

# **Performance Comparison of Second-Generation Oxygen Self-Rescuers**

**By Nicholas Kyriazi**



**UNITED STATES DEPARTMENT OF ENERGY**

**PITTSBURGH RESEARCH CENTER**



***Cover photo: Second-generation oxygen self-rescuers.***

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**By Nicholas Kyriazi**

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### UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	L/min	liter per minute
g	gram	m	meter
h	hour	min	minute
Hz	hertz	mm H <sub>2</sub> O	millimeter water pressure
kg	kilogram	mL/min	milliliter per minute
L	liter	%	percent

Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

# PERFORMANCE COMPARISON OF SECOND-GENERATION OXYGEN SELF-RESCUERS

By Nicholas Kyriazi<sup>1</sup>

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## ABSTRACT

A performance study of second-generation oxygen self-rescuers approved for use mostly in U.S. underground coal mines was undertaken by the U.S. Bureau of Mines (USBM) to assess present technology. It provides a side-by-side comparison for the benefit of consumers—the mine operators—and a tool for evaluating apparatus by their performance characteristics. The apparatus were tested on a breathing and metabolic simulator in USBM life support laboratories. Parameters monitored were inhaled levels of CO<sub>2</sub> and O<sub>2</sub>, inhaled wet- and dry-bulb temperatures, and breathing pressures. The metabolic demand on the apparatus represented the average demand of the 50th-percentile miner performing a 60-min, man-test 4 as described under 42 CFR 84. Apparatus service life, quantity of usable O<sub>2</sub>, and averages and peaks of monitored parameters are presented.

Additionally, a brief study was performed to assess the estimated impact of the underground environment on the apparatus. No significant effects were found except on an early version of the Ocenco M-20 in which the CO<sub>2</sub>-absorbent, LiOH, leaked through the filters into the mouthpiece. The manufacturer has modified the early version by adding impact-absorbing bumpers on the case top and bottom.

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## INTRODUCTION

Since June 21, 1981, U.S. coal mine operators have been required to make available to each underground coal miner a self-contained self-rescuer (SCSR) device. The Mine Safety and Health Administration (MSHA) under 30 CFR 75.1714 requires that each person in an underground coal mine wear, carry, or have immediate access to a self-rescuer that provides an O<sub>2</sub> source. Prior to this, a filter self-rescuer (FSR) was required, which protects only against low levels of CO.

In keeping with the U.S. Bureau of Mines' (USBM) mission to ensure and improve the safety of our Nation's miners, a study was undertaken to compare the performance of the apparatus developed to satisfy the new requirement shortly after their deployment; the results were published in 1984 (1).<sup>2</sup> The purpose of the study was to provide a side-by-side comparison of apparatus performance, not available elsewhere, for the benefit of both users and manufacturers. Apparatus approved by the National Institute for Occupational Safety and Health (NIOSH) and MSHA are not evaluated in such a way that they can be compared.

Technology advancement has resulted in the development of four second-generation SCSR's that are lighter and smaller than

their predecessors. This report contains the results of testing these apparatus. A breathing and metabolic simulator (BMS) at the USBM's Pittsburgh Research Center was used to test the apparatus because the BMS permits more quantifiable comparisons of breathing apparatus than human subject testing. The chosen work rate is equal to the average rate of a 50th-percentile miner performing the 60-min man-test 4, as described in 42 CFR 84, the same as in the previous USBM study. All of the apparatus tested are listed in table 1, with their rated durations, oxygen sources, weights, and approximate volumes.

Approval by NIOSH and MSHA implies acceptable design; the impact of the underground environment on apparatus is not a major focus. In order to determine how well an apparatus will survive underground, three of the apparatus were subjected to treatments of heat, cold, shock, and vibration. The apparatus omitted in the environmental impact study, the CSE SR-100, was studied previously (2) when it first became available. The first-generation SCSR's were also studied with regard to environmental impact (3-4).

