CHAPTER IV

RESULTS

The data of T_1 and T_2 relaxation times of phosphate buffer solution (PBS) and the data of T_1 and T_2 relaxation times of dissolved oxygen solutions containing red blood 30%, 15%, and 7.5% by volume are summarized in table 4-1 to 4-8.

Because of T_1 and T_2 values at the same time which were recorded in each experiment were varied with the oxygen consumption of red blood cells and the variation of the measurement, average T_1 and T_2 values ($T1_{av}$ and $T2_{av}$) were calculated and present in table 4-1 to 4-2 , 4-10 and 4-12 and figure 4-1 was shown the linear-relation curve between measured times and $T1_{av}$ of all concentrations of red blood cells.

To evaluate the relationship between oxygen consumption of red blood cells and T_1, regression analysis was used and present in figure 4-2. Figure 4-3 show the plot T_1 change against percentage of red blood cells and figure 4-4 show the plot of rate of spin-spin relaxation against percentage of red blood cells.

To assess the possibility of the applied proton NMR relaxation times for the evaluation of the hematocrit values (HCT), the HCT values were determined using hematology analyzer and presented in table 4-9. All HCT values that were calculated using the relaxation techniques were presented in table 4-13 to 4-14 comparing with the HCT values from hematology analyzer.

Table 4-1 Proton spin-lattice relaxation time (T1) of PBS without degassing oxygen and with degassing oxygen, average T1 values ($T1_{av}$) and sample standard deviations.

Type of samples	No. of T1 measurements			T1av (s)	Std dev
	1	2	3		
PBS without degassing	0.182	0.177	0.228	0.197	0.028113
PBS with degassing	1.106	1.201	1.218	1.175	0.060357

Table 4-2 Proton spin-lattice relaxation time (T2) of PBS without degassing oxygen and with degassing oxygen, average T2 values ($T2_{av}$) and sample standard deviations.

Type of samples	No. of T2 measurements			$T2_{av}$ (s)	Std dev
	1	2	3		
PBS without degassing	0.543	0.433	0.501	0.492	0.055510
PBS with degassing	0.497	0.540	0.449	0.495	0.045523

Table 4-3 Proton spin-lattice relaxation time (T1) of dissolved oxygen solutions containing red blood cells at 30% by volume between the measured times 0 to 120 minutes.

No. of samples	T1 (sec)						
	at 0 min	at 20 min	at 40 min	at 60 min	at 80 min	at 100 min	at 120 min
1	0.626	0.484	0.559	0.690	0.757	0.896	0.860
2	0.313	0.416	0.523	0.653	0.549	0.855	0.858
3	0.774	0.826	0.512	0.740	0.569	0.696	0.889
4	0.390	0.520	0.768	0.549	0.313	0.653	0.858
5	0.664	0.764	0.665	0.760	0.970	0.862	0.891
6	0.767	0.484	0.542	0.919	0.760	0.499	0.870
7	0.662	0.529	0.354	0.521	0.891	0.920	0.892
8	0.533	0.820	0.813	0.792	0.873	0.826	0.884
9	0.346	0.918	0.852	0.727	0.901	0.973	0.845
10	0.574	0.507	0.685	0.869	0.953	0.810	0.821
11	0.373	0.726	0.578	0.830	0.984	0.829	0.854
12	0.535	0.820	0.813	0.792	0.873	0.826	0.898

Table 4-4 Proton spin-lattice relaxation times (T1) of dissolved oxygen solutions containing red blood cell at 15% by volume between measured times 0 to 120 minutes

