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The Physico-Chemical Analysis of Compressed Medical Air from Breathing Apparatus

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Abstract*— The quality of the compressed medical air[1], which is used in breathing apparatus [2] (SCBA) [3], and also in diving apparatus (SCUBA)[4], is regulated by the European standard EN 12021 [5] (Table I). These requirements relate primarily to: permissible concentrations of oxygen, carbon dioxide, carbon monoxide, humidity, odours, and particles of dust and oil vapour. Compressed medical air must meet certain criteria – not to have any flavour or odour. When filling breathing apparatus cylinders, it should be taken into account that vehicle exhaust gases, vapours of hazardous liquids, smoke and other harmful substances are not in the vicinity of the suction pipe because they may get inside the cylinder of SCBA and with their presence disrupt the microclimate (strictly defined parameters of medical air) and directly endanger the user. The breathing process depends on the percentage of moisture in the air (regulates physical stress) and on condensation and freezing during the use and storage as well. Particular attention should be paid to the maintenance and regular servicing of compressors and breathing apparatus, which eliminate the sudden appearance of a system failure system failure [2].

***Index Terms*—breathing apparatus, compressed medical air, permissible concentrations.**

I. INTRODUCTION

Using the breathing apparatus, a user is completely isolated from the atmosphere environment, as well as from the affecting of contaminated atmosphere. They are used in the environments with the lower concentration of oxygen in the air, or where concentration of toxic gases are over permitted limits etc. in the fire [1]. The fire is every uncontrolled burning, which does not only cause financial damage and endangers human lives, but it also endangers the lives of the other human beings. The main fire products are smoke and heat, and they present the biggest threat in the open space or in the building [3]. As it was mentioned in the previous chapters, users of breathing apparatus are completely isolated from external factors, so that during this isolation they are placed in a specific working environment in which they are exposed to specific microclimate conditions. Determination of conditions for achieving maximum user's results are enabled by experimental analyses of basic aspects of the mentioned specific working environment with specific microclimate conditions, which is primarily related to his safety. It is obligatory before immediate cylinder filling to be sure about not smoking in the vicinity of the suction port of the compressor and pre-filter of the compressor; not using volatile, irritant and aggressive substances such as thinner or other solvents, and also not to burn a fire or other vehicles.

Composition of compressed medical air	JUS standard	dr Gošović	Bauer	EN 12021
Oxygen O_2	20-21 %	20-22 %	20-21 %	20-22 %
Moisture	50 mg/m^3	No limit	30 mg/m^3	200 bars 50 mg/m^3 300 bars 35 mg/m^3
Carbon monoxide CO	0.001 % (10 ppm)	0.001 % (10 ppm)	0.001 % (10 ppm)	5 mg/m^3
Carbon dioxide CO_2	0.05 % (500 ppm)	0.05 % (500 ppm)	0.04 % (400 ppm)	500 mg/m^3
Oil vapours	0.3 mg/m^3	0.5 mg/m^3	0.25 mg/m^3	0,5 mg/m^3

Table I. The Composition of medical air according to [2]

In this way a majority of hazardous substances which can reach the inside part of the cylinders of breathing apparatus can be eliminated and as such can harm the quality of compressed medical air in them. Also, if it is possible, it is necessary to avoid filling the bottles of breathing apparatus at very low temperatures and high air pollution concentration. Occurrence of non-pathogenic microorganisms in compressed medical air can be caused by inadequate and replacement of compressor filters. If these filters have not been changed according to manufacturers' advice, then they represent a convenient surrounding for microorganism development. The inside part of the filter possesses humidity and is protected from sunlight so all conditions for life and microorganisms are filled. According to an "unwritten rule", i.e. according to internal agreement within fire units (professional, territorial, industrial) and voluntary fire departments, CMA in cylinders is replaced every 3 months, 6 months, one year because there is no manual which strictly defines the time when the air should be replaced in cylinders.

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Usually the air in cylinders is replaced according to "individual judgment" i.e. after smelling "unpleasant odour" during control emission of air from a cylinder. That indicates that there have been some changes in the quality of air inside the cylinder with the compressed air.