Table 1.—Apparatus tested

Apparatus	O <sub>2</sub> source	Rated duration, min	Weight, kg		Volume in case, L
			In case	In use	
CSE SR-100 . . . . .	Chemical . . . . .	60	2.791	2.186	3.6
Draeger OXY K Plus ..	Chemical . . . . .	60	2.887	2.450	5.0
MSA Portal-Pack ....	Chemical . . . . .	60	3.047	2.075	4.5
Ocenco M-20 . . . . .	Compressed ..	10	1.465	0.9	2.2

## DESCRIPTION OF APPARATUS

The three 60-min-rated apparatus—the CSE SR-100, Draeger OXY K Plus, and Mine Safety Appliances (MSA) Portal-Pack—are marketed as direct replacements for their predecessors, the AU-9A1, OXY-SR 60B, and 60-min SCSR, respectively. The 10-min-rated Ocenco M-20, however, is intended to be used in conjunction with its predecessor, the 60-min-rated Ocenco EBA 6.5. It was designed to be worn on the belt, replacing a similarly sized FSR. The others are intended to be belt-worn as well, but there has been some resistance to this among users even though they are much smaller than their predecessors.

All of the apparatus tested are one of two types: chemical- or compressed-oxygen (table 1). The chemical-oxygen apparatus use potassium superoxide (KO<sub>2</sub>) as both their O<sub>2</sub> source and CO<sub>2</sub>-absorbent (Draeger), or a combination of KO<sub>2</sub> and lithium hydroxide (LiOH), a CO<sub>2</sub> absorbent (CSE and MSA). Adding

LiOH to the KO<sub>2</sub> results in less overproduction of O<sub>2</sub>, characteristic of KO<sub>2</sub>. The single compressed-oxygen apparatus (Ocenco) has a separate chemical bed of LiOH for CO<sub>2</sub> absorption.

The two types of apparatus share many components, such as a mouthpiece, chemical bed canister, breathing bag, and relief valve. The compressed-oxygen self-rescuer also contains a high-pressure storage cylinder, a regulator to reduce the pressure of the stored O<sub>2</sub>, a constant-flow valve, and a demand valve. All of the apparatus are pendulum-flow, the inhalation flow path being the reverse of the exhalation flow path, with no check valves. The three 60-min-rated apparatus all have volume-activated relief valves versus the pressure-activated relief valve on the Ocenco M-20.

Following are descriptions of each apparatus, accompanied by schematics, and photographs of the apparatus in and out of their protective cases.

<sup>2</sup>Italic numbers in parentheses refer to items in the list of references at the end of this report.

**CSE SR-100**

The SR-100 (figures 1 and 2) is a one-use-only, chemical-oxygen device with a chemical bed containing both  $KO_2$  and  $LiOH$ . A small cylinder of compressed  $O_2$  provides an initial supply (7 to 8 L) while the chemical bed starts up. It has a bi-directional flow path and a volume-activated relief valve. The relief valve purges high  $CO_2$  breathing circuit gas from the breathing hose before it has entered the chemical bed, thus sparing the bed to some extent. The 9-L breathing bag contains a loose chemical water absorbent (calcium chloride) used to further control the reaction of  $KO_2$  in the canister. The breathing hose contains a metal-mesh heat exchanger.



Figure 1.—Cased and uncased CSE SR-100 self-rescuer.

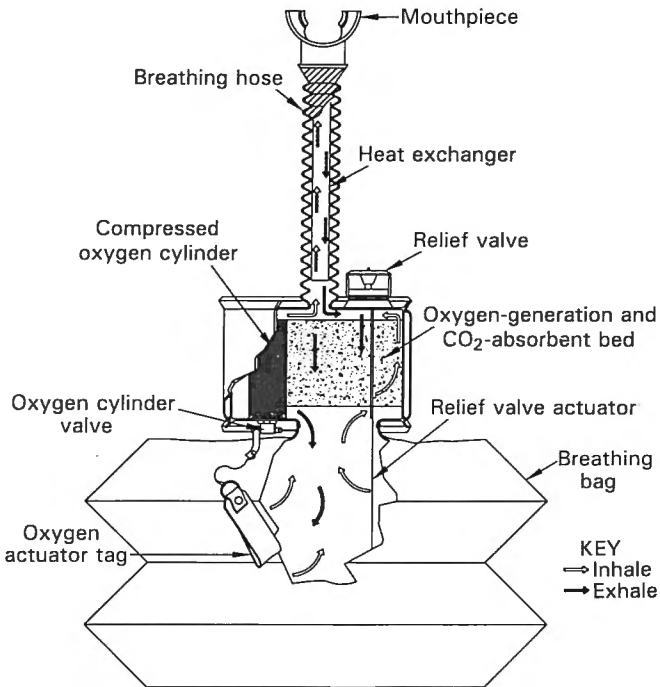


Figure 2.—Schematic of CSE SR-100 self-rescuer.

