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COMPARATIVE ANALYSIS OF FEATURES OF CONSUMPTION GAS – AIR MIXTURE DURING WORK OF SMOKE – DIVERS USING REGENERATIVE BREATHING APPARATUSES

In the article it is shown that regularity of oxygen consumption using regenerative breathing apparatuses with 5% - the significance level is normal-valued function of the distribution of this indicator in the selected operating mode. At the same time supply of oxygen during performing the whole complex of works in unbreathable environment is 2 l / min.

Keywords: RBA, oxygen consumption, operating mode.

Problem statement. In scientific and technical literature is recordedtime of working using regenerative breathing apparatuses and it is determined by oxygen supply q [1], norms are given in normative [2], scientific and technical [3] literature. However, the practice of using regenerative breathing apparatuses (RBA) shows that real consumption can (during taking out affected using the fixed escalator $q \approx 2,6$ l/min [4]) differ from calculation made during being on security post in unbreathable area due to oxygen supply $q \approx 1,4 l/min$ [2]. As a result, estimated time of work using RBA can be much longer than the one which apparatus provides for safe performing of emergency rescue operations in environments unsuitable for breathing.

Analysis of recent achievements and publications showed that the basis of definition of normative value of oxygen supply index is used connection [5] between indicator of pulmonary ventilation and dose of oxygen consumption by human

$$q = \varpi_{л} \cdot (S_{in} - S_{out}) = 0,0455 \cdot \varpi_{л}, \quad (1)$$

where $S_{in} \approx 0,2095$ – the proportion of oxygen in the inspired air; $S_{outд} \approx 0,164$ – the proportion of oxygen in expired air.

At the same time, a significant difference between air consumption during work of when working in the rescue devices on compressed air from the lung ventilation values given in the scientific literature [6, 7], and raises the question of research, in practice,how oxygen is consumed during the rescue in RBA.

Formulation of a problem and its solution. Based on this, there is a task to make comparative analysis of features of oxygen consumption during different heaviness of work made by smoke - divers using RBA.

Experimental studies were conducted the same way as was done in the study of air flow in a compressed air apparatus [6, 7]. Indicator of the oxygen flow rate with the dimension [l / min] in accordance with law of Boyle - Mariotte calculated as

$$q = \frac{Q}{\Delta t} = \frac{\left(P_{in} - P_{fin}\right) \cdot V_b}{\Delta t \cdot P_a}, \quad (2)$$

where Q – a mount of consumed air during the reporting period of time Δt in [min] in apparatus, l; P_{in} – initial pressure in EBR bomb, MPa; P_{fin} – final pressure, MPa; $P_a \approx 0{,}1$ MPa – atmosphere pressure; V_b – volume of bomb, l (in this case $V_б = 1 \text{liter}$, as during experiments were used regenerative breathing apparatuses КІП-8 [5]).

The results for each type of work, as in this case may was used selection with volume n = 24, selections were tested for normality using Shapiro-Wilk criteria [8].

For this, for example, is used for performing very hard work by examinee (see Table. 1) at first were calculated average value of the oxygen consumption index

$$\overline{q} = \frac{\sum_{i}^{n} q_i}{n}, \quad (3)$$

where q_i – the value of oxygen consumption index for i-examinee, l / min.; standard deviation

$$G_q = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} \left(q_i - \overline{q}\right)^2}, \quad (4)$$

and

$$n \cdot m_2 = \sum_{i=1}^{n} \left(q_i - \overline{q}\right)^2 = 63{,}33, \quad (5)$$

where m_2 – selective central moment of the second order.

Since the estimates q_i are result of processing of independent observations, they were arranged in decreasing order and marked with symbols q_1, q_2, ..., $q_{n=24}$. In table 2 it is shown an ordered series of obtained values of oxygen consumption. It helped us to calculate intermediatesum S using formula

$$S = \sum_{i}^{k} a_{n-i+1} \cdot (q_{(n-i+1)} - q_i) = 3{,}00, \quad (6)$$

where k – index, that has value from 1 to $n/2=12$; a_{n-i+1} – coefficient that has special value for sample size n (its values given in Table. 2, are taken from Table 10 [8]).

