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DETERMINATION OF CO2 AND O2 AT VARIOUS STAGES OF THE DIVES USING THREE DIFFERENT TYPES OF SELF CONTAINED BREATHING APPARATUS UNDER IDENTICAL CONDITIONS AND THE APPRAISAL OF THEM FROM A STANDPOINT OF COMFORT, BREATHING RESISTANCE, DURATION, VISIBILITY AND OTHER FACTORS PERTINENT TO THEIR PRACTICAL USE.

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OBJECT

The object of this experiment is to determine the CO_2 and O_2 at various stages of the dives of various self contained breathing apparatus under identical conditions and to appraise them from a standpoint of comfort, breathing resistance, duration, visibility and other factors pertinent to their practical use.

PROCEDURE

Three types of self contained breathing apparatus were used in these tests. They were the Lambertsen, Mine Safety Appliance and the Browne. They are fundamentally the same. Each consists of a breathing bag, an oxygen cylinder, a canister for the carbon dioxide absorbent, a relief valve, a weighed belt and a face mask. In all types a recirculating system is used whereby the oxygen is used repeatedly after passing through a carbon dioxide absorbent. The cycle is controlled by the inhalation and exhalation valves in the system. Oxygen is supplied by means of a needle valve from the oxygen cylinder.

Three types of carbon dioxide absorbent were used in these tests. They were soda lime, Cardoxide and Baralyme. The soda lime and the Cardoxide were of 4 to 8 mesh size. Cardoxide is made by the Mine Safety Appliance Company and has the appearance of soda lime. Baralyme is manufactured by the Thomas A. Edison Co., Medical Gas Division, Bloomfield, N. J. It consists of $Ba(OH)_2$ $(8H_2O)$ 20%, and $Ca(OH)_2$, 80%. The soda lime was manufactured by the Dewey and Almy Chemical Co., Cambridge, Mass. It was of a high moisture type and contained a violet indicator. Soda lime normally consists of NaOH 5%, $Ca(OH)_2$, 65%, and an inert binder, (silicates) 30%.

All controlled tests were of an identical nature. They were made in a deep sea diving tank. Runs were made at atmospheric and 20 foot depths, with different apparatus and different carbon dioxide absorbents. A summary of these runs is outlined on one of the data sheets.

A run consisted of using the bottle to exhaustion. Each subject used the outfit thirty minutes. Then another man would use it for another thirty minutes. This would continue until the oxygen supply was exhausted. This was accomplished in about 90 minutes. Each subject would spend the thirty minutes in the following manner: The first five minutes would be spent in rest. The next ten minutes would be spent working. The next five minutes would be spent in rest. The last ten minutes would be spent working. Rest consisted of sitting down. Work consisted of lifting a weight weighing 68.5 pounds (submerged) a distance of 27.25 inches, 5 times per minute. Samples of the gas on the inhalation side were taken immediately upon purging of the system by the first subject, at the end of the 30 minute run made by each subject and at exhaustion. They were taken by means of a Luer syringe and then injected into a mercury sampling tube.

Each oxygen bottle was filled to a pressure of 1800 psi. The water in the tank was kept at a temperature of 88 to 90 degrees F. All subjects wore swimming suits. A weighted belt of 15 to 20 pounds was worn to keep subject on the bottom of the tank. When the mask was donned, approximately 5 breaths were used to purge the system of nitrogen.

Each subject purged the outfit as it was donned. In addition to the controlled tests in the diving tank, approximately 50 actual swimming runs were made in a swimming pool by experienced swimmers and two underwater demolition personnel to test the general swimming characteristics of all outfits. Care was taken in these and in the tank tests, that the various types of apparatus were rotated so that a preferential inclination for a specific type would not be developed through continual use of one type.

Before controlled runs were made, the Jack Browne face mask was replaced by the MSA face mask because the boundary surfaces of the former cut so deeply into the subjects face that it was impossible to wear it for even 30 minutes without acute discomfort.

Peak or maximum inhalation and exhalation resistances were measured before and after 27 dives. These were made by a Mine Safety Appliance Respiratory Resistance Machine. This machine was operated at 15 cycles per minute with a volume of .075 cubic feet per stroke. This would give a simulated pulmonary ventilation of about 32 liters per minute. This is somewhat more than the approximate pulmonary ventilation during moderate work. Moderate exercise in this case is based on pedaling a bicycle at 20 miles per hour.

