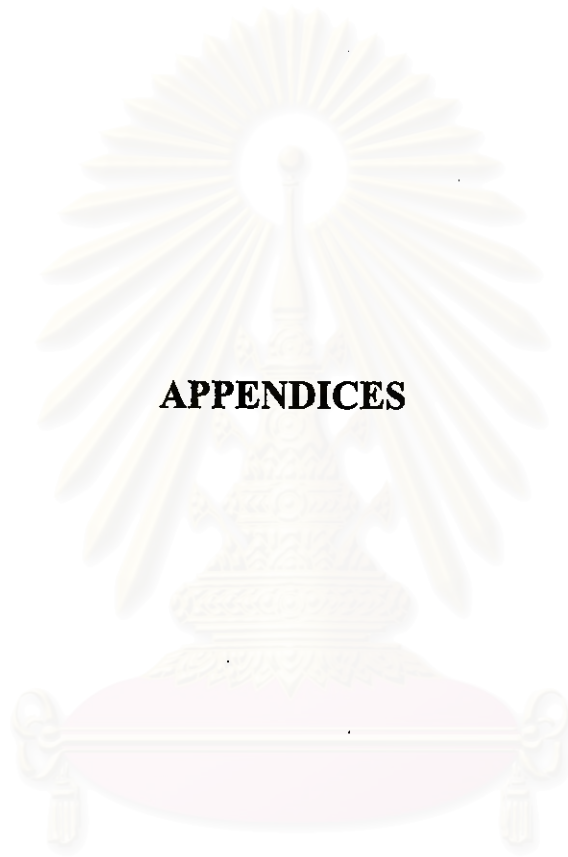


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**APPENDICES**

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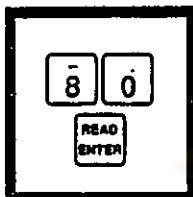
## A.1 Instrument using instruction

Method 8167

### CHLORINE, TOTAL (0 to 2.00 mg/L)

For water, wastewater and seawater

DPD Method\* (Powder Pillows or AccuVac Ampuls), USEPA accepted for reporting drinking water analysis\*\*  
USING POWDER PILLOWS



1. Enter the stored program number for free and total chlorine (Cl<sub>2</sub>)—powder pillows.

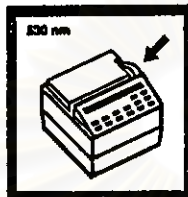
Press: 8 0 READ/ENTER

The display will show:  
DIAL nm TO 530

*Note:* DR/2000s with software versions 3.0 and greater will display "P" and the program number.

*Note:* Instruments with software versions 3.0 and greater will not display "DIAL nm TO" message if the wavelength is already set correctly. The display will show the message in Step 3. Proceed with Step 4.

*Note:* Samples must be analyzed immediately and cannot be preserved for later analysis.



2. Rotate the wavelength dial until the small display shows:

530 nm



3. Press: READ/ENTER

The display will show:  
mg/l Cl<sub>2</sub>



4. Fill a sample cell with 25 ml of sample.

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\*Adapted from Standard Methods for the Examination of Water and Wastewater.

\*\*Procedure is equivalent to USEPA method 330.5 for wastewater and Standard Method 4500-Cl<sub>2</sub> G for drinking water.

## CHLORINE, TOTAL, continued



5. Add the contents of one DPD Total Chlorine Powder Pillow to the sample cell (the prepared sample). Stopper the sample cell and shake for 20 seconds. Remove stopper.

*Note: A pink color will develop if chlorine is present.*

*Note: Accuracy is not affected by undissolved powder.*

*Note: Shaking the cell dissipates bubbles which may form in samples containing dissolved gases.*



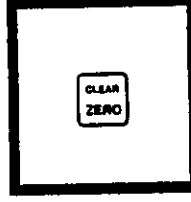
6. Press: **SHIFT** **TIMER**  
A 3-minute reaction period will begin.



7. When the timer beeps, the display will show:  
mg/L Cl<sub>2</sub>

Fill another sample cell (the blank) with 25 mL of sample. Place it into the cell holder.

*Note: The Flow-Thru Cell can be used with this procedure if it is rinsed shortly after each analysis with demineralized water.*



8. Press: **ZERO**  
The display will show:  
**WAIT**  
then:  
0.00 mg/L Cl<sub>2</sub>



9. Within three minutes after the timer beeps, place the prepared sample into the cell holder. Close the light shield.



10. Press: **READ/ENTER**  
The display will show:  
**WAIT**  
then the result in mg/L chlorine (Cl<sub>2</sub>) will be displayed.

*Note: If the sample temporarily turns yellow after sample addition, or shows OVER-RANGE, dilute a fresh sample and repeat the test. A slight loss of chlorine may occur because of the dilution. Multiply the result by the appropriate dilution factor (see Sample Dilution Techniques in Section I).*

*Note: In the constant-on mode, pressing READ/ENTER is not required. WAIT will not appear. When the display