Tabl. 1. The results of oxygen consumption during performing very hard work by examinees

Examinee	$P_{нач}$	$P_{кон}$	$V_б$	t	q	$(q_i-\bar{q})^2$
1	19,75	18,00	1	5	3,50	0,0729
2	19,50	18,25	1	5	2,50	1,6129
3	18,75	16,50	1	5	4,50	0,5329
4	18,75	17,00	1	5	3,50	0,0729
5	19,25	17,50	1	5	3,50	0,0729
6	18,25	16,25	1	5	4,00	0,0529
7	18,00	15,75	1	5	4,50	0,5329
8	19,00	17,25	1	5	3,50	0,0729
9	20,00	18,00	1	5	4,00	0,0529
10	18,50	17,25	1	5	2,50	1,6129
11	19,50	17,75	1	5	3,50	0,0729
12	19,25	17,25	1	5	4,00	0,0529
13	19,75	17,50	1	5	4,50	0,5329
14	20,00	18,25	1	5	3,50	0,0729
15	19,00	17,00	1	5	4,00	0,0529
16	19,75	17,85	1	5	3,80	0,0009
17	18,25	16,25	1	5	4,00	0,0529
18	19,50	17,25	1	5	4,50	0,5329
19	18,25	16,50	1	5	3,50	0,0729
20	18,75	16,75	1	5	4,00	0,0529
21	18,75	16,50	1	5	4,50	0,5329
22	18,50	17,25	1	5	2,50	1,6129
23	18,75	16,50	1	5	4,50	0,5329
24	18,25	16,25	1	5	4,00	0,0529
$\bar{q}$					3,77	
σ_q					0,63	
$n \cdot m_2$					8,91	

Table 11 [8] for significance level α=0,05 and n = 24 gives the value $W_{табл}=0{,}916$. Inasmuch as

$$W=1{,}011 \geq W_{tabl}=0{,}916, \quad (7)$$

distribution according to [8] is normal.

Experimental results of oxygen consumption, taking into account heaviness of work, external conditions and nature of work are summarized in Table 3, where the rate of pulmonary ventilation $\varpi_л$ is calculated from (1).

Tabl. 2. Ordered series of obtained values of pulmonary ventilation while examinees are in rest

k	$q_{(24-k+1)}$, l / min	q_k, l / min	$q_{(24-k+1)} - q_k$, l / min	a_{n-k+1}	$a_{n-k+1} \cdot (\omega_{л(n-k+1)} - \omega_{лk})$
1	4,5	2,5	2,00	0,4493	0,8986
2	4,5	2,5	2,00	0,3098	0,6196
3	4,5	2,5	2,00	0,2554	0,5108
4	4,5	3,5	1,00	0,2145	0,2145
5	4,5	3,5	1,00	0,1807	0,1807
6	4,5	3,5	1,00	0,1512	0,1512
7	4	3,5	0,50	0,1245	0,06225
8	4	3,5	0,50	0,0997	0,04985
9	4	3,5	0,50	0,0764	0,0382
10	4	3,5	0,50	0,539	0,2695
11	4	3,8	0,20	0,0321	0,00642
12	4	4	0,00	0,0107	0
S					3,00162
S^2					9,009723

The analysis of results given in Table 3, allowed us to assume equal values of oxygen supply while smoke divers are in rest, and during performing of easy and mediumheaviness of work.Besides, it is desirable to check the equality of average values of oxygen supply during performing medium heaviness of work and all the works in smoke and heat training facility, as in [5] it is regarded, that in general during work using RBA, the work refers to medium heaviness. Also, comparing oxygen supply during taking out affected from smoke and heat training facility with supply during performing hard heaviness, because (see. Tab. 3) pulmonary ventilation during taking out manikin from smoke and heat training facility complies with the values indicative to performing very hard work.

Tabl. 3. Summarizing results of experimental studies

The severity of work (Nature of work)	Standard value [9] oxygen supply indicator, l / min.	$\bar{q}$, l / min.	σ_q, l / min.	Skos	$\varpi_л$, l / min.
1	**2**	**3**	**4**	**5**	**6**
Rest	0,55	1,40	0,18	0,07	30,8
Easy	0,91	1,40	0,16	0,58	30,8
1	**2**	**3**	**4**	**5**	**6**
Medium heaviness	1,37	1,42	0,19	0,55	31,2
Hard heaviness	2,73	2,79	0,36	0,07	61,3
Very hard	3,82	3,77	0,63	-0,83	82,9
All complex of works in smoke and heat training facility	1,37	1,98	0,28	0,52	43,5
Taking outaffected from smoke and heat training facility	3,82	2,55	0,48	0,46	56,0

For comparison oxygen consumption rate during performing different types of work using RBA (see Table. 4) was considered the hypothesis

$$H_0 : q_1 = q_2 \tag{7}$$

and its alternative

$$H_1 : q_1 \neq q_2 , \tag{8}$$

which proves the difference of averages.