The horizontal and vertical angles of vision were measured by having a subject face a blank wall and measuring the maximum subtended angle.

The dead air space in the masks was measured by holding the mask horizontally and filling it with water. The subject would then hold his breath, and place his face in the mask, and displacing the water occupied by his face. The water left in the mask would be then measured. This was the dead air space in the mask. Three runs with each of the three subjects were made.

RESULTS AND DISCUSSION

Two controlled dives were made with each outfit and using the same CO_2 absorbent. This was not true of Baralyme at atmospheric depth because the supply of Baralyme was exhausted. However, the runs at 20 feet were completed and therefore are good comparative data.

It appears from the summary of the dives, that there is not a great deal of difference between the various absorbents with regard to effective CO_2 concentration. This would corroborate other tests made by manufacturers of anaesthetic equipment which indicated that there is practically no difference between Baralyme and soda lime as CO_2 absorbents. At the 20 foot depth, soda lime absorbent produced a slightly higher effective CO_2 concentration than Cardoxide or Baralyme. The maximum effective CO_2

with the use of the soda lime was 2.41%. This is not excessive, and it may be due to the individual differences of the diver. From past experience, the effective CO_2 evolved by a diver under controlled conditions change enormously from dive to dive even when made by the same person. For this reason, an average is not too reliable a criterion. At atmospheric depths, there is not too great a difference in the effectiveness of the absorbents, with the exception of the use of Cardoxide in the Browne outfit. The maximum CO_2 reading here was 4.9%. The average effective CO_2 at atmospheric depth was 0.517% with a high of 2.79%. The Browne runs on Cardoxide were ignored on this average because of the high CO_2. The average effective CO_2 at 20 feet was 0.928% with a high of 3.48%. It would appear as if the Baralyme is most consistent of the CO_2 absorbents, but the difference between it and the other absorbents is not enough to indicate a clear advantage. Moreover, as stated before, even under rigid test conditions with the same subjects, the vacillation of the effective carbon dioxide would cause questioning of any but the most clearly decisive results. All CO_2 absorbents were effective for the duration of the dive. The data indicates that the CO_2 at the end of dive is about what it was at other stages of the dive. There was no perceptible difference between the water absorbing qualities of the absorbents.

When the various types of equipment were compared under identical test conditions, it was found that there were no clear advantages of one over the other with regard to CO_2 concentration. Generally speaking, the MSA and the Lambertsen were the most consistent in results. The Browne outfit seemed to have greater CO_2 at atmospheric depths.

In the above evaluation of the absorbents, it was in the first case necessary to hold the outfits the same and change the absorbents. In the evaluation of the outfits, it was necessary to change the outfits and keep the absorbent the same. This is a valid manipulation, but the preponderant effect of the individual differences with regard to the CO_2 evolved effects both test conditions. Thus, even a large number of tests would not improve this situation to a great extent. In our tests, two dives made by different people under identical conditions were made, i.e. under the same depth and using the same absorbent.

All of our samples were taken from the inlet side of the breathing tube. This is the only place in the system where consistent samples could be expected. It is also the point of least CO_2. The diver undoubtedly inspires a mixture with greater carbon dioxide concentration because the dead space in the mask contains a portion of expired air. That last portion of the expired air contains the greatest CO_2 concentration and it is that air that is found in the dead air space of the mask.

The purging technique used in these tests is satisfactory. Five breaths were used to purge the system. After purging, the oxygen percentage at atmospheric depth ranged from 70 to 90%. At 20 feet it was 100 to 140%. These oxygen percentages remained fairly constant during all dives and at no time did the oxygen percentage drop below 47%. This is more than enough for an adequate breathing mixture.

It is rather unlikely that oxygen deficiency would ever be a problem if the outfit is properly purged. If one person used this outfit for 2 hours there would be some nitrogen elimination that would tend to decrease the oxygen percentage. A volume of about 600 cc of nitrogen is eliminated in a period of two hours from the tissues. However, it is felt that this would not be a problem under ordinary conditions, and the excess of CO_2 would be of greater concern. Should the diver forget to purge the system, it would be possible for him to become asphyxiated, normally, a swimmer opens the oxygen valve when he feels he is not getting enough breathing media. This automatically prevents anoxia. If there is an excess of nitrogen due to improper purging in addition to the nitrogen that is eliminated, his breathing bag may be full and given him a sense of adequate oxygen. Actually, the oxygen percentage in the bag may be at the danger point.