No of sample	T1 (sec)						
	at 0 min	at 20 min	at 40 min	at 60 min	at 80 min	at 100 min	at 120 min
1	0.258	0.292	0.446	0.664	0.777	0.766	0.826
2	0.296	0.367	0.321	0.420	0.418	0.636	0.656
3	0.198	0.230	0.391	0.694	0.428	0.573	0.667
4	0.490	0.350	0.510	0.632	0.378	0.482	0.466
5	0.559	0.450	0.626	0.484	0.690	0.757	0.658
6	0.364	0.393	0.686	0.434	0.430	0.466	0.738
7	0.280	0.362	0.403	0.600	0.629	0.508	0.642
8	0.326	0.276	0.486	0.558	0.752	0.778	0.801
9	0.409	0.430	0.499	0.621	0.532	0.655	0.787
10	0.418	0.380	0.636	0.532	0.621	0.760	0.770
11	0.362	0.402	0.629	0.486	0.558	0.774	0.678
12	0.268	0.229	0.402	0.462	0.778	0.672	0.752

Table 4-5 Proton spin-lattice relaxation time (T1) of dissolved oxygen solutions containing red blood cells at 7.5% by volume between measured time 0 to 120 minutes.

No. of sample	T1 (sec)						
	at 0 min	at 20 min	at 40 min	at 60 mon	at 80 min	at 100 min	at 120 min
1	0.234	0.233	0.273	0.356	0.310	0.258	0.494
2	0.197	0.193	0.371	0.281	0.229	0.270	0.578
3	0.256	0.386	0.323	0.210	0.390	0.392	0.416
4	0.196	0.376	0.271	0.239	0.461	0.257	0.466
5	0.149	0.262	0.251	0.440	0.417	0.402	0.484
6	0.284	0.297	0.321	0.410	0.393	0.364	0.486
7	0.257	0.245	0.243	0.384	0.425	0.641	0.420
8	0.200	0.229	0.350	0.466	0.420	0.632	0.500
9	0.251	0.220	0.200	0.285	0.305	0.410	0.366
10	0.261	0.270	0.360	0.287	0.375	0.523	0.514
11	0.153	0.268	0.304	0.269	0.246	0.456	0.465
12	0.197	0.229	0.258	0.416	0.313	0.402	0.362

Table 4-6 Proton spin-spin relaxation time (T2) of dissolved oxygen solutions containing red blood cells at 30% by volume.

No. of samples	T2 (sec)		
	1st measurement	2nd measurement	3rd measurement
1	0.703	0.881	0.535
2	0.654	0.392	0.549
3	0.881	0.313	0.522
4	0.735	0.342	0.216
5	0.886	0.357	0.470
6	0.783	0.740	0.552
7	0.391	0.246	0.559
8	0.513	0.318	0.259
9	0.667	0.436	0.520
10	0.542	0.390	0.319
11	0.586	0.477	0.507
12	0.587	0.313	0.627

Table 4-7 Proton spin-spin relaxation time (T2) of dissolved oxygen solutions containing red blood cells at 15% by volume.

No. of samples	T2 (sec)		
	1st measurement	2nd measurement	3rd measurement
1	0.446	0.289	0.292
2	0.591	0.298	0.367
3	0.521	0.398	0.320
4	0.391	0.559	0.530
5	0.483	0.499	0.392
6	0.494	0.364	0.476
7	0.434	0.436	0.480
8	0.550	0.623	0.494
9	0.512	0.419	0.684
10	0.497	0.326	0.491
11	0.650	0.628	0.494
12	0.398	0.559	0.667

Table 4-8 Proton spin-spin relaxation time (T2) of dissolved oxygen solutions containing red blood cells at 7.5% by volume.

No. of samples	T2 (sec)		
	1st measurement	2nd measurement	3rd measurement
1	0.511	0.324	0.303
2	0.591	0.297	0.419
3	0.339	0.526	0.500
4	0.398	0.511	0.381
5	0.499	0.483	0.294
6	0.421	0.527	0.359
7	0.391	0.512	0.372
8	0.398	0.279	0.291
9	0.391	0.351	0.498
10	0.444	0.531	0.339
11	0.456	0.482	0.392
12	0.494	0.521	0.299

Table 4-9 The T1 values of number of red blood cells (RBC), hematocrit (HCT) and mean cell volume (MCV) of dissolved oxygen solutions containing red blood cells at 30%, 15% and 7.5% by volume: measurements were carried out using a hematology analyzer.