In order to select a specific method for calculating the t-criteria [10] at first was checked hypothesis of equality of variances. As a criterion to check the zero-hypothesis

$$H_0 : \sigma^2_{q_1} = \sigma^2_{q_2} \tag{9}$$

WaschosenF-criteria

$$F = \sigma_1^2 / \sigma_2^2 , \tag{10}$$

where σ_1^2 –bigger from variance estimates in two samples.

At this critical value $F_{кр}$, which is at a significance level α=0,05 and number of degrees of freedom

$$\upsilon_q = n_q - 1 = 23 , \tag{11}$$

where $n_q = 24$ – number of examinees which oxygen consumption was defined using RBAduring performing each considered type of work, equals [10]

$$F_{кр} = F_{табл} = 2{,}3. \tag{12}$$

Tabl. 4. Comparison of oxygen consumption during work using RBA received at the fresh air and in smoke and heat training facility

The nature of the work being compared	F	$F_{кр}$	$S_{\omega л}$	υ	t_{nabl}	$t_{tab}(\alpha = 0{,}05)$
1	**2**	**3**	**4**	**5**	**6**	**7**
Rest – medium heaviness	0,90	2,3	0,053	46		0,37
Mediumheaviness – all complex of works in smoke and heat training facility	0,46	2,3	0,069	46	8,11	2,01
Hardheaviness – taking outaffected from smoke and heat training facility	0,56	2,3	0,122	46	1,96	2,01
Very hard – taking outaffected from smoke and heat training facility	1,72	2,3	0,162	46	7,55	2,01

It can be seen (look at columns 2 and 3 Table. 2), that in these cases right is zero-dimensional hypothesis (7) and equality of variances is permitted during performing work, related [3] to same severity.

Accordingly, the standard error of difference S_q, taking into account that small samples (<30) and the number degrees of freedom υ during calculation of t-criteriais calculated [10] as follows

$$S_q = \sqrt{\frac{(n_1 - 1)\cdot\sigma_1^2 + (n_2 - 1)\cdot\sigma_2^2}{n_1 + n_2 - 2}\cdot\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}; \tag{13}$$

$$n_1 + n_2 - 2 = 46. \tag{14}$$

As a result

$$t_{nabl} = \frac{|q_1 - q_2|}{S_q}. \tag{15}$$

It can be seen (look atcolumns 6 and 7 Table. 2) that in most cases due to significance level α=0,05you can talk about the coincidence of oxygen consumption values obtained during performing tasks, characterized by the same degree of severity, at the fresh air and smoke and heat training facility. This suggests that the standard load [3] adequately reflects the load with which rescuers faced during preparation using smoke and heat training facility.

An exception is educational situation with taking out manikin. It can be explained by the fact that (the same case and during the rescue operations, not related with rescuing people) there is a natural alternation of execution very hard work with short periods of rest.

In summary, the oxygen consumption of the distribution function in RBA with combined supply can be represented as illustrated in Fig. 1

It is seen when being in rest and performing light and medium heaviness can be assumed that the oxygen supply can be considered equal to 1.4 l / min., which, providing combined supply [5] oxygen used during modification studies of RBA type КІП-8 actually corresponds to a constant supply of reductor [9]. At the same time, during taking out affected from smoke and heat training facility, which was supposed to correspond to performing very hard work, the oxygen supply is actually matched the one that should be during performing the hard work.

It can be explained by the fact that smoke divers who are using RBA, well aware of the very good characteristics of these devices (concerning time of protective action) as compared which SCBA and can alternate execution very hard work (transferring the affected) with short periods of rest.