The breathing resistance of all of the outfits is approximately the same. In 27 measurements of inhalation and exhalation resistance before and after dives, the average maximum resistance in both inhalation and exhalation was 1.74 inches of water. The breathing resistance after the dive was slightly higher, that is, about 0.1 or 0.2 inches of water. This was probably due to the moisture in the system. The type of absorbent used had no perceptible effect on breathing resistance. It should be remembered that this is the peak inhalation resistance and not the average. There were no complaints of the divers concerning inhalation and exhalation, except in cases of water entrance due to leaks. All of the outfits were old and there was much difficulty with leaks. At least 50% of the runs had to be discontinued because of leakages of one type or another.

The duration of the oxygen flask was about 90 minutes for all outfits. This was true for atmospheric and 20 foot depths. This is an aggreement with physiological fact that a human being can only consume so much oxygen regardless of the depth. In actual practice there would be slightly greater consumption of oxygen at greater depths because of leaks and the volume in the mask is greater when converted to standard conditions. Also in our case, considerable oxygen was used in purging since each subject purged the outfit when he donned it. In most instances there were several hundred pounds of oxygen left in the bottle. However, for subjects engaged in moderate work, 90 minutes is the average endurance limit. Harder work, poor fitting masks, excessive purging, leaks and untrained personnel would reduce this somewhat. Nervous tension caused by operation in enemy waters would reduce this somewhat. Nervous tension caused by operation in enemy waters would have the same effect. All dives shown on the data sheets are of 90 minute duration unless indicated otherwise. At depths greater than 10 feet accompanied by hard or moderate work the duration of the dive would be determined by the possibility of oxygen poisoning rather than the capacity of the equipment. This subject is beyond the scope of this experiment. Cold water would increase this danger. It should be emphasized that most conditions are those of hard work and further tests under these conditions should be made for complete evaluation.

The dead air space in the MSA mask was found to be 587 cc. The dead air space in the Lambertsen mask was 426 cc. However, the total air space in the Lambertsen must include the breathing tubes since the inhalation and exhaust valves are located at the end of them. The two tubes had a volume of 360 cc. Therefore, the total dead space in the Lambertsen is 786 cc. This is 199 cc more than the MSA. Three readings on three subjects, all of which had different facial characteristics provided reasonably accurate readings. In the selection of the three subjects, one subject with a long angular face, the second with a round face and the last with an in-between face were used. It is felt that the dead air space in the Lambertsen is excessive and is caused to a great extent by the location of the inhalation and exhalation valves at the canister. The consequences of a large dead air space are a fast build-up and poor absorption of CO_2, the danger of this can not be over-emphasized, especially under conditions of hard work.

The Lambertsen unit breathing bag had a capacity of 5520 cc. The canister had a capacity of 1440 cc. The MSA breathing bag had a capacity of 9225 cc, the canister 1100 cc and each breathing tube 140 cc. The Jack Browne components had the following capacities; the breathing bag 9840 cc, the canister 1240 cc, each breathing tube 140 cc, and the exhalation tube inside of the bag leading to the canister 90 cc. From the above it is seen that the breathing bag of the Lambertsen unit is much smaller than that of the other units. This is reflected in the complaints of the divers with regard to this. Most of them complained that they were unable to get a full breath when desired. In order to learn to use the Lambertsen unit, a subject had to learn to breathe shallow and uniformly. This complaint was also voiced by the two underwater demolition swimmers who assisted in the tests. These subjects had long experience in the use of the Lambertsen unit. After hard work it is necessary to stop and rest in all the outfits, but it was more true in the case of the Lambertsen.

In all tests, the preference of the MSA mask over the Lambertsen was overwhelming. The MSA seated very easily on all subjects with very little strap pressure and it was possible to wear it for long periods without discomfort. It fitted all facial contours with little trouble. The Lambertsen mask was most uncomfortable in that it required excessive strap tightening to make it water tight. In some cases, it was most difficult to make it fit certain facial contours. However, the Lambertsen has two fine features. They are the shut-off valve and the air breathing valve. The latter permits breathing of outside air rather than oxygen when the mask is work topside. This conserves oxygen. The shut-off valve has two functions. It prevents the entrance of water into the respiratory system if the mask is removed under water and it enables the breathing bag to be inflated for use as an emergency flotation bladder. Both masks expel water satisfactorily. It is thought that the MSA could be improved by turning the valve 45 degrees down from the horizontal. Due to the poor seating of the Lambertsen mask, there was danger of its displacement when looking directly up.