No. of samples	30% red blood cell solutions			15% red blood cell solutions			7.5% red blood cell solutions		
	RBC	HCT	MCV	RBC	HCT	MCV	RBC	HCT	MCV
1	4.41	37.0	84	1.61	13.6	84	0.81	7.2	89
2	3.31	29.4	89	1.51	12.7	84	0.95	8.0	84
3	3.85	32.4	84	1.84	15.4	84	0.97	8.2	85
4	3.37	30.0	89	1.62	13.6	84	0.97	8.0	83
5	3.11	28.1	90	1.59	14.5	91	0.75	6.9	91
6	3.02	29.0	96	1.53	14.6	96	0.81	7.5	93
7	3.45	31.8	92	1.69	15.9	94	0.87	8.2	95
8	3.58	33.4	93	1.73	15.9	92	0.88	8.3	94
9	3.35	31.0	92	1.78	16.6	93	0.85	7.8	91
10	3.57	32.0	90	1.74	15.2	87	0.78	6.8	87
11	3.29	30.5	93	1.61	13.1	81	0.86	8.9	94
12	3.18	30.0	91	1.74	16.2	90	0.81	7.6	90

Table 4-10 Averag proton spin-lattice relaxation time (T_1) of dissolved oxygen solutions containing red blood cells at 30%, 15%, and 7.5% by volume respectively between 0-120 minutes and sample standard deviations.

Times (min)	30% red blood cells		15% red blood cells		7.5% red blood cells	
	$T1_{av}$ (s)	std dev	$T1_{av}$ (s)	std dev	$T1_{av}$ (s)	std dev
0	0.546	0.160746	0.352	0.103724	0.220	0.043860
20	0.651	0.176123	0.347	0.073880	0.267	0.059668
40	0.639	0.152462	0.503	0.117417	0.294	0.052779
60	0.737	0.119525	0.549	0.092894	0.337	0.085327
80	0.783	0.206423	0.583	0.147445	0.374	0.084820
100	0.804	0.129883	0.652	0.119690	0.417	0.129888
120	0.868	0.023165	0.703	0.098140	0.463	0.062381

Table 4-11 Percentage consumed oxygen of red blood cells at 30%, 15%, and 7.5% by volume respectively and sample standard deviations.

Times (min)	30% red blood cells		15% red blood cells		7.5% red blood cells	
	$\Delta T1_{av}$ (s)	$\%O_2$ (v)	$\Delta T1_{av}$ (s)	$\%O_2$ (v)	$\Delta T1_{av}$ (s)	$\%O_2$ (v)
0	0.349	35.69	0.155	15.85	0.023	3.27
20	0.454	46.42	0.150	15.34	0.070	7.16
40	0.442	45.19	0.306	31.29	0.097	9.92
60	0.540	55.21	0.352	35.99	0.140	14.31
80	0.586	59.92	0.386	39.47	0.177	18.10
100	0.607	62.07	0.455	46.52	0.220	22.49
120	0.671	68.61	0.506	51.74	0.266	27.20

Table 4-12 Average T2 values and standared deviations of dissolved oxygen solutions containing red blood cells at 30%,15%, and 7.5% by volume respectively.

No. of samples	30% red blood cells		15% red blood cells		7.5% red blood cells	
	$T2_{av}$ (s)	std dev	$T2_{av}$ (s)	std dev	$T2_{av}$ (s)	std dev
1	0.706	0.173024	0.342	0.089790	0.379	0.114509
2	0.532	0.131857	0.419	0.153181	0.436	0.147707
3	0.572	0.287282	0.413	0.101336	0.455	0.101297
4	0.431	0.270705	0.493	0.089802	0.43	0.070661
5	0.571	0.278587	0.458	0.057715	0.425	0.114019
6	0.692	0.122851	0.445	0.070437	0.436	0.084955
7	0.399	0.156641	0.450	0.026000	0.425	0.075941
8	0.363	0.132930	0.556	0.064686	0.323	0.065516
9	0.541	0.116923	0.538	0.134448	0.413	0.076002
10	0.417	0.113925	0.438	0.097041	0.438	0.096141
11	0.523	0.056306	0.591	0.084435	0.443	0.046318
12	0.509	0.170915	0.541	0.135367	0.438	0.121132

Table 4-13 The calculated hematocrit value (HCT) of dissolved oxygen solutions containing at 30%, 15%, and 7.5% by volume respectively: using T2 data.