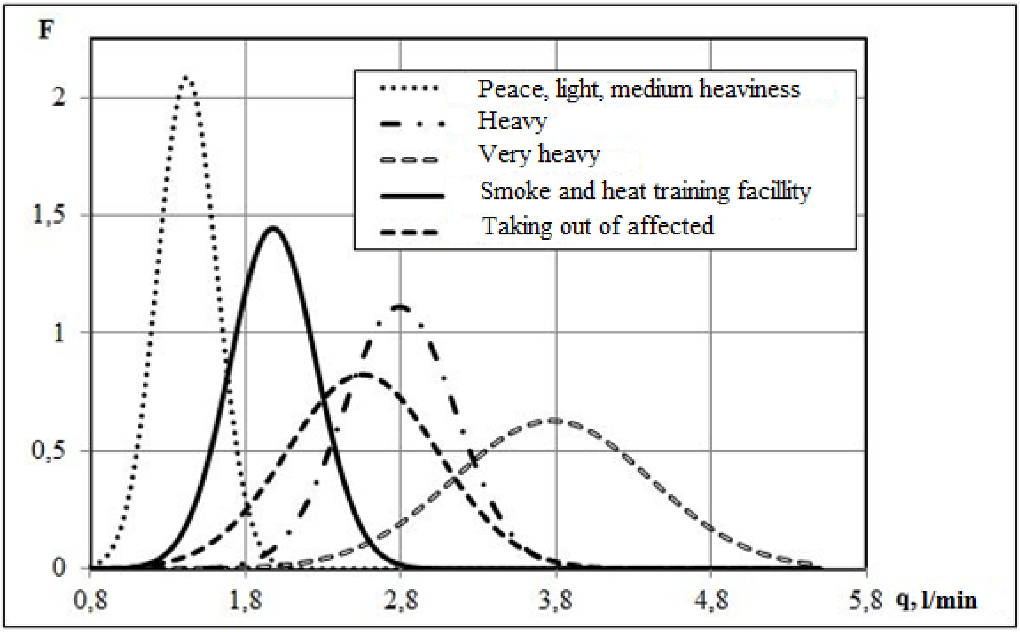

Fig. 1. The oxygen consumption of the distribution function in RBA

A similar situation occurs in the case of the consideration of all complex of works in smoke and heat training facility, when there is an alternation of execution very hard work with short periods of rest.

A similar situation (look at. fig. 1) takes place in the process of using RBA during rescue operations at subway stations. In [4, 11], it is shown that in this case for all complex of works oxygen density distribution is given by

$$f(q_\Sigma)=\frac{1}{0{,}09\cdot\sqrt{2\cdot\pi}}\cdot e^{-\frac{(q-1{,}98)^2}{2\cdot 0{,}09^2}}, \quad (16)$$

where – $\overline{q}_\Sigma \approx 1{,}98$ l/min – is the expectation of oxygen supply to RBA during performing all complex of rescue activities at the subway stations; $\sigma_{q_\Sigma} \approx 0{,}09$ l/min – is the standard deviation of oxygen supply to RBA during performingall complex rescue activities at the subway stations; and to lift affected unresponsive

$$f(q')=\frac{1}{0{,}13\cdot\sqrt{2\cdot\pi}}\cdot e^{-\frac{(q-2{,}6)^2}{2\cdot 0{,}13^2}}, \quad (17)$$

where $\overline{q}' \approx 2{,}6$ l/min – is expectation of oxygen supply in RBA while lifting affected unresponsive; $\sigma_{q'} \approx 0{,}13$ l/min – is the standard deviation of oxygen supply in RBA while lifting affected unresponsive.

The results show that RBA provides more economical expenditure reserve of gas mixture not only by usingconstructive features of such devices, but also due to the fact that during shallow breathing, that is character for performing hard work, reduces the amount of carbon dioxide, which must purify the air in a regenerative cartridge unit.

Conclusions. feature of oxygen consumption using regenerative breathing apparatus is that this indicator with a with 5% -th significance level is normal-valued function for all operating mode of smoke dyers work. In this case the oxygen supply to the RDA is:

– In re-stand performing easy and medium heaviness 1,4 l/min;

– Performing all complex of works in unbreathable environment 2 l/min, which corresponds to consumption of gas-air mixture in the 40 l/min, during taking out of affected 2,6 l/min – pulmonary ventilation during performing hard work (60 l/min).

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Особливості витрати запасу газоповітряної суміші при роботі газодимозахисників в регенеративних дихальних апаратах

Показано, що закономірністю витрати кисню при роботі в регенеративних дихальних апаратах з 5% -им рівнем значущості є нормальна функція розподілу розглянутого показника всередині обраного режиму роботи. При цьому подача кисню під час виконання всього комплексу робіт в непридатному для дихання середовищі дорівнює 2 л/хв.

Ключові слова: РДА, витрата кисню, режими роботи.

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Особенности расхода запаса газовоздушной смеси при работе газодымозащитников в регенеративных дыхательных аппаратах

Показано, что закономерностью расхода кислорода при работе в регенеративных дыхательных аппаратах с 5%-ым уровнем значимости является нормальная функция распределение рассматриваемого показателя внутри выбранного режима работы. При этом подача кислорода при выполнении всего комплекса работ в непригодной для дыхания среде равна 2 л/мин.

Ключевые слова: РДА, расход кислорода, режимы работы.