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INTRODUCTION

To assure the quality of breathing air used in diving, and in industrial life support systems, specifications are set to limit the maximum concentration of contaminants which the air may safely contain. Special attention is given to the quality of the air to be compressed, the operation of the compressor and its filtration system. Of equal importance is the remaining portion of the total life support system. In this particular investigation the air hose utilized to deliver the air to the diver downstream of the compressed air source was examined to ensure the integrity of the total system.

A number of samples of diver's air hose were assessed by analysing the quality of air passed through them. This was carried out at normal room temperature and at an elevated temperature to simulate the conditions which may be encountered on the deck of a ship.

The analysis of the air was subsequently carried out by infrared spectrophotometry.

METHODS

Sampling

Preliminary data was obtained from different samples of short lengths of air hose. These hoses were assayed by passing N_2 directly through them into the gas cell of the I.R. Spectrophotometer, purging the cell for 2 minutes, then pressurizing the cell to 140 psi. In instances where the hose was analysed following exposure to an elevated temperature, it had been immersed in hot water maintained at 80°C for the time specified (5 min and 1 hr), or exposed to direct sunlight on a dark surface.

Long lengths of hose (410' to 426') were analysed under four different operational type conditions. These were as follows:

(1) The hose was at room temperature and the sample bottle pressurized directly from a high pressure air source passed through the hose without prior purging.

(2) The hose was at room temperature and the sample bottle pressurized directly from a high pressure air source passed through the hose. The sample was taken after five minutes of air purging.

(3) The hose was exposed to direct sunlight on a concrete surface for one hour then the sample bottle was pressurized as in condition (1), without prior purging.

(4) The hose was exposed to direct sunlight on a concrete surface for one hour, then the sample bottle was pressurized as in condition (2), 5 to 8 minute air purge.

All samples were collected in a purged and evacuated D2 cylinder. The sample bottle was pressurized to 400 psi. The temperatures reported were taken from a thermometer placed 1/2" above the hose at the time of sample collection. The samples collected in the D2 cylinders were analysed by connection to the I.R. gas cell. The cell was pressurized to 140 psi following a 2 minute cell purge.

A control analysis was conducted on the air utilized from the high pressure source. The analysis indicated it to be free of contaminants and containing no toluene.

I.R. Analysis

All analyses were conducted on a Beckman IR-4 spectrophotometer. Samples were introduced into a 10 meter gas analytical cell with the initial scans carried out between 1 to 15 micro meters. Operating parameters were as follows:

Scale Selection	- 0 -100% T
Gain: Fine	-2.0
Coarse	-10.0
Operational Selection	-Double beam
Slit control	-3X
Period	-2 seconds
Scan Speed	-0.5 micro meters/min
Cell Volume	-3765 cc
Sample Pressure	-140 psia
Reference	-Air
Windows	-NaCl

Toluene was quantitated using the base line method. A major absorption band at 13.7 micro meters was utilized. A standard curve for toluene was established and utilized for subsequent quantitation. Toluene I.R. absorption follows Beer's Law in that a close fit regression line was established with concentration vs log absorbance.

Analysis of this regression line gave the following straight line fit:

Source of Variance	S.S.	D.F.	M.S.	F
Regression	0.05764	1	0.05764	97.7
Error	0.007639	13	0.00059	
TOTAL	0.05	14		

Regression coeff. 0.000403 ± 0.000088 (95% confidence limits).

The estimated error in the method of quantitative analysis used was:

About regression line	10.9%
Dilution	1.0%
Standard	1.0%
TOTAL	12.9%

RESULTS

The results from the analysis of pure nitrogen or pure dry air after passing through the hose being assessed, appear in the following tables:

TABLE I

Analysis of pure nitrogen after passing through three separate samples of Gates hose

DATE	HOSE	LENGTH	TEMPERATURE	ANALYSIS
7-11-74	Gates SAE 100R 3 3/8 Made in Canada ACK283-3	4'	Ambient	Nil Contaminants detected
9-1-75	Gates SAE 100R3EB 3/8 Lot 6C3 Supplier: U.S. Divers Assembly - Argosy Sports, Toronto	30'	Ambient	Toluene 8 ppm. No other contaminants detected
10-3-75	Gates SAE 100R3 3/8	4'	Ambient	Nil Contaminants detected
			$80^{o}C$ for one hr	Toluene 22 ppm. No other contaminants detected

TABLE II

Analysis of pure nitrogen after passing through four different 10' lengths of Gates hose - SAE 100 R3 3/8 A CKC03125G Canadian manufacture

HOSE	HOSE TEMPERATURE AT TIME OF TESTING	CONDITION	TOLUENE DETECTED
1	Ambient	N_2 2-min purge	320 ppm
	80°C for 5 min	N_2 2-min purge	670 ppm
2	Ambient	Hose flushed with warm water for 8 hrs, air dried. N_2 2-min purge	48 ppm
	Ambient	Same hose after 5 days at room temp. N_2 2-min purge.	32 ppm
	Ambient	Same hose after 8 days at room temp. N_2 2-min purge.	29 ppm
3	Ambient	N_2 2-min purge	54 ppm
4	Ambient	N_2 2-min purge	58 ppm