No. of samples	30%red blood cells			15%red blood cells			7.5%red blood cells		
	$1/T2_{av}$ (s^{-1})	HCT_{cal} (%)	HCT_{obs} (%)	$1/T2_{av}$ (s^{-1})	HCT_{cal} (%)	HCT_{obs} (%)	$1/T2_{av}$ (s^{-1})	HCT_{cal} (%)	HCT_{obs} (%)
1	1.416	54.6	37.0	2.924	NC	13.6	2.639	NC	7.2
2	1.880	30.7	29.3	2.387	4.6	12.7	2.294	9.4	8.0
3	1.748	37.5	32.4	2.421	2.9	15.4	2.198	14.3	8.2
4	2.320	8.1	30.0	2.028	23.1	13.6	2.326	7.8	8.0
5	1.751	NC	28.1	2.183	15.1	14.5	2.353	6.4	6.9
6	1.445	53.1	29.0	2.247	11.8	14.6	2.294	9.4	7.5
7	2.506	NC	31.8	2.222	13.1	15.9	2.353	6.4	8.2
8	2.755	NC	32.4	1.799	34.9	15.9	3.096	NC	8.3
9	1.848	32.4	31.0	1.859	31.8	16.6	2.421	2.9	7.8
10	2.398	4.0	32.0	2.283	9.9	15.2	2.283	9.9	6.8
11	1.912	29.1	30.5	1.692	40.4	13.1	2.257	11.3	8.9
12	1.965	26.3	30.0	1.848	32.4	16.2	2.283	9.9	7.6

Note: NC mean cannot calculate the values.

Table 4-14 The calculated hematocrit value (HCT) of dissolved oxygen solutions containing at 30%, 15%, and 7.5% by volume : using T1 data.

No. of samples	30%red blood cells			15%red blood cells			7.5%red blood cells		
	$T1_{av}$ (s)	HCT_{cal} (%)	HCT_{obs} (%)	$T1_{av}$ (s)	HCT_{cal} (%)	HCT_{obs} (%)	$T1_{av}$ (s)	HCT_{cal} (%)	HCT_{obs} (%)
1	0.663	28.2	37.0	0.629	26.2	13.6	0.297	6.7	7.2
2	0.661	28.1	29.3	0.459	16.2	12.7	0.381	11.6	8.0
3	0.692	29.9	32.4	0.470	16.9	15.4	0.219	2.1	8.2
4	0.661	28.1	30.0	0.269	5.0	13.6	0.269	5.0	8.0
5	0.694	30.0	28.1	0.461	16.3	14.5	0.287	6.1	6.9
6	0.673	28.8	29.0	0.541	21.0	14.6	0.289	6.2	7.5
7	0.695	30.1	31.8	0.445	15.4	15.9	0.223	2.3	8.2
8	0.687	29.6	33.4	0.604	24.6	15.9	0.303	7.0	8.3
9	0.648	27.3	31.0	0.590	23.9	16.6	0.169	-0.8	7.8
10	0.624	25.9	32.0	0.573	22.9	15.2	0.317	7.8	6.8
11	0.657	27.9	30.5	0.481	17.5	13.1	0.268	5.0	8.9
12	0.701	30.4	30.0	0.555	21.8	16.2	0.165	NC	7.6

Note: NC mean cannot calculate the values.