II. THE AIM OF THE COMPRESSED MEDICAL AIR ANALYSIS

During the compression of medical air in medical air compressors, the air from the surrounding area must go through the system of filters where the extraction of dust and larger particles of dust, micronic dust, oil and water vapours (a result of lubrication, abrasion and high pressure compaction) micronic particles of oil and water, take place and therefore, at the end of its cycle the air goes through the chemical procedure of removing excess moisture and other harmful additives. The last cycle takes place in the filter cartridges which have limited lifetime and which ought to be replaced regularly because they cannot fully filter harmful components from air because of saturation. Non-pathogenic and pathogenic microorganisms and also moulds can, of course, occur in these filter cartridges (and in other filters too) due to improper use and servicing and because of the presence of moisture. Due to too high concentration of harmful components of air and the mentioned microorganisms, user's health is directly endangered. The samples of chosen cylinders which are the object of analysis (three steel and one composite cylinder) were taken for the mentioned experiment. Some of the cylinders were previously filled, 7÷8 months before the analysis and before filling again, samples were taken from them and then they were completely emptied. The samples were taken from: pre-filter, i.e. air from the environment and then the samples of medical air on the outputs of both compressors which are used in the Fire Unit of the city of Banja Luka. [2] During the sampling for experimental research the weather was sunny (meteorological parameters are shown in the Table II)

Table II . Microclimate parameters:

METEOROLOGICAL PARAMETERS				
Date	Time (h)	Air temperature °C	Air pressure (mbar)	Humidity (%)
24/09/2010	07^{00}	11.5	996	97
	12^{00}	24.1	991	63
23/10/2010	07^{00}	0.5	1003.4	97
	12^{00}	20.4	1001.0	36
01/11/2010	07^{00}	11.1	996.5	83
	12^{00}	15	997.5	70
01/06/2011	08^{00}	21	994	71
	11^{00}	26	994	46

Hydro-meteorological data were obtained from The Republican Hydro-meteorological Institute Republic of Srpska (one entitets of Bosnian and Herzegovina). Measurements of meteorological parameters are carried out every hour and reports are given every three hours:01^{00}; 04^{00}; 07^{00}; 10^{00}; 13^{00}, 16^{00}; 19^{00}; 22^{00}; (in the winter time which is relevant to Banja Luka area), while in the summer time reports are given every three hours, but one hour later than "winter" time. The percentage of oxygen from the environment and bottles at the beginning, during and at the end of the test was 20.8 %.

III. PHYSICO-CHEMICAL FEATURES OF MEDICAL AIR

Immediately before new filling of specifically chosen cylinders, which are the object of the analysis, the samples or medical air from the same cylinders were taken (picture 1). Cylinders were previously filled, 7÷8 months before, and before filling again, and they were completely emptied. The samples were taken from : pre-filter, i.e. air from the environment and then the samples of medical air on the outputs of both compressors which are used in the Fire Unit of the City of Banja Luka, (Table III).

Picture 1.Taking physico- chemical sample of the medical air.

With the experimental part of the analysis we based on the composition of the main components of compressed medical air which composition was precisely defined in Table I.

During the analysis other components in the environment air and medical air which have not been defined by the mentioned Standards were found. At the same time they were analysed in the Gasmet DX-4030 device for air quality analysis. All the components and detected concentration from samples of the environment air and compressed medical air were post compared in the Institute for Protection, Ecology and Computing, and they are in the frame of regulatives according to law, or according to Regulation of Yugoslav Standard for Maximum Allowed Concentration of Hazardous Gases, Vapours and Aerosols (Official Gazette SFRJ 54/9

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Table III. Measured values of all components of the environment air and medical air (ppm).

Sample	Measuring on pre-filter	Compressor DON 300 bars	Compressor Bauer (I sample) 300 bars	Compressor Bauer (II sample) 200 bars
Date of measurement	01/06/	01/06/	01/06/	01/06
Carbon dioxide	< LOD[6]	112	194	149
Carbon monoxide	0.07	0.21	0.2	0.04
Nitrogen-suboxide	0.036667	< LOD	< LOD	< LOD
Methane	<LOD	<LOD	<LOD	<LOD
Nitrogen -dioxide	0.21667	0.19	0.62	< LOD
Sulfur-dioxide	0.12	<LOD	<LOD	0.17
Acetaldehyde	0.27667	<LOD	<LOD	<LOD
Acetone	<LOD	0.39	<LOD	<LOD
Formaldehyde	<LOD	0.04	0.12	<LOD
Bensen	<LOD	0.12	<LOD	<LOD
Toluene	0.01	0.14	0.14	0.34
M-xilene	<LOD	<LOD	< LOD	< LOD
Isopropanol	< LOD	0.15	0.37	0.29
Ammonia	0.01	< LOD	< LOD	< LOD
Acrolein	0.343333	0.17	< LOD	< LOD
Acetic ether	< LOD	< LOD	< LOD	< LOD
Phenol	0.41	< LOD	0.38	0.37
Nicotinic acid	0.113333	0.06	< LOD	< LOD
Carbon disulfide	0.17	< LOD	< LOD	< LOD
Trichlorethylene	< LOD	< LOD	< LOD	< LOD
Styrene	0.12	< LOD	< LOD	< LOD
Chlorohydrogen	0.156667	< LOD	< LOD	< LOD
Methanol	< LOD	< LOD	0.67	0.51
Ethanol	< LOD	0.1	< LOD	0.55