TABLE III

TOLUENE DETECTED FROM DIVER'S HOSE (PPM)
GATES SAE 100R3 3/8ACKC03125G
CANADIAN MANUFACTURE

	INDOORS				1 HR EXPOSURE TO SUN			
LENGTH FT	NO PURGE	T°C	5 MIN PURGE	T°C	NO PURGE	T°C	5-8 MIN PURGE	T°C
426	1140	22	225	22	1590	34	280	34
409	920	23	190	23	1270	34	200	34
410	1550	23	650	23	1870	44	360	44
410	990	23	200	23	1720	45	330	45
433	360	24	180	24	1640	49	290	49
409	1970	24	200	24	1340	37	270	37

TABLE IV

Analysis of pure dry air after passing through two different lengths of Gates Hose G06125 6C3 3/8 SAE 100R3ER

HOSE	HOSE LENGTH	HOSE TEMPERATURE AT TIME OF TESTING	CONDITIONS	TOLUENE DETECTED
1	30'	37.6°C	No pre-treatment. Hose heated in the sun for 1 hour	10 ppm
2	400'	32.3°C	Hose flushed with hot water for 2 hours, air dried, then heated in the sun for 1 hour and tested	60 ppm

DISCUSSION

Toxicity of Toluene

The toxic effects produced by toluene have been extensively investigated over the last 50 years. The presently accepted acute effects attributed to toluene inhalation (4, 6, 7) are as follows:

CONCENTRATION PPM	DURATION OF EXPOSURE	TOXIC SYMPTOMS
600	3 hrs	Extreme fatigue, mental confusion, exhilaration, nausea, headache, dizziness
200-500	8 hrs	Headache, nausea, loss of appetite, bad taste, lassitude, impairment of reaction time and coordination
300	8 hrs	Fatigue, weakness, confusion, paresthesia of the skin
200	8 hrs	Mild symptoms as above
100	8 hrs	Current ACGIH (7) threshold limiting value (TLV) for industrial exposure

The standards utilized for the quality of compressed air in Canada do not specify a separate limit for toluene, thus the ACGIH figure of 100 ppm is utilized (7). With respect to diving air quality, the Canadian Forces are guided by the Canadian Forces Technical Order: "Purity of Compressed Breathing Air and Gases for Divers" (1). This standard specifies the acceptable concentrations for contaminants, as they relate to diving. For the non-specified contaminants, the standard states that "allowable contaminant levels shall be 1/10 the threshold limit values documented by ACGIH". Testing for these other contaminants will be limited to "those instances where their presence is suspected". In addition, the standard states that the gas shall be "free of any detectable odors". With respect to the particular contaminant of significance found in this investigation (toluene) the limit is therefore 10 ppm. This is based upon one tenth of ACGIH Threshold Limit Value.

Toluene is a common compound utilized in the manufacture of fiber braid reinforced polymer hose. The particular hose in question was constructed of an acrylonitrile polymer tube, rayon braid reinforcement and a chloroprene polymer cover. A cement made of chloroprene dissolved in toluene was utilized to bond the fiber braid to the tube (2). As toluene was found as the major contaminant arising from the hoses examined, it was assumed that it occurred as a result of off-gassing of residual toluene which had been utilized in manufacturing.

The degree of off-gassing of toluene from the hose samples tested was found to vary between the different manufactured lots and to be affected by the temperature of the hose (Table III and IV). The effect of temperature is very significant when one considers that the hose may readily be exposed to the direct rays of the sun while on a hot steel deck during a diving operation. With respect to manufactured lots of hose, the lengths analysed and reported in Table III from Gates SAE 100R 3 3/8 ACK C031256, Canadian manufacturer, were found to be unacceptable for diver's air delivery. The lot assessed and reported in Table IV, G06125 6C3 3/8 SAE 100R3ER proved to be much more suitable. It is to be noted that the level of toluene measured in the air delivery from this latter lot of hose (Table IV), was in excess of the limit for non-specified contaminants allowed in (1), i.e. levels of toluene greater than 1/10th TLV were obtained when the hose was heated (32.2^{0}C). As this was a new lot of hose it is the opinion of the authors that this level would decrease over time, Table II. The level only exceeded the 1/10th TLV limit when the hose was tested when hot (Table IV).

This study emphasises the necessity of testing all aspects of the total life support system utilized to deliver pure air to the operational diver. With respect to the hoses in question, the gross variability in the quality of air delivered by the different manufactured lots of hose tested suggests that each new item should be tested prior to use and that the standards employed for the purity of diving air be applied to quality of air delivered through the total system utilized, with testing for air quality carried out at the farthest downstream delivery point of the system.

RECOMMENDATIONS

(1) Assessment of the quality of air used for diving purposes should be made on the final outlet of the system to give a true indication of the air as presented to the diver.

(2) Air hose tendered for purchase by the Canadian Forces for use in delivery of breathing air should be tested under realistic conditions of actual use prior to acceptance. The hose must deliver to the diver, air which meets the specifications of CFTO C-87-003-000/SG-001.

(3) Air hose used in any life support system must not release toxic substances into the air under operational conditions.

(4) As a standard operation procedure, all air lines should be flushed with pure air from the air bank or compressor prior to connecting to the diver.

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