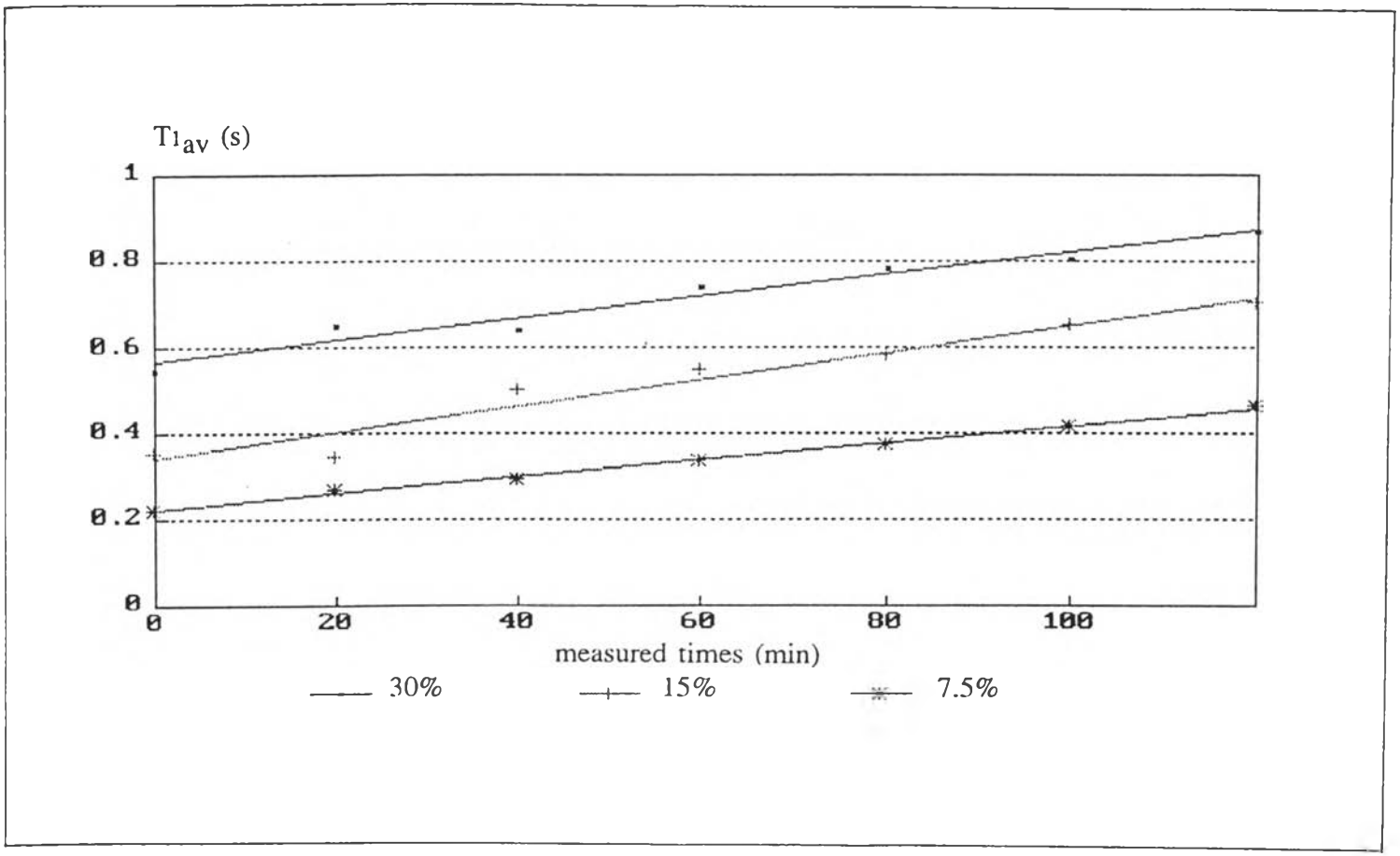

Figure 4-1 Average T1 values ($T1_{av}$) of dissolved oxygen solutions containing red blood cells 30%, 15% and 7.5% by volume and measured times 0 to 120 minutes.