Table 4. Parameter values of the environment air on pre-filter and medical air on compressors before cylinder filling (ppm).

Composition of air/medical air	Pre-filter	Compressor DON	Compressor Bauer 300 bars	Compressor Bauer 200 bars
Oxygen O_2 (%)	20.8	20.8	20.8	20.8
Moisture (relative %)	56	24.3	24.2	24.1
Carbon dioxide CO_2	< LOD	112	194	149
Carbon monoxide CO	0.07	0.21	0.2	0.04

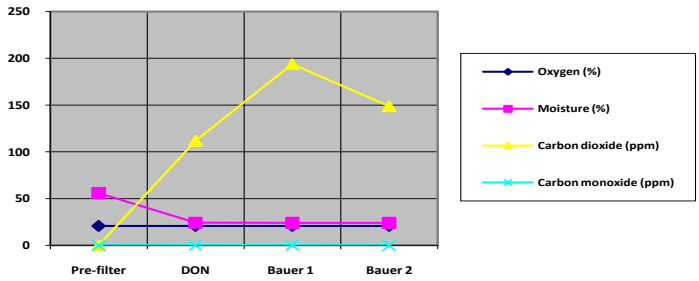

Diagram 1. Basic components in the environment air and medical air according to Standards.

[6] **< LOD** –Values less than Limit of Detection.

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Table V. Measured values of all components of the medical air from composite cylinder No. 7(ppm).

Sample	COMPOSITE CYLINDER No 7						
Date of measurement	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.	04.10.
Carbon dioxide	29.5	115	29.1	20.785	53.22	37.6	52
Carbon monoxide	0.03	0.37	0.14	0.025	0.44	0.33	0.38
Nitrogen-suboxide	< LOD	< LOD	< LOD	0.03	0.006667	0.0475	0.027
Methane	0.03	< LOD	< LOD	0.085	0.026667	0.01	0.07
Nitrogen -dioxide	0.13	0.21	0.17	0.745	0.41	0.405	0.54
Sulfur-dioxide	< LOD	0.28	0.11	< LOD	0.664667	0.255	0.12
Acetaldehyde	< LOD	< LOD	0.07	< LOD	0.006667	< LOD	0.18
Acetone	0.11	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Formaldehyde	< LOD	0.12	0.06	< LOD	< LOD	0.0425	0.1
Bensen	< LOD	< LOD	< LOD	< LOD	< LOD	0.105	< LOD
Toluene	0.06	0.49	0.06	< LOD	0.063333	0.01	< LOD
M-xilene	< LOD	< LOD	0.02	< LOD	< LOD	0.0425	< LOD
Isopropanol	0.18	0.27	< LOD	< LOD	< LOD	< LOD	< LOD
Ammonia	0.1	< LOD	< LOD	< LOD	0.006667	0.0075	< LOD
Acrolein	< LOD	< LOD	0.14	< LOD	< LOD	0.1575	0.03
Acetic ether	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Phenol	0.01	0.51	0.02	0.075	0.326667	0.27	0.20
Nicotinic acid	0.13	< LOD	0.41	0.335	< LOD	0.1525	0.56
Carbon disulfide	< LOD	< LOD	0.25	0.2	< LOD	0.1425	< LOD
Trichlorethylene	0.04	< LOD	< LOD	< LOD	< LOD	< LOD	0.06
Styrene	< LOD	< LOD	< LOD	0.01	0.093333	0.055	0.02
Chlorohydrogen	0.11	0.17	< LOD	0.215	0.133333	0.13	0.37
Methanol	0.32	0.26	< LOD	< LOD	< LOD	< LOD	< LOD
Ethanol	< LOD	0.55	< LOD	< LOD	< LOD	< LOD	< LOD

