degree of dust load, mg;

C is the degree of average shift dust concentration, mg/m^3;

t is the duration of working shift, min;

Q is the volume of lung ventilation, m^3/min;

$$П = 0{,}06 C_{м} Q t, \tag{1.4}$$

where $C_м$ is maximum single dust concentration, mg/m^3;

t is the duration of working shift, hour;

Q is the volume of lung ventilation, dm^3/min.

Let us try to determine which approach to dust load calculation represents the facts to the most. Compare calculated values with test measurements within stoping sites of Pavlograd region. Level of miners' actual dust load during working shift can be evaluated by gravimetric method under laboratory conditions according to the mass of dust deposit on filtering element of respirator. Such categories as shearer operators, assistant operators, and miners had respirators. About 80 replaceable filters were processed. Table 1.7 displays the most reliable data concerning dust deposit masses as a result of six working shifts. Value of average shift dust concentration was determined using portable dust meters of ІЗША type recording its average value during a shift. The meters were located at two points: the first one was in airway at the distance of 10 meters from the joint of entry and longwall according to the requirements of Safety Instructions and the second one was in a longwall at the distance of 5 – 10 m from this joint (Fig. 1.5).

Degree of average shift dust concentration in a longwall was calculated according to the formula [4]

$$C_L = \frac{\overline{C_k} - c}{L \cdot b}\left[1 - \exp(-b \cdot L)\right] + c,$$

where $\overline{C_k}$ is average values of dust concentration level per shift, mg/m^3;

c, b are coefficients;

L is the length of a mine working, m.

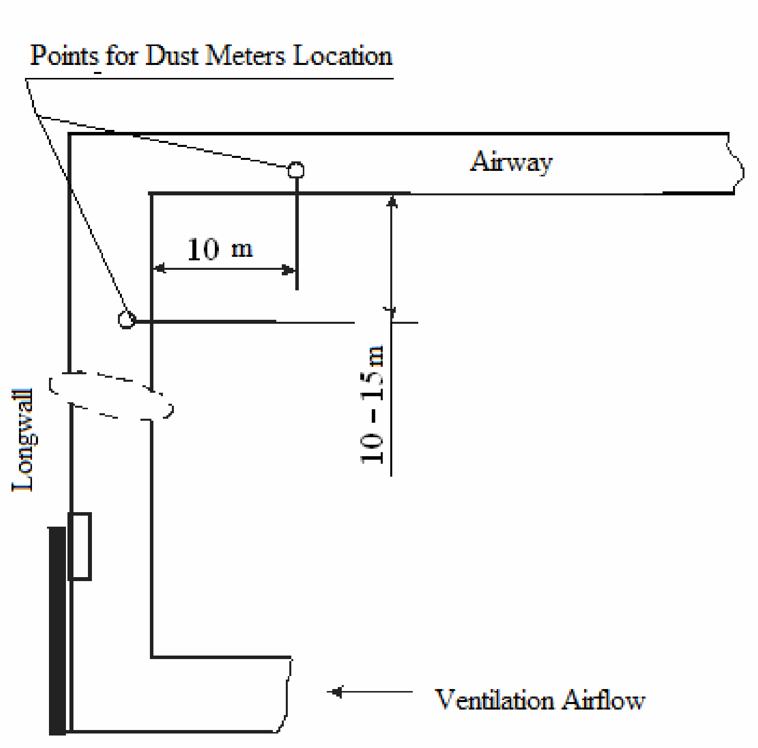


Fig. 1.5. Location scheme of meters for continuous dust accumulation control

Table 1.7

Experimental values of dust deposit mass accumulated on respirator filters per shift depending on worker's category

Worker's category	Dust deposit mass Δm accumulated on filters (g) per six shifts						Average value of dust deposit mass, g	Standard deviation, %
	1	2	3	4	5	6		
Shearer operator	0.44	0.457	0.874	1.01	1.01	0.788	0.763	0.258
Assistant operator	0.368	0.481	1.09	0.84	1.106	0.784	0.779	0.305
Miners	0.333	0.6	0.899	0.80	0.831	0.94	0.7345	0.229
	0.511	0.529	0.867	0.81	1.085	1.07	0.812	0.251
	0.298	0.333	0.897	0.67	0.385	0.394	0.497	0.237
Average value of dust deposit mass, g	0.39	0.48	0.93	0.83	0.88	0.80	0.763	0.226

Note. Table gives average values of dust deposit mass on two filters

Average shift dust deposit mass on filtering elements of respirator is measured according to the data of Table 1.7 in average value equal to 0.763 g (763 mg) at standard deviation on categories being ± 126 mg (± 16.5 %) and ± 226 mg (± 29.6 %). Scatter of readings is stipulated by operating mode of shearer. Shearer operation period under loading as well as period of intensive dust generation was within 3 - 4 hours. It is proved by the data about dynamics of air dustiness in airway (Fig. 1.6) according to recording instrument connected with air dustiness meter of ДЗП-500 type. Values of average shift and maximum dust concentration were calculated according to the obtained readings (Table 1.7) and tabulated (Table 1.8).

Table 1.8

Values of average shift and maximum coal concentration

Parameter	Shift					
	1	2	3	4	5	6
Average shift dust concentration, mg/m^3	52	59	110	94	98	95
Maximum dust concentration, mg/m^3	144	171	301	287	275	260

Table 1.9 contains values of calculated dust load upon miners based on the value of average shift dust concentration in mine workings according to formulas (1.3) and (1.4) as well as being compared to average dust mass deposited on respirator filters taking into account its penetration coefficient. Deviations of calculated values of dust load from experimental data are calculated according to the formula

$$\Delta = \frac{П_p - \Delta m}{П_p} 100, \%,$$

where $П_p$ is calculated value of dust load upon miners, g;

Δm is average mass of dust deposit on filters, g.

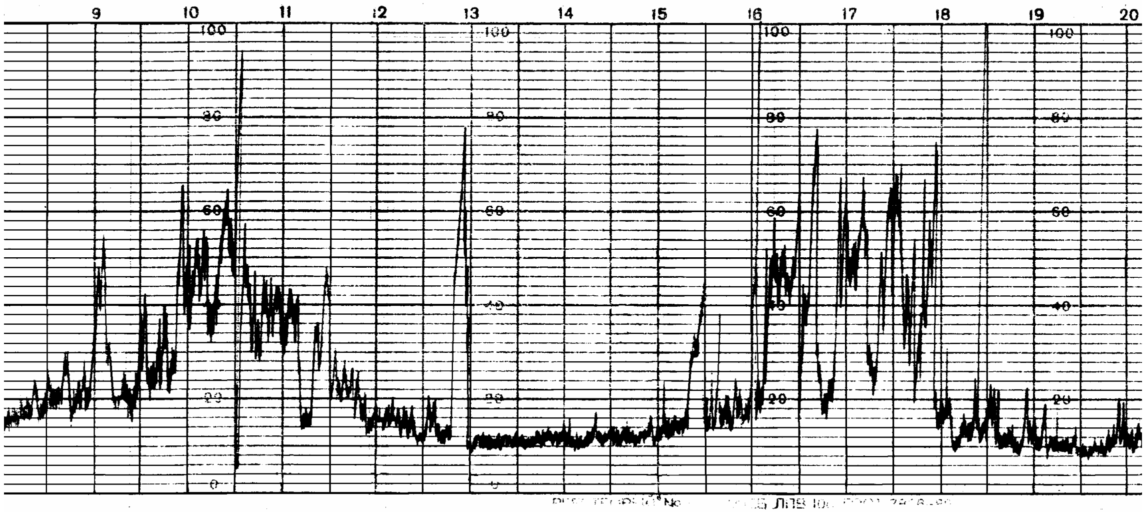


Fig. 1.6. Dynamic phases of dust concentration in airway during two working shifts

Table 1.9

Comparison of experimental calculations and theoretical data

Calculation type	Average mass of dust deposit Δm accumulated on filters (g) per six shifts					
	1	2	3	4	5	6
Experiment	0.39	0.48	0.93	0.83	0.88	0.80
	Calculated values of dust load upon miners Π_p, g					
	Π_{p1}	Π_{p2}	Π_{p3}	Π_{p4}	Π_{p5}	Π_{p6}
According to formula (1.3)	0.56	0.63	1.18	1.01	1.05	1.02
Δ, %	30	23	21	17	16	21
According to formula (1.4)	1.18	1.33	2.84	2.71	2.41	2.33
Δ, %	66	63	67	69	63	65

Experimental results are the basis for the following conclusion: dust load is calculated according to average shift dust concentration; it expresses actual situation best of all. Divergence between calculated and experimental values can be explained by the fact that mostly dust of up to 20 mcm deposits on the filters when coarser dust is filtered through filter cartridge or does not fall on filters at all (some part of dust penetrates through obturation line not entering to filters). Values of average shift dust concentration of all fractions were taken for calculations.

Determining dust load at maximum single concentration in the air of operating area gives overrated results, i.e. more dust mass that has entered workers' lungs.

Nowadays there is the Instruction for Dust Concentration Measuring and Dust Loads Recording in Mines approved by State Committee of Ukraine for the Supervision of Safety Practices in Work; it has been put into effect since 01.01.03. According to this document, it is necessary to know average shift dust concentration in the air of operating area (C, mg/m^3), average shift volume of lung ventilation (Q, m^3/min), working shift duration (t, min) and number of working shifts (N) to determine dust mass deposited in human lungs per definite time [6]

$$\Pi = 0{,}001kCQtN \text{, g,} \tag{1.5}$$

where k is coefficient that takes into account available respirator.

The mentioned Instruction contains degree of critical dust load upon miners' organisms that excludes pneumonoconiosis with a probability of 95 % (Table 1.10 [6]).

Table 1.20

Critical pneumonoconiosis level of dust load upon miners' organisms

Volume of lung ventilation, m^3/min	Boundary allowable level of dust load (g) according to dust type			
	Rock	Coal rock	Coal	Anthracitic
	Content of free silicon dioxide, %			
	10 – 70	5 – 10	Up to 5	Up to 5
0.02	290	510	1450	880
0.03	330	540	1800	940
0.04	335	545	1850	950

While calculating value of dust load it is necessary to take into account respirator efficiency being one of the main protective means against dust at some mines. On the one hand, manufacturers of respiratory protective devices state their high efficiency (about 99 %); on the other hand, even available respirators cannot be guaranteed means against diseases. Various studies contain scarce data concerning the importance of respiratory protective devices as for the reduction of dust etiology diseases. It is stipulated by several reasons. The main reason here is the difficulty to control proper and systematic use of protective devices. Miners often reject it because they do not know how to select and use it properly.

The aim of the book is to determine effect of respiratory protective device (RPD) on physical state of the workers as well as to introduce main aspects of RPD functioning, structural parameters, filtration mechanisms and evaluation of protective efficiency of respirators so that this information would help in reducing pneumonoconiosis and dust bronchitis incidence rate.

Division 2

Peculiarities of selecting respiratory protective devices

Data concerning dust respirators used at mining enterprises are given. Their properties and aspects of use under definite working conditions are characterized. Main achievements in the sphere of miners' respiratory protective devices are described.

Due to current complex situation at mining enterprises as for miners' dust load, selection of respiratory protective devices is of high importance to save their health and even life. Thus, low efficiency of collective antidust methods in coal mines do not allow reaching boundary allowable dust concentrations (from 2 – 10 mg/m^3 depending on SiO_2 content), moreover it often does not ensure even calculated levels of air dustiness (Table 1.5). It is typical when dust concentration in the air of operating area is within 200 – 300 mg/m^3. That is why possible mistakes while respirator selections reduce considerably general protective effect of miners' respiratory organs facilitating serious occupational diseases: pneumonoconiosis and dust bronchitis. Besides, meteorological conditions and complexity of operations to be performed also have their negative effect; moreover, we can mention wrong selection of RPD resulting in unjustified defatigation of functional systems of organism – hence there is dramatic performance decrement. That is why RPD regulations should pay great attention to minimum influence of respirator on life-sustaining activity of workers dealing with underground operations at their maximum protection against harmful substances.

To substantiate selection of the required type of protective device for specific working conditions taking into account ensuring maximum working capacity it is necessary to evaluate each factor revealing distinctive features of respiratory protective devices and effecting their qualitative characteristics (Fig. 2.10).

2.1. Principles of functioning and purpose of respiratory protective devices

All the RPD are divided into filtering and isolating (Fig. 2.2). **Filtering** ones purify air to be inhaled with the help of filters, sorbents, and absorbers. They are used when concentration and content of harmful substances in the air of working area are known. Such RPDs include the group of filtering self-rescue breathing apparatuses used by miners only in case of emergency. These are single-use gas masks to protect respiratory organs against carbon dioxide.

Isolating devices protect human respiratory organs against negative environmental effects. Pure air for breathing comes either from uncontaminated zones or from the source with breathing mixture. They are used in case of oxygen deprivation (less than 18 %) if composition of harmful substances is unknown as well as in cases when filtering RPD cannot protect properly. They include fresh-air hose breathing apparatuses and self-contained breathing apparatuses.

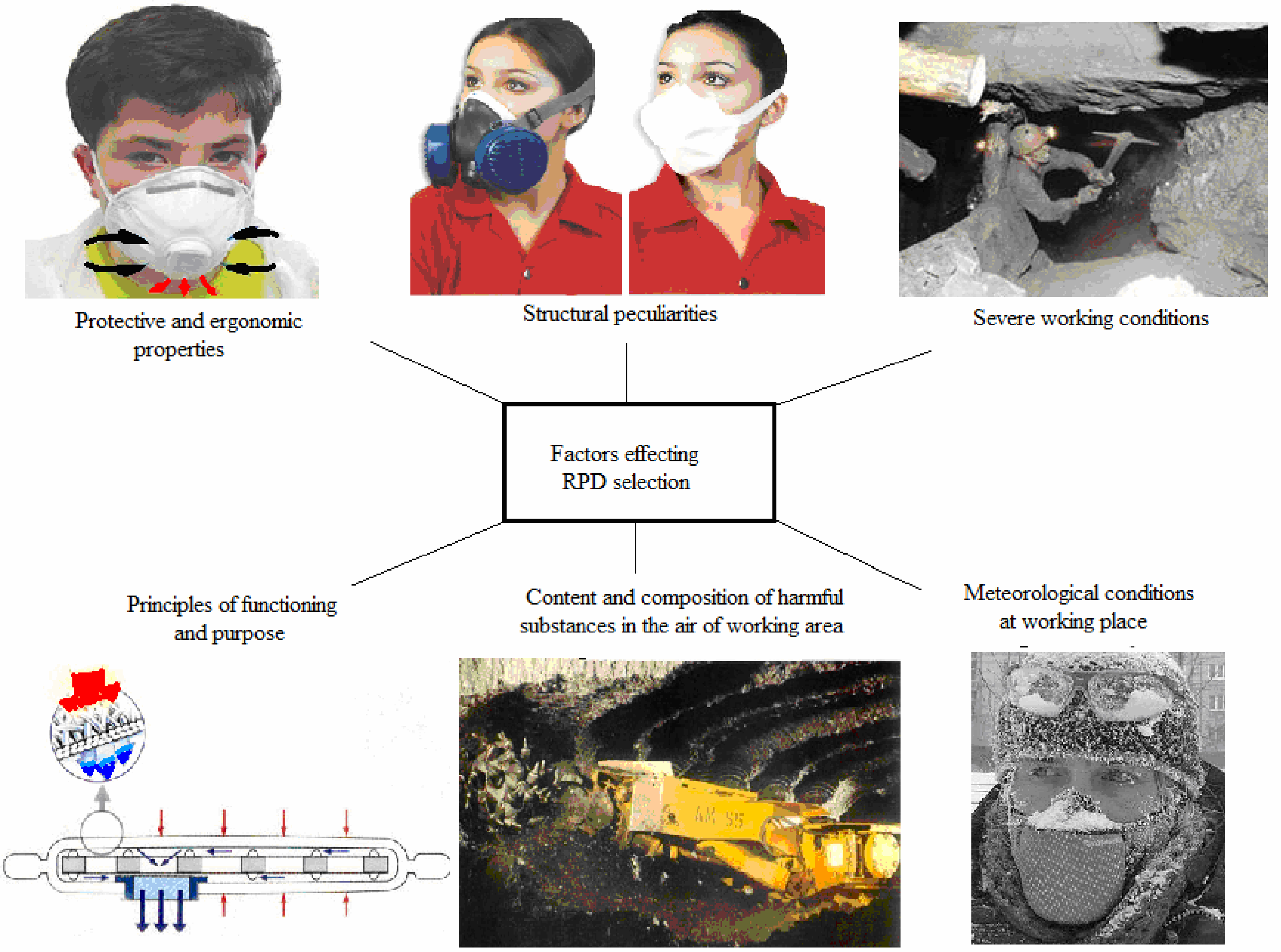


Fig 2.1. Factors for RPD selection

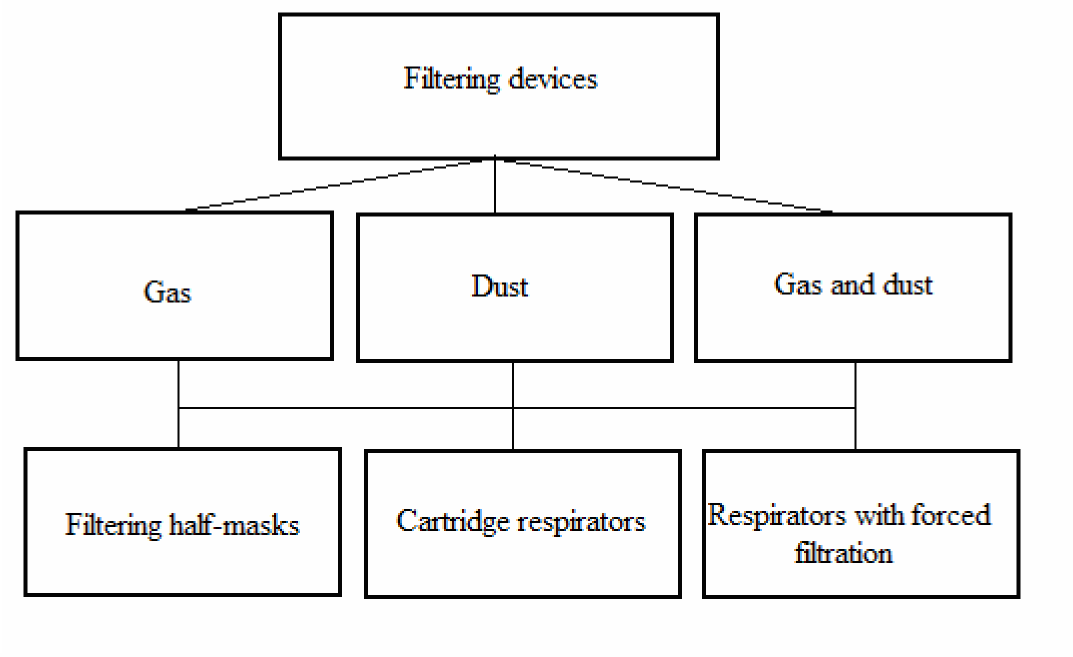


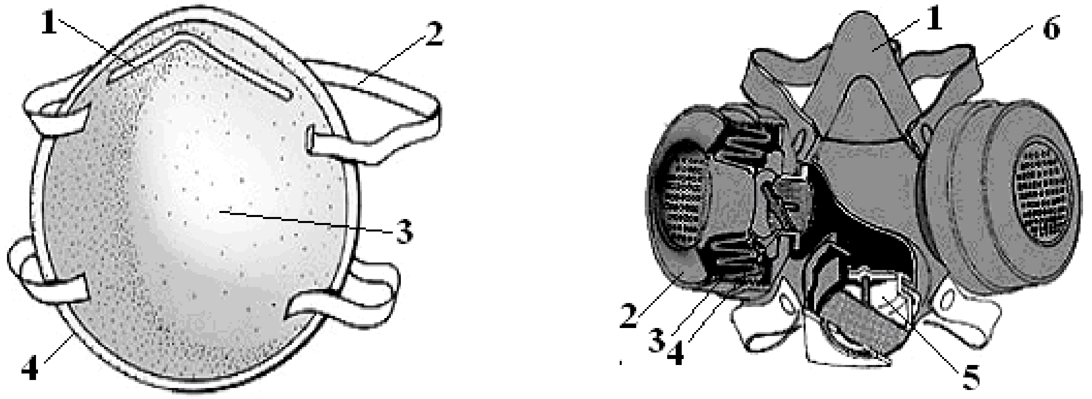
Fig. 2.2. RPD classification according to operating principle and purpose

2.2.Structural peculiarities of filtering RPD

Filtering RPDs are divided into disposable and nondisposable (Fig. 2.3 a, b). Disposable ones are characterized by the fact that filtering layer is a filter and frame at the same time – they are used so that their term of validity would be equal to one working shift, i.e. concentration of harmful substances would be not more than 50 mg/m^3. If this condition is violated it is necessary to use nondisposable respirators which half-mask is made of elastic material (rubber, silicone, triplex etc.) with the connected filtering cartridges with filters.

Disposable respirators are widely used in manufacturing first of all because of their usage convenience and low costs. They consist of filtering half-mask, headband (special bands to fix respirator on a head), nose clip and obturator (Fig. 2.3 a).

