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FINAL REPORT ON THE PROJECT TO VERIFY IF CO_2 IS LIKELY TO CONCENTRATE IN THE LOWER REGION OF A DIVING BELL

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FINAL REPORT ON THE PROJECT TO VERIFY IF CO_2 IS LIKELY TO CONCENTRATE IN THE LOWER REGION OF A DIVING BELL.

(PROJECT OT/F/777)

17th OCTOBER, 1983

C M CHILDS

R H M DINGWALL

S E WILCOCK

FOREWORD

This report is published by the Health and Safety Executive as part of a programme of work which was commissioned in support of the Offshore Safety Division's (OSD) diving research strategy. The full programme of work covers the period from the late 1970's to 1997; some reports from the programme have hitherto not been published.

Some research was sponsored by the Department of Energy prior to the transfer of their responsibilities for offshore safety to the Health and Safety Executive. Other studies were originally commissioned by OSD for internal use. It has now been decided to issue the reports relating to this work so that the information they contain is in the public domain.

In view of the extended period of the research programme, some reports may contain information or recommendations which have been superseded. The structure of others may not meet the standard now expected of an Offshore Technology series report. Nevertheless it is HSE's intention that all such documents should be in the public domain.

INTRODUCTION

As presented in the Introduction of project proposal (OT/F/777) carbon dioxide, produced as a by-product of metabolism can cause severe metabolic disturbances. These include sustained increased levels of minute ventilation and eventually unconsciousness if this excess carbon dioxide is not eliminated by the normal mechanisms.

Carbon dioxide gas is an ever present danger in the hyperbaric environment and it has been postulated (Childs, 1977; Astrup, 1957) that because CO_2 is more dense than helium and oxygen, it could separate from the constituent gases in the bell forming a blanket of gas with a high pCO_2 over the bell trunking. Thus divers re-entering the bell after an excursion would be subjected to a high partial pressure of CO_2. Indeed, divers have reported experiencing "foul" gas on re-entry to the bell.

These experiments were designed to test the hypothesis that CO_2 may partition from less dense gas in the simplest of environments. Gas samples were withdrawn from the top and bottom of gas cylinders containing heliox and CO_2 at low ambient temperatures. Apart from sampling, the cylinders were left undisturbed. If no layering occurred in this situation then it would be even more unlikely to occur <u>in situ</u> inside the bell when gas mixing would occur by diver movement and the action of CO_2 scrubbers.

PROCEDURE

Two standard (size K) gas cylinders were obtained and stripped of all fittings. Attached to each gas cylinder was a SS-22 RS4 micro-metering valve (orifice diameter 0.020") capable of extremely fine flow rates (effective flow coefficient better than 0.0005).

This type of valve was chosen to minimise disturbance when gas samples were withdrawn. A $\frac{1}{8}$" port connector, fitted to each Swagelok end-connection as the micro-metering valve allowed the attachment of a 1 litre Douglas bag for gas collection. All connecting threads were Teflon taped to ensure a good seal was made. The cylinders were filled with 92.6% He 3% O_2 and 4.4% CO_2 gas mixture and allowed to stand for four days prior to being re-checked for any leaks.

The cylinders were then vented and refilled with the correct gas mixture to 16 ATA pressure over a ten minute filling period. This rate of filling ensured complete mixing of the constituent gases prior to experimentation.

The gas cylinders were then transported to a cold chamber constantly maintained at 5^{o} C $\pm$ 1^{o} C. Once installed, they were left undisturbed for a period of three weeks, apart from sampling periods. After a temperature equilibration period of 12 hours the control samples were taken and analysed. Subsequently gas sampling took place weekly. Gas samples (200 - 300 mls) were withdrawn over a period of 15 minutes and immediately analysed. This slow withdrawal rate ensured minimal mixing.

During the experiment two gas cylinders were used, one standing upright and one, by attaching a specially made bridle was able to stand upside down. Thus samples, then, were effectively taken from the top of one column and the bottom of another column of gas. At the end of the three weeks the cylinders were again tested for any leaks during the experimental period.

Gas analysis. (i) Lloyd-Haldane (Lloyd, 1958). This technique is based upon the absorption of CO_2 by KOH. (ii) Infra-red (IR) CO_2 analysis Measurements were made at the standard flow rate of 0.5 litres/min in the prescribed manner. The analyser was calibrated at the beginning of each analysis with a gas mixture of known CO_2 fractional concentration.

RESULTS AND DISCUSSION

Gas samples taken from the cold chamber were analysed immediately by the two techniques described above. The results for each technique are shown in Table 1:-

RESULTS

UPRIGHT CYLINDER

Haldane (%CO_2)	*Infra-red (%CO_2)*	*Haldane (%CO_2)*	*Infra-red (%CO_2)*
4.38%	*4.46%*	*4.46%*	*4.48%*
4.41% x = 4.40%		*4.43% x = 4.44%*	
4.41%		*4.44%*	
↓ *7 days*	↓ *7 days*	↓ *7 days*	↓ *7 days*
4.44%	*4.40%*	*4.41%*	*4.48%*
4.43% x = 4.43%		*4.41% x = 4.41%*	
4.43%		*4.43%*	
↓ *7 days*	↓ *7 days*	↓ *7 days*	↓ *7 days*
4.37%	*4.37%*	*4.31%*	*4.42%*
4.34% x = 4.35%		*4.28% x = 4.29%*	
4.34%		*4.29%*	
↓ *7 days*		↓ *7 days*	
4.18%		*4.25%*	
4.18% x = 4.19%		*4.28% x = 4.26%*	
4.20%		*4.24%*	

DISCUSSION

The hypothesis under test would suggest that the fractional concentration of CO_2 will increase at the bottom of a vertical gas column as stratification occurs and it will decrease at the top of the column (Childs, 1977; Astrup, 1957). A similar experiment was performed by Hill (Hill 1961) using 4.5% CO_2 in compressed air (1900psi). Over a period of several weeks he found no evidence of CO_2 stratification.. In these experiments, however, CO_2 had a greater density relative to helium, perhaps increasing the tendency for gas settling.

In the experiment described a control value of 4.40% CO_2 for the upright cylinder was obtained; this fell to 4.19% CO_2 after 3 weeks using the Lloyd-Haldane technique - a reduction of 0.210% CO_2 $\pm$ 0.015% CO_2. Results using infra-red (IR) gas analysis showed a smaller fall of 0.9% CO_2. In the inverted cylinder, Lloyd-Haldane analysis showed a change in the CO_2 concentration from 4.44% CO_2 to 4.26% CO_2 - a drop of 0.18% CO_2 $\pm$ 0.02% CO_2 over the same time. IR analysis showed a smaller drop of 0.06% CO_2 from 4.48% CO_2 to 4.42% CO_2. It could be postulated, therefore, that a certain amount of layering occurred in the upright cylinder over 3 weeks, although the results for the inverted gas cylinder are more difficult to explain.

CONCLUSION

It is reasonable to conclude from these experiments that no convincing evidence of stratification was found in either cylinder using two techniques of gas analysis. Furthermore these results were obtained where optimum conditions were present to facilitate stratification. In situ this would certainly not be the case.

Finally these results imply that it requires at least one week, under optimum conditions, for any evidence of CO_2 layering to be found. Such conditions would certainly not be found during routine diving, further strengthening the argument against CO_2 layering in diving bells.

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