Table VI. Parameter values of the environment air on pre-filter and medical air on composite *cylinder No. 7(ppm).*

Composition of air/medical air	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.	04.10.
Oxygen O_2 (%)	20.8	20.8	20.8	20.8	20.8	20.8	20.8
Moisture (relative %)	25.2	24.4	24.4	24.4	24.4	24.4	24.4
Carbon dioxide CO_2	29.5	115	29.1	20.785	53.22	37.6	52
Carbon monoxide CO	0.03	0.37	0.14	0.025	0.44	0.33	0.38

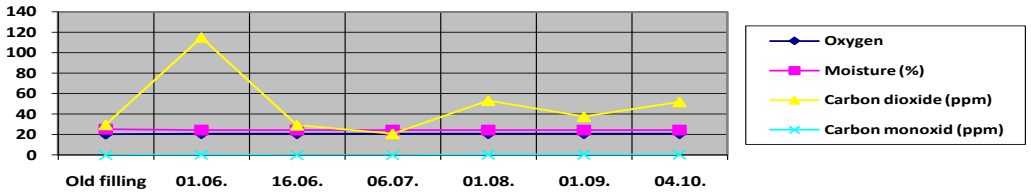

Diagram 2. Basic components in the medical air from composite cylinder No. 7 according to Standards.

Table VII. Measured values of all components of the medical air from steel cylinder No. 69 (ppm).

Sample	STEEL CYLINDER No 69					
Date of measurement	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.
Carbon dioxide	161	263	105	< LOD	59.725	44.95

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Carbon monoxide	0.01	0.3	< LOD	0.193333	0.3	0.185
Nitrogen-suboxide	0.01	< LOD	0.01	0.036667	0.0075	0.03
Methane	0.35	< LOD	< LOD	0.056667	< LOD	0.175
Nitrogen -dioxide	0.26	< LOD	0.21	0.15	0.0475	0.295
Sulfur-dioxide	< LOD	< LOD	0.08	0.123333	1.1875	0.755
Acetaldehyde	< LOD	< LOD	< LOD	0.146667	< LOD	< LOD
Acetone	< LOD	0.4	< LOD	0.356667	0.1775	< LOD
Formaldehyde	0.01	0.01	0.05	0.003333	0.0125	0.05
Bensen	0.28	0.08	< LOD	< LOD	< LOD	< LOD
Toluene	1.4	0.29	0.24	< LOD	0.035	< LOD
M-xilene	0.24	< LOD	< LOD	0.083333	0.04	< LOD
Isopropanol	0.59	0.25	< LOD	0.016667	< LOD	< LOD
Ammonia	0.01	< LOD	0.01	0.07	< LOD	0.04
Acrolein	< LOD	0.27	< LOD	< LOD	< LOD	< LOD
Acetic ether	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Phenol	< LOD	0.23	0.05	0.176667	0.46	0.305
Nicotinic acid	< LOD	< LOD	0.58	0.183333	0.505	0.515
Carbon disulfide	< LOD	< LOD	0.23	0.41	0.1325	< LOD
Trichlorethylene	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Styrene	< LOD	< LOD	0.34	< LOD	< LOD	< LOD
Chlorohydrogen	0.08	0.18	0.22	0.3633333	0.24	0.19
Methanol	0.67	0.7	< LOD	< LOD	< LOD	< LOD
Ethanol	< LOD	0.23	< LOD	0.06	< LOD	< LOD

Table VIII. Parameter values of the environment air on pre-filter and medical air on steel cylinder No. 69 (ppm).

Composition of air/medical air	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.
Oxygen O_2 (%)	20.8	20.8	20.8	20.8	20.8	20.8
Moisture (relative %)	25.5	24.7	24.7	24.7	24.7	24.7
Carbon dioxide CO_2	161	263	105	< LOD	59.725	44.95
Carbon monoxide CO	0.01	0.3	< LOD	0.193333	0.3	0.185

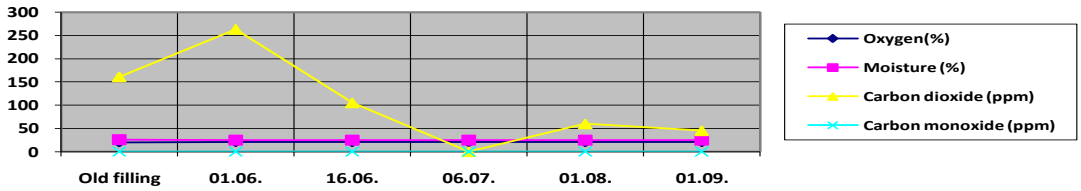

Diagram 3. Basic components in the medical air from steel cylinder No. 69 according to Standards.