Filtering half-mask is meant for respiratory organs protection against contaminated air; it is made of several layers of special-purpose material (the best variant is with three layers, Fig. 2.4):



a b

Fig. 2.3. RPD types: a – disposable respirator: 1 – nose clip; 2 – headband; 3 – filtering half-mask; 4 – obturator;
b – cartridge respirator: 1 – half-mask made of elastic material; 2 – filter box; 3 – filter; 4 – inhale valve; 5 – exhale valve; 6 – headband

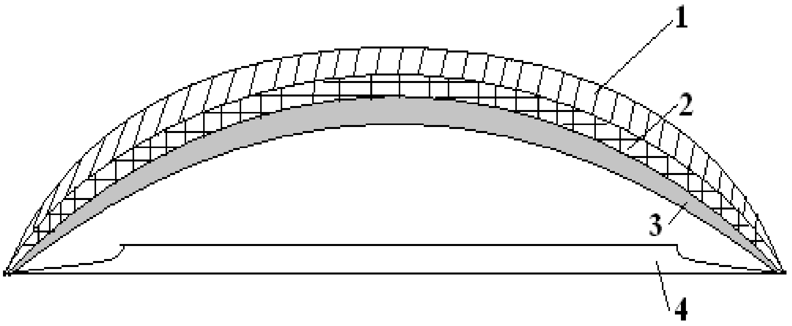


Fig. 2.4. General sectional view and scheme of filtering half-mask:
1 – external frame layer;
2 – filtering layer;
3 – internal frame layer;
4 – obturator

– the first (external frame) functions as protection of filtering material against mechanical damage; it ensures respirator resistance to deformation and is required for removal of the largest dust particles from the air that allows increasing RPD lifespan;

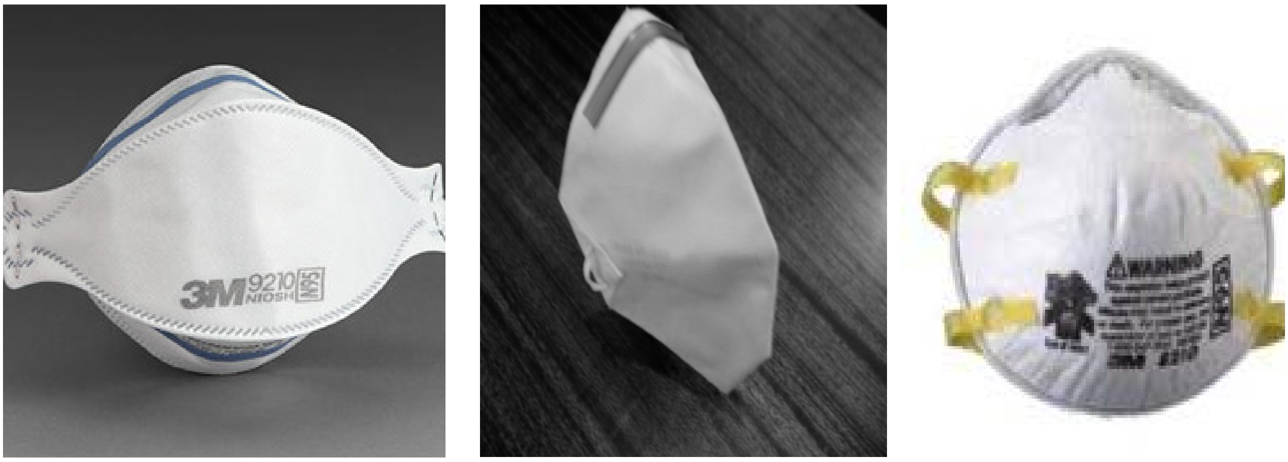
– the second (filtering) is meant for air purification to remove harmful admixtures; having the highest load it determines degree of protective efficiency of respirator;

– the third (internal frame) is the base for filtering material. Since this layer is adjacent to a face, it should be as smooth to the touch as possible without skin irritation.

External layer is mostly made of coarse fibres (lavsan, polyamide, polypropylene etc.) of comparatively low density. Second layer can be manufactured of various filtering materials being selected depending on respirator purpose and protection degree. The last layer is most often made of anallergic elastic materials.

Manufacturers of respirator devices offer three types of filtering half-masks to meet consumers’ requirements:

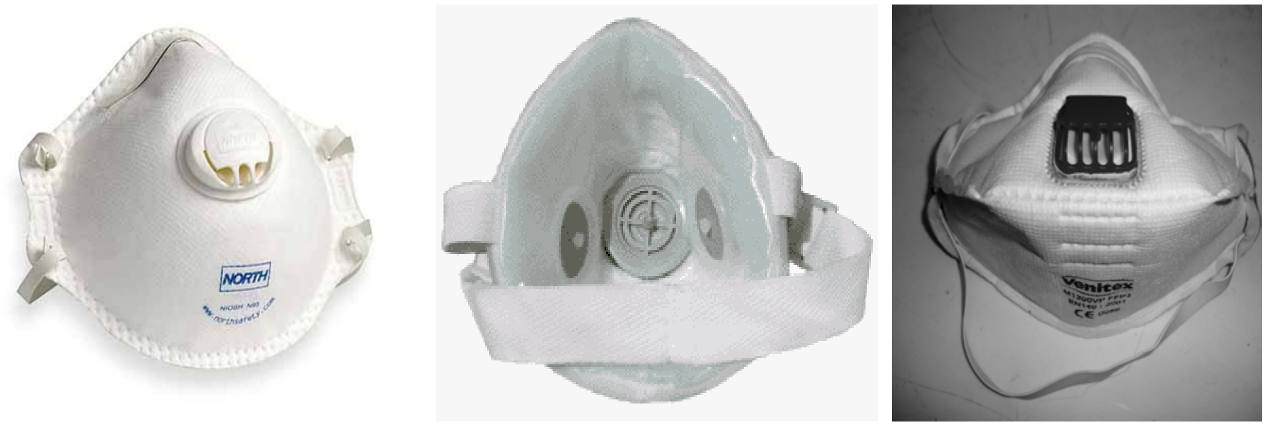
- “envelope” (Fig. 2.5 a): large area of filtration allows improving some respirator characteristics (in particular, reducing initial breathing resistance and increasing life-span);
- of pocket type (Fig. 2.5 b): small dimensions, convenient in service;
- formed (Fig. 2.5 c): it is characterized by high protection degree.



a b c

Fig. 2.5. Filtering half-masks: a is of “envelope” type by *3M*; b is Rostok-2 of pocket type by *Фільтр (Filter)*;
c is formed one by *3M*

Filtering material gets wet during intensive operation accompanied by excess sweat with exhaling, i.e. water drops get into pores between fibers, eventually, these drops coagulate resulting in breathing resistance. To remove moisture and reduce this resistance exhale valves are put into disposal respirators (Fig. 2.6). This is the same reason why internal material layer in some structures is covered with polyethylene film (Fig. 2.6 b).



a b c

Fig. 2.6. Disposable respirators with exhale valves: a is half-mask by *North*; b is respirator У-2К by *Kama-Breathe*; c is half-mask by *Venitex*

There can be disk inhale valves and mushroom or petal exhale valves (Fig. 2.7). The latter can be built into half-masks which are planned to be used with protective visors to avoid their weeping. Petal valves direct flow of exhaled warm air downwards consequently it does not contact visor material and does not generate condensate on it.

a B c

Fig. 2.7. Inhale valves (a – disk valves) and exhale valves (b – mushroom valves; c – petal valves)

Valves are placed in special-purpose protective cases mostly made of special-purpose plastics (Fig. 2.8 represents the ones being most widely used) to protect them against mechanical damage.

Fig. 2.8. Protective cases of exhale valves

Respirator headbands are required to fix half-mask on a user's head. There is great deals of their structures but disposable respirators are manufactured mostly with two rubber (textile, rubber-textile) bands jointed to half-mask (Fig. 2.9).

a b c

Fig. 2.9. Headband structures: a is textile band (respirator „Lepestok" by *Стандарт (Standard)*; b is two rubber bands (respirator by *Moldex*); c is respirator of "snaffle" type (respirator by *Moldex*)

Nose clip is necessary to have hermetic sealing of obturation line within the area of nose bridge and in most cases it is a strip of soft metal (for example, aluminum, special-purpose foil) or plastic (Fig. 2.10). Some formed types of half-masks have no nose clip as the structure of half-mask itself acts as hermetic sealing component.

a b

Fig. 2.10. Types of nose clip: a is metal strip of respirator by *3M*;
b is plastic strip of respirator by *Moldex*

Depending on protection degree of disposable respirator, obturation line can partially (near nose bridge) or totally (along obturation line) consist of special-purpose strip of elastic porous materials (for example foamed polyurethane triplex etc.) to ensure proper adjacency of half-mask to human face – Fig. 2.11.

American company *North* has offered quite interesting respirator structure: obturator is made of soft rubber resulting in low degree of aspiration of unfiltered air through leakages to have better and comfortable adjacency. Filtering half-mask is clamped securely between two rubber strips forming obturator (Fig. 2.12). This type does not belong either to disposable or nondisposable RPD as it is the intermediate stage. The advantages of such structures are obvious: more reliable protective efficiency, costs reduction for RPD purchase.

a b

c d

Fig. 2.11. Obturation line designs: a is respirator by *3M* without gasket along obturation line; b, c are rubber gasket and polyurethane strip round nose bridge (respirator by *Willson*); d is polyurethane strip all along obturation line (respirators by *Willson*)

Fig. 2.12. Respirator with rubber obturator and disposable half-mask, RTN-1 model (*North*)

Nondisposable respirators are for conditions of high harmful substances concentration in working area as the coverage of their filtering elements is mush more than the one of filtering half-masks. Besides, used filters are easy to replace while operating.

Nondisposable RDP do not differ from each other structurally: they have two symmetrical filtering boxes made of elastic material on each half-mask sides; inhale and exhale valves; obturators and headbands (Fig. 2.3 b). However, definite structure of a particular component can have significant differences depending on manufacturing company. For example, filtering cartridge is connected to half-mask by means of several methods: with the help of bayonet device (Fig. 2.13 a), flange embedded into half-mask (Fig. 2.13 b) or flange located on filtering box (Fig. 2.13 c) with the use of intermediate piece – sealing ring with flange (Fig. 2.13 d).

a b c

d e

Fig. 2.13. Methods to connect filtering box and half-mask using: bayonet device on half-mask by *3M* (a); flange embedded into half-mask by *Chief Supply* (b); flange embedded on filtering box of РПА-ТД-2 respirator by *Стандарт* (*Standard*) (c); sealing ring with flange fixed on half-mask of respirator РУ-60М by *СИЗОД* (d); fixation in half-mask body of respirator by *Moldex* (e)

Specialists of *Moldex* Company have offered original solution – to fix filtering cartridge in special port of half-mask all along its perimeter that allows enlarging viewing area of a respirator (Fig. 2.13 d). Variety of fixing devices to connect filtering elements to half-mask shows efforts of each RPD manufacturer to protect its own sale market so that consumers would buy filters and half-masks of the same company.

In some cases, cartridge respirators are made with one filtering box (Fig. 2.14) that allows widening viewing area round respirator and reducing its mass and costs.

a b c

d e

Fig. 2.14. Respirators with one filtering cartridge: a – by *Sundstrom*; b – by *Стандарт* (*Standard)*; c – by *Sorbent*; d – by Physical and Chemical Institute of Human Protection; e – by *North*

The most important thing is that RPD should have minimum effect on human physiological state without reducing work efficiency. Consequently, it is necessary to minimize breathing resistance, RPD mass, to ensure wide viewing area and minimum visibility of “dead spot” area under mask where CO_2 is accumulated. ПРШ 741 model is one of such respirators in which minimum breathing resistance is ensured with the help of non-conventional structure of inhale valve being exhale valve at the same time. Besides, it allows decreasing volume of harmful under-mask area (Fig.2.14 c).

Cartridge respirators also differ with the number and location of valves. Generally, one exhale valve is usually used located in the lower part of half-mask (Fig. 2.15 a), sometimes it is located opposite a nose (Fig. 2.15 b). If such valve is embedded opposite a nose it allows reducing CO_2 content in under-mask area but in this case such respirators cannot be used with protective shield as organic glass sweats because of exhaled warm humid air. However, structural designers of *3M* Company have solved this problem by originally manufactured half-mask with specific channel to direct exhaled air (Fig. 2.15 c).

a b c

d e

Fig. 2.15. Half-masks of cartridge respirators with one exhale valve: by *Half Mask Air Purifyin* (a), by *Moldex* (b), by *3M* (c) and with two exhale valves by *JSP* (d), by *Filter* (e)

Some companies manufacture respirators with two exhale valves to reduce breathing resistance (Fig. 2.15 d). However, such structure results in decrease of protective efficiency of respirator because of additional channel for harmful substances to penetrate into under-mask area through exhale valve. Nondisposable respirators have the same structures of exhale valves as the disposable ones.

Fig. 2.16. Domestic rubber half-mask

It is necessary to mention the structure of half-masks: domestic half-masks are mainly made of three types of rubber (Fig. 2.16) and differ with the distance from bridge of the nose to chin. There are also silicone half-masks (Fig. 2.17 a) which implementation is limited due to high costs of die molds. There are also three types of them ensuring maximum usability. Recently foreign manufacturers have begun using samples with inserts of hard plastic combined with elastic material (rubber, silicone, and plastesol). As the result, there is maximum convenience of using general and hermetic sealing in particular (Fig. 2.17 b). Such half-masks are characterized by comparatively low mass and high protective level; they have better adjacency to face.

a

b

Fig. 2.17. Cartridge respirators: a is with silicone half-mask by *Sorbent*;
b is with half-mask with frame and elastic obturator by *MSA*

Obturation line especially near bridge of the nose is usual weak point of half-masks but interesting engineering solution has allowed finding a way out: corrugations are made to ensure convenient half-mask face adjacency (Fig. 2.18). Producers take different measures to prevent aspiration of unfiltered air along obturation line. As we can see, some half-masks have wide obturator, in other cases its surface is made with different inclination angle relative to respirator axis while the others have obturator narrowed on the bridge of the nose (Fig. 2.19).

a b

Fig. 2.18. Cartridge respirators with corrugated half-masks on the bridge of the nose: a – by *Combitox Nova*; b – by *Cirrus*

a b c

Fig. 2.19. Obturator forms of half-masks by *Half Mask Air Purifyin*:
a – Elit; b – Normal; c – Classic

Restriction of human viewing area is one of the most important parameters of respiratory protection devices. The more dimensions of filtering box are, the more difficult to orient oneself while wearing such respirator. That is why manufacturers try to reduce dimensions of both half-masks and filtering box. Besides, reduction of dimensions improves RPD quality. “Dead-spot” under-mask area where CO_2 is accumulated is one more important parameter. Fig. 2.10 shows samples of half-masks characterized by low restriction of viewing area and “dead-spot” under-mask area.

Thus, each RPD manufacturer wants to offer such half-mask structure differing from other ones not only structurally but also with their protective and ergonomic properties. Various scientific and engineering issues of RPD problematic zones are being solved constantly that is why new high-efficiency half-masks for cartridge respirators are believed to appear soon.

Fig. 2.20. Respirators with minor under-mask space

Quality of respirator can depend considerably upon half-mask structure. First, it is obturation line, especially near bridge of the nose, units of exhale valves which leakiness allows entering of unfiltered air into lungs. However, the most important RPD parameters (breathing resistance, protective efficiency, term of validity, and dust holding capacity) depend upon the structure of filtering components. That is why here there are special requirements:

1) test-aerosol coefficient of penetration (oil fog) is not more than 0.1 % for the first class of protection and not more than 1 % for the second one;

2) initial protection under standard conditions with air consumption of 30 l/min should not be more than 60 Pa while final one should not be more than 100 Pa;

3) term of validity is not less than working shift period;

4) filters should be compact.

First three requirements are met at quite low filtration rate – less than a centimeter per second along with increasing of filtering surface area. Here the fourth requirement means that it is necessary to squeeze developed working surface of a filter into limited dimensions of a filtering box. It is quite a challenge that is why currently there are numerous corrugated and noncorrugated structures of filtering components to satisfy exacting customers. Filter of CCC type (corrugated cut cone CCC) developed in the early 60s of the 20th century is the most widespread one among such structures (Fig. 2.21) [7]. It is placed in cylindrical filtering box and pressed tightly between external surface of cover 3 and internal surface of body 1. Advantages of this structure include use of the whole filtering surface under conditions of correct correlation between the heights of corrugations and distances between them. Besides, owing to simplicity and low price of manufacturing process such type of filtering components has become common use worldwide (Fig.2.21). Considerable part of the material becomes wastes while cutting out conic blank part that is the disadvantage of this structure.

Some developers of RPD make filters corrugated in one plane. Thus, body 1 in figure 2.22 contains corrugated filtering material 2. Paper separators 3 being glued on the surface of filtering layer are put between adjacent folds to prevent their sticking. Filter is sealed in a body using special-purpose mixture 4. Rectangular structure of filters is quite economical as there are no wastes of filtering material but manufacturing process is much more complex and expensive. It is necessary to note that dustiness of this filtering element is not uniform: areas opposite the hole with breathing valve take the main load. Problem is partially solved with the help of inlet and outlet holes located in the opposite corners of filtering box as well as special-purpose guide paths ensuring ventilation over the whole filter surface. (Fig. 2.23).

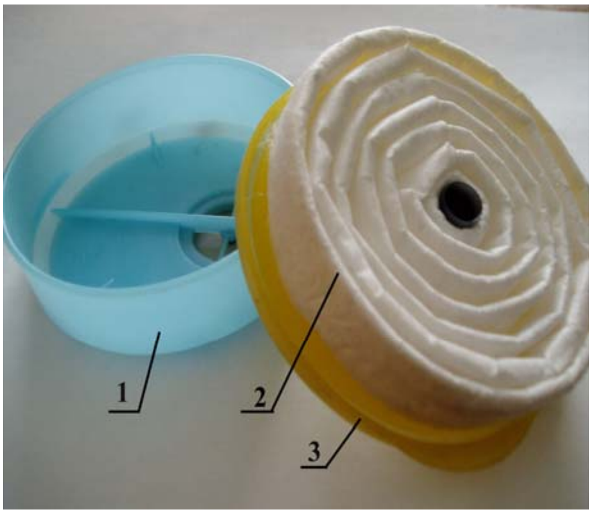


Fig. 2.21. Filtering elements of CCC type: 1 – body of filtering box; 2 – filtering element; 3 – cover of filtering box

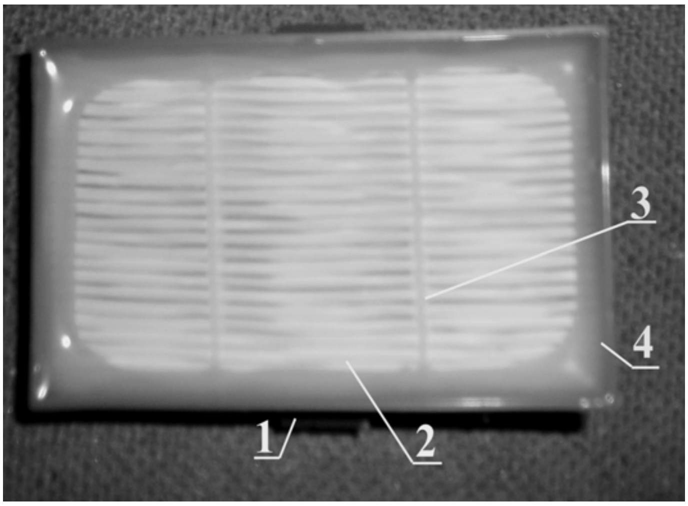


Fig. 2.22. Filtering elements, corrugated in one plane: 1 – body; 2 – filter; 3 – separator; 4 – sealer

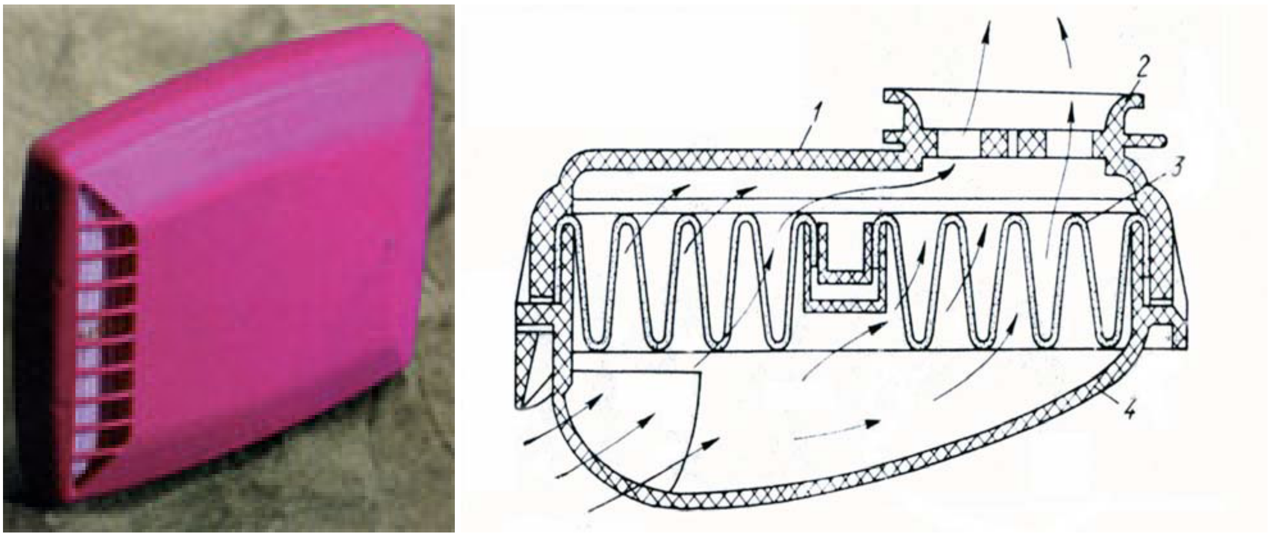
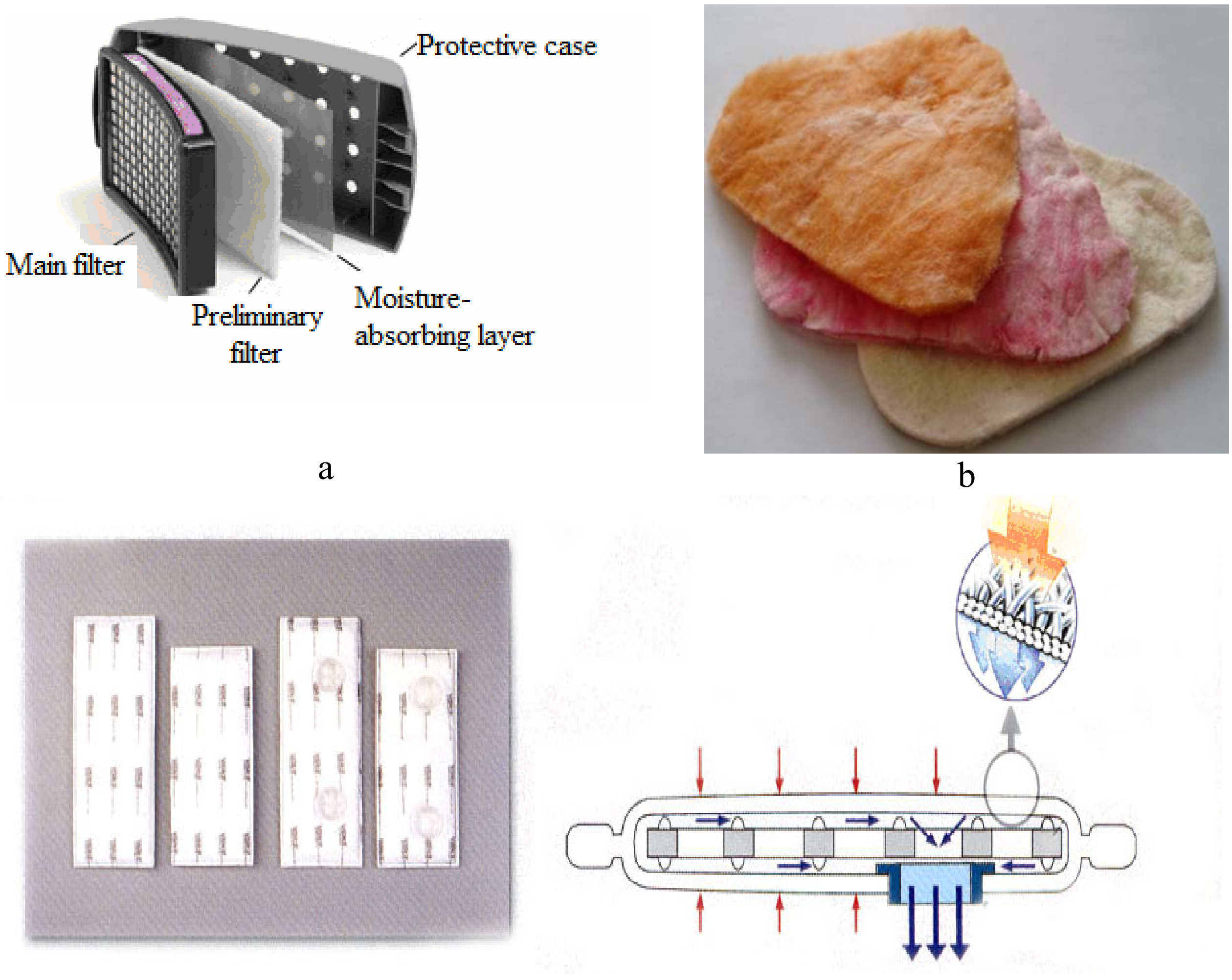


Fig. 2.23. Filtering box with a filter corrugated in one plane: 1 – body; 2 – space for inhale valve; 3 – filter; 4 – protective cover

There are structures of noncorrugated multilayered filters (Fig. 2.24) in which filtering layers differ in surface density: the first (with the least density) is meant for removal of coarse aerosol particles while the last (with the highest density) catches fine dust particles. Sometimes manufacturers add layer of special-purpose material to absorb moisture and as a result there is comparatively high dust holding capacity (Fig. 2.24 a). Usually such filters consist of two layers though there can be more then two of them (Fig. 2.24 b). There are double sided flat filters with stiffening ribs located inside the structure (Fig. 2.24 c). They are made of two-layer filtering material with enlarged filtering area comparing to previous structures. So-called preliminary filters (PF) are often fixed to filtering box; they intercept coarse dust and, as a result, they extend service life of main filter. PF can be quickly replaced when it is necessary (Fig. 2.25).



a

b

c

Fig. 2.24. Structure of noncorrugated filters: a – honeycomb; b – simple noncorrugated with layers of filtering material of different density; c – double-sided noncorrugated two-layered

Fig. 2.25. Preliminary filters

Consequently, filters can have such structures which would ensure high protection level for the workers and long working period, maximum comfort, quick change for new ones (if it is necessary). Information about each filtering element being most efficient under definite conditions can be found on special insert card of RPD manufacturer (along with the purchased item).