**DRAEGER OXY K PLUS**

The OXY K Plus (figures 3 and 4) is a one-use-only, chemical-oxygen device with a chemical bed of  $KO_2$ . A sodium chlorate candle provides startup  $O_2$ . The apparatus has a bi-directional flow path and a volume-activated relief valve. Like the SR-100, its relief valve also purges breathing circuit gas from the breathing hose before it has entered the chemical bed. The breathing bag contains approximately 6.5 L. A metal-mesh heat exchanger is contained in a hard-plastic housing to which the mouthpiece is attached.

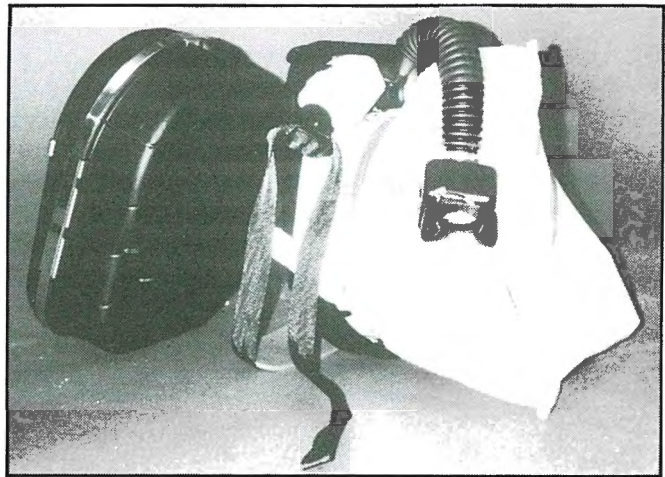


Figure 3.—Cased and uncased Draeger OXY K Plus self-rescuer.

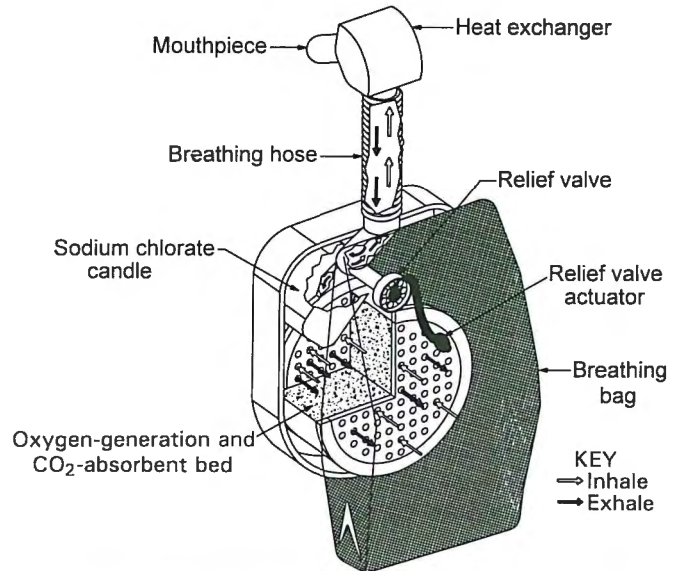


Figure 4.—Schematic of Draeger OXY K Plus self-rescuer.

### MSA PORTAL-PACK

The MSA Portal-Pack (figures 5 and 6) is a one-use-only, chemical-oxygen device with a chemical bed combining  $KO_2$  and  $LiOH$ . The startup  $O_2$  is provided by a sodium chlorate candle. It has a bidirectional flow path and a volume-activated relief valve that purges excess breathing circuit gas from the breathing bag of approximately 13 L. In an attempt to improve communication between users, there is a small device near the mouthpiece termed a "voice mitter," which transmits vibrations from inside to outside the breathing hose. The breathing hose contains a metal-mesh heat exchanger.