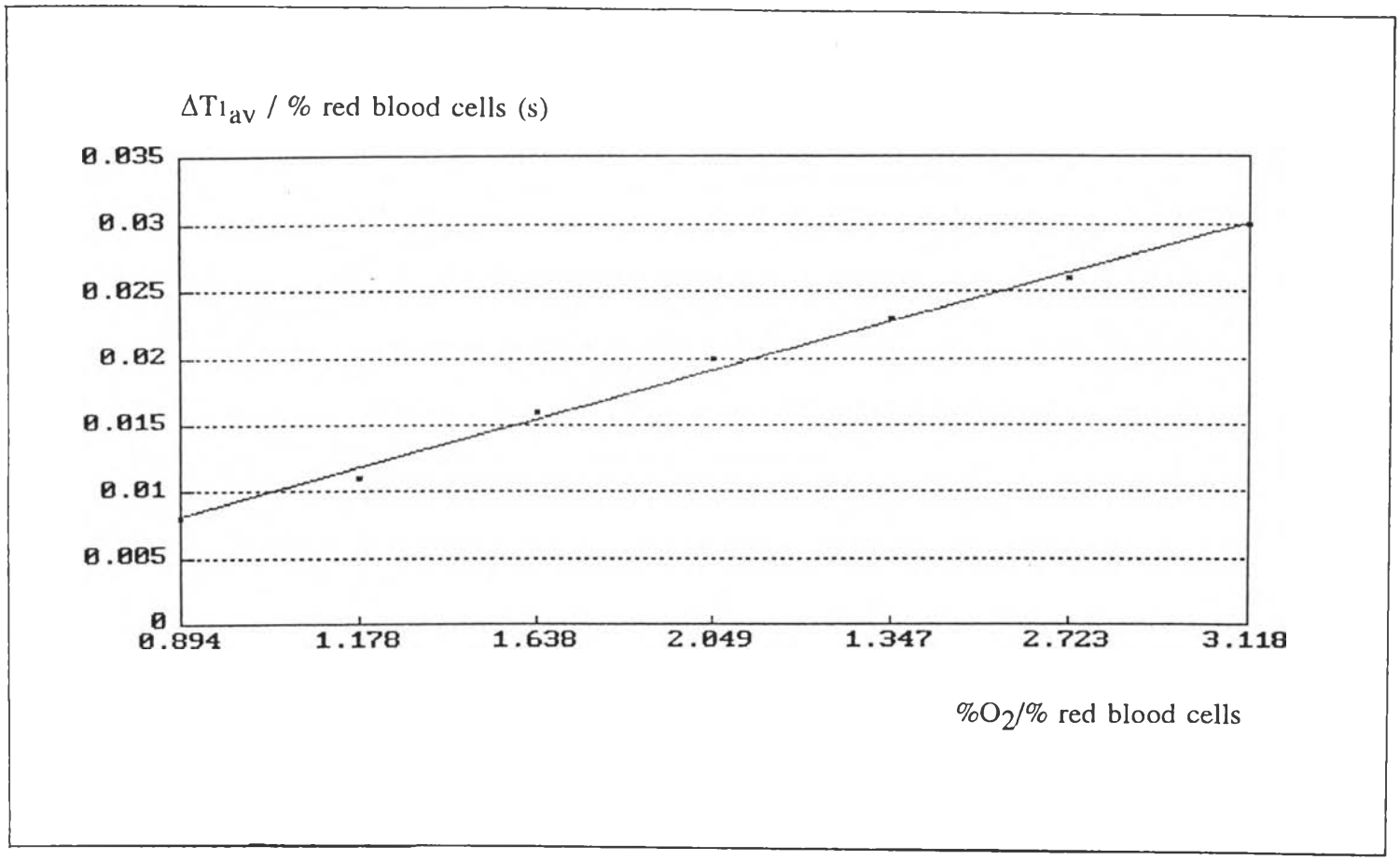

Figure 4-2 Δ Average T1 values ($\Delta T1_{av}$) per unit volume of red blood cells by volume and percent of consumed oxygen per unit volume of red blood cells.