Having familiarized with the structures of the most widespread RPD, we can see their great variety. Each manufacturer tries to develop the respirator that would protect workers to the maximum against pneumonoconiosis and dust bronchitis at minimum disablement. Today there is a problem concerning selection of personal protective equipment for definite working conditions which solution requires good knowledge of main mechanisms of respirator performance according to specific environmental factors.

2.3. Protective efficiency and its connection with ergonomic figures of respirators

Main task of respiratory protective devices is to provide workerrs with clean air. That is why their main quality parameter is protective efficiency assessed by protection coefficient $K_{з}$. According to this coefficient all filtering RPD are divided into three groups of protection: low ($K_{з} < 10$), medium ($K_{з} = 10…100$), and high ($K_{з} > 100$). According to European standards, there is the following digital notation of protection level: low – 1, medium – 2, and high – 3.

Efficiency of respirators is determined experimentally by determining penetration coefficient K_n that expresses correlation of concentration of harmful substances in under-mask space of a respirator and the environment [7]:

$$K_{з} = 100 / K_n , \tag{2.1}$$

where $K_n = \frac{C}{C_0}$ is penetration coefficient of harmful substance through RPD;

C is concentration of harmful substances in under-mask space of a respirator, mg/m^3;

C_0 is concentration of harmful substances in the environment, mg/m^3.

Fig. 2.26 shows principal scheme for determining level of protective efficiency of a respirator. There is the following testing procedure: pressurized air is supplied into generator with special-purpose liquid. The obtained test-aerosol comes to a mixing box where it is diluted with clean air up to the necessary concentration; then it comes into a chamber with respirator or filtering material. Indicator of aerosol particle is used to determine inlet and outlet concentration of test-aerosol; formula (2.1) is used to calculate penetration coefficient. Turbine oil, paraffin or vaseline oil, sodium chloride etc. can be used as liquids for test-aerosol.

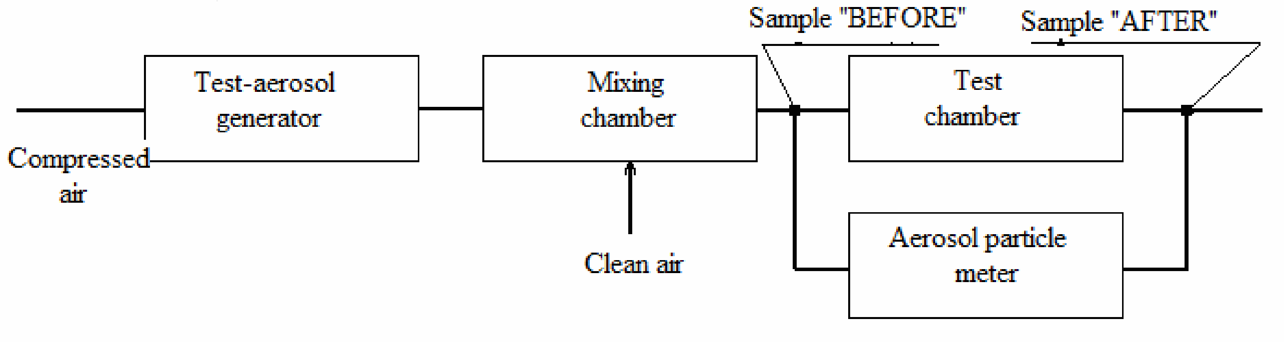


Fig. 2.26. Principal scheme of respirator testing using test-aerosols

RPD protective capacity depends upon specific features of the materialwhich filtering element is made of as well as upon process of aspiration of contaminated air through leakiness of valve system (in case of nondisposable respirators) or obturation line- the most vulnerable areas.

Special-purpose filtering materials characterized by random ultrathin fibers (with the diameter of 1 – 10 mcm), available electrostatic charge and low airflow resistance are used to manufacture filters. Materials of ФПП type (filters of Petryanov which fibers are made of chlorinated polyvinylchloride), polypropylene materials and definite types of filtering paper are the most widespread ones. Their quality is determined accoridng to catching efficiency of aerosol particles that depends upon density and diameter of fibers, thickness of filtering layer, filtration rate and diameter of aerosol particles. It is necessary to note that aerosol dispersion is one of determining factors to be used for correct RPD selection. There were some cases when bulky dressing and foam plasticrespirator were recommended as efficient protective devices. However, tests showed that they were efficient if aerosol radius is more than 20 – 25 mcm; if particles had radius less than 0.5 – 1 mcm then protective efficiency is not more than 5 %. Concequantly, corresponding research methods were developed with the use of particles with approximately 0.15 mcm in radius being the most penetrative ones to have objective evaluation of RPD quality. It is concsidered that aerosol catching of the radius being more or less than the specified onewill be more efficient. It is explained by the fact that filtration pocess is determined by several mechanisms stipulating impact of aerosol particle with fibers eliminating them out of gas flow. Here are these mechanisms: Brownian diffusion, direct fiber contect, action of inertial forces, and electrostatic attraction. Fig. 2.27 represents general scheme of aerosol particle motion near cross cylindrical fiber of filtering material [8]. Actuating quantity of each mechanism is characterized by coverage coefficient η that is equal to the ratio of the cross area of the particle flow directed to fiber from which they are caught to the projection area of the proper fiber:

$$\alpha = \frac{y}{a},$$

where y is the distance from the fiber center to the trajectory of the particles in gas flow which turn to be on fiber surface as the result of action of one of depositional mechanisms;

a is the radius of cylindrical fiber.

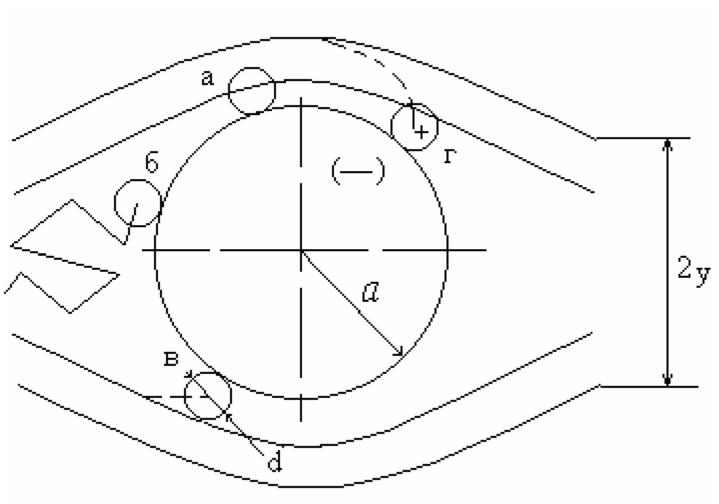


Fig. 2.27. Scheme of deposition of aerosol particles on a separate cylindrical fiber:
а – effect of contact;
б – Brownian diffusion;
в – gravity sedimentation;
г – electrostatic attraction

1. *Brownian diffusion*. As aerosole particles which are less than 1 mcm are in heat motion, some of them can touch fiber and come out of the flow. As the result area of decreased aerosol concentration appears with the following diffusive flow directed to the fibers. This effect depends upon the filtration rate and size of particles [9]:

$$\eta_D \approx \left(\frac{1}{vr}\right)^{1/2},$$

where v is filtration rate;

r is radius of a particle.

2. T*ouch effect*. If aerosol particle is at the distance not more than the half of its linear dimension while fiber rounding then it will thouch a fiber and come out of gas flow. This effect depends mostly upon the size of aerosol particles for specific filtering material, i.e.

$$\eta_R \approx r\,.$$

3. *Gravity sedimentation*. As the result of the fact that the particles have final mass, they shift from current line while fiber rounding and collide with it while coming out of a current. Effect value is directly ptoportional to the square of particle radius and motion rate, i.e.

$$\eta_I \approx r^2 v\,.$$

4. *Electrostatic attraction*. Filtering materials have eletrostatic charge on their fibers. Having entered into the field of this charge, perticles are polarized and attracted to the fiber. The more the size of particles is, the more intense and the nigher probability is that some of these particles will come out of the flow.

$$\eta_{ел} \approx \frac{r^2}{v}\,.$$

Fig. 2.28 shows functions of coverage coefficients stipulated by different mechanisms of aerosol particles catching depending on their size at constant filtration rate up to 1 cm/s. As we can see, particles with radius 0.15 – 0.25 mcm are caught worst that because sedimentation at the expense of Brownian diffusion is already not efficient and even less efficient at toughing and inertial mechanism. It is seen on a curve characteriszing similar implementation of all the mechanisms. Its calculation complexity is in the fact that each of the aforementioned effects of deposition is a mixed-level function depending on size, mass, dielectric properties of aerosol particles, fiber diameters, and densily of their location as well as viscosity and rate of filtering medium, besides influence of definite coverage mechanisms is not similar within different areas of these parameters. Fig. 2.29 shows dependence of coverage coefficients stipulated by different mechanisms upon filtration rate. It is clear that at low rate main influence while covering particles with fibers belongs to diffusive mechanism. Along with the rate growth, this function is taken by effect of tough being practically independent upon it and then it is taken by inertial mechanism. As the result total coverage coefficient and its corresponding filtration coefficient have minimum within rate range of 10 – 30 cm/s. Along with the growth of particle sizes the latter shifts to less rate. Thus, total coefficient of coverage of aerosol particles is a complex superposition that can be expressed in the form of components calculated according to formulas and some corrections considering mutual actions of depositional mechanisms [9], i.e.

$$\eta_{\sum} = \eta_D + \eta_R + \eta_{DR} + \eta_I + \eta_{IR} + \eta_{ел}, \qquad (2.2)$$

here η_{DR} is coverage coefficient stipulated by mutual action of diffusion and effect of touch;

η_{IR} is coverage coefficient stipulated by mutual action of inertia and touch.

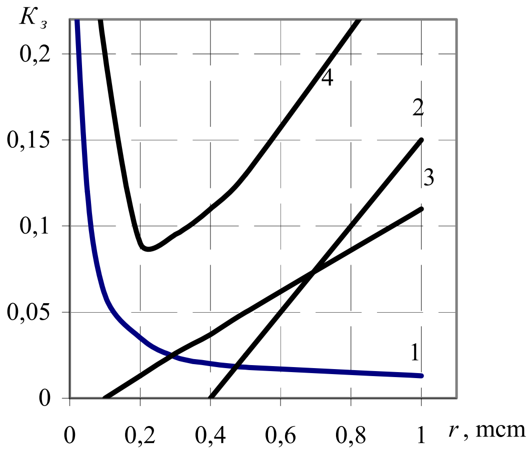


Fig. 2.28. Dependence of coverage coefficients of particles stipulated by different mechanisms upon their size: 1 – diffusive; 2 – touch; 3 – inertial; 4 – all together

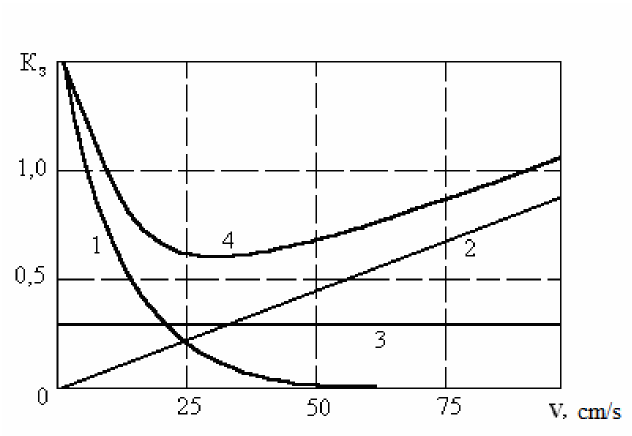


Fig. 2.29. Dependence of coverage coefficients of particles stipulated by different mechanisms upon filtration rate: 1 – diffusive; 2 – inertial; 3 – touch; 4 – all together

Elctrostatic catshing mechanism is of the highest interesy as charges available on the fibers of filtering materials increase considerably filtration efficiency (Fig. 2.10). Research has shown that efficiency of aerosol particles catching increases along with the growth of surface density of electrostatic charge on a filtering material (Fig. 2.31).

It should be noted that the component of electroctatic mechanism of catching at determining general coverage coefficient is almost 90 % at filtration rate of up to 6 m/s. Taking into account that air loss through RPD is up to 30 – 90 l/min and that their area is 500 – 1000 cm^2, maximum air rate here will be about 4 cm/s. That is why it is possible to neglect action of inertial and diffusive mechanisms in calculations of protective efficiency as it is less the 10 % from the general one.

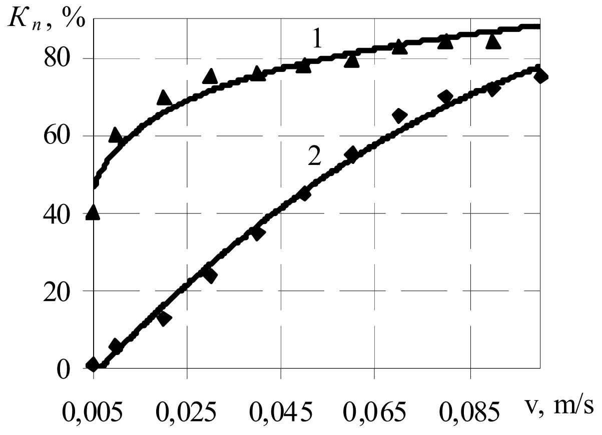


Fig. 2.30. Dependence of penetration coefficient upon filtration rate of filtering material made eleflen withour charge (1) and made of eleflen with charge $E = 350$ V/m^2 (2)

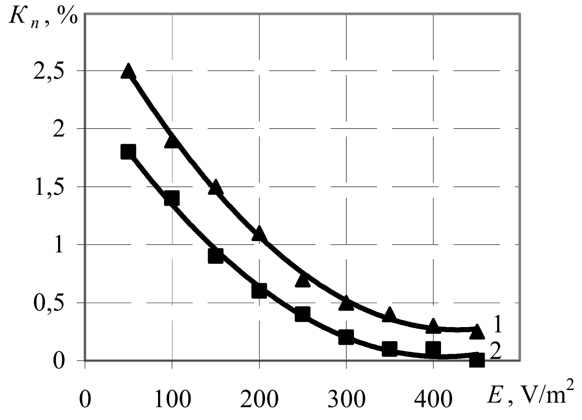


Fig. 2.31. Curves of dependence of penetration coefficient upon the value of surface density of electroctatic charge on filtering materials made of eleflen (1) and ФПП 15-1,0 (2)

While evaluating filtration process using fibrous filters it is clear that owing to the complex of actions of all the described mechanisms definite amount of aerosol particles deposits on each layer of filtering material being constant from layer to layer for homogeneous filtering material and monodisperse aerosol. Thus, aerosol particles are caught accoring to exponential law being expressed in a differential form as follows [10]

$$dN = -N\gamma dt ,$$

where dN is the amount of particles deposited in the layer of filter dt;

N is the amount of extraneous particles;

γ is coefficient of proportionality.

Coefficient γ is connected with total coverage coefficient by the ratio [11]

$$\gamma = \frac{2k}{\pi a(1-k)}\eta_{\Sigma} \ ,$$

where a is radius of fibers;

k is hydrodynamic parameter taking into account fiber arrangement in a filtering layer;

$$k = \frac{1}{-\lambda - 0{,}5\ln\beta},$$

where β is density of fibers;

λ is the coefficient of correction (it is 0.5 for ФПП material and 1.5 for polypropylene material [12]).

Coefficient of penetration

$$K_n = \frac{C}{C_0} = \exp(-\frac{2\eta_{\Sigma}\ kH}{\pi a}), \qquad (2.3)$$

where H if the thickness of a filtering layer.

RPD protective efficiency is determined according to the formula [8]

$$E = 1 - K_n .$$

Pressure differential determined by breathing resistance is one more important parameter of both RPD and filtering materials. Breathing resistance as physiological characteristics is the value connected with the volume of lung ventilation (structure of breathing cycle and working conditions) on the one hand and influence of structural peculiarities of respirators upon it on the other hand. However, at fixed meteorological parameters of the environment and human breathing parameters pressure differential depends only upon properties of filtering material which RPD is made of [7]:

$$\Delta p = 4k^{-1}v\mu\frac{\beta H}{a^2}, \qquad (2.4)$$

where μ is dynamic viscosity of gas, N·s/m^2.

Taking into account the factthat the resistance of air flow depends linearly upon thickness of fileting layer it is possible to establish interrelation between penetration coefficient and pressure differential

$$K_n = 10^{-\eta'(\Delta p/v)}, \qquad (2.5)$$

where $\eta^{/}$ is coefficient of proportionality:

$$\eta^{/} = 0,434\frac{a\beta\eta_{\Sigma}}{2\pi\mu}.$$

Having analyzed formula (2.5) the following conclusion can be made: protective efficiency is possible to improve at the expense of increasing thickness of filtering layer and fiber density as well as by reducing their diameters. In its turn, pressure differential increases on filtering material and consequantly on RPD (Fig. 2.32). Thus, while manufacturing respirators it is necessary to select the type of filtering material that corresponds to their protective degree. It is made to secure maximum efficiency of aerosol particles catching taking into account their size and minimum breathing resistance through respirator.

Table 2.1 gives basic parameters of domestic filtering materials used for RPD manufacturing [13 – 14].

Table 2.1

Main parameters of foltering materials

Grade of filtering material	Mean fiber diameter , mcm	Rupture load, N	Fiber density, g/m^2	Airflow resistance Pa, at a rate of 1 cm/s	Penetration coefficient K_n according to test-aerosol OF at the rate of 1 cm/s
ФПП 15-0,6	1.5	0,5	13 – 19	5 – 7	0.5
ФПП 15-1,5			25 – 30	12 – 15	0.01
Eleflen 5P	2.5	11	45 – 50	3 – 5	6 – 9
НФП 0,5-0,1	2.0	10	40 – 45	4 – 6	6 – 8

*OF – oil fog.

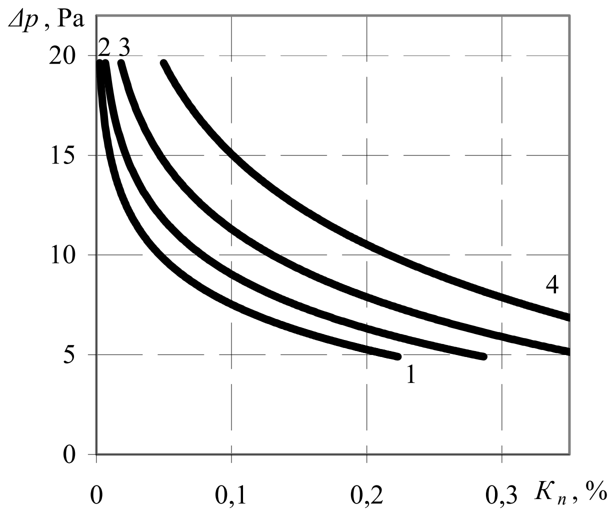


Fig. 2.32. Curves of penetration coefficient dependence upon pressure differential on filtering material made of eleflen at different fiber diameters $d_в$, mcm: 1 – 1.5; 2 – 2; 3 – 2.5; 4 – 3

The aforementioned grades of filtering materials (Table 2.1) are used to manufacture almost all domestic RPD; as for foreign RPD mostly polypropylene filtering materials similar to domesitc ones are used: eleflen, UFP – unwoven filtering polypropylene though there can be special-purpose filtering paper or paperboard.

Having defined the notions of penetration coefficient according to test-aerosol and breathing resistance for filtering materials it is necessary to evaluate main RPD parameters (Table 2.2) which requirements are represented in DSTU (Ukrainian national standardization system) 12.4.041-89 (Appendix B).