Table IX. Measured values of all components of the medical air from steel cylinder No. 70 (ppm).

Sample	STEEL CYLINDER No 70						
Date of measurement	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.	04.10.
Carbon dioxide	177	192	81.2	< LOD	82.65	62.95	69.3
Carbon monoxide	< LOD	0.47	0.16	0.346667	0.325	0.12	0.426
Nitrogen-suboxide	0.02	0.01	< LOD	< LOD	0.025	0.055	0.005
Methane	0.5	< LOD	< LOD	0.046667	< LOD	0.1	0.153
Nitrogen -dioxide	0.02	0.17	< LOD	0.62667	0.185	< LOD	1.255
Sulfur-dioxide	< LOD	0.43	0.22	0.66	1.105	0.475	0.445
Acetaldehyde	< LOD	< LOD	< LOD	0.66667	0.065	< LOD	0.271
Acetone	< LOD	< LOD	< LOD	< LOD	0.43	< LOD	< LOD
Formaldehyde	< LOD	0.01	0.01	0.036667	0.025	0.04	0.095
Bensen	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD

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Toluene	0.63	0.12	0.09	< LOD	< LOD	< LOD	< LOD
M-xilene	< LOD	< LOD	< LOD	0.226667	0.115	0.065	< LOD
Isopropanol	0.53	0.01	< LOD	< LOD	< LOD	< LOD	< LOD
Ammonia	0.02	0.01	0.03	0.076667	0.135	0.04	< LOD
Acrolein	< LOD	< LOD	< LOD	< LOD	< LOD	0.01	0.423
Acetic ether	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Phenol	< LOD	0.58	0.12	0.47	0.495	0.36	0.408
Nicotinic acid	< LOD	< LOD	0.84	< LOD	0.45	0.445	0.615
Carbon disulfide	< LOD	< LOD	0.33	0.14	0.125	0.035	< LOD
Trichlorethylene	0.06	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Styrene	< LOD	< LOD	0.25	< LOD	0.17	< LOD	< LOD
Chlorohydrogen	< LOD	< LOD	0.11	0.256667	0.175	0.005	0.256
Methanol	0.92	0.45	< LOD	< LOD	< LOD	< LOD	< LOD
Ethanol	< LOD	0.58	< LOD	< LOD	< LOD	< LOD	< LOD

Table X. Parameter values of the environment air on pre-filter and medical air on steel cylinder No. 70 (ppm).

Composition of air/medical air	01.06. Old filling	01.06. New filling	16.06.	06.07.	01.08.	01.09.	04.10.
Oxygen O_2 (%)	20.8	20.8	20.8	20.8	20.8	20.8	20.8
Moisture (relative %)	25.4	24.5	24.5	24.5	24.5	24.5	24.5
Carbon dioxide CO_2	117	192	81.2	< LOD	82.65	62.95	69.3
Carbon monoxide CO	< LOD	0.47	0.16	0.346667	0.325	0.12	0.426

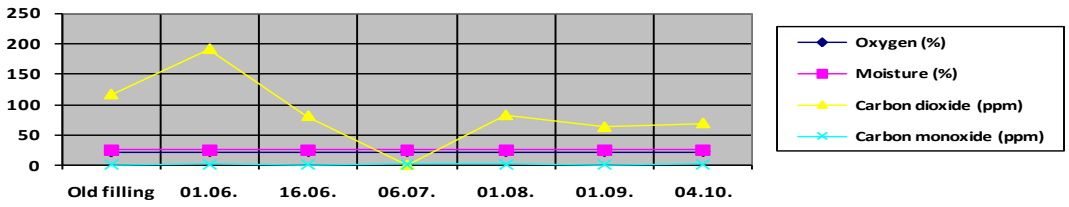

Diagram 4. Basic components in the medical air from steel cylinder No. 70 according to Standards.