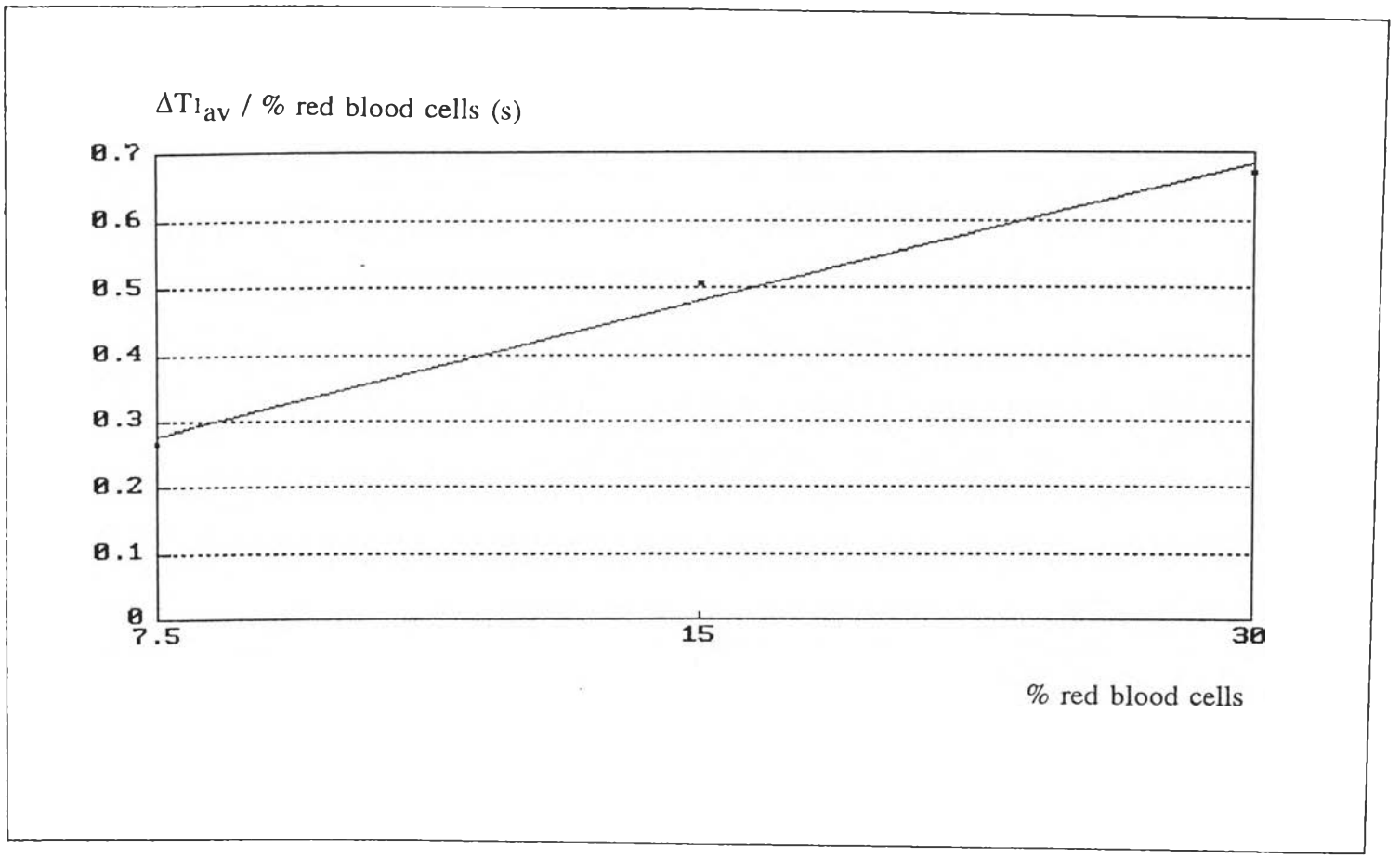

Figure 4-3 Δ Average T1 values ($\Delta T1_{av}$) per unit volume of red blood cells by volume and percent of red blood cells.