The research analyses of the main RPD parameters obtained in the testing laboratory of technical expertise of collective and individual protection equipment (the National Mining University) allows making the following conclusions:

- In general foreign samples of respirators meet the requirements of national standard;
- Pressure differential on nondisposable respirators at air loss of 30 l/min is within the ranges of: 30 – 63 Pa during inhale, 9 – 60 Pa during exhale; scattering is explained by the available exhale valve which reduces breathing resistance in RPD;

Table 2.2

Main parameters of some national and foreign RPD

Type of respirator	Breathing resistance Pa, at air loss, 30 l/min		Degree of protection* (quality)	Penetration coefficient за MT**	Available exhale valve
	During inhale	During exhale			
Moldex 2400	50	12	FFP 1	–	+
Moldex 2500	60	12	FFP 2	–	+
Willson 2201	30	9	FFP 1	–	+
Willson 2210	61	60	FFP 2	–	-
Willson 2211	59	10	FFP 2	–	+
Willson 2293	65	14	FFP 3	–	+
3M 8812	37	11	FFP 1	–	+
3M 8822	48	20	FFP 2	7	–
3M 9210	20	20	FFP 1	–	–
3M 9220	25	24	FFP 2	1.5	–
3M 9230	41	40	FFP 3	0.2	–
Filgif 4020	30	30	FFP 1	–	–
Filgif 4020 (V)	35	21	FFP 1	–	–
“Puls - M”	25	15	2nd class	1.8	+
Picco – 20	95	75	FFP 3	0.6	+

Dustfoe – 66	74	73	FFP 2	2.1	+
РПА - ТД – 1	55	30	2nd class	2.3	+
РПА - ТД – 2	25	30	2nd class	1.8	+
“Klyon – P”	30	30	2nd class	1.9	+
“Lepestok - 200”	30	30	1st class	0.4	–
“Lepestok - 40”	12	12	2nd class	2.0	–
“Lepestok – 100E”	11	11	2nd class	1.0	–
“Rostok - 2”	30	30	2nd class	3.2	–
“Rostok - 3”	15	15	3nd class	–	–
“Rostok – 1П” (ПК)***	40	40 (15)	FFP 3	0.9	– (+)
“Rostok – 2П” (ПК)	30	30 (15)	FFP 2	–	– (+)
“Rostok - 2Ф” (ФК)	30	30 (15)	FFP 2	–	– (+)
“Rostok – 3П” (ПК)	20	20 (15)	FFP 1	–	– (+)
“Rostok – 3Ф” (ФК)	20	20 (15)	FFP 1	–	– (+)
“Snezhok – П”	30	15	2nd class	3.2	+
“Antareks – П”	30	15	2nd class	–	+
“Kama - 200”	35	35	2nd class	0.8	–
Affinity Pro with valve	60	70	FFP 2	–	+
Advantage – 200	20	60	FFP 3	0.1	+

*Degree of protection (quality) of foreign respirators has been determined according to characteristics given according ot European standards EN 141, EN 149; degree of protection of national ones has been determined according to DSTU 12.4.041-89.

**Penetration coefficient according to test-aerosol of oil fog at air lass of 30 l/min.

***In brackets – grading and data for respirators with exhale valve (ПК, ФК are half-masks with exhale valve).

- Pressure differential grows along with the increase of protection level that can be explained as follows: to improve protective efficiency of respirator it is necessary to use filtering material with higher fiber density. Moreover, obturation line in reinforced with the help of special strips,for example, made of foamed polyurethane that eliminates air aspiration;
- Pressure differentical of cartridge respirators is next higher order comparing to disposable ones;
- Breathing resistance of domestic respirators is almost twice less comparing to foreign ones. It is explained by the difference in structures of filtering boxes. Thus, foreign respirators usually have filters with honeycomb structure with comparatively limited filtration area (Fig. 2.24 a).

While comparing technical characteristics of filtering material which RPD are made of to analogue respirator parameters (for example, breathing resistance and penetration coefficient of a sample made of eleflen and ШБ-1 “Lepestok-100E”, from

Table 2.3) we can see great difference between them. It can be explained by imperfect structure both of half-masks (see point 2.2.) and filtering elements, m particular when they are selected incorrectly.

Table 2.3

Main parameters of respirator ШБ-1 “Lepestok-100E” and examples made of eleflen

Type	Filtration rate m/s	Breathing resistance Pa	Penetration coefficient K_n, %, as for OF,
Samples made of eleflen	0.015	7.1 ± 0.5	0.3 ± 0.005
ШБ-1 “Lepestok - 100E” respirator	0.015	10.9 ± 0.4	0.9 ± 0.005

Long-term research and practical experience has allowed to establish that the loss of protective efficiency due to imperfection of half-masks takes place first of all at the expense of redistribution of airflows. It results in aspiration of unfiltered air through leakiness along obturation line with the following deterioration of RPD protective properties.

Functioning of any respirator can be represented in a simplified form in the following way: unfiltered air with mass component of harmful impurities W_1 (during inhale) near respirator is distributed into two flows (Fig. 2.33). One of them ($W_{ф.е}$) goes through filtering element and the second one ($W_{c.o}$) goes through airspaces along obturation line. If filter resistance is more than the resistance of obturation line then there is considerable aspiration of contaminated air into under-mask space. IN such case penetration coefficient of aerosol through respirator can be determined according to the formula [15]:

$$K_n = \frac{K_n^{ф.е} + \sqrt{R_{ф.е} / R_{c.o}}}{1 + \sqrt{R_{ф.е} / R_{c.o}}},$$

where $K_n^{ф.е}$ is penetration coefficient of aerosol through filtering element of respirator;

$R_{ф.е}$ is the resistance of filtering element (kgf)/m^5;

$R_{c.o}$ is the resistance of obturation line (kgf)/m^5.

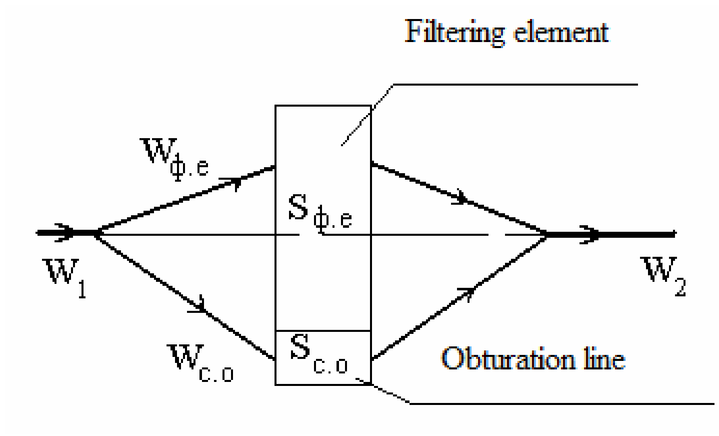


Fig. 2.33. Simplified scheme of airflow redistribution in respirator

Fig. 2.34 shows dependence of penetration coefficient of test-aerosol through respirator upon the ratio of resistance values of filtering element and obturation line.

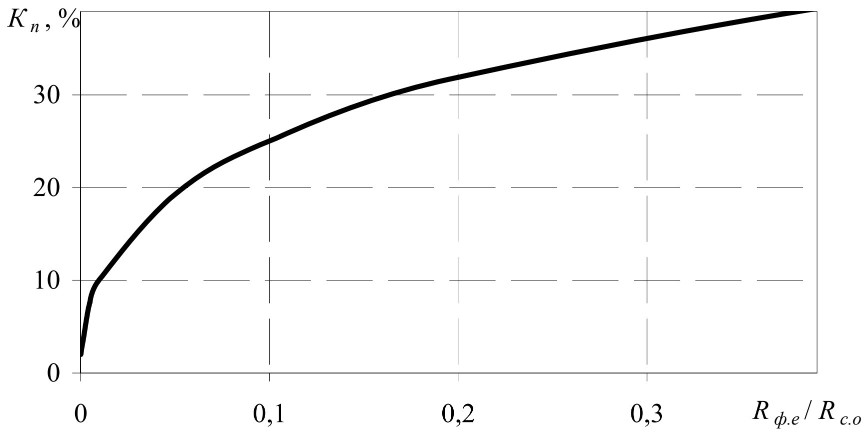


Fig. 2.34. Dependence of penetration coefficient of test-aerosol through respirator upon ratio of resistance values of filtering element and obturation line

To analyze redistribution of airflows take widely used РПА-ТД respirator. Fig. 2.35 shows experimental dependence of levels of its protective efficiency upon protective efficiency of filters made of different materials obtained at studying penetration coefficient according to OF test-aerosol. It is seen that first protective efficiency of respirator increases then decreases along with the improvement of filter quality owing to fiber density or thickness of filtering layer (at that its breathing resistance grows) [15].

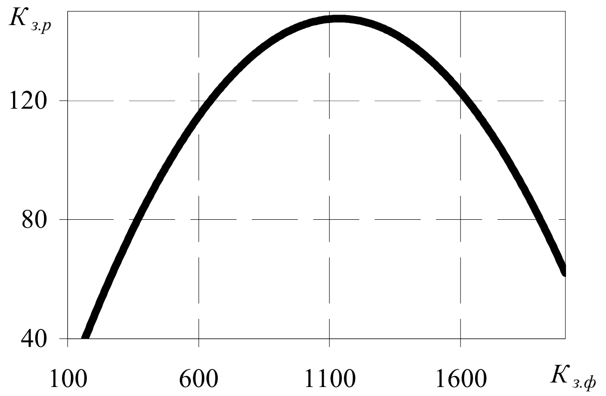


Fig. 2.35. Experimental dependence of protection coefficient of respirator upon protection coefficient of filter

It seems that respirators which filters of ФПП 15 – 1,5 material should have higher protection efficiency than RPD filters made of polypropylene materials. However, in general protection efficiency of respirator is lower due to high breathing resistance of filter made of ФПП 15 – 1,5 to airflow. It proves the assumption concenrning airflows redistribution in respirator when filter highly resists breathing (Table 2.4).

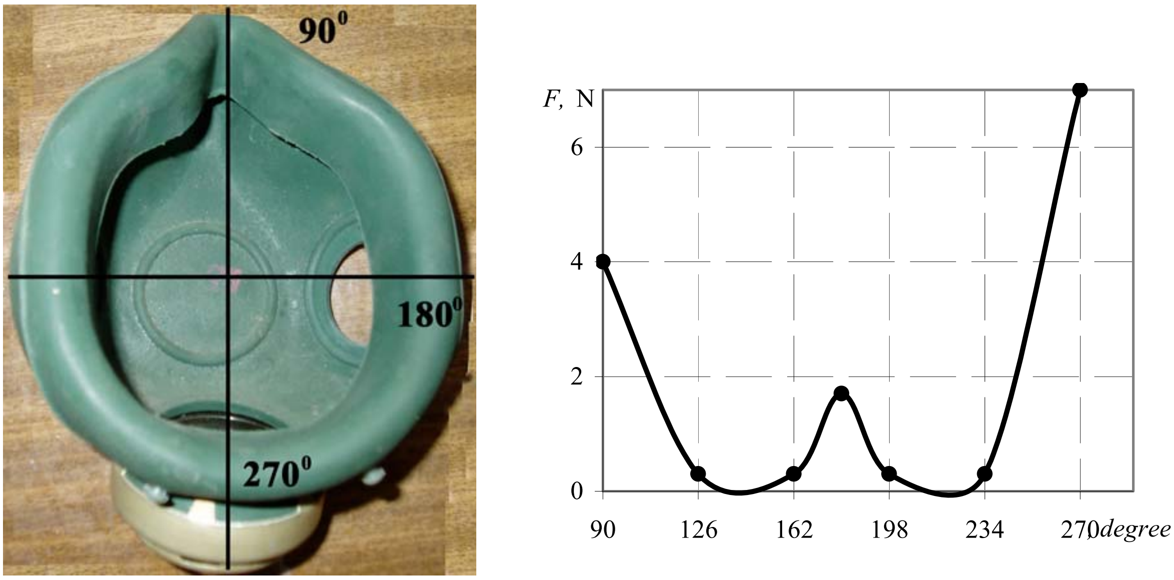
Table 2.4

Protective efficiency of РПА-ТД respirator with different filters

Parameter	Filter of the 1st class of protection made of ФПП15-1,5	Filter of the 2nd class of protection made of eleflen	Respirator with filters of the 1st class of protection	Respirator with filters of the 2nd class of protection
Airflow resistance Pa, at air consumption of 30 l/min	73 ± 3.5	54 ± 2.7	39 ± 3.2	25 ± 2.4
Penetration coefficient K_n, %, according to test-aerosol OF at air consumption of 30 l/min,	0.05 ± 0.005	0.7 ± 0.03	2.8 ± 0.2	1.9 ± 0.5

Thus, as Table 2.4 shows despite the fact that filtering elements of the 1st class of protection has low penetration coefficient, in general protective efficiency of РПА-ТД respirator is lower comparing to protective efficiency of the same respirator with filters made of eleflen at the expense of their increased breathing resistance. It is obvious that along with the increasing filers resistance resisatance of obturation line should be intensified as well otherwise RPD with high-efficiency filtering elements wil not ensure the required class of protection because of their increased resistance.

Nonuniform distribution of clamping pressure along obturation line to a face is one more reason for penetration of unfiltered air into under-mask space. It is established that to ensure high protective efficiency of a half-mask pressing force should be within 4 – 10 N; here value of mechanical pressure to skinwillbe about 2.5 – 5.2 – kPa [2]. However, as studies have shown distribution of these forces along obturation line of half-mask is not uniform: maximum pressure is fixed around bridge of the nose and chin (Fig. 2.36).



Fog. 2.36. Distribution of mechanical force along obturation line of РПА-ТД respirator

Set up system of equations describing boundary state of half-mask balance, for example, of РПА-ТД respirator (Fig. 2.37). Its solution will allow determining distribution of forces along obturation line to reduce painsense and minimize aspiration of unfiltered ait into under-mask space [16]

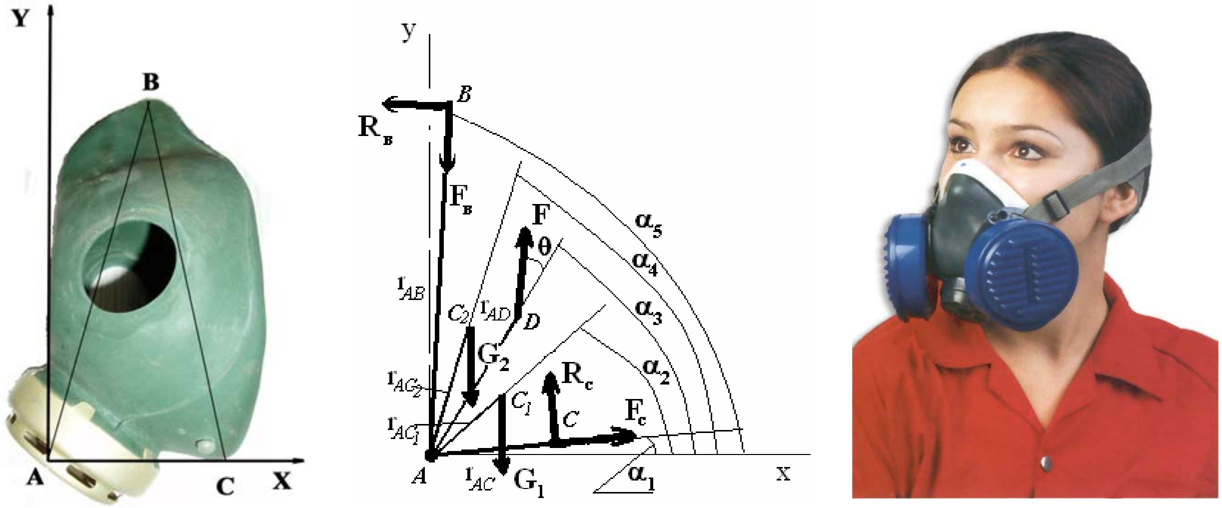


Fig. 2.37. Calculation schemeof half-mask of РПА-ТД respirator

$$\begin{cases} \sum M_A = 0; \; R_B r_{AB} + R_C r_{AC} + F r_{AD} \sin\theta - G_1 r_{AC_1} \cos\alpha_4 - G_2 r_{AC_2} \cos\alpha_2 = 0; \\ \sum F_{ix} = 0; \; -F_C \cos\alpha_1 - R_C \sin\alpha_1 + F\cos(\theta+\alpha_3) + F_B \cos\alpha_5 - R_B \sin\alpha_5 = 0; \\ \sum F_{iy} = 0; \; -F_C \sin\alpha_1 + R_C \cos\alpha_1 + F\sin(\theta+\alpha_3) + F_B \sin\alpha_5 + R_B \cos\alpha_5 - G_1 - G_2 = 0, \end{cases} \tag{2.6}$$

where G_1, G_2 is attractive force of half-mask and filter;

F is tension force of headband;

F_B, F_C is friction force;

R_B, R_C are reactions around bridge of the nose and chin.

While analyzing solution of system (2.6) the following should be summed up: raction within chin (curve 2) is more intense than around bridge of the nose (curve 1) – Fig. 2.38. This fact is confirmed by intense aspiration of contaminated air within the area from the bridge of the nose and nasolabial area while using respirator that proves correctness of the offered model of distribution of pressing forces of half-mask along obturation line of РПА-ТД respirator.

Evaluate inpact of tension force of headband F on the reaction around chin and bridge of the nose. We will find the following using first equation of system (2.6)

$$F = {G_1 r_{AC_1} \cos\alpha_4 + G_2 r_{AC_2} cos\alpha_2 - R_B r_{AB} R_C r_{AC}} \Big/ {r_{AD} \cos\theta}. \tag{2.7}$$

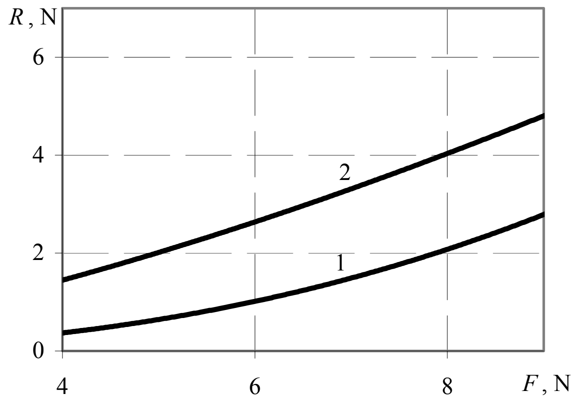


Fig. 2.38. Dependence of reaction values around bridge of the nose (curve 1) and chin (curve 2) upon tension force

Fig. 2.39. Facial areas of contamination (nasolabial rea is the most contamined one)

Set down the second and third equations of system (2.6) by means of functional connection of friction force upon friction coefficientin the following form

$$\begin{cases} R_C(f_C\cos\alpha_1-\sin\alpha_1)+F\cos(\theta+\alpha_3)+R_B(f_B\cos\alpha_5-\sin\alpha_5)=0; \\ R_C(f_C\sin\alpha_1+\cos\alpha_1)+F\sin(\theta+\alpha_3)+R_B(f_B\sin\alpha_5-\cos\alpha_5)-G_1-G_2=0. \end{cases} \quad (2.8)$$

Having replaced value of force F in last equations by functional connection (2.7) and havinf introduced values

$$a_{11}=-f_c\cos\alpha_1+\sin\alpha_2-\frac{r_{AC}\cos(\theta+\alpha_3)}{r_{AD}\sin\theta};$$

$$a_{12}=f\cos\alpha_5-\sin\alpha_5-\frac{r_{AB}\cos(\theta+\alpha_3)}{r_{AD}\sin\theta};$$

$$a_{21}=-f_C\sin\alpha_1+\cos\alpha_1-\frac{r_{AC}\sin(\theta+\alpha_3)}{r_{AD}\sin\theta};$$

$$a_{22}=f_B\sin\alpha_5+\cos\alpha_5-\frac{r_{AB}\sin(\theta+\alpha_3)}{r_{AD}\sin\theta};$$

$$b_1=-\frac{\cos(\theta+\alpha_3)}{r_{AD}\sin\theta}\left[G_1\cos\alpha_4 r_{AC_1}+G_2\cos\alpha_2 r_{AC_2}-R_B r_{AB}-R_c r_{AC}\right];$$

$$b_2=G_1+G_2-\frac{\cos(\theta+\alpha_3)}{r_{AD}\sin\theta}\left[G_1\cos\alpha_4 r_{AC_1}+G_2\cos\alpha_2 r_{AC_2}-R_B r_{AB}-R_c r_{AC}\right],$$

We willhave system of equations

$$\begin{cases} R_C a_{11}+R_B a_{12}=b_1 \\ R_C a_{21}+R_B a_{22}=b_2 \end{cases},$$

Which solution willallow determining reactions around bridge of the nose R_B and chin R_C depending on place of force F:

$$R_C = \frac{b_1}{a_{11}} - \frac{a_{12}(b_2 a_{11} - b_1 a_{21})}{a_{11}(a_{22}a_{11} - a_{12}a_{21})}; \; R_B = \frac{b_2 a_{11} - b_1 a_{21}}{a_{22}a_{11} - a_{12}a_{21}}. \tag{2.9}$$

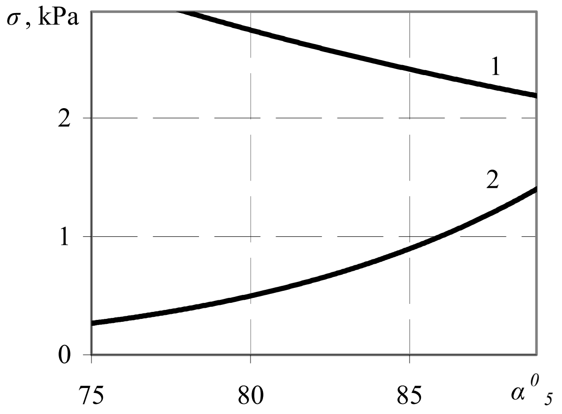
To improve protective properties and reduce pain sense along obturation line it is necessary to reach uniform pressure around bridge of the nose σ_B and chin σ_C. Neglacting nonuniform distribution of this pressure over contact area its average values can be calculated using the following formulas

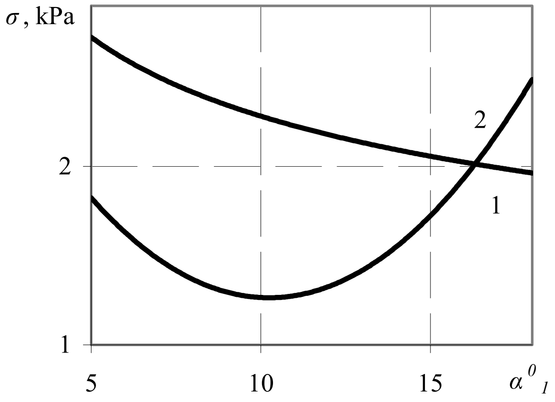
$$\sigma_B = \frac{R_B}{S_B}; \qquad \sigma_C = \frac{R_C}{S_C}, \text{ kPa}, \tag{2.10}$$

where S_B, S_C are areas of contact zones around bridge of the nose and chin, m^2.