Of the lenses fog. The effect was overcome by filling the hollow section partly with water so that it could be sloshed about to clear the surfaces. The other alternative is to fill the hollow section with dry gas and to strengthen the structure so that it will take a greater pressure. The present lenses collapse at about 40 feet. The type of absorbent had no perceptible effect on fogging.

All outfits required from one to five pounds added weight to keep them at satisfactory swimming buoyancy. One subject had a tendency to sink without any weights in the Lambertsen. This subject was in an unusually fine physical condition. In general, it was easier to keep neutral buoyancy in the MSA or Browne outfits. This was partially due to the larger breathing bag.

In general, the Lambertsen outfit is more rugged and will stand much more rough usage than the other two outfits. It is also quite comfortable. The MSA is quite comfortable except for the fact that it does not fit well and has a tendency to slide around. The Browne outfit is comfortable, but the bag has a tendency to float. It is not desirable for a breathing bag to be constructed like the Browne because the buoyant volume is not distributed over the entire chest. A change of swimming position is difficult. It is difficult to swim on the back or side. Both the Jack Browne and the Lambertsen are more accessible for repair, disassembly and leak detection. Due to heavy vest, the Lambertsen does not need a jock strap. This counteracts its otherwise less comfortable characteristics. A horizontal rather than a vertical position of the oxygen bottle is preferable from a stand point of gauge reading interference. It is felt that the horizontal MSA system for bottle attachment is preferable. The gauge is also much easier to read than the Lambertsen type. The valve handle is not in the way since the arms are not used in the normal swimming position.

All outfits can be donned by one man. The small neck opening in the Lambertsen makes it slightly more difficult to handle. The canister is easily filled on all types. A cartridge CO_2 absorbent would be preferable. This would provide uniform density of loading and ensure that a definite amount of absorbent was used at all times. It would also prevent channeling.

There were no casualties either in the swimming pool or in the tank. There were some cases of dizziness after hard work. There were also complaints in some instances about the odors in the mask. In some cases there was a little absorbent dust at the beginning of the dive. There were some cases of extreme moisture, but these were probably caused by leaks in the apparatus, since all the outfits were quite old and very much subject to leaks.

In the use of all types of outfits, hard work for a sustained period is not possible. The CO_2 soon builds up and can only be reduced by rest. A 2% increase in CO_2 causes the minute respiration rate to increase about 34%. 4% CO_2 causes about a 100% increase in minute respiration rate.

Obviously, as the velocity of the expired air increases through the absorbent, less CO_2 is absorbed. This in turn increases the CO_2 concentration which causes the subject to breathe harder. The only method to alleviate this situation is to rest. Oxygen poisoning is a function of CO_2, work, depth and time. A trained swimmer can become fairly adept at identifying incipient concentrations of CO_2 and reduce his activity. Oxygen poisoning sometimes does not have these preliminary symptoms.

The subjects used in these tests were the personnel of the Experimental Diving Unit, all of whom were first class divers with considerable experience. None of them had ever used any of the self contained breathing apparatus and thus had no preconceived ideas concerning any particular outfit. All of the tank dives were made by them. In the swimming tests at the swimming pool, they were joined by two underwater demolition personnel, who assisted greatly in helping the Unit men acquire swimming proficiency. Approximately 100 swimming runs were made with an average of about ten minutes each. No specific work was done in these tests. All swam and did what they chose. It was a swimming characteristic evaluation under ideal conditions.

Dives deeper than 20 feet were not made because a qualified doctor was not available. Cold water tests could not be made because of lack of protective suits.

CONCLUSIONS

There is no perceptible difference between the various types of absorbents. The Lambertsen and the MSA outfits were generally lower in effective CO_2 concentration than the Browne. The average effective CO_2 at atmospheric depth was 0.517% and at 20 feet it was 0.928%. This is not excessive. Heavy work would undoubtedly raise these percentages considerably. Most underwater swimming should be considered hard work.