### OCENCO M-20

The Ocenco M-20 (figures 7 and 8) is a compressed-oxygen device with a  $LiOH$   $CO_2$ -absorbent canister. After use, it can be sent back to the manufacturer to be refurbished. It has a bidirectional flow path and a pressure-activated relief valve,

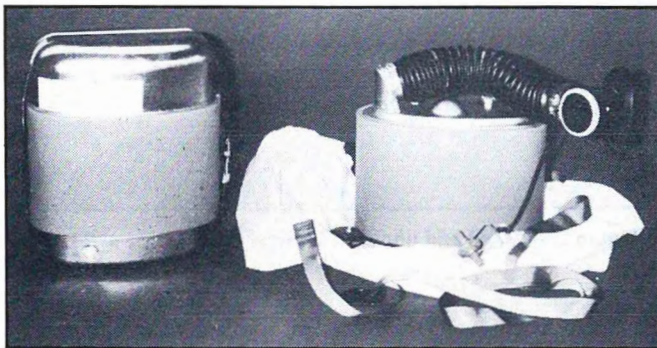


Figure 5.—Cased and uncased MSA Portal-Pack self-rescuer.

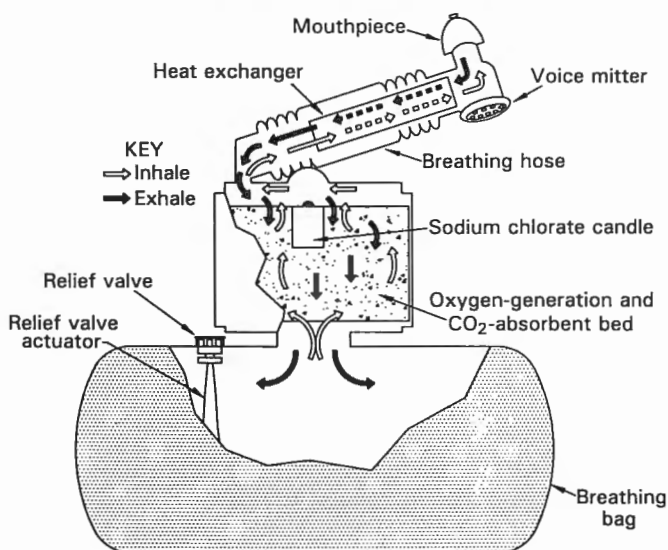


Figure 6.—Schematic of MSA Portal-Pack self-rescuer.



Figure 7.—Cased and uncased Ocenco M-20 self-rescuer.

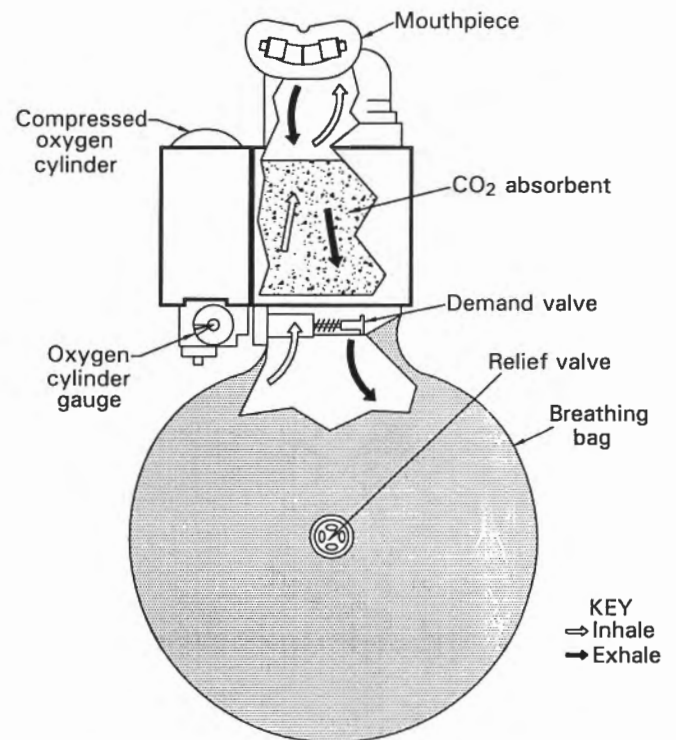


Figure 8.—Schematic of Ocenco M-20 self-rescuer.

releasing excess breathing circuit gas from the breathing bag, which holds approximately 5.5 L. The M-20 has no breathing hose; the mouthpiece connects directly to the body of the apparatus. The  $O_2$  cylinder contains approximately 25 L of  $O_2$  at standard temperature and pressure, dry (STPD). The  $O_2$ -delivery system consists of a constant flow of at least 1.5 L/min at ambient temperature and pressure, dry (ATPD) plus demand. The demand valve is volume-activated.