Evaluate influence of geometricla dimensions of half-mask of respirator upon value of stresses σ_B and σ_c using functional connecitons (2.9) and (2.10).

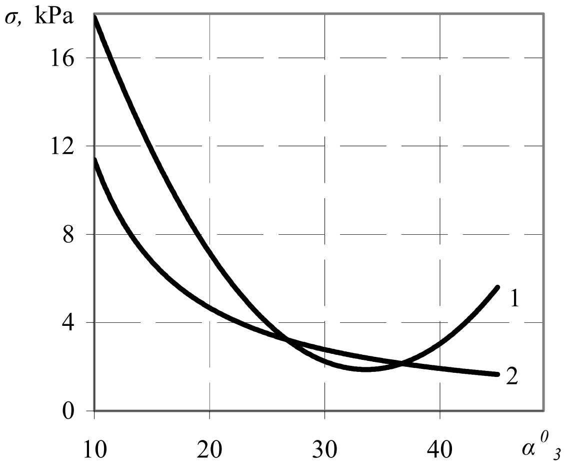
Boundaries of changes of geometrical dimensions are minor and limited by anthropometric dimensions of a human face. However, even this relatively small range alllows finding such values of geometricla dimensions at which parameters of reactions around bridge of the nose and chin will be similar or close. Thus, graphs of Fig. 2.40 draw values of changes σ_B and σ_C depending on values of angles α_1, α_5, determined according to half-mask shape. As we can see the least difference (about 35 %) between σ_B and σ_C will be with angle $\alpha_5 = 90^0$ and difference between reactions around bridge of the nose and chin will grow along with the decrease of the latter. There is the value of ($\alpha_1 = 16^0$) at which $\sigma_B = \sigma_C$ (Fig. 2.40 b) within the area of change of sngle α_1. Nevertheless, half-mask with similar angle is not convenient to be used. On the other hand, change of neadband positionwill influence considerably upon redistribution of pressure value (Fig. 2.41). Thus, according to the obtained functional connections developed using expressions (2.9) and (2.10) σ_B and σ_C are close to each other at $23.5 < \alpha_3 < 33.5$. They difference increases beyond this area because of unbelenced half-mask structure as place of tension force F is lower than the mass center. When headbans position as for fixation is changed by varying angle θ (Fig. 2.41 b) it is possible to find such value $\theta = 14^0$ at which presses would be levelled off as well.

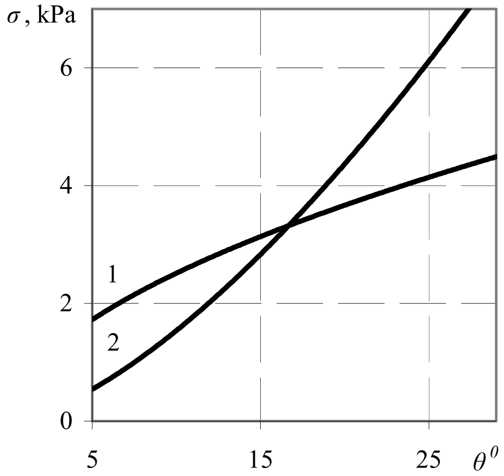




a B

Fig. 2.40. Dependence of pressures σ_B (curve 1) and σ_C (curve 2) upon geometrical parameters of half-mask (angles α_1, α_5)





a B

Fig. 2.41. Dependence of pressures σ_B (curve 1) and σ_C (curve 2) upon headband position

Fig. 2.42. Respirator with two strips of headband fixation

Thus, experimental and analytical studies have revealed nonuniform pressure distribution along obturation line of respirator. However, as the result of defining impact of structural parameters upon pressure intensity their following values have been determined at which forces around bridge of the nose and chin become balanced. To solve this problem respirators with two strips of headband fixation are manufactured: one of them is connected to the lower part of a half-mask for tight contact with a chin and another one is connected to the upper part to have no leakiness along obturation line – around nasolabial area (Fig. 2.42).

As it is already proved, structure of filtering elements influences protective efficiency as well. It is known that to meet the requirements for filters large working area is necessary. Corrugation is the simplest and quite widespread way of enlarging filtering area (Fig. 2.21, 2.22) when channels are made being larger along the flow and smaller across it (Fig. 2.43). Corrugated filters are characterized by linear value: fold spacing that includes thickness of filtering material $T = t_1 + t_2 + H$, where t_1, t_2 are width of inlet and outlet channels.

Breathing resistance of such filter consists of airflow resistance of the proper filtering material and channels made between corrugations that explains difference between parameters of both filtering elments and filtering materials.

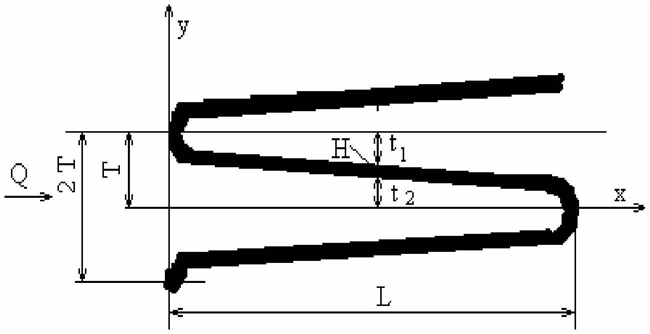
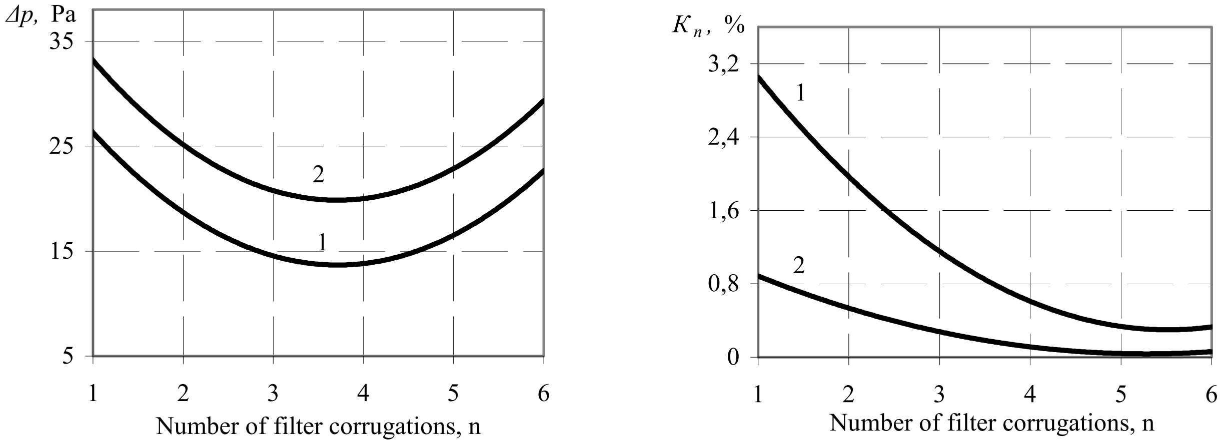


Fig. 2.43. Scheme of corrugated part of a filter

If filtration area is increased by several times then airflow rate coming onto protective device should be reduced; consequently, breathing resistance and penetration coefficient if test-aerosolshould decrease as well. However, there is no appreciable divergence in figures of penetration coefficient and breathing resistance even increases.

While analyzing experimentaldata of dependence of penetration coefficient of test-aerosol upon filtration rate specified for samples made of eleflen with the dimensions of 50 cm^2 andsix-fold filters made of this material with the area of 500 cm^2 (Table 2.5) we can make sure that figures of filtering elements are worse than the ones of noncorrugated samples at similar filtration rate. Thus, filtration rate should decrease along with the increase of filter area and consequaently pressure differential on it should decrease as well. However, thickening of filtering material to improve its protective efficiency (because of limited dimensions of filtering boxes) increases breathing resistance as adjacent corrugation areas are eliminted from the process of air purification, i.e. enlarged filtering surface at the expense of material corrugation does not always improve RPD performance. It is obvious that there is optimal correlation between thickness and area of filtering element which is expressed by the distance between corrugations when the least breathing resistance (a) and low coefficient of test-aerosol penetration (b), Fig. 2.44, can be observed. It means that there is final fold spacing with minimum filtration rate for each specified filter (corrugation) height. Further distance shortening between corrugations is not reasonable because filtration rate will increase at the expense of decrease of working surface of a filter due to sticking of adjacent folds. On the contrary, airflow rate willincrease along with distance increase between corrugations as general filtration rate will decrease.



a B

Fig. 2. 44. Curves of dependence of breathing resistance (a) and coefficient of test-aerosol penetration (b) upon the number of filter corrugations to РПА-ТД respirator: 1 – filters made of eleflen; 2 – filters made of ФПП 15 – 1,5

Resistance of filter respirator can be calculated according to the formula [17]

Table 2.5

Values of penetration coefficient of noncorrugated and corrugated samples

Sample type made of eleflen	Filtration rate, cm/s	Breathing resistance, Pa	Penetration coefficient K_n, %, according to OF test-aerosol,
Noncorrugated	0.6	6.4 ± 0.1	0.4 ± 0.005
Corrugated (filter)	0.6	21.3 ± 2.0	0.5 ± 0.004

$$\Delta p = \frac{3\mu v\, h}{t^2}(1 + \frac{2ch\lambda h}{\lambda hsh\lambda h}), \tag{2.11}$$

where h is corrugations height, m;

t is channel width, m;

λ is configuration parameter, 1/m.

Configuration parameter λ characterizes impact level of both filtering material and filter geometry upon of nonuniformity level of airflow distribution throughout corrugations height (Fig. 2.44). Besides it takes into account corrugations closing that depends upon the amount of air and filter deformation in a box, i.e.

$$\lambda = \sqrt{\frac{6\mu k_1 Q}{C_f t^3}}, \tag{2.12}$$

where k_1 is coefficient of nonuniformity of air load distibution throughout corrugations height that depends upon the amount of air;

Q is air consumption, l/min;

C_f is filtering material resistance, N/m^3·s.

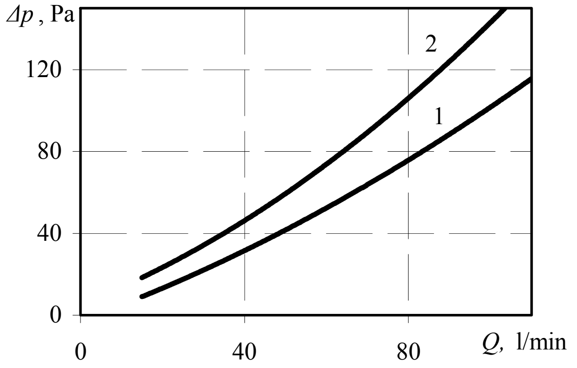


Fig. 2.45. Dependence of filter resistance upon air consumption: 1 – filters made of eleflen; 2 – filters made of ФПП 15-1,5

Coefficient of nonuniformity of air load distibution throughout corrugations height is determined experimentally: at level 10 for filters made of ФПП; at level 8 for filters made of eleflen.

Thus, under conditions of minimum Δp (2.11) it is possible to determine optimal dimentions of filters with minimum breathing resistance:

$$\frac{shz}{z}+2chz-5=0,\ \ z=\lambda h=h[(6\mu k_1 Q)/(C_f t^3)]^{1/2}\ ,$$

$$z\cong 1{,}234\,.$$

$$\frac{h^3}{t^3}=\frac{z^2 C_f h}{6\mu k_1 Q},\quad t=\sqrt[3]{\frac{6\mu h^2 k_1 Q}{z^2 C_f}}\,. \tag{2.13}$$

Formula (2.13) at known air consumption (through filter) can be used to determine channel width as well as length of fold with the specified height of filtering element at which pressure differential will be the least.

2.4. Effect of operation mode upon RPD selection

On the one hand, use of respiratory protective devices has positive results seeing in reduced probability of pneumonoconiosis and dust bronchitis; on the other hand, it is accompanied by the complex of factors influencing cardiovascular system performance, function of external respiration etc. that results in performance decrement and quick fatigue cumulation. To evaluate effect of respirator upon miner’s physical state it is necessary to clearify the changes in the organism during operation. First of all, it is change of respiratory mode: duration of inhale and exhale phases increases, oxygen need grows as well as continual volume and breathing frequency; respiratory depth changes. Respiratory movements become less frequent and deeper to compensate lack of oxygen which is spentduring phisical loading. Besides, there are definite changes in heart performance (Table 2.6 [17]).

There is performance decrement and health deterioration due to defatigation of physical systems of the organismin general and change of pulmonary mechanics in particular. Since each RPD type is characterized by aerodynamic breathing resistance and “connection” to human lungs results in changes in the structure of respiratory cycle then it is necessary to select them very carefully. Thus the research based on standard enthods according to GOST 12.4.061-88 “Methods for determining working capacityof a man wearing respiratory protective devices” shows considerable influence of pressure differential inrespirator upon miners' working capacity especially during high loads (Table 2.7, 2.8)

Table 2.6

Change of lung ventilation during operation of different efficiency

Type of operation	Energy consumption, W	Oxygen consumption, ml/min	Heart rate, beat/min	Respiratory volume per minute, l/min	Respiratory frequency, cycle/min	Respiratory depth, ml
At rest	–	250	70	8	12	660
Light	105-140	750	100	20	14	1430
Moderate	141-175	1500	120	35	15	2330
Hard	176-232	2000	140	50	16	3130
Fatigable	233-290	2500	160	60	20	3000
Maximum	291-349	3000	180	80	25	3200

Table 2.7

Results of veloergometer experiment

Parameter	Physical load, W, Without RPD			Physical load, W, With breathing resistance 20 Pa			Physical load, W, With breathing resistance 40 Pa			Physical load, W, With breathing resistance 60 Pa		
	150	200	250	150	200	250	150	200	250	150	200	250
Absolute performance period, min	3.3	2.6	2.2	3.1	2.4	1.9	2.9	2.2	1.7	2.4	1.8	1.4
Working ability, %	100			95.2	92.5	87.2	85.4	81.9	73.1	62.0	54.7	41.0
Loss of working ability, %	–			4.8	7.5	12.8	14.6	18.1	26.9	38.0	45.3	59.0

While performing standard operations on veloergometer with random breathing testees (men) worked with the load of 200 W for about 2.6 min up to absolute performance period; while working wearing respirator with breathng resistance of 20 Pa time went down up to 2.4 min. It proved that the vailable RPD resilts in fatigue quicker, thus it results in reduced amount of work [18]. Fig. 2.46 represents dependence curves of human working capacity value upon pressure differential on respirators with different load types.

Table 2.8

Average parameters of functional state of testees (men) according to the test "stairs" [19]

Parameters	At rest	At load without RPD	At load with breathing resistance, Pa		
			20	40	60
Body mass, kg	68	–	–	–	–
arterial tension, mm hg	126/87	142/91	148/98	156/103	162/109
Pulse, beat/min	72	157	163	168	176
Number of ascents per minute	–	39	39	38	35

Load can be also determined quite accurately while having test "stairs" without respirator and wearing respirator: if you know human body mass, stairs height, and number of ascents per minute [18]

$$\mathrm{N} = Mht - 1{,}33\,,$$

where N is load, kg·m/min; M is body mass, kg; h is height of a stair, m; t is number of ascents per minute; 1.33 is a float coefficient that takes into account physical efforts for stairs descending (they are about 1/3 of efforts for ascending).

According to the the data obtained indicate deterioration of functional state of the testees wearing respirators comparing to the performance of test exercises without RPD. Thus, at free breathing average arterial tension (after exercise) was 140/90 while at available respirator with 60 Pa it increased by almost 15%.

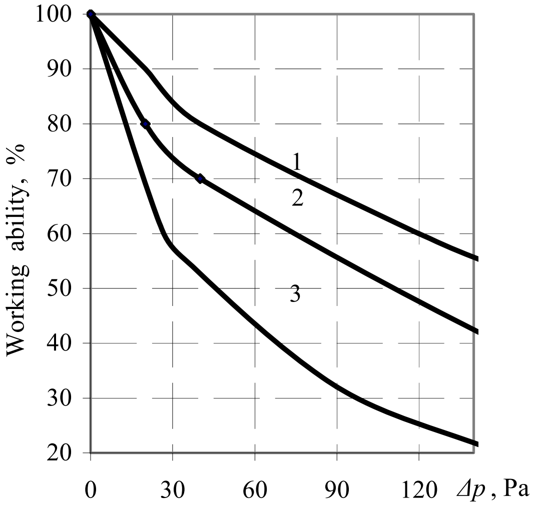


Fig. 2.46. Dependence of working capacity value on pressure differential at loading, W: 1 – 150; 2 – 200; 3 – 250

Significant pulse rising indicates the change of physical activity while RPD using. It is especially seen when breathing resistance reaches 40 Pa. Pulse rising by 10 units confirms significant physical fatigue [20]. While comparing the obtained figures of functional states of the testees, impact of breathing resistance on the value of human load was determined (Table 2.9).

Table 2.9

Impact evaluation of breathing resistance through RPD on human working capacity

Parameter	At loading withour RPD	At load with breathing resistance, Pa		
		20	40	60
Load value, W/min	608.6	594.3	546.1	483.5
Loss of working capacity, %	–	2.5	11.3	25.7

Table 2.9 shows: the testees wearing respirators could not adapt to the rhythm of ascending. At breathing resistance of 60 Pa maximum possible working load was about 530.4 W/min that is by 25.7% less than at free breathing. Difference between the figures of the loss of working capacity at working on veloergometer and while ascending stairs is stipulated by different energy consumptions.

Loss of working capacity can be evaluated according to the work of breast muscles that is determined as total product of general pressure P (it occurs while breathing) by air volume V that moves every single moment [21]

$$A = PV. \tag{2.14}$$

General pressure P taking into account available respirator can be represented as the sum of three pressure typres:

$$P = P_{e1} + P_{\partial} + P_{r}, \qquad (2.15)$$

where P_{e1} is pressure componnt connected with elastic resistance of the system;

P_{∂} is pressure component combined by dynamic system resistance;

P_{r} is pressure component in combination with external RPD resistance.

Elastic capacity of respiratory system canbe evaluated using formula $P_{e1} \approx V(1/C)$, where C is lung compliance (for healthy person C is within the range of 0.1 – 0.2 l/s·millimeter of water [19]). To determine lung pressure to overcome non-elastic breathing resistance it is possible to use the expression $P_{\partial} = k_1 V^{1,3}$, where k_1 is aerodynamic breathing resistance at air motion rate of 1 l/s is within the range of 11.7 – 24.5 Pa [21].

Minute respiratory volume (MRV) that depends on respiratory volume (BV) and number of respiratory movements (NRM) per minute, i.e. MRV = BV· NRM, is the qualitative parameter of ventilation. Respiratory volume characterizes respiration depth; number of respiratory movements characterizes its frequency. At quiet breathing of a healthy person, respiratory muscles function within some definite ranges depending on individual features: according to different authors- within the range of 1 – 5 J/min. If MRV increases up to 60 l/min then work of respiratory muscles reaches 60 – 120 J/min. On reaching MRV boundary increase (about 200 l/min), work of respiratory muscles is about 2500 J/min that is much more than the value at quiet breathing. Moreover, there is rapid incrase of oxygen amount consumed by respiratory muscles [21].

Table 2.10 shows physical parameters of a human respiratory system while using respirator. Average figures of lung functions are taken for the analysis. It is established that additional breathing resistance, i.e. respirator, resulted in the fact that at 20 Pa respiratory muscles works more intensively by 16% comparing to lung load without RPD, at 50 Pa and 150 Pa the figures increased by 56 % and 110 % correspondingly. While studying respiratory biomechanics, it is established that the value of respiratory system work being more than 5 J/min at rest confirms that there is a state close to suffocation [22]. That is why respirators in which presssure differential is 100 Pa and more aggrevate miners' breathing.

Table 2.10

Physical parameters of human respiratory system at using respirator

Parameter	Without additional breathing resistance, Pa		Additional breathing resistnace, Pa, At rest			
	At rest	At light load	20	50	100	150
Pressure differential in breastwhile breathing, Pa	375	750	395	425	475	525
MRV, l/min	8	20	9	11	12	12
Work of respiratory muscles per minure (J/min)	3	15	3.5	4.7	5.7	6.3
Relative increase of the work of respiratory muscles with additional breathing resistance	–	–	16	56	90	110

Thus, while selecting RPD special attention should be paid to the value of breathing resistance as while performing effort-consuming operations requiring large lung ventilation volume half-mask structure can not only reduce working capacity but also be useless. According to the data of Tables 2.6 – 2.8, RPD with pressure differential of less than 50 Pa are the most efficient ones, as they do not aggrevate breathing. In cases of respirators with aerodynamic breathing resistance of more than 50 Pa, their wearing allows working for not more than 30 – 45 min with compulsory 15 – 20-minute break.

Each type of operation has definite air consumption (Table 2.11), i.e. pressure differential while using RPD depends upon the type of operation to be performed. MRV increases along with the increase of physical load; at the same time, breathing resistance in respirator goes up.

Table 2.11

Pressure differential on respirator depending on air consumption and operation type

Respirator type and filter material	Breathing resistance, Pa, at corresponding operation type and air consumption, l/min				
	Light		Moderate	Hard	Fatiguing
	15	30	60	95	110
РПА-ТД-1 with filters made of ФПП 15-1,5	17	38	73	134	163
РПА-ТД-1 with filters made of eleflen	11	23	52	86	106
РПА-ТД-2 with filters made of ФПП 15-1,5	–	73	134	163	201
РПА-ТД-2 with filters made of eleflen	–	52	86	106	125
“Astra-2” with filters made of eleflen	13	28	63	96	117
Ф-62Ш with filters made of ФПП 15 – 1,0	12	26	58	93	121

Taking into account that miners’ work if hard or fatiguing (correspondingly, MRVis about 50 – 60 l/min), RPD makes significant additional load that accelerates fatigue feeling. Moreover, filtration efficiency changes along the increase of air consumption as well (Fig. 2.47). However, use of protective devices with the least breathing resistnace will result in deterioration of RPD protective efficiency as well because they are interlinked (2.5). That is why while selecting respirators it is necessary to take into account concentration and disperse composition of aerosols.