The oxygen percentage at atmospheric depth ranged from 70 to 90% and 100 to 140% effective at 20 feet during all stages of the dives.

The purging technique used in these tests is satisfactory. This is evident from the oxygen percentages in the preceding paragraph. The effect of improper purging may result in asphyxiation.

The maximum breathing resistance of all of the outfits is approximately the same, about 1.74 inches of water.

The duration of the flask in all outfits is about 90 minutes at moderate work conditions.

The dead air space on the Lambertsen is excessive because of the valve location. It is 786 cc and that of the MSA is 587 cc. This is a significant difference.

The breathing bag on the Lambertsen unit is too small. Its capacity is 5520 cc, the MSA 9225 cc and that of the Browne 9840 cc.

The canister on the MSA is smaller than the ones on the Lambertsen or Browne.

The angle of vision of the two masks is approximately the same. For the Lambertsen the angle of vision was 95 degrees laterally and 43 degrees vertically. For the MSA the angle of vision was 85 degrees laterally and 46 degrees vertically. There was no distortion in either mask.

Both lenses fog but can be cleared by sloshing water on them.

Approximately 1 to 5 pounds of weights were required to overcome the buoyant effect of apparatus. It was easier to obtain neutral buoyancy with the Browne and the MSA outfit.

The MSA mask is superior to the Lambertsen in all respects. However, the Lambertsen mask has two features that are very desirable. They are the air breathing valve and the shut off valve.

The Lambertsen is easier to maintain and is more accessible for repairs and leaks. It is also more rugged and will stand rough use.

The bottle position is poor on the Lambertsen because it interferes with the mask and the gauge is difficult to read. It is suggested that the bottle be placed in a horizontal position as on the MSA unit.

The swimming characteristics on the Lambertsen and the MSA are superior to that of the Browne. The Lambertsen needs no jock strap and it is felt that this is advantageous. The fabric is rough and unyielding in the latter, but this is necessary to obtain ruggedness. As stated before, the limited size of the Lambertsen breathing bag prevents a full inspiration when needed most. The neck opening in the Lambertsen is too small.

All canisters fill easily. However, a cartridge type of absorbent is recommended.

The water expulsion valve works satisfactorily on both types. It is thought that one mounted 45 degrees from the horizontal would be best.

Some of the mechanical appurtenances of the Lambertsen required occasional oiling. This is considered dangerous unless special lubricants for oxygen are used.

RECOMMENDATIONS

The following specifications and characteristics are recommended for a satisfactory self contained breathing apparatus:

FACE MASK

To be made similar to the MSA, but retaining the shut off valve, air breathing valve and excess pressure valve, as on the Lambertsen. The breathing valves to be located at the mask to reduce dead air space.

The water expulsion valve to be located at an angle of 45 degrees from the horizontal if possible. All these metal components to be made of light metal, be salt water resistant and require no lubrication.

BREATHING BAG

To have a capacity of about 9000 cc and made of flexible but rugged material that is easily repaired. It should be of the distributed vest type as in the Lambertsen. It should be readily detachable for repair or change.

BOTTLE

To be of the same capacity as used in these outfits. To be located in a horizontal position with an easily read gauge. The charging hose to be rugged and pinch proof. The needle valve should operate easily. The Hoke valve is not too satisfactory.

VEST

The vest to be made of rugged fabric similar to the Lambertsen with accommodations for the oxygen bottle and canister. Lead plate pockets to be built into the vest.

CANISTER AND HOSE

To be made of durable material and easily filled and designed so that there is no channeling. To be located in the back below the neck. Capacity of canister to be approximately 1400 cc. A cartridge type of absorbent is recommended. Hose to be pinch and tear resistant, similar to Lambertsen type.

GENERAL

The outfit to be rugged and fungus resistant. Should be readily disassembled for repair and replacement. Should require minimum maintenance and no lubrication.

If the manufacture of the above is not feasible, it is recommended that the following changes be made to the Lambertsen to make it conform as nearly as possible to above specifications:

1. The breathing bag to be enlarged to about 9000 cc.

2. The mask to be replaced by one similar to the MSA and retaining the Lambertsen mechanical features. In addition, the inspiration and exhalation valves should be located at the mask to eliminate the dead space. The valves at the canister should be eliminated.