IV. ANALYSIS OF EXPERIMENTAL RESULTS

Analyzing the results of psysico-chemical and microbiological analyses, obtained during the medical air from cylinders of breathing apparatus (three steel and one composite) testing, we can conclude that: Medical air in cylinders has retained its pysico-chemical characteristics of the legally prescribed limits and previously mentioned standards for medical air quality during air testing in the time period of 3 (three) and 6 (six) months. With continual physico-chemical sampling, given results were entered in the tables, and then presentedgraphically using diagrams. Inside the cylinders there were no any chemical reactions between the individual components, taking into account the presence of: a constant percentage of oxygen, moisture and impact of high pressure of 300 bars, which were declining due to sampling. Also, percentage of oxygen from the moment of air sampling from the environment to the last sampling remained constant, i.e. it did not vary. Analysing the results of air samples from the environment and medical air, it is noticeable that some harmful components appeared in medical air samples (within permissible limits) compared to samples of the environment air. These changes were caused in the working cycle of the compressor; i.e. as the consequence of heating oil for lubrication to reduce abrasion; and also caused by compressed air which directly affects the formation of oil vapours. These types of vapours together with air in the compression process purify in compressor filters, but they appeared in small harmless quantities in final obtained medical air. Also, the presence of some harmful components in CMA samples can be attributed to bacteria. Some types of bacteria from ethanol produce acetaldehyde or from CO_2 produce methane, formaldehyde and methanol. Given results are shown in the Table 18 where the results of sampling of the

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environment and medical air are displayed on the outputs of compressors from two different producers: DON- 300 bars: Bauer 300 and 200 bars. From the above it can be concluded that it is important to comply with the manufacturer's recommendations on the proper maintenance of compressors, regular oil and filter change, but the size of a filter affects better purification. DON Compressor has the final filter label P 41,Bauer compressor has the final filter label P 21. These filters are the same in structure except that P 41 is bigger than P 21, which directly reflects on the final purity of medical air (Table IV and Diagram No. 1). Differences are slight, but still observed. The first samples of medical air were taken from cylinders, which previously were filled,7÷8 months before the start of analysis. Also, it could be confirmed that these results are in the normal range, but do not know reliably what were the initial physico-chemical and microbiological parameters before their filling, so that it cannot be confirmed that medical air in cylinders can be kept more than 6 months. Also, there was no continuous monitoring of quality, and taking into account during the analysis number of charging cycles, on the compressor between the predicted intervals of filter replacement. Of course, air pollution from the environment (especially in winter conditions when there is the increased concentration of smog) and saturation of filters on compressors affect the final quality of compressed medical air.

V. CONCLUSION

This analysis was conducted in order to increase safety of users in accidental situations and diagrams formed with the analysis will indicate of physical, chemical and microbiological qualities of medical air in composite and steel cylinders. The safety of respiratory organs during firemen's interventions is very demanding as physical, chemical and microbiological parameters of CMA. Supply of up-to-date equipment, education and trainings reduce the risks of users' getting hurt and damages to the equipment. As it was mentioned – microorganisms cannot multiply in air and its environment, they decay relatively quickly while their existence depends on its characteristics and on the temperature and moisture of air. However, while conducting these analysis it was proved that microorganisms can still grow in CMA with constant pressure (of 200 or 300 bars) and with constant moisture of air. Analysing diagrams No. 1 and 2, one could notice logarithm curve of evolution of bacteria, where the cycle of growth and decay of microorganisms in CMA from the interior of cylinders was prolonged. It should be mentioned that the tests were successfully conducted on only two cylinders (1 steel and 1 composite) by the end of analysis because there were mechanical vent failures on the other two cylinders because they were about five years old. This indicates that we are responsible to keep precise records of periodical and regular control and conduct educations of personnel in charge of technical functionality and also comply with the manufacturer's recommendations on timely replacement of pieces on insulating apparatus, which directly reflects on the reliability itself during use and on the safety of users. The CMA analysis should be conducted at least once a year after servicing medical air compressor, which would increase the safety of users. [2] Protection of the repiratory organs during the intervention of firemen is very demanding because any protection is not 100 % safe, and there is always possibility that this one let down. Understanding the principle of working and the intention of the braething apparates, it can be guessed what kind of consequences might be caused by their incorrect using and maintaining. To avoid these dangers, it is necessary to follow the producer`s instruction, to have everyday checks, and periodic checks (after using) in the own workshops of firebrigades, as well as regular annual attesting at the authorized institutions. It would be desirable that all bigger fire brigades are eqipped with the control devices, and to test insulating apparates, but also to modernize all these ones with new apparates in which move sensors and transmitters are already intergarted, with which the safety of users would increase and their monitoring during the intervention. Purchase of current equipment, education and trainings, reduce the risks of injuring of a user and damaging the equipment. [1]

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