## TEST APPARATUS AND EXPERIMENTAL PROCEDURE

The BMS used for testing the apparatus in this study is shown in figure 9. The DEEC Inc. BMS is different from the Reimers manual BMS used in the first performance comparison of oxygen self-rescuers. The differences are described in a previous USBM report (5).

The metabolic parameters used in the performance comparison study follow (all volumes measured at STPD):

$\dot{V}O_2$ (O <sub>2</sub> consumption)	= 1.35 L/min
$\dot{V}CO_2$ (CO <sub>2</sub> production)	= 1.30 L/min
$\dot{V}_e$ (ventilation)	= 30 L/min
$V_t$ (tidal volume)	= 1.67 L/breath
RF (respiratory freq)	= 17.9 breaths/min
$\dot{Q}_{peak}$ (peak flow rate)	= 67 L/min (exhalation)
	= 83 L/min (inhalation).

In the environmental treatment study, the  $\dot{V}CO_2$  values for the Draeger OXY K Plus and the MSA Portal-Pack were 1.1 L/min STPD. At the time of the testing of these apparatus, this had been the USBM standard until it was found that some human test subjects had higher  $\dot{V}CO_2$  values. This had the effect on KO<sub>2</sub> apparatus of more quickly reacting the chemical bed, thus resulting in shorter durations. In order to be more conservative in BMS testing, the  $\dot{V}CO_2$  was elevated. The environmental treatments on the Ocenco M-20 were performed later than those on the MSA and Draeger, after the  $\dot{V}CO_2$  had been elevated. The two untreated tests for each apparatus had the same  $\dot{V}CO_2$  values as the treated unit.

The stressors monitored were average inhaled CO<sub>2</sub> and O<sub>2</sub>, minimum inhaled CO<sub>2</sub>, end-of-breath wet- and dry-bulb temperatures, and peak inhalation and exhalation breathing pressures. The average inhaled levels of gas concentrations take into account the effect of apparatus dead airspace, which is the volume in the breathing circuit components that contains exhaled gas, inhaled back upon inhalation without being cleansed of CO<sub>2</sub>. The minimum inhaled CO<sub>2</sub> is simply the lowest concentration of CO<sub>2</sub> measured during inhalation. If there were no dead airspace in an apparatus, the average and minimum inhaled gas concentrations of CO<sub>2</sub> would be identical. The larger the difference, the greater the dead airspace volume.

The wet-bulb temperature is a reflection of both temperature and humidity. The wet-bulb, not the dry-bulb, temperature is the one actually perceived by the wearer because the human respiratory tract functions essentially as a wet-bulb thermometer. It is measured by a fast-response, wet-bulb thermocouple developed by the USBM (6).