GENERAL (CONT)

3. The bottle to be placed in a horizontal position, or lowered approximately one inch.

4. The neck opening to be made larger.

It is recommended that future tests be made with the Lambertsen and the MSA units at 30 and 40 foot depths under conditions of these experiments.

SUMMARY OF DIVES WITH SELF CONTAINED BREATHING APPARATUS

Apparatus	No. of Dives	Effective Max.002	Effective Min.002	Effective Average CO2
DEPTH: ATMOSPHERIC		ABSORBENT:	SODA LIME	DATA SHEET NO. 1
LAMBERTSON	2	.701	.059	.066
MSA	2	.590	.303	.475
BROWNE	2	2.24	1.00	1.55
DEPTH: ATMOSPHERIC		ABSORBENT:	BARALYME	DATA SHEET NO. 2
MSA	2	.108	.017	.063
BROWNE	2	1.40	.852	1.20
DEPTH: ATMOSPHERIC		ABSORBENT:	CARDOXIDE	DATA SHEET NO. 3
LAMBERTSON	2	.170	.060	.115
MSA	2	.166	.092	.139
BROWNE	2	4.9	1.80	3.54
DEPTH 20 FEET		ABSORBENT:	SODA LIME	DATA SHEET NO. 4
LAMBERTSON	2	2.41	1.12	1.80
MSA	2	1.66	1.09	1.72
BROWNE	2	2.28	1.16	1.23
DEPTH 20 FEET		ABSORBEBT:	BARALYME	DATA SHEET NO. 5
LAMBERTSON	2	.475	.231	.319
MSA	2	1.46	.669	.985
BROWNE	2	.510	.121	.269
DEPTH 20 FEET		ABSORBENT:	CARDOXIDE	DATA SHEET NO. 4
LAMBERTSON	2	.710	.282	.527
MSA	2	.873	.707	.790
BROWNE	2	.980	.530	.700

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT ATMOSPHERIC DEPTH AND USING SODA LIME AS THE CO_2 ABSORBENT

APPARATUS: LAMBERTSON

Run	After Purging		After 30 min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	
1	.036	77.39	.056	76.37	.062	75.26	.033	47.57	.033	47.51	
2	.110	89.75	.085	84.62	.073	76.42	.086	51.80	.086	51.80	
Average	.073	84.6	.071	80.5	.068	75.8	.059	49.7	.060	49.7	

APPARATUS: MSA

1	.232	70.1	.581	73.2	.908	79.5	.977	72.2	.977	72.2	Soda Lime Slightly Purple after run
2	.058	83.6	.024	70.3	.272	75.4	.089	67.3	.089	67.3	
Average	.145	76.9	.303	71.8	.590	77.5	.533	69.9	.533	69.9	

APPARATUS: BROWNE WITH MSA MASK

1	.210	75.3	.738	84.6	1.69	89.7	.169	85.6	.169	85.6	87 Min. run. Faster breathing rate
2	.116	88.6	1.27	79.2	2.79	82.4	2.65	81.3	2.65	81.3	Hard breathing in all subjects
Average	.163	81.9	1.00	81.9	2.24	86.1	1.41	83.5	1.41	83.5	

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT ATMOSPHERIC DEPTH AND USING BARALYME AS THE CO_2 ABSORBENT

APPARATUS: MSA

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	
1	.056	70.5	.017	54.2	Sample	Lost	.108	66.4	.108	66.4	

APPARATUS: BROWNE WITH MSA MASK

1	.043	89.7	.010	65.0	.044	79.4	.182	71.5	.072	85.7	One moderate headache 120 Minute run
2	.057	89.7	2.38	81.7	1.66	84.5	2.62	77.4	2.62	77.4	
Average	.050	89.7	1.20	73.4	.852	81.9	1.40	74.5	1.35	81.5	

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT <u>ATMOSPHERIC DEPTH</u> AND USING <u>CARDOXIDE</u> AS THE CO_2 ABSORBENT

APPARATUS: LAMBERTSON

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	
1	.674	80.5	.118	70.4	.161	75.3	.215	79.5	.215	79.5	
2	.280	75.4	.200	82.6	.022	71.4	.116	77.5	.116	77.5	
Average	.477	78.5	.159	76.5	.092	73.4	.166	78.5	.166	78.5	

APPARATUS: MSA

1	.107	73.4	.061	86.7	.334	66.2	.112	87.7	.112	87.7	
2	.111	73.5	.059	72.5	.006	79.6	.118	77.6	.118	77.6	
Average	.109	73.5	.060	79.6	.170	72.9	.115	82.7	.115	82.7	