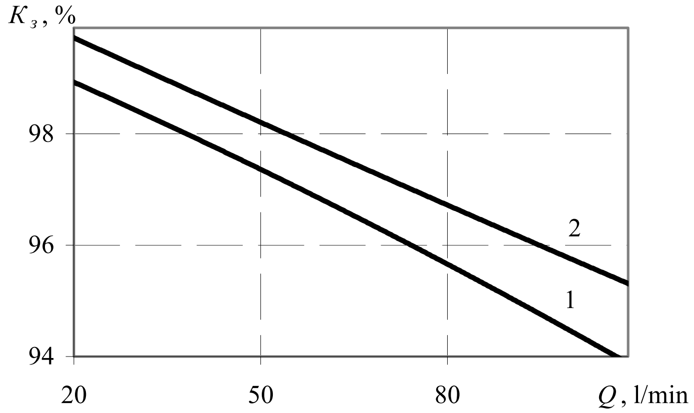


Fig. 2.47. Curves representing dependence RPD efficiency upon air consumption: 1 – filters made of polypropylene; 2 – filters made of ФПП 15 - 1,5

It will allow minimizing influence of respirators upon functional state of miners at maximum efficiency.

2.5. Influence of concentration and disperse composition of aerosols upon the selection of respiratory protective devices

Minimum protection level of respirator is calculated on the basis of saturation degree of harmful substance taking into account itsbiological hazard that is evaluated according to the value of ГДК, boundary allowable concentration (BAC)

$$K_з = C_1 / ГДК\ ,$$

where C_1 is dust concentration within working area, mg/m^3.

For example, coal dust accumulation within working area is equal to 300 mg/m^3 and its BAC at available SiO_2 is up to 10%, i.e. 4 mg/m^3. Consequently, worker should use protective device with protective coefficient of not less than 75 $(300/4 = 75)$. Table 2.12 represents trademarks of respirators that are recommended to be used at coal enterprises depending on composition and quantitative content of harmful substances in the air [22].

RPD selection is greatly unfluences by sizes of particles of harmful aerosols. Fiber dimeter of filtering material can be increased along with the growth of dust particle radius, at that its general protective efficiency does not change. Such materials are characterized by low breathing resistance that reduces significantly RPD impact on working capacity. Further, there is the dependence of the diameter of eleflen fiber (new filtering material) $d_{в}$ on the diameter of aerosol particles $d_{ч}$ under condition that their protective efficiency is 99.9% (Fig. 2.48).

Table 2.12

Recommendation for RPD selection depending on the composition and quantitative content of harmful substances in the air

<table>
<tr><td colspan="3">RPD trademarks recommended for protection against aerosols of high and medium degree of dispersion with the diameter of aerosol particles of not more than 2 mcm
at excess of coal dust BAC</td></tr>
<tr><td>By up to 10 times</td><td>By 10 - 100 times</td><td>By more than 100 times</td></tr>
<tr><td>Filtering half-masks “Rostok-3П” (Ф), У-2К, “Kama-40”, Moldex 2400, Willson 2201, 3M of 8810, 9210 series and others in which quality (protection) class corresponds to FFP 1</td><td>Filtering half-masks “Lepestok-40”, “Rostok-2П” (Ф), “Snezhok-П” (Ф), “Antareks-П”, “Kama-200”, Moldex 2500, Willson 2200, 3M of 8820, 9220 series and others in which quality (protection) class corresponds to FFP 2.
Cartridge respirators with rubber half-masks РПА-ТД, “Puls”, “Klyon-П”, Ф-62Ш, Dustfoe-66, 3M of 6500 series with filters of P2* class</td><td>Filtering half-masks „Lepestok - 200”, „Rostok-1П” (Ф), 3M of 9230 series, Willson 2293, Willson 5321.
Cartridge respirators with rubber half-masks Picco-20, 3M of 7500 series with filters of P3* class, Advantage-200.
Respirators with forced air supply into under-mask space</td></tr>
<tr><td colspan="3">RPD trademarks recommended for protection against coarsely dispersed aerosols with the diameter of aerosol particles more than 2 mcm
at excess of coal dust BAC</td></tr>
<tr><td>By up to 10 times</td><td>By 10 - 100 times</td><td>By more than 100 times</td></tr>
<tr><td>“Rostok-3П” (Ф), У-2К, “Kama-40”, Moldex 2400, Willson 2201, 3M of 8810, 9210 series and others in which quality (protection) class corresponds to FFP 1</td><td colspan="2">Filtering half-masks: “Lepestok-40”, “Rostok-2П” (Ф), “Snezhok-П” (Ф), “Antareks-П”, “Kama-200”, Moldex 2500, Willson 2200, 3M of 8820, 9220 series and others in which quality (protection) class corresponds to FFP 2.
Cartridge respirators with rubber half-masks: РПА-ТД, “Puls”, “Klyon-П”, Ф-62Ш, Dustfoe-66, 3M of 6500 series with filters of P2* class</td></tr>
</table>

*Quality (protection) class of filters (P2 is penetration coefficient according to test-aerosol of paraffin oil is not more than 6 %, and in case of P3 it is not more than 0.5%).

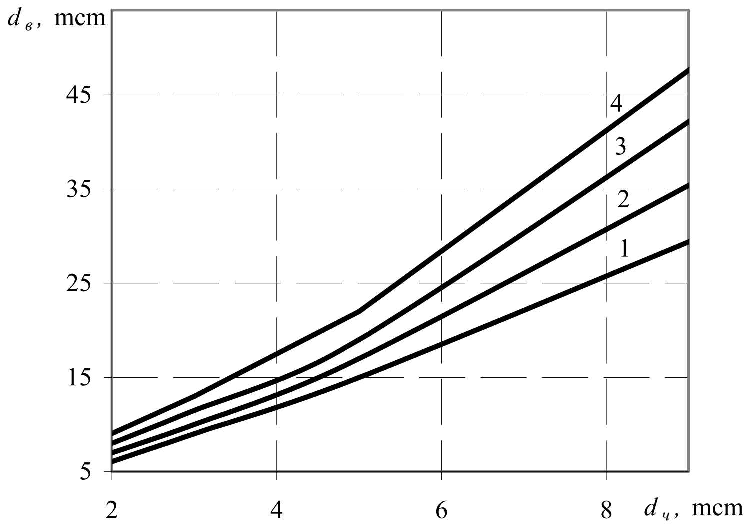


Fig. 2.48. Curves of dependence of eleflen fiber diameter on aerosol particle diameter under condition that its protective efficiency makes 99.9 % at filtering layer thickness of 4 mcm (1), 6 (2), 8 (3) and 10 (4) taking into account fiber density of 45 mg/m^2

Thus, if we know sizes of the most part of dust particles it will be possible to select corresponding filtering material with maximum protective efficiency and minimum breathing resistance.

While selecting RPD it is very important to pay attention to its respiratory-protection period. This parameter is one of the basic ones under conditions of high dustiness. Respiratory-protection period of filters is determined at reaching pressure differential within the allowable value of 100 Pa with air consumption through respirator of 30 l/min (DSTU GOST 12.4.041:2006). Dust content is considered to be important characteristics of particle filters as its value is used to determine RPD respiratory-protection period. The higher the value of dust content is, the slower breathing resistance grows, consequently, useful life of respirator will continue. Table 2.13 gives main characteristics of dust filtering elements for the most widely used respirators.

Table 2.13

Main characteristics of dust filtering elements for the most widely used respirators

Filter type	Working area of filter, cm^2	Pressure differential on filter Δp, Pa, at air consumption of 15 l/min	Dust content of filter, g, at coal dust concentration in the air of 300 mg/m^3	Coefficient of efficiency of filtering material use $\eta_{еф}$
1	2	3	4	5
Filters for РПА-ТД respirator				
Filters made of eleflen	500	17.9 ± 2.5	6.9 ± 0.15	0.72
Filters made of ФПП 15-1,5 with gauze backing		34.2 ± 2.3	4.9 ± 0.14	0.43
Filters made of ФПП 15-0,6 with gauze backing		28.3 ± 2.5	5.7 ± 0.17	0.51
Filters made of ФПП 15-0,6 with spunbond* backing		31.4 ± 2.0	5.3 ± 0.21	0.46
Filters made of ФПП 15-0,6 with gause spunbond backings		29.6 ± 1.8	6.6 ± 0.23	0.63
Filters for respirator “Astra-2”				
Filters made of eleflen	250	22.2 ± 1.1	3.93 ± 0.16	0.87
Filters made of ФПП 15-0,6 with gauze backing		34.3 ± 1.2	3.42 ± 0.31	0.63
Filters made of ФПП 15-0,6 on meshwork		33.4 ± 1.6	3.72 ± 0.12	0.72
Filters for respirator Ф-62Ш				
Filters made of polypropylene material	800	28 ± 1.3	10 ± 0.4	0.82
Filters made of ФПП 15-1,5 with gauze backing		31 ± 1.4	8.82 ± 0.2	0.71
Filters for some foreign respirator				
Filter 3M of 7093 series	300	16.3	4.3	0.90
Filter 882 FMP3 by Drager	200	22.5	20.3	0.83
Filter 8080 P3 by Moldex company	350	60.2	3.1	0.43
Filter 2106310 P3 by Sundntrom company	750	26.5	11.2	0.81

*Spunbond is a thermal bonding material made of lavsan and polyamide fibers.

The results of the study show that high dust content is ensured first of all by the enlarged filtration surface. It is well seen while comparing the amount of dust deposited on filters of “Astra-2” and РПА-ТД respirators (working surface of their filters differ twice). However, not all the working surface of filtering elements is used. Especially it concerns РПА-ТД respirator as the coefficient of effective use of filtering material in its filters is too low due to the closure of adjacent folds (Fig. 2.49) because of its multilayer nature (two backings and filtering material). Materials ФПП 15-1,5 and ФПП 15-0,6 are characterized by low mechanical strength that is why while filter manufacturing producers should use additional layers of stiffer materials. Thus, respiratory-protection period is reduced (Fig. 2.50). As laboratory research has proved, polypropylene filters shows the best result under dusty conditions as they have comparatively low initial resistance. Filters made of ФПП 15-1,5 with the initial breathing resistance more than 30 Pa (Table 2.11) have the shortest respiratory-protection period; besides about half of its working surface is not used due to the closure of adjacent folds (Fig. 2.49, position 1).

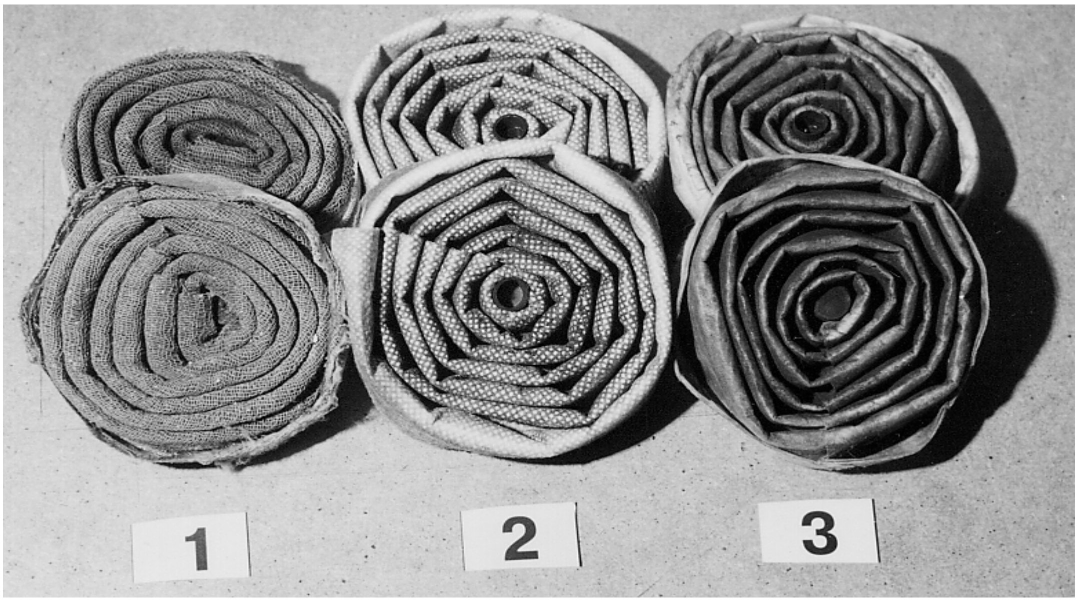


Fig. 2.49. Filters of РПА-ТД respirator made of ФПП 15-1,5 with gauze backing (1);
made of ФПП 15-0,6 with spunbond backing (2);
made of eleflen (3)

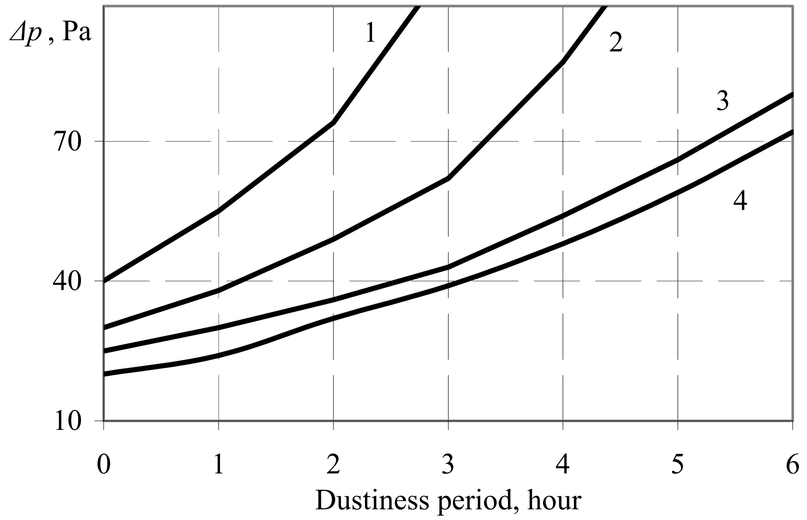


Fig. 2.50. Curves of the influence of pressure differential on РПА-ТД respirator on dustiness period (at coal dust concentration of 300 mg/m^3 and air consumption of 30 l/min). Filters: made of ФПП 15-1,5 (1); made of ФПП 15-0,6 (2); made of НФП (3); made of eleflen (4)

The same conclusion can be made at comparing indexes of filters made of ФПП 15-0,6 with spunbond backing of "Astra-2" and РПА-ТД respirators. The first ones have coefficient of efficiency of filtering material use higher as there is almost no closure of adjacent folds (Fig. 2.51). However, small filtering surface, filters for "Astra-2" respirator have relatively low dust content and, consequently, shorter respiratory-protection period that is why it is not reasonable to use them at coal enterprises. Besides, technology of filter manufacturing is violated (use of low-quality filtering and backing material, unreasonable economy) that makes operational characteristics worse.

Fig. 2.51. Filters of "Astra-2" respirator made of eleflen (1); made of ФПП 15-0,6 on meshwork (2); made of ФПП 15-0,6 with gauze backing (3)

It should be noted that filters made of ФПП 15-0,6 with gauze backing showed better results comparing to the filters with spundbond ones. It is explained by the fact that airflow coming onto filter forces soft filtering cloth against stiff backing and as the result it reduces active filtration area by approximately 10 – 15 %. When gauze is used, filtering layer becomes more flexible and airflow rounds the obstacle. However, this effect results in the following: adjacent folds in lower part of such filter stick together and filteration area is reduced. The rational decision is in the following: filters having spundbond backing on one side and gauze backing on the other side will have higher dust content as coefficient of effective use of filtering materialis low as well because of their thickness. There is optimal distance between folds at which there is the lowest breathing resistance and the higest dust content (Fig. 2.44 a).

The mentioned studies are the basis for the following conclusion: to increase protective efficiency of filters it is necessary first to reduce the initial breathing resistance and second to change their structure to eliminate sticking of folds.

One more way to improve dust content of filters is to manufacture filtering materials with changeable fiber thickness density. Nevertheless, nowadays it is quite difficult to commercialize such materials. Set of several filtering layers of different filtering density is a simple solution here. For example, external layerof preliminary layer is not dense but internal or main filter is dense. Use of preliminary layer with low initial resistance will allow increasing dust content at the expense of elimination of coarse aerosol particles (Fig. 2.52) which will choke pores and reduce its operating time on falling on main denser filtering layer. Fig. 2.53 shows developed views of filtering element made of ФПП 15-0,6 (position 1) with soundbond backing of 35 g/m^2 density and fiber diameter of about 4 mcm (position 2). We can see that backing has deposited coarse dust and filtering material has deposited fine dust.

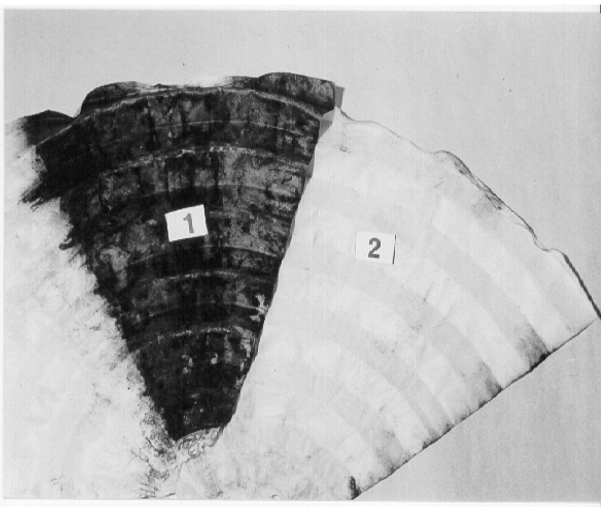


Fig. 2.52. Developed view of five-fold filtering element made of eleflen: 1 – external layer; 2 – internal layer

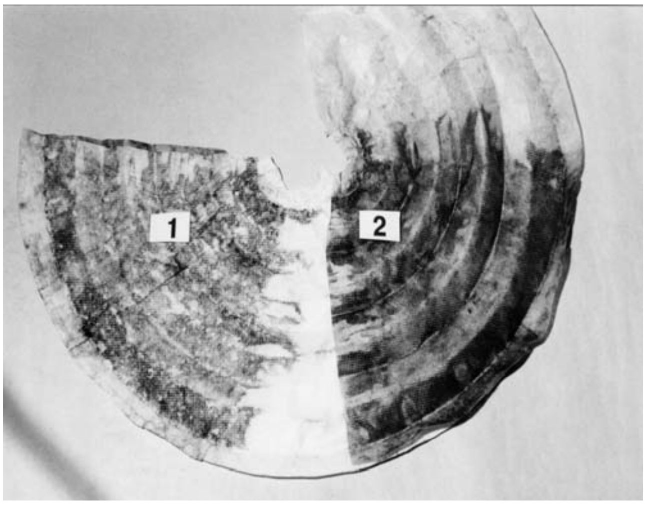


Fig. 2.53. Developed view of five-fold filtering element made of ФПП 15-0,6: 1 – layer of filtering materisl; 2 – spunbond backing

Table 2.14 contains experimental results of filters of РПА-ТД respirator made of filtering materials ФПП 15-1,5 and ФПП 15-0,6 differing with the type of external layer. Studies have been carried out according to the methods of [1]. As the data of the table shows, filters with spunbond surface layerhave the highest specific dust content provided it is located from the side of airflow incoming. It is explained by the fact that sounbond is characterized by relatively low fiber density. Consequentlywhile RPD manufacturing it is necessary to select layers of filtering materials is such way so that there would be the highest dust content value.

Table 2.14

Results of studying filters of РПА-ТД respirator
with different types of external layers

Parameter	Parameter value			
	Filters made of ФПП 15-1,5 with spunbond backing	Filters made of ФПП 15-1,5 with gauze backing	Filters made of ФПП 15-0,6 with spunbond backing	Filters made of ФПП 15-0,6 with gauze backing
Pressure differential *Δp*, Pa, on filter, with air consumption of 15 l/min	38 ± 2.3	34 ± 1.9	30 ± 1.2	31 ± 2.0
Dust content of filters, g, at coal dust concentration in the air up to 300 mg/m^3	5.4 ± 0.4	5,1 ± 0.09	5.9 ± 0.13	5.6 ± 0.2
Specific dust content of filter, g/m^2	11.4	10.4	12.8	11.2

Today eleflen, НФП and other polypropylene filtering materials are used to manufacture filters of РПА-ТД respirators consequantly it is of special attention tostudy mechanism of their contaminationwith dust particles. With this objection in mind effect of additional layers of fibers with different densityondust content of 10 cm^2 polypropylene samples which dustiness lasted up to the boundary resistance of 100 Pa is evaluated (Table 2.15).

Table 2.15

Dust content of the samples with additional external layer

Material of the additional layer of sounbond with fiber density of, g/m^2	Sample mass, g	Breathing resistance, Pa	Maa od sample with dust, g	Dust mass, g
33	0.885	2.35	2.238	1.353
37	0.931	2.35	1.958	1.227
30	0.925	2.26	2.541	1.616
18	0.776	2.14	1.906	1.130

The mentioned data show that the optimal parameters of additional layer ensure maximum dust content of a filter in general. Use method from [2] to determine parameters of such two-layer polypropulene material. Layers of filtering material are studied as two filters set one by one; here initial dust concentration of external layer relative to the internal one will be entering dust concentration, i.e.

$$C_2 = K_n C_1,$$

where C_2 is harmful substance concentration after preliminary layer, mg/m^3.

Since main dust mass sediments on the external layer then the diameter of its fibers is determined according to the allowable value of pressure differential of 100 Pa at air consumption through filtering element being $Q = 30$ l/min:

$$M = \frac{(F(\Delta p) - F_B^2) d\rho_n \varphi F_0}{4F_B},$$

where $F(\Delta p) = \{[{}^{6(100-\Delta p_0)\pi^2 L}\!\big/_{k_n \rho_n \varphi F_0}] + F_B^3\}^{2/3}$;

M is dust content of a filter (or filtering material), kg/m^2;

Δp_0 is pressure differential on a clean filtering material, Pa;

k_n is coefficient of proportionality that depends upon filtration rate, m^4/s^2;

L is general fiber length of filtering material sample of the specified area, m;

F_0 is general area of filtering material, m^2;

$F_B = {}^{2\beta H}\!/_{a}$ is total fiber surface;

c_n is bulk density of dust particles, kg/m^3;

φ is coefficient of nonuniformity of the sedimented dust on material fibers.

Fig.2.53 shows curves of dependence of pressure differential upon dust content at different diameters of eleflen fiber that are determined at airflow rate $v = 1.5$ m/s, fiber density $\beta = 0.05$ and thickness of filtering layer $H = 6$ mcm.