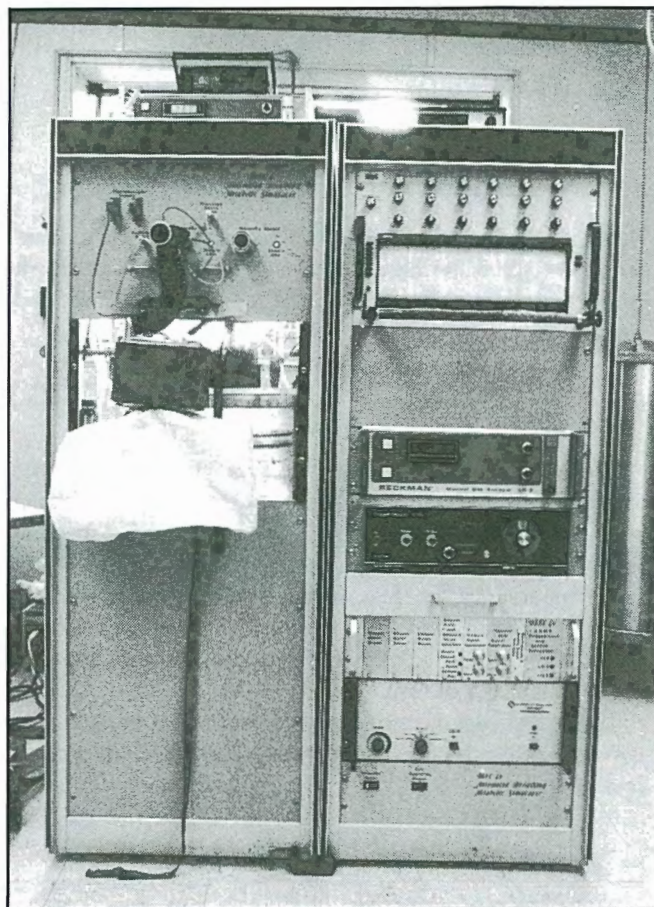


Figure 9.—Breathing and metabolic simulator at the USBM Pittsburgh Research Center, Bruceton, PA.

The test termination criterion was an expended O<sub>2</sub> source as determined by a flat bag and an inhalation pressure exceeding -200 mm H<sub>2</sub>O. Five units of each model were tested with the exception of the Ocenco M-20, of which only four were tested because of availability problems.

Breathing circuit tightness was determined by drawing a pressure of -70 mm H<sub>2</sub>O on the apparatus and measuring the decay time to a pressure of -60 mm H<sub>2</sub>O. This is a Draeger test, performed with the Draeger RZ-25 test stand designed for testing their BG-174 rescue breathing apparatus. A decay time of less than 1 min is considered a failure. The USBM has determined that a decay time of 1 min is equivalent to an in-leakage rate of 0.9 mL/min for a contained volume in both tester and apparatus of 1 L. This is considered by the USBM to be a very conservative test.

The environmental simulation treatments performed on the apparatus were temperature extremes (71 °C for 48 h (7) and -45 °C for 16 h) and shock and vibration. A shaker table of the type used in military standard vibration tests was used in the

vibration treatment with motion along the vertical axis only. The apparatus were vibrated loose as opposed to being strapped down. The test conditions were—

Frequency, Hz	Acceleration, g ( $\pm$ peak)
5- 92	2.5
92- 500	3.5
500-2,000	1.5

The shock treatment was a 1-m (belt-height) drop onto a concrete surface on each of the three axes. These treatments are described in more detail in a previous USBM report on the CSE SR-100

(2). In past such studies, each of the treatments was performed separately on multiple apparatus; additional apparatus were subjected to all of the treatments. In order to conserve resources in this study, one apparatus was subjected to all treatments and then tested on the BMS. If performance were compromised, additional apparatus would be subjected to separate environmental impacts to discover which treatment were responsible for the problem. If no performance degradation were found in the apparatus subjected to all of the treatments, we would assume that individual treatments would have caused no problem. The performance of the apparatus subjected to the environmental treatments was compared with that of two new, untreated units.

## RESULTS AND DISCUSSION

Table 2 shows the means of the average and peak values of monitored parameters for all of the apparatus tested. Four units were averaged for the Ocenco M-20; five units were averaged for the others. It should be noted that in the cases of CO<sub>2</sub> levels and temperatures, at least, levels usually start low and progressively increase throughout the test. The average levels in the tables camouflage the extremes of these stressors usually obtained at the ends of tests.

Table 3 shows the monitored parameters of one treated and two untreated units of each model in the simulated environmental impact study.

The efficiencies of the apparatus, in terms of usable O<sub>2</sub> per kilogram of weight and per liter of volume in their cases, are shown in table 4. Usable O<sub>2</sub> is used as a measure of capacity rather than duration because duration is entirely dependent on use rate. The use rate, in turn, is entirely dependent on the weight and activity of the user. The quantity of usable O<sub>2</sub> is much less variable with different use rates. Some apparatus are more affected than others. This will be a topic for a future report.

