T_1 and D of Perfluorocarbon-O_2 Mixtures for Lung Imaging

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1. Introduction Hyperpolarized ^{3}He gas MRI has become a popular research tool for studying lung diseases over the past several years. It is, however, not yet widely used clinically mainly because of the high cost of the polarizing equipment and the ^{3}He itself. Recent studies [1,2] have shown that perfluorocarbon (PFC) gases (C_2F_6, C_3F_8, etc.) are promising for replacing hyperpolarized ^{3}He in at least some of its applications in lung imaging. These PFC gases gain NMR signal strength by having multiple equivalent ^{19}F nuclei in each molecule and they have short T_1 to allow rapid signal averaging. They also have much lower free diffusivities than ^{3}He. Thus these gases could potentially be used to determine the local surface-to-volume ratio (S/V) of the lung [3], which would be an important parameter in diagnosing emphysema [2]. To do this one needs to know the free diffusivity in each imaging pixel. The free diffusivity is a function of the local gas concentration, which will be different from that of the inspired gas because blood removes O_2 from the gas phase. One approach is to use T_1 to calculate the local gas concentration, which in turn determines the free diffusivity. We present our experimental measurements on the free diffusivity D and T_1 for C_2F_6 and C_3F_8 gases in mixtures with oxygen, to allow determination of the free diffusivity for lung S/V measurements.

2. Methods Pure PFC gas and pure oxygen were first mixed at a specific concentration in a 150 cc container with beads inside. Then the container was removed and shaken for one minute for better gas mixing. The pre-evacuated sample tube was filled with the mixed gas from the container and was flame-sealed at pressure 0.94 atm. Pure PFC gas samples were also made at several pressures. The relaxation time T_1 was measured using a home-built spectrometer at both 4.7 T and 1.5 T, using the standard inversion-recovery sequence. The diffusion measurements were performed at 4.7 T in a constant field gradient generated by a Maxwell pair. We used the spin-echo sequence for diffusion measurements, with the T_2 decay corrected by explicit measurement of T_2 (with no applied gradient). We used a simplified theory of relaxation to fit all the T_1 data by assuming that a single spin-rotation interaction is the dominant relaxation mechanism, with a single correlation time τ for molecular angular momentum. This results in a set of formulas for relaxation with only 3 parameters for each gas mixture.

3. Results and Discussion Fig. 1 shows that at both 1.5 T and 4.4 T for the two PFC gas mixtures with oxygen, T_1 is almost linear in gas concentration at a given total pressure. Curves are fits using the simplified theory of relaxation. The small field dependence of T_1 indicates the fast collision regime. The increase of T_1 with increasing PFC concentration demonstrates that collisions with other PFCs are more effective in reorienting the angular momentum of a given PFC than are collisions with oxygen. Fig. 2 shows the dependence of reciprocal diffusivity (1/D) upon gas concentration at a fixed total pressure. Here 1/D is linear with PFC concentration, as expected from the general theory of binary gas mixtures [4]. Thus, based on the data presented here we have constructed formulas relating T_1 and diffusion in PFC mixtures with oxygen. This will allow determination of free diffusivity pixel by pixel from localized T_1 measurements.

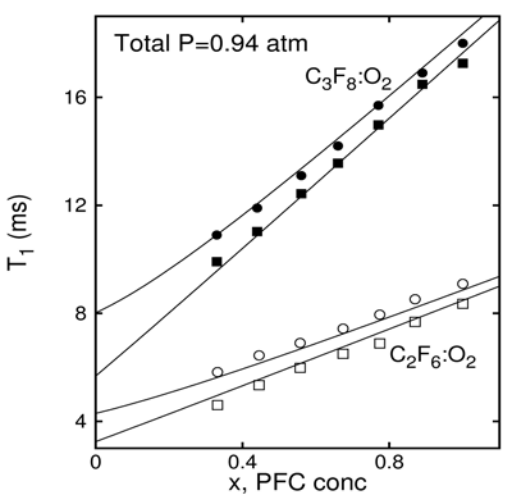

Figure 1. T_1 of PFC gas mixtures with oxygen plotted as a function of PFC gas concentration. Circles are at 4.4 T and squares are at 1.5 T.

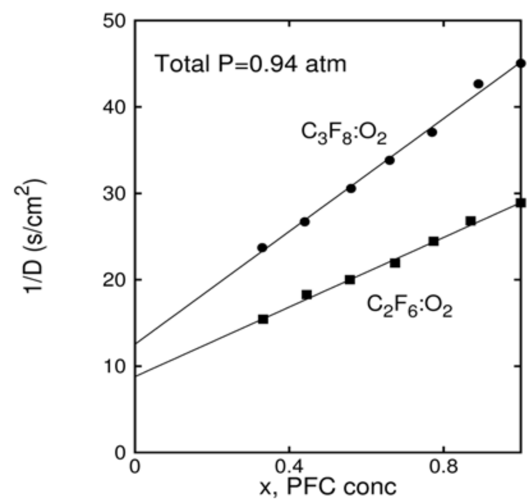

Figure 2. Reciprocal diffusivity (1/D) of PFC gas mixtures with oxygen plotted as a function of PFC concentration.

4. Conclusions The data presented here allow the local concentration of C_2F_6-O_2 and C_3F_8-O_2 mixtures to be determined from localized measurements of T_1. In turn, the free diffusivity of the gas mixture is then known. These results will support practical applications of restricted diffusivity and surface-to-volume determinations of lungs *in vivo*.

References 1. D.O. Kuethe, et. al., Imaging lungs using inert fluorinated gases. Magn. Reson. Med. 38 (1998) 85-88. 2. R.E. Jacob, et. al., ^{19}F MR imaging of ventilation and diffusion in excised lungs. Magn. Reson. Med. 54 (2005) 577-585. 3. M.S. Conradi, et. al, Feasibility of diffusion-NMR surface-to-volume measurements tested by calculations and computer simulations, J. Magn. Reson. 169 (2004) 196-202. 4. C.R. Wilke, Diffusional Properties of Multicomponent Gases, Chemical Engineering Progress, 42 (1950) 95-104.

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