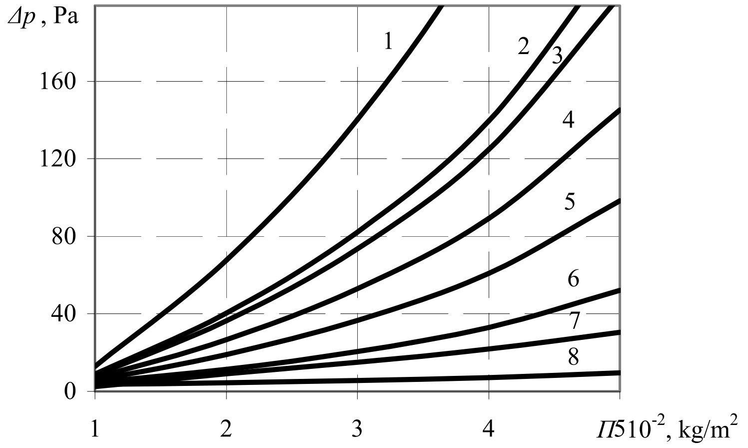


Fig. 2.53. Curves of dependence of pressure differential on dust content at different eleflen fiber diameters $d_в$, mcm: 1 – 2; 2 – 2.5; 3 – 3; 4 – 3.5; 5 – 4; 6 – 4.5; 7 – 10; 8 – 15

As it is seen, filter life (as for the amount of separated dust) grows along with the increasing fiber radii that results in deterioration of aerosol particles separation (according to (2.3)). Longstanding research has established that protective efficiency of the external layer should not be less than 90% to ensure maximum filter efficiency in general. If protective efficiency is lower then internal layer will not be able to ensure the required level of air purification that is stipulated by optimum pressure differential on RPD.

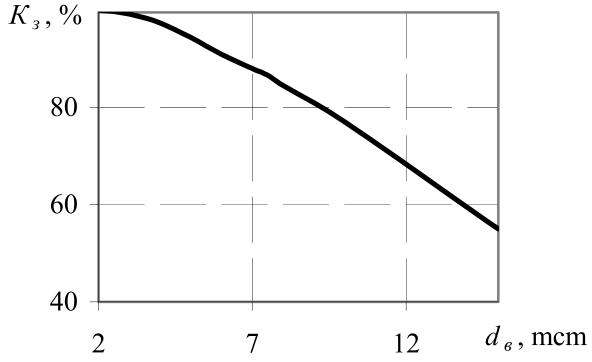


Fig. 2.54. Curve of dependence of protective efficiency of filtering material layer on fiber diameter $d_в$

Specialists of Research and Development enterprise „Standart-1" (Dnirpopetrovsk) have developed filtering material eleflen 5CM which external layer contains fibers of 5 – 7 mcm inidameterand internal one contains fibers of 1 – 5 mcm in diameter. Filter made of this material functions as follows: dusty air comes on the surface of filtering element corrugations; dust particles more of than 15 mcm hit even surface of external layer and fall without any delays; particles of 5 – 15 mcm deposited on surface and penetrate into filter due to relatively small pore sizes. That is why filter surface is not supersaturated with dust that enables penetration of smaller dust particles being less then 5 mcm indiameter into inter-layer spare where they remain.

Table 2.16 gives basic results of comparative studies of five-fold eleflen filters 5C and 5CM grades. Besides, it contains testing results of eleflen filters which external layer has no electrostatic charge.

Table 2.16

Results of comparative testing of filters according to coal dust concentration

Filtering material to manufacture filters	Initial sample mass, g	Pressure differential, Δp, Pa, on filter with air consumption of 15 l/min	Dust content of filters, g, at coal dust concentration in the air of 300 mg/m^3	Protective efficiency, %
Eleflen 5C	4.88 ± 0.05	16.3 ± 1.1	7.43 ± 0.24	99.93 ± 0.01
Eleflen 5CM	4.84 ± 0.07	15.8 ± 1.3	8.82 ± 0.03	99.93 ± 0.01
Eleflen without electrostatic charge	4.86 ± 0.03	16.7 ± 1.1	8.32 ± 0.15	99.90 ± 0.02

Thus, dust content of multilayered materials of different fiber density is by 20 – 25% higher comparing to standard filtering material.

2.6. Use of respiratory protective devices for various meteorological conditions

Unfavourable environment and physical overexertion at mining enterprises effect people that reduces considerably their working efficiency. Climatic conditions of underground workingshave their peculiarities: higher air temperature from 28- to 35^0C, humidity of 90 – 100 % and high atmospheric pressure growing by 9 – 10 mm hgeach 100 m. That is why it is necessary to pay constant attention to the influence of microclimate upon respirator functioning as their basic parameters (airflow resistance and protective efficiency of respiratory protective device) are determined according to standard conditions ($t = 20\ ^0$C; $\varphi = 50$ %; $P = 101.1$ kPa).

Air temperature of working area as well as other parameters of the environment (moisture, airflow rate, atmospheric pressure) influence considerably RPD performance figures, state of cardiovascular system and respiratory systems, and temperature regulation. Here action of local thermal heating should be mentioned that results in sense of discomfort, heart disorder, and vascular distention even at points being far from heating. Functional changes in organism deteriorating working efficiency considerably are the consequences of these. That is why while selecting RPD it is iportant to take into account climatic and environmental conditions that makes it possible to set important tasks for the workers. According to the research, nondisposable respirators complicate breathing within the shift at the temperautre of 35 ^{0}C comparing to the temperature of 20 ^{0}C. It is explained by direct proportional dependence of breathing resistance upon gas viscosity that changes depending on the temperature (Fig. 2.55). While working, it feels that under mask face sweats with the following sense of discomfort. For example, while working wearing “Astra-2” and РПА-ТД respirators miners often complain about intensive moisture accumulation in semi-mask. Later this moisture enters filtering elements and wet them with the following increase of breathing resistance due to dust particles adhesion and sticking of adjacent corrugations especially in case of filters with gauze backing. The result is quick fatigue and loss of working efficiency (Fig. 2.55).

Moisture effect on respirator function is shown in Fig. 2.56. It has been established that while passing through filtering elements moist air (more than 80 %) increases considerably RPD breathing resistance that is connected with the origin of liquid drops in middle filtering layers. First, film appears on the fibers of material that enlarge their diameter. On growing, it blows out and liquid drops form at the points of fiber crossing. These drops close pores and complicate airflow motion through respirator (Fig. 2.57).

Evaluate temperature effect upon protective efficiency of disposable RPD: along with its growth RPD quality deteriorates (Fig. 2.58) as the temperature makes aerosol particles more active. However, if we know the nature of the protective effficiency dependence on pressure differential on filtering layer it is possible to assume that penetration coefficient will decrease along with the following temperature growth due to the increase of filtering fiber resistance.

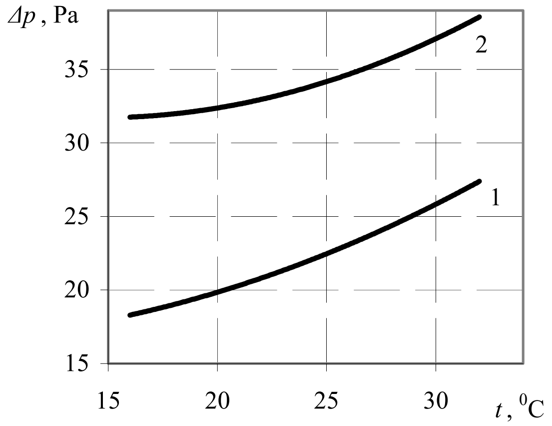


Fig. 2.55. Curves of the dependence of RPD pressure differential on the environmental temperature: 1 – filters made of eleflen; 2 – filters made of ФПП 15 – 1,5

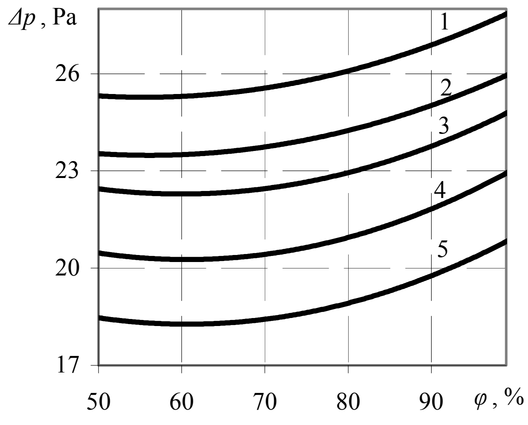


Fig. 2.56. Curves of dependence of pressure differential of respirators on the moisture of the air passing through filter at different environmental temperature, ^{0}C: 1 – 30; 2 – 26; 3 – 24; 4 – 20; 5 – 16

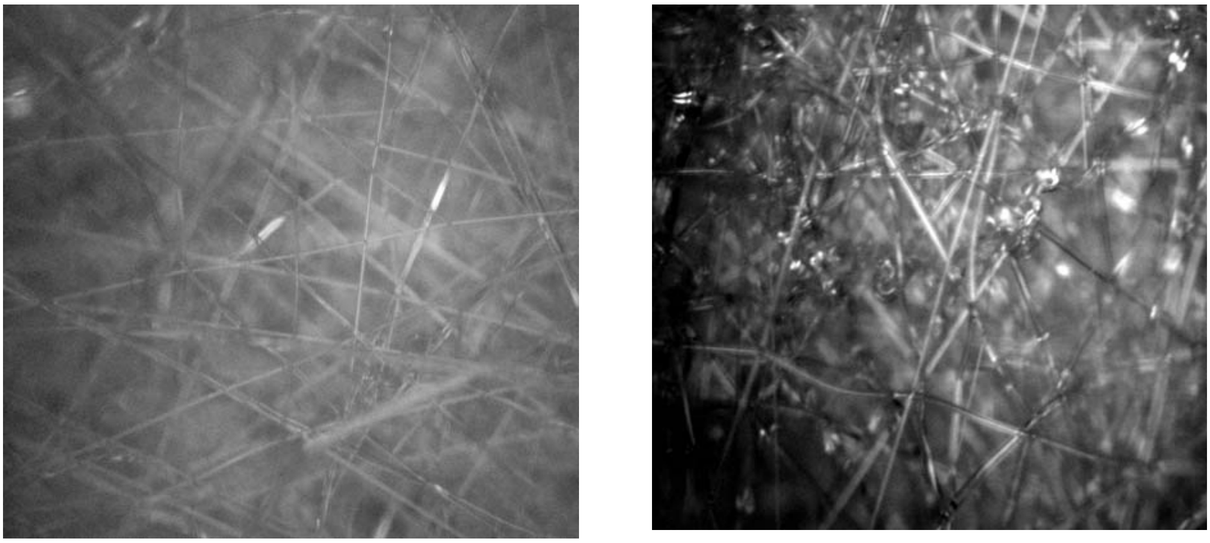

a b

Fig. 2.57. Appearance of eleflen structure scaled-up by 300 times: before (a) and after (b) study

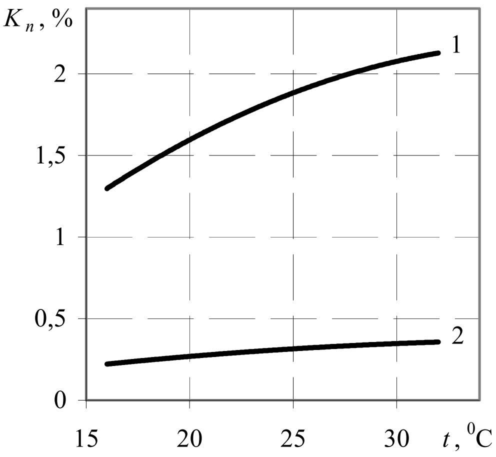


Fig. 2.58. Curves of dependece of penetration coefficient upon environmental temperature: of folters made of eleflen (1) and filters made of ФПП 15-1,5 (2);

Manufacturing testing has established that there is significant influence of moisture upon dust content of nondisposable RPD. Filters conteining gauze in their structure are characterized by rapid increase of resistance. When gauze swells out filter get out of its shape. Judging by the amount of dust accumulated on such filters, their resistance (at high moisture content in mines) is three times higher comparing to other filters (Fig. 2.59).

While comparing dust content of filters with gauze and spunbond backings dust mass of the latter ones is by several times higher. It is connected with the fact that fibers with thermal bonding do not absorb moisture. Difference between dust content of filters made of the same material on spunbond backing at different relative moisture can be explained by formation of liquid film on fibers that is the reasong of increasing breathing resistance. It is also true in case of eleflen filters.

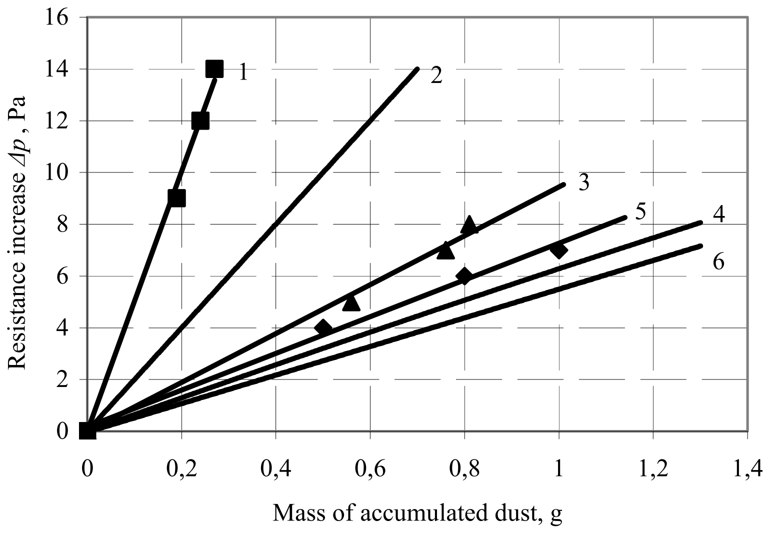


Fig. 2.59. Dependence of the increase of breathing resistance on the mass of accumulated dust: 1, 2 – filters made of ФПП 15-1,5; 3, 4 – filters made of ФПП 15-0,6; 5, 6 – filters made of елефлен at different relative moisture of the environment, %:
1, 3, 5 – 95
2, 4, 6 – 50

RPD quality is also influenced negatively by cold air. While evaluating operational properties of half-masks under cold conditions (– 3 – 5 ^{0}C) it was notices that in 30 – 40 min after beginning of operations workers rejected RPD: it was impossible to breathe due to moisture condensation of exhaled air (Table 2.17).

Table 2.17

Exudation of moisture on filters while working wearing respirators in cold seasons

RPD type	Amount of mointure, g on filtering elements at the temperature of – 6 ^{0}C and physical load W	
	140	200
РПА-ТД with filters made of eleflen*	4.1	5.8
РПА-ТД with filters made of ФПП 15-1,5*	5.4	7.2
“Lepestok - 200”	5.6	6.4
“Snezhok - П”	5.1	6.8

*Mass of moinsture is given for both filters.

Data of Table 2.17 shows that not only temperature but also physical load influences considerably the process of moisture accumulation. Polypropylene eleflen appeared to be one of the most efficient materials as it accumulated the least amount of moisture. Manufacturing testing has showed the increase of penetration coefficient increases at the expense of aspiration of unfiltered air through obturation line that is well seen on dusty faces of workers. As it is pointed out despite the fact that nondisposable respirators are characterized by high concentration of condensate there are no major obstacles while breathing that is not true in case of disposable respirators. It can be explained by the fact that some part of moisture is removed through exhale valves. However, when moisture appers in filtering boxes filters are frozen around, process of breathing is aggrevated and they should be replaced immediately. That is why it is very important that inhale valves would always be hermetical.

Thus, while selecting RPD attention should be paid to to microclimatic conditions at working areas as their changes are the reason to make corresponding (sometimes even considerable) allowances.

DIVISION 3

Importance of respiratory protective device for dust etiology prevention

Problem connected with reduction of dust etiology diseases is studied. Protective efficiency of respiratory protective devices against coal dust is evaluated. Risk level of pneumonoconiosis at availale respirator is calculated.

Occupational diseases of dust etiology are high of the list among other diseases that is why their reduction is of great importance nowadays. Its successful solution is possible owing to permanent and reliable individual control of dust load on miners' lungs while long-term storage of information concerning dynamics of the received doses (for example, using electronic media) will allow obtaining such critical dust value at which pathogenic mechanisms of pneumonoconiosis and dust bronchitis are possible to begin their development. It will help prognosticate workers' state of health on the basis of accurate data for medical examinations and evaluations.

While calculating dust load it is also necessary to consider respirator importance as it reduces by far dust concentration entering into lungs. RPD effect upon dust load degree is evaluated using he coefficient that takes into account availability of these devices (1.5). The authors [1] offered 0.1 to be the value of this coefficient if respirator is available and 1 if it is absent. However each type of respirator has its own quality parameters depending on both half-mask structure and filtering properties of the material which RPD is made of. Besides, both different types of respirators and types of filters can be used at coal enterprises. Consequently it is not reasonable to use one and the same coefficient values. It means that while calculating dust load it is necessary to take into account efficiency of respiratory protective devices as they reduce considerably risk of pneumonoconiosis and dust bronchitis.

It is quite difficult to study level of the mentioned diseases depending on respirator use due to the range of subjective and objective reasons. One of the latter is in the fact that obtaining statistically substantiated data means long-term observation of the process of workers' incidences of disease. Nevertheless, some research was carried out. Thus, the monograph [7] contains results of mass medical four-year monitoring of the workers of Ust-Kamenogorsk Lead and Zinc Integrated Works before use of respirators and while working wearing them (from 1957 to 1960).

At that time technology of lead smelting and refining was characterized by vapors from the open surface of molten metal being available in the air that resulted in high concentration of high-disperse aerosol of lead and its compounds. It was the reason of high rate of disease incidence of the workers of agglomerative and melting shop (about 70 – 80 % of their general number). According to medical observations, use of ШБ-1 “Lepestok-200” respirators allowed occupational diseases to be reduced by several times. In general number of diseased workers reduced up to 80%. The authors state that this fact shows not only the effect of respirators use but also the result of the whole complex of preventive arrangements being made at the enterprise.

The same source describes another research based on biophysical examination of the workers dealing with radioactive substances. The authors paid attention to harmful elements which were excreted as it were after their entering into organism (for example, plutonium). Thus, RPD efficiency has been determined according to the relative mass of these elements

$$E = T_B^{0,26} - 1(1 - K)(T_B - T_A)\,, \tag{3.1}$$

where E is amount of plutonium urinary excretion (relative units, r.u.);

K is penetration coefficient of test-aerosol through respirator;

T_A, T_B are initial and final time of working with radioactive substances, hours.

Figure 3.1 shows that during the first years of intensive dealing with radioactive substances without respiratory protective devices, workers showed increase of daily average plutonium urinary excretion [8]. After using respirators the amount of such excretion started going down. Scientists explained this fact exactly by the use of RPD as contamination level of the environment stayed almost the same at that moment. Having compared experimental results and calculated data to the average plutonium content in daily amount of urina (curves 1, 2 on Fig. 3.1) they concluded that the use of RPD reduces risks of occupational disease rate.

Y.O. Polukarpov offered interesting solution concerning the influence of respiratory protective devices upon the disease hazard while modeling the degree of dust load upon welder's lungs. He ranked all respiratory individual devices using points according to their protective efficiency [22, Table 3.1]. While calculating dust load using formula (1.5) the author evaluated decreased amount of sedimented dust with the help of RPD using values of coefficient k (Table 3.1).

Table 3.1

Coefficient taking into account available respirator according to Y.O. Polukarpov

Protective devices to be used	Value of coefficient k
RPD with forced under-mask air supply	0
Respirators with dust protective degree being more than 98 %	0.01 – 0.20
Winning assemblies with dust protective degree within 91 – 98 %	0.21 – 0.40
Exhaust systems with dust protective degree within 85 – 90 %	0.41 – 0.60
Means of dust removal with less than 85 %	0.61 – 0.80
Welder's protective screen or mask	0.85 – 1.0

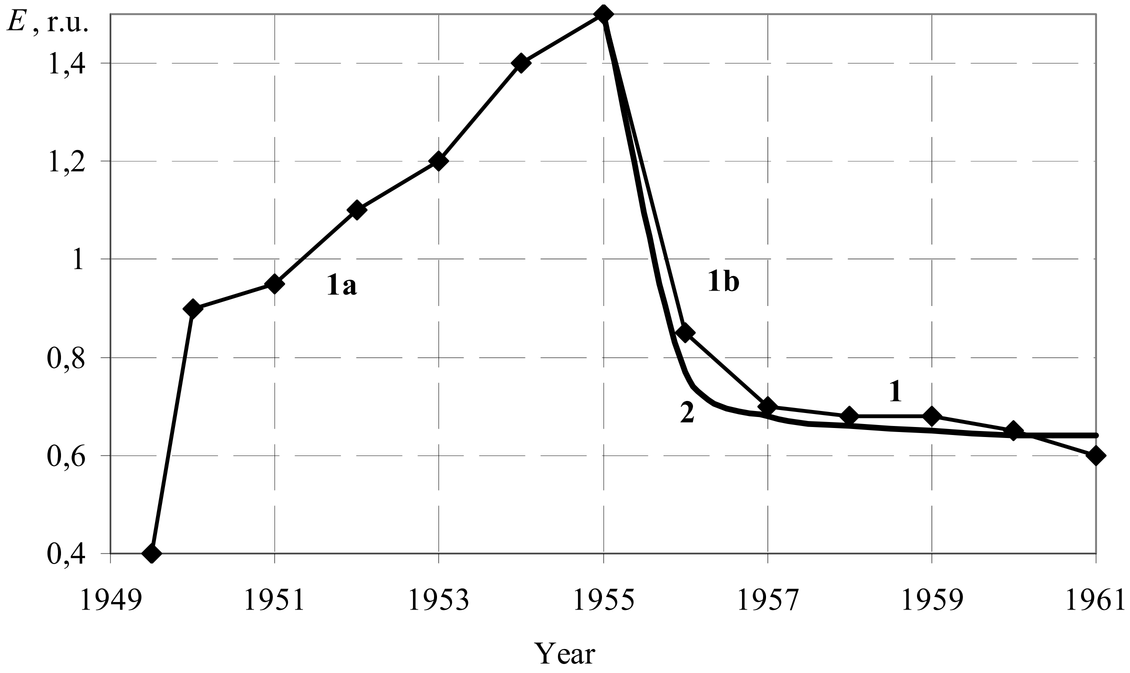


Fig. 3.1. Average plutonium content in workers' urina:
1a – before respirator use; 1b – after its use

We consider that the idea of RPD ranking represented in Table 3.1 has one considerable disadvantage: disperse composition of the dust entering the lungs on passing through respirator is not taken into account. It is established that the particles of 0.1 – 1 mcm in diameter are the most dangerous ones. They are deposited in respiratory organs resulting in diseases. On the other hand, it is known that the particles of 0.2 – 0.4 mcm in diameter are the ones being most penetrative through respirator filters. Thus, all the particles, entered respiratory system through RPD, remain there. Consequently, we have risk to underreport real figures of dust load because according to the calculations worker should be healthy but in reality he/she is very ill. These conclusions are based on the analysis of 20-year study of pneumonoconiosis rate dynamics of Donbas miners published in the study [24]. The authors emphasize that the use of respirators made figures of dust exposition closer to the moment of disease contraction of miners working under different geological and mining conditions as well as reduced gap between the number of diseased miners with different work record. It is explained by the fact that along with the appearance of protective devices dust loads on miners of different professions has been leveling off. However as we can see use of respirators has not eliminated health risks.