Table 2.—Means of average and peak values of monitored parameters (standard deviations in parentheses)

Apparatus	Duration, min	Usable O <sub>2</sub> , L	Inhaled CO <sub>2</sub> , %		Average inhaled O <sub>2</sub> , %	Temperature, °C		Pressure, mm H <sub>2</sub> O		
			Average	Minimum		Wet-bulb	Dry-bulb	Inhalation	Exhalation	
AVERAGES										
CSE SR-100 . . . . .	65 (1)	88 (1)	2.0 (0.1)	0.4 (0.2)	80 (7)	32 (0)	48 (1)	-73 (9)	53 (7)	
Draeger OXY K Plus	72 (6)	97 (8)	1.4 (0.2)	0 (0)	87 (1)	31 (2)	48 (2)	-45 (8)	38 (5)	
MSA Portal-Pack ..	71 (3)	96 (4)	3.3 (0.4)	0.9 (0.5)	83 (8)	29 (1)	45 (3)	-56 (3)	41 (3)	
Ocenco M-20 . . . . .	18 (1)	24 (1)	2.3 (0.2)	1.5 (0.2)	48 (5)	46 (0)	55 (1)	-60 (6)	38 (1)	
PEAKS										
CSE SR-100 . . . . .	NAp	NAp	4.2 (1.0)	2.1 (1.2)	89 (5)	45 (2)	60 (2)	-190 (61)	125 (40)	
Draeger OXY K Plus	NAp	NAp	1.9 (0.3)	0 (0)	95 (1)	45 (2)	57 (3)	-77 (24)	74 (62)	
MSA Portal-Pack ..	NAp	NAp	10.1 (4.0)	6.5 (4.6)	90 (5)	48 (2)	53 (4)	-63 (4)	44 (2)	
Ocenco M-20 . . . . .	NAp	NAp	6.2 (0.8)	4.1 (0.5)	50 (7)	51 (1)	66 (2)	-69 (17)	42 (1)	

Table 3.—Individual test averages of monitored parameters for environmentally treated versus new apparatus

Apparatus	Duration, min	Inhaled CO <sub>2</sub> , %		Average inhaled O <sub>2</sub> , %	Temperature, °C		Pressure, mm H <sub>2</sub> O	
		Average	Minimum		Wet-bulb	Dry-bulb	Inhalation	Exhalation
OXY K Plus, treated . . .	83	0.89	0	70	28.4	45.2	-51	44
OXY K Plus, new 1 . . . .	86	0.94	0	71	31.8	46.1	-50	37
OXY K Plus, new 2 . . . .	83	0.85	0	71	28.6	47.0	-49	44
Portal-Pack, treated . . .	70	1.53	0	71	25.8	41.4	-58	48
Portal-Pack, new 1 . . . .	76	1.93	0.46	71	23.3	42.6	-58	37
Portal-Pack, new 2 . . . .	73	1.34	0	81	25.5	43.9	-55	39
M-20, treated . . . . .	18	3.31	2.65	52	46.6	56.9	-59	45
M-20, new 1 . . . . .	18	2.46	1.78	47	45.9	55.1	-56	39
M-20, new 2 . . . . .	17	2.33	1.56	45	45.9	54.6	-68	38

**Table 4.—Self-rescuer efficiencies by weight and volume**

Apparatus	L of O <sub>2</sub> /kg of mass apparatus	L of O <sub>2</sub> /L of volume apparatus
CSE SR-100 . . . . .	32	24
Draeger OXY K Plus . . .	34	19
MSA Portal-Pack . . . . .	32	21
Ocenco M-20 . . . . .	16	11

The efficiency of the short-duration apparatus, the Ocenco M-20, was significantly lower than those of the others. This is because the weight and volume of the requisite components—breathing bag, mouthpiece, canister, case, etc.—comprise a larger fraction of the total weight and volume with decreasing quantities of O<sub>2</sub> supply and CO<sub>2</sub>-absorption capacity. To the extreme, an apparatus with no O<sub>2</sub> or CO<sub>2</sub>-absorbing chemical would still have weight and volume. The efficiencies of the three longer duration apparatus, with regard to both weight and volume, were all within 5% of each other; the Draeger OXY K Plus was slightly more efficient with regard to weight, and the CSE SR-100 was slightly more efficient with regard to volume.

Discussions of each model of SCSR follow.

### CSE SR-100

Four of five of the SR-100 units passed the Draeger RZ-25 leak test.

It can be seen from table 2 that the SR-100 had the highest peak pressures, which occurred at the test ends. During an actual test, the pressures begin low (in the range of 30 mm H<sub>2</sub>O), but increase continually, especially after approximately 50 min.

