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THE SOLUBILITY OF OXYGEN IN AQUEOUS FLUOROCARBON EMULSIONS

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SUMMARY

The solubility of oxygen in aqueous fluorocarbon emulsions has been measured directly for several perfluorocarbons and monobromo or monoiodoperfluorocarbons. The measured oxygen solubilities are consistent with results for the solubility of oxygen in neat liquid perfluorinated organic compounds.

INTRODUCTION

The experimental use of aqueous emulsions of perfluorinated compounds as oxygen carriers has been reviewed extensively [1,2]. An extensive study of the solubility of oxygen in neat perfluorocarbon liquids was reported recently. Since perfluorocarbon compounds are not used directly in artificial blood but rather as emulsions in water, it was considered important to measure the oxygen-carrying capacity of selected perfluorocarbon compounds in emulsions. The objective was to determine if the solubility of oxygen in aqueous fluorocarbon emulsions correlated directly with the oxygen solubility in neat perfluorocarbon compounds. This paper reports such a correlation.

RESULTS AND DISCUSSION

Emulsions of fluorocarbons in water were prepared by sonification of 1.5 g of fluorocarbon in 5.0% Pluronic-F68 solution made up to a final volume of 10.0 ml. Emulsions were degassed for 20 minutes with 97% N_2/3% CO_2 and the oxygen content measured. The emulsions were then oxygenated for 20 minutes with room air and the oxygen content measured. Finally the emulsions were oxygenated with 97% O_2/3% CO_2 and a final measure of oxygen content made. All oxygen measurements were made with a LEX-O_2-CON instrument manufactured by Lexington Instruments Corp. and are for a temperature of 37°C. At least three measurements were made and standard deviations obtained. Table I reports the results in ml of O_2 dissolved per 100 ml of emulsion at 37°C and compares the values obtained with earlier reports for neat liquids at 25° [3]. The solubility of oxygen in the dilute emulsions (1.5 g per 10 ml solution) at 37°C parallels the solubility of oxygen in neat liquids at 25°. Emulsified bromoperfluoroalkanes show the greatest ability to dissolve oxygen, a result consistent with oxygen solubility studies of neat liquids [3]. The observations on perfluorodecane (mp 37°) and 1-bromoperfluorodecane (mp 53°) are of particular interest because these compounds are solids at room temperature. Initial results with 1-bromoperfluorodecane in dilute emulsions were particularly encouraging because it was expected that an emulsified solid would give a more stable emulsion.

A few compounds were selected for preparation of more concentrated emulsions containing approximately 40% perfluorocarbon by volume. The results were used to calculate the solubility of oxygen for the neat perfluorocarbons and are given in Table II. The results calculated for 37°C give lower oxygen solubilities than earlier reported values at 25°, as would be expected. The important point is that the results of this study are consistent with the earlier report [3].

The results for the emulsion of 40% 1-bromoperfluorodecane (mp 53°) were disappointing. Apparently, the concentrated emulsion particles contained solid fluorocarbon which did not exchange oxygen with the aqueous medium. The slow exchange of oxygen with emulsions of solids is in agreement with non-zero values for deoxygenated samples in Table I.

TABLE 1

The solubility of oxygen in aqueous high-fluorocarbon-content emulsions[a]

Fluorocarbon Emulsified[a] Formula	Name	ml O_2/100 ml emulsion deoxygenated sample	ml O_2/100 ml emulsion saturated with room air	ml O_2/100 ml emulsion saturated with 97% O_2/3% CO_2
$(CF_3)_2CFC_6F_{13}$-n	Perfluoro-2-methyloctane	0.2 ± 0.1	1.2 ± 0.2	4.7 ± 0.3
$[(CF_3)_2CF]_2C_3F_7$-n	Perfluoro-2-methyl-3-isopropylpentane	0.2 ± 0.2	1.3 ± 0.2	4.7 ± 0.3
n-$C_{10}F_{22}$	Perfluorodecane	0.0 ± 0.0	0.8 ± 0.1	4.3 ± 0.2
$(CF_3)_2CF(CF_2)_4CF(CF_3)_2$	Perfluoro-2,7-dimethyloctane	0.1 ± 0.1	1.3 ± 0.2	4.1 ± 0.1
n-$C_6F_{13}Br$	1-bromoperfluorohexane	0.1 ± 0.1	1.3 ± 0.1	5.0 ± 0.3
n-$C_7F_{15}Br$	1-bromoperfluoroheptane	0.0 ± 0.0	1.2 ± 0.2	4.4 ± 0.2
n-$C_8F_{17}Br$	1-bromoperfluorooctane	0.0 ± 0.0	1.0 ± 0.4	5.3 ± 0.2
n-$C_{10}F_{21}Br$ (mp 52.5 - 54.0)	1-bromoperfluorodecane	0.3 ± 0.2	1.6 ± 0.2	5.5 ± 0.4
n-$C_{12}F_{25}Br$ (mp 87.0 - 88.0)	1-bromoperfluorododecane	0.8 ± 0.1	1.8 ± 0.2	4.3 ± 0.1
n-$C_{10}F_{21}I$ (mp 65.0 - 66.0)	1-iodoperfluorodecane	0.4 ± 0.1	1.8 ± 0.2	5.2 ± 0.3
$(C_4F_9)_3N$	FC-47; perfluorotributylamine	0.1 ± 0.1	1.0 ± 0.4	3.8 ± 0.2
none	5% Pluronic F-68 surfactant	0.0 ± 0.2	0.3 ± 0.1	2.0 ± 0.1
none	Pure Water	0.1 ± 0.1	0.3 ± 0.1	1.9 ± 0.1
none	5% Hydroxyethyl starch	0.0 ± 0.0	0.3 ± 0.1	1.8 ± 0.2

[a] Emulsions prepared by sonification of 1.50 g of fluorocarbon made up to 10.0 ml with 5% Pluronic F-68 solution.

[b] All perfluorocarbons except FC-47 were purchased from the Customs Chemical Products Division of the E. I. duPont de Nemours Co., Inc., Wilmington, Delaware. FC-47 was obtained from the 3M Corporation.

TABLE 2

The solubility of oxygen in aqueous high-fluorocarbon-content emulsions[a]

Volume percent fluorocarbon	Fluorocarbon	ml O_2/100 ml emulsion saturated with room air	ml O_2/100 ml emulsion saturated with 97% O_2/3% CO_2	Calculated solubility (37°) of O_2 in neat fluorocarbon (ml O_2/100 ml)	Literature [3] solubility (25°) (ml O_2/100 ml)
43%	$[(CF_3)_2CF]_2C_3F_7$-n	4.4	14.4 ± 0.3	37	none - 49.6 for n-C_9F_{20}[b]
43%	n-$C_{10}F_{22}$	3.7	11.6 ± 0.2	30	none - est. 45[c]
40%	$C_8F_{17}Br$	3.2	16.9 ± 0.6	44	52.7
40%	$C_{10}F_{21}Br$	0.7	1.8 ± 0.1	low	none
43%	FC-47	4.5	15.0 ± 0.2	25	38.4

[a]Emulsions prepared on a volume-volume basis using 5% Pluronic-68 aqueous solution

[b]Reportedly 85% pure n-perfluorononane

[c]Estimated from data of Table 2, Reference 3 for C_8F_{18}, C_9F_{20}, $C_9F_{19}Cl$, $C_{10}F_{18}$

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