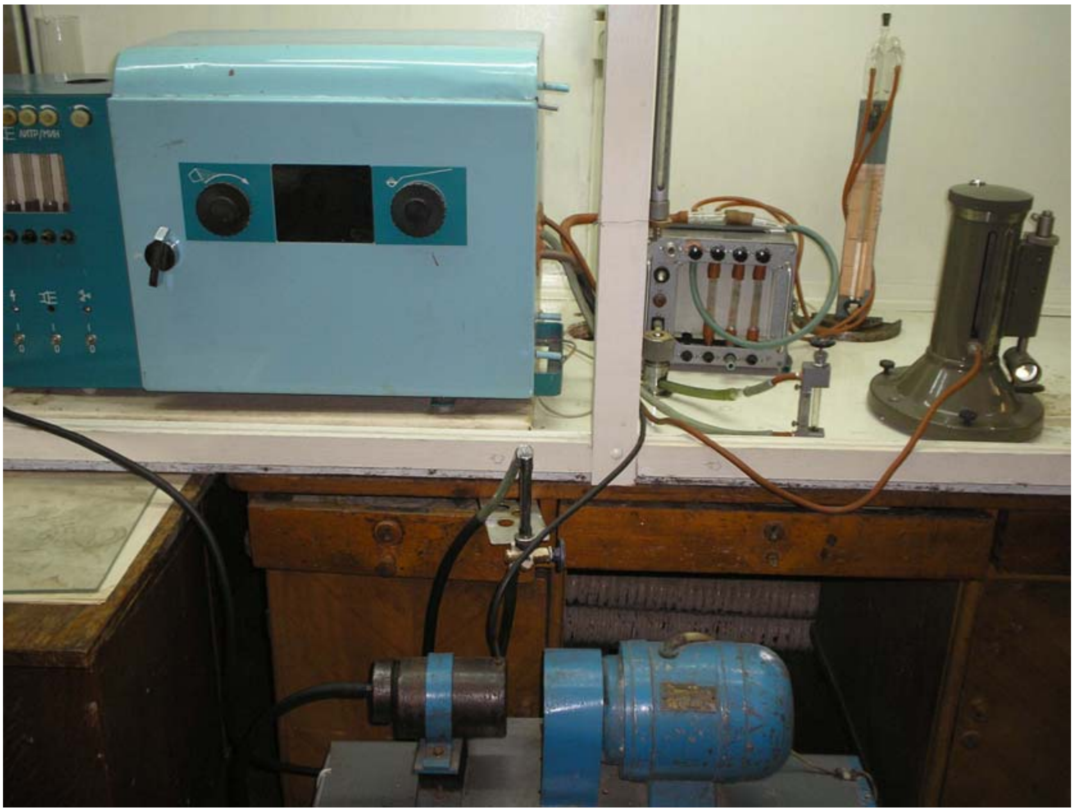
The other result is obtained while clinical researching of allergic people (fungus spores are allergic agents). The authors of the study used provocation tests: by means of air contact of the examined people being supersensitive to antigens within the period from 20 minutes up to five hours, comparing reactions with and without RPD. It was established that respirators protected people successfully. Only two cases of 60 showed weak allergic symptoms that was only 3% of maximum possible reactions [3].

Foreign media often gives information concerning RPD efficiency to reduce influence of harmful substances on workers' health. Thus, authors of the study [25] pointed out that the use of filters with the efficiency of 98% relative to aerosol particles of 0.8 mcm in diameter eliminates allergic reactions of farmers. At the same time the authors offer other allergy-suffering to use respirators with the forced clean air supply as here under-mask pressure is higher than atmospheric one. All the facts results in elimination of unfiltered air aspiration into under-mask space along obturation line. It is of special importance while performing hard physical operations.

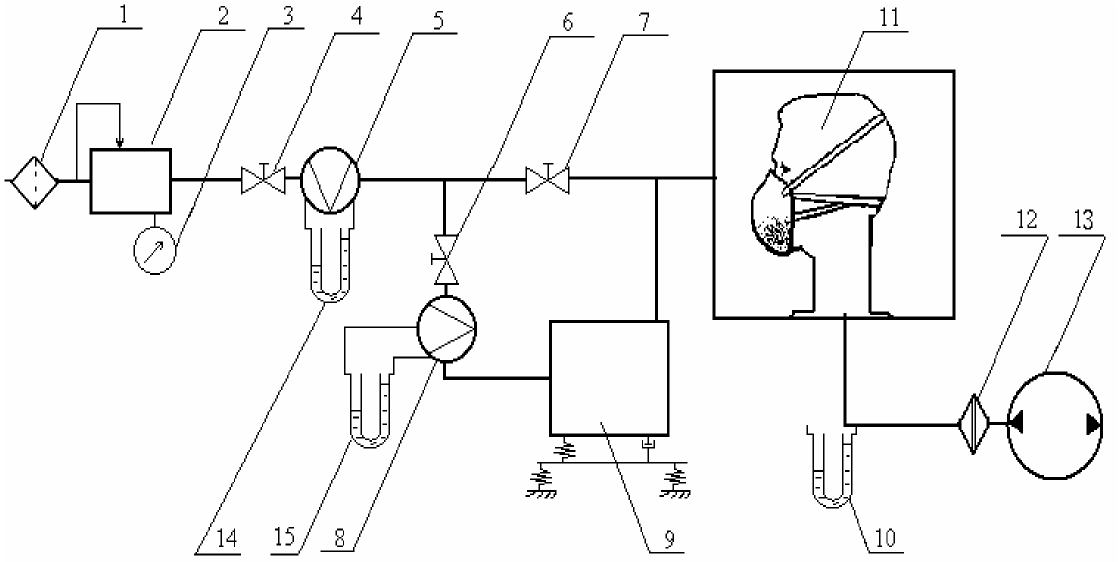
The latter point explains partially why in one cases RPD use eliminates health risks completely but in other cases this use just plays for time up to the first disease symptoms. If there are sever climatic conditions, in particular, under high dust concentration at the place of production, even minimum breathing resistance of respirator results in additional physical load on a worker. It often can be followed by a lot of air entering lungs along obturation line. Moreover, sometimes miners tear their respirators off because they disturb them during operation or mismatch their parameters. The situation is quite opposite when respirator is used during light operations under habitual conditions. It should be noted that using RPD to prevent occupational diseases is just one of protective components along with collective dedusting devices which should reduce concentration of harmful substances up to the specified standards. However, the given analysis shows that respirators are the necessary condition for miners' health protection at mining enterprises; sometimes it is even one and only protective device.

As it is known all the RPD are characterized by two main parameters: breathing resistance and penetration coefficient. The latter proves respirator efficiency and depends upon half-mask structure and properties of filtering material it is made of. Having analyzed the essence of coefficient that takes into account respirator availability the following conclusion can be made: it can be set equal to RPD penetration coefficient and it can be determined experimentally (Fig. 2.26) as the correlation of coefficient of test-aerosol disperses particles before and after respirator use. If coal dust is used as test-aerosol it will allow simulating processes taking place in respirators while their dusting under real conditions of mining enterprises with the following determining of coefficient value at a first approximation taking into account respirator availability. Multi-purpose integration stand to simulate dusting and to feed it with the specified disperse composition has been developed on the basis of test technical expertise laboratory of workers' individual and collective respiratory protection devices (National Mining University) [25, 26]. It allows evaluating efficiency degree of devices to protect against coal dust (Fig. 3.2).

The mentioned unit operates as follows: air enters under pressure from compressor through preliminary filter 1 onto pressure stabilizer 2. Air volume entering into unit is regulated by faucet 4 and controlled by manometer 3 ensuring the required pressure differential specified by calibrated diaphragm 5. To develop dust aerosol, clean air at the rate of 2 – 10 l/min (depending on specified dust concentration) is supplied into vibration generator 9.



a



b

Fig. 3.2. General arrangement (a) and structural scheme of RPD testing machine (b): 1 – preliminary filter; 2 – pressure stabilizer; 3 – manometer; 4,6,7 – regulating faucets; 5 – diaphragm; 8 – rotameter; 9 – dust generator; 10 – micromanometer; 11 – testing chamber with a model; 12 – prolong with АФА filter; 13 – vacuum pump; 14, 15 – liquid manometers

Vibration dust generator 9 is a steel cup with inlet and outlet connections where about 100 g of previously milled coal is loaded. Coal dust is generated intensively in this steel cup under vibration. Steel balls of 10 – 15 mm in diameter are loaded into dust generator to accelerate milling. Air volume entering generator is regulated by faucet 6 and rotameter 8. It allows obtaining not only different moisture concentration but also different disperse composition. The other part of clean air is supplied into testing chamber 11 with the respirator in it. Cleaned air from RPD under-mask space is supplied by vacuum pump 13 through prolong with АФА filter 12 at 30 l/min. Dust accumulation on a protective device is controlled according to the data of aerodynamic resistance increasing that are determined according to the readings of micromanometer 10; the dust that is not held in respirator, i.e. entered human lungs, is controlled by АФА filters (test of one respirator requires four filters) being previously weighed using analytical balance.

Thus, by reference to the difference between dusty and clean АФА filters it is possible to determined dust mass that can enter worker's lungs that allows evaluating dust load degree. In this case coefficient that takes into account respirator availability can be calculated using the formula [27]

$$k = \frac{M_1 - M_\phi}{(M_1 - M_\phi) + (M_2 - M_p)}, \text{ g},$$

where M_1 is mass of contaminated АФА filter, g;

M_2 is mass of contaminated filters of respirator, g;

M_ϕ is mass of clean АФА filter, g;

M_p is mass of cleaned filters of respirator, g.

Such respirators as ШБ-1 “Lepestok-200”, ШБ - 1 “Lepestok-40”, РПА-ТД-1, РПА-ТД-2 being widely used in mining and metal mining industry have been used for research. As it has been already mentioned, filtering elements for nondisposable RPD can be made of materials that differ with their technical characteristics. It can have great influence upon respirator quality in general. That is why efficiency ranking at using protective devices should be evaluated only according to the quality of filtering element. The results of study and coefficient taking into account respirator availability are represented in Table 3.2.

Table 3.2

Results of the experiment on determining coefficient that takes into account respirator availability

RPD type with filtering element	Dust concentration on *C*, mg/m^3, in a chamber	Dusting time *t*, хв	Dust mass M_2, g, On respirator	Dust mass M_1, g, on АФА filters	Value of coefficient *k*, r.u., that takes into account respirator availability
ШБ-1 “Lepestok-200”	Up to 300	120	1.06 ± 0.03	0.021 ± 0.002	0.021
ШБ-1 “Lepestok-40”		120	1.07 ± 0.04	0.026 ± 0.002	0.024
РПА-ТД-1 with filters made of ФПП 15-0,6		120	1.07 ± 0.07	0.021 ± 0.001	0.019
РПА-ТД-1 with filters made of ФПП 15-1,5		120	1.06 ± 0.08	0.022 ± 0.001	0.022
РПА-ТД- with filters made of eleflen 5C		120	1.09 ± 0.05	0.021 ± 0.001	0.020

To evaluate the role of respiratory protective devices for dust etiology prevention it is reasonable to use special method for calculation of disease rate probability of workers coming in contact with dust. This method was developed and implemented in Russia. According to this method the probability can be determined using integral index of disease rate risks [28, 29]

$$R = 8{,}6x_1 + 6{,}0x_2 + 19{,}4x_3k_1 + 6{,}4x_4k_2k_3, \qquad (3.2)$$

where R is integral index of disease rate risks;

x_1 is the age of a worker;

x_2 is general work record;

x_3 is work record in contact with dust;

x_4 is dust load, g;

k_1 is coefficient taking into account SiO_2 content (from 0.6 up to 1.2);

k_2 is coefficient taking into account mineral composition and concentration of dust in the air (for coal dust with free silica of up to 5% it is within 0.47 – 2.2 depending on excess of dust BAC in the air of working area);

k_3 is coefficient taking into account job class (within 1.1 – 1.8).

Miners' disease rate risk is determined according to the value of integral index of Table 3.3 [30].

Table 3.3

Disease rate risk

General index R	1000 – 1150	1151 – 1200	1201 – 1250	1251 – 1300	1301 – 1350	1351 – 1400
Disease rate risk, %	До 2	5	10	20	30	40
Integral index R	1401 – 1450	1451 – 1500	1501 – 1550	1551 – 1600	> 1600	–
Disease rate risk, %	50	60	70	80	90	–

Using the data about miners' work record in mining industry and period of their contact with dust as well as values of coefficients concerning SiO_2 content, mineral composition, concentration of dust in the air and job class, it is possible to calculate the value of integral index as for disease rate risk varying dust load degree at respirator availability or absence. For example, general work record of 30-year miner is 9 years, 7 of them are spent in contact with dust. It allows determining how respirator reduces risks of dust etiology disease and evaluating its role for disease prevention. Table 3.4 shows calculation results.

As we can see, RPD use reduces considerably disease risk comparing to calculation results without respirators.

Table 3.4

Calculation results of miners’ disease risks

RPD type with filtering element	Integral index *R* of disease risk with RPD use	Disease rate risk with RPD use, %	Integral index *R* of disease risk without RPD use at dust concentration of 300 mg/m^3	Disease rate risk without RPD use, %
ШБ-1 “Lepestok-200”	1031	Up to 2	43789	More than 90
ШБ-1 “Lepestok-40”	1167	Up to 5	43789	
РПА-ТД-1 with filters made of ФПП 15-0,6	1011	Up to 2	43789	
РПА-ТД-1 with filters made of ФПП 15-1,5	1061		43789	
РПА-ТД-1 with filters made of eleflen 5C	1025		43789	

It is clear that it is impossible to simulate all the factors influencing probability of pneumoconiosis development under laboratory conditions. For example, during complex operations miners’ standard air volume through respirators can reach up to 300 l/in than increases possibility of dust penetration. Nobody controls whether workers put on respirators properly and how value of unfiltered air aspiration through obturation line increases when filter is contaminated with dust. It is just some part of the problem dealing with the evaluation of respirator quality and determining dust load degree which is going to be studied more by the authors. One thing is absolutely clear: there will be much more pneumoconiosis cases without respirator use.

CONCLUSIONS

The monograph is focused on the problems dealing with the evaluation of dust conditions in coal mines and properties of various RPD structures to selection them correctly for respiratory organs protection at mining enterprises. Besides, issues concerning determining dust etiology diseases at available respirators are studied. The research makes it possible to make the following conclusions:

- Irrespective of preventive measures, amount of dust etiology diseases grows every year, especially among the miners of basic mining professions, i.e. the ones who work in the working areas with the highest dustiness;
- Air dustiness within miners' working areas is often much higher than not only BAC but also specified technically achievable levels of residual dustiness;
- To reduce level of dust bronchitis and pneumonoconiosis disease rate it is necessary to implement constant and positive control of dust load upon miners working deep underground;
- While calculating dust load it is necessary to take into account real efficiency of respirator, not the one indicated in its certificate by the manufacturer as a lot of factors influence RPD quality;
- While selecting the devices to have maximum protection it is necessary to pay attention not only to the content of harmful substances and protective and ergonomic parameters but also to their structural peculiarities, meteorological parameters of working area as well as to the complexity and intensity of the operations to be done;
- RPD structure can result in some discomfort while its using, influencing protective efficiency, respirator term of validity, and psychological state of the worker;
- Protective efficiency of respirator depends upon numerous factors such as: quality if filtering material, corrugation of filtering elements, reliability of hermetic sealing along obturation line, which in its turn depends on half-mask pressing to a face, and air consumption through protective devices;

- Respirator use is accompanied by the whole complex of factors influencing workers; these factors impact cardiovascular system, external respiration etc.;
- It is recommended to select RPD taking into account ***composition and quantitative content of harmful substances in the environment*** as minimum protection level ensured by any respirator is calculated according to concentration of harmful substance and its biological hazard depending on BAC value;
- First of all, climatic conditions of underground mining enterprises differ from the surface ones with the increased air temperature, that is 28 ^{0}C on average but in some cases it can be 30 – 35 ^{0}C, as well as high relative humidity (90–100 %) and increased atmospheric pressure that stipulates taking into consideration influence of meteorological parameters upon respirator function as they often deteriorate RPD operational characteristics;
- Taking into account the fact that most workers do not follow mentioned rules of respirator use or the latter being used as protective devices only in case of threatening dust concentration within working area, RPD use does not guarantee decrease of disease risk but it only marks time of disease onset.

Appendix A

Table A.1

Influence coefficient of seam thickness on dust generation

Seam thickness, m	0.6	0.8	1.0	1.2	1.3	1.4	1.6	1.8	2.0	2.2
Coefficient value k_H	0.4	0.5	0.75	0.9	1.0	1.1	1.3	1.5	1.7	1.9

Table A.2

Influence coefficient of seam moisture content on dust generation

Moisture content, %	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0
Coefficient value k_W	1.1	1.0	0.9	0.75	0.7	0.5	0.4	0.3	0.2	0.15

Table A.3

Influence coefficient of airflow rate on dust generation

Airflow rate, m/s	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
Coefficient value $k_{в}$	1.5	1.1	1.0	1.2	1.5	2.1	3.0	4.0	5.0

Table A.4

Value of coefficient k_n to recalculate air dustiness

during different operating process

Operating process	Value of coefficient k_n for seams	
	flat, inclined	Steep
Coal extraction with shearers	1.0	0.75
Plowing, shield mining	0.65	0.6
Coal extraction with air hammers	–	1.5
Coal extraction in stable holes	0.4	
Coal haulage under longwall	0.5	1.0
Blasthole drilling: with hand drills, drill-press	0.1 0.95	
Machine drilling	0.35	
Roadway drivage: ventilation haulage	 0.5 0.6	
Belt conveyor coal transportation	0.3	
Overthrow coal discharge	0.1	

Appendix B

Main requirements to RPD according to DSTU 12.4.041-89

Parameter	Class of protection		
	1st	2nd	3rd
Coefficient of protection	< 10	10 – 100	>100
Coefficient of penetration through respirator, %	10	10 – 1.0	< 1.0
Resistance of gas and aerosol RPD to constant airflow, Pa, with air consumption of 30 l/min, not more:			
at inhale	50	50	50
at exhale	60	60	60
Initial inhale resistance of aerosol RPD to constant airflow, Pa, with air consumption of 30 l/min, not more:			
Structures without inhale valve	50	50	50
Structures with inhale valve	60	60	60
Initial exhale resistance of aerosol RPD to constant airflow, Pa, with air consumption of 30 l/min, not more	80	70	60
Boundary resistance of aerosol RPD to constant airflow, Pa, with air consumption of 30 l/min, not more:			
at inhale	100	100	100
at exhale	80	70	70
Volume carbon dioxide concentration at inhaling 0.5 ± 0.1 l of air, %, not more	2	2	2
RPD mass creating load on head, kg, not more:			
if facial part is made of insulating material	0.35	0.8	0.85
if facial part has the form of filtering mask	0.10	0.10	0.10
RPD mass creating load on a worker, kg, not more	0.35	1.80	5.00
RPD visibility restriction, %, not more:			
if facial part is made of insulating material	30	40	50
if facial part has the form of filtering mask	20	20	20

Appendix C
RPD: differences of protection (quality) control

European standards have quite another approach to evaluate RPD quality classes ("protection classes" in national standards) though methods of analysis are principally the same. First of all it is necessary to note that according to national specifications there is no preparation of respirators for testing while it is stipulated in European Union standards (EN 133, EN 136, EN 140, EN 143, EN 149). Thus, preparation means that one sample series is first exposed to temperature influence (24-hour holding, at 70 °C and the same period at –30 °C). Second sample series is subject to "wearing mode simulation" when two-way airflow with artificial air moistening is blown through filtering half-masks fixed on "sheffield" head model. Third sample series is subject to mechanical impact (simulation of low-frequency vibration) with the inflammability test, i.e. RPD are taken to the open fire with the temperature of 800 ^{0}C. Besides, according to EN 149:1991, protective devices with the level of air consumption of not only 30 l/min but also 95 l/minaret tested. Table B.1 gives standard values of main RPD parameters according to EN 149:1991.

Table C.1

Quality classes according to EN 149:1991	Penetration coefficient of test-aerosol through RPD, %	Breathing resistance to constant airflow, Pa, not more		Carbon dioxide volume concentration in the air being inhaled with inhale volume of 2 l, %, not more	RPD mass creating load on head, kg, not more
		30 l/min	95 l/min		
FFP1	< 25	60	210	1.0	0.3
FFP2	< 11	70	240	1.0	0.5
FFP3	< 5	100	300	1.0	0.5

Moreover, European classification assumes three levels of filtering half-mask quality according to their protective efficiency parameters: low efficiency corresponds to the 1st quality class (FFP1), medium efficiency corresponds to the 2nd one (FFP2), and high efficiency corresponds to the 3rd one (FFP3). Table C.2 compares requirements of home and foreign standards.

Table C.2

Requirements according to DSTU 12.4. 041-89		Requirements according to DSTU EN 149:1991	
Protection level	Penetration coefficient of test-aerosol through RPD, %	Quality level	Penetration coefficient of test-aerosol through RPD, %
1st	< 0,1	FFP3	< 5
2nd	< 1	FFP2	< 11
3rd	More than 1	FFP1	< 25

Consequently, figures of RPD protective efficiency according to EN 149:1991 are lower than the ones according to DSTU 12.4.041-89. It is stipulated by temperature impact on protective device as well as by testing modes that increases considerably probability of test-aerosol penetration.

European standards also stipulates determining RPD operational properties by means of recording subjective senses of the testees during simulation of working activity: walking and crawling. There are other requirements for product labeling as well. Each respirator should have its name and quality level (protective properties), name of manufacturer or its trade mark, number of state standard according to which tests are performed. Packed products should be accompanied by recommendations as for RPD use where the following data should be highlighted:

- Sphere of application with the possible limitations;
- Methods of quality control before use;
- Storage precautions.

Thus, in our opinion, implementation of European standards will improve quality of respirators.

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