### DRAEGER OXY K PLUS

All five of the OXY K Plus units failed the RZ-25 leak test.

This was the only apparatus to have no CO<sub>2</sub> breakthrough at any time during the testing, i.e., minimum inhaled CO<sub>2</sub> was always zero. One test ended with very high exhalation pressures in the last several minutes, resulting in an average exhalation peak pressure with a relatively high standard deviation in table 2.

As table 3 indicates, the simulated environmental impact treatments appeared to have no effect on the monitored parameters.

### MSA PORTAL-PACK

All five of the Portal-Pack units passed the RZ-25 leak test.

The Portal-Pack had the highest average inhaled CO<sub>2</sub> levels. It also had the highest difference between the average and

minimum levels, reflective of the large dead airspace volume in its breathing hose.

As can be seen from table 3, the simulated environmental impact treatments appeared to have no significant effect on most performance measures, with the treated unit having only a slightly lower duration and somewhat higher exhalation pressure, although well within the physiologically acceptable range.

### OCENCO M-20

Three of the four M-20 units failed the RZ-25 leak test.

Having no breathing hose with large dead airspace, this unit had the smallest dead airspace volume, reflected in the small difference between average and minimum inhaled CO<sub>2</sub> levels. With a LiOH chemical bed, this unit had the most humid breathing gas, as reflected in the smallest difference between wet- and dry-bulb temperatures.

It can be seen in table 3 that there may be some slight effects of the environmental treatments on CO<sub>2</sub> that may or may not be noticed by a user. Otherwise, the apparatus was unaffected. However, it should be noted that the environmentally treated unit was a later modified version having impact-absorbing bumpers on the case top and bottom. The earlier version, without the bumpers, was treated a year before; this resulted in the unit's loss of most of its O<sub>2</sub> supply (with a resulting duration of 6 min), which was evident from reading the cylinder gauge. Additionally, the unit leaked LiOH from the bed through the filters into the breathing bag and mouthpiece, which was *not* evident upon inspection. It was believed that the vibration treatment was the likely cause of the LiOH leaking through the filters because dissection inspection revealed that the bed screens were intact. However, additional apparatus were vibrated without similar results. It was then theorized that because the original unit was vibrated while still hot from the heat test (71 °C for 48 h), the shock and vibration absorption components may have been compromised in their performance. The supply of new units, however, was expended before this theory could be tested. More apparatus were ordered from the manufacturer but were not received for more than a year, after the units had been modified with the addition of the bumpers.

A new unit was then subjected to all of the treatments and went directly from the oven to the vibration table. This unit is the treated one in table 3, showing somewhat higher CO<sub>2</sub> levels but no leakage of either O<sub>2</sub> or LiOH.

The manufacturer has stated that all field units of original design are to be retrofitted with case bumpers.

## CONCLUSIONS

As mentioned earlier, the CSE SR-100 and the Draeger OXY K Plus purge excess exhalation gas through their volume-activated relief valves before the high-CO<sub>2</sub> gas enters their chemical beds, thus sparing the chemical beds somewhat. These

two also had the lowest CO<sub>2</sub> levels, but this could be the result of more effective CO<sub>2</sub> absorption by the chemical beds.

The MSA Portal-Pack has the largest breathing bag volume, approximately 13 L, over 40% larger in volume than the next

largest. It also had the lowest average wet- and dry-bulb temperatures. The Ocenco M-20, with the smallest breathing bag and no breathing hose to exchange heat, had the highest average wet- and dry-bulb temperatures. Large breathing bags with large surface areas can disperse heat well if the environment is cool; if the ambient temperature is high, however, this heat-exchange mechanism may work in reverse. In addition, whereas large breathing bags enable the user to utilize more of the O<sub>2</sub> produced by the apparatus that would otherwise be purged in

apparatus with smaller breathing bags, they increase the chances for the occurrence of the hypoxia scenario: the user can experience hypoxic conditions if there is sufficient N<sub>2</sub> in the breathing circuit to permit volumetric gas exchange while O<sub>2</sub> levels fall below ambient. Compressed-O<sub>2</sub> apparatus are more susceptible to this phenomenon than pure-KO<sub>2</sub> apparatus which, through overproduction of O<sub>2</sub>, tend to purge the breathing circuit of N<sub>2</sub>.

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