APPARATUS: BROWNE WITH MSA MASK

1	.746	81.6	2.77	67.1	4.64	63.0	7.18	82.5	7.18	82.5	1 Breathing difficulty & dizziness. 72 Min. Dive
2	.380	76.4	.027	78.6	3.39	82.5	2.40	83.6	2.40	83.6	74 Min. Dive
Average	.563	79.0	1.80	72.9	4.02	4.02	4.79	83.1	4.79	83.1	

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT A DEPTH OF 20 FEET AND USING SODA LIME AS THE CO_2 ABSORBENT.

APPARATUS: LAMBERTSON

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	
1	3.74	126	.465	137	.558	124	3.48	143	3.48	143	One case of malaise. Bad odor
2	4.42	128	3.72	147	1.68	141	1.34	144	1.34	144	
Average	4.08	127	2.10	142	1.12	133	2.41	144	2.41	144	

APPARATUS: MSA

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
1	.087	128	.035	116	.568	121	.90	101	.90	101	
2	.076	119	2.14	136	2.25	124	2.41	141	2.41	141	Reading at 18,48 and 64 Min Headaches and bad odor
Average	.082	123	1.09	126	1.41	123	1.66	121	1.66	121	

APPARATUS: BROWN WITH MSA MASK

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
1	.452	111	3.22	144	1.27	139			1.27	139	60 Min run. Hard Breathing
2	.620	112	1.33	131	1.05	149	1.25	127	1.25	127	O2 poisoning Symptom. Bad odor
Average	.54	112	2.28	138	1.16	144			1.26	133	

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT A DEPTH OF 20 FEET AND USING BARALYME AS THE CO_2 ABSORBENT.

APPARATUS: LAMBERTSON

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	
1	.018	122	.170	110	.350	82.2	.369	76.7	.390	90.3	120 Min run. Could not get full breath.
2	.422	85.5	.356	114	.600	99	.093	102	.226	97.2	Could not get full breath. 120 Min run.
Average	.200	104	.263	112	.475	90.6	.231	89.4	.308	93.8	

APPARATUS: MSA

Run	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	Remarks
1	.119	92	.825	112	1.26	113	1.61	87.4	2.38	127	Two divers dizzy 105 Min run.
2	.054	75.8	.513	134	.218	122	.538	135	.538	135	
Average	.087	84	.669	123	.739	118	1.07	111	1.46	131	

APPARATUS: BROWN WITH MSA MASK

Run	CO2	O2	CO2	O2	CO2	O2	CO2	O2	CO2	O2	Remarks
1	0	139	.053	118	.106	117	.112	126	.204	136	118 Min run. Hard breathing in late stages of dive.
2	.140	130	.212	111	.135	121	.509	91.[illegible]	.809	71.8	105 Min run. Water found in bag.
Average	.070	135	.133	115	.121	119	.311	109	.510	104	

COMPARISON OF EFFECTIVE CO_2 AND O_2 EVOLVED BY VARIOUS TYPES OF SELF CONTAINED BREATHING EQUIPMENT UNDER IDENTICAL CONDITIONS AT A DEPTH OF 20 FEET AND USING CARDOXIDE AS THE CO_2 ABSORBENT.

APPARATUS: LAMBERTSON

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	
1	.048	139	.170	134	.164	91.2	.035	103	.035	103	
2	.100	124	.394	121	1.02	127	1.38	131	1.38	131	One man had headache. Bad odor.
Average	.074	132	.282	128	.59	109	.710	117	.710	117	

APPARATUS: MSA

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	
1	0	154	.883	115	.847	105	1.02	105	1.02	105	
2	.456	106	.862	128	.567	136					90 Minute Sample broken.
Average	.228	130	.873	122	.707	121					

APPARATUS: BROWN WITH MSA MASK

Run	After Purging		After 30 Min.		After 60 Min.		After 90 Min.		At Exhaustion		Remarks
No.	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	
1	.136	146	.035	122	.037	124	.136	141	.136	141	83.5 Min dive. One headache.
2	1.34	124	1.91	136	1.01	136	1.03	140	1.03	140	Hard breathing.
Average	.740	135	.98	129	.530	130	.590	141	.590	141	