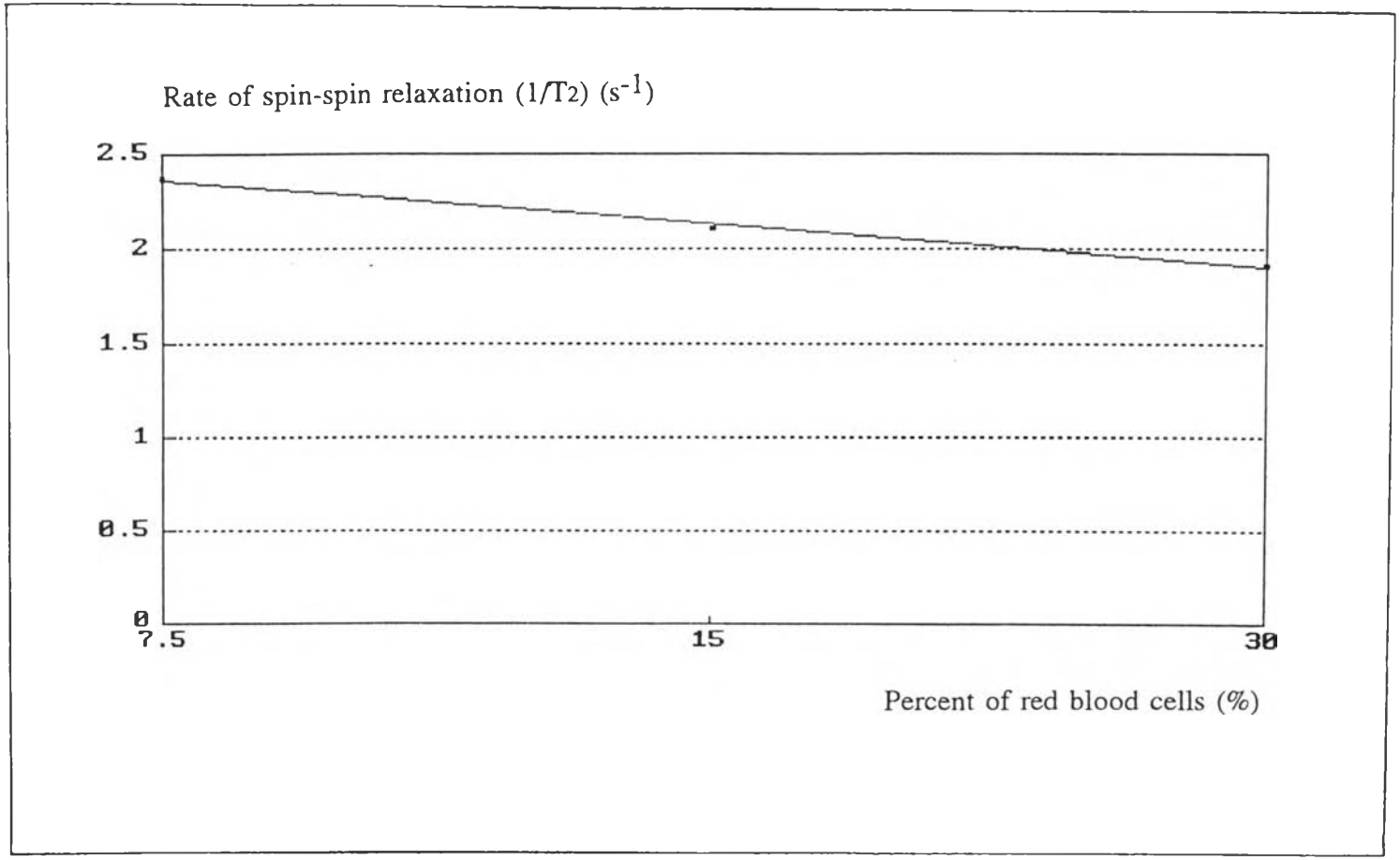

Figure 4-4 Rate of spin-spin relaxation (1/T2) and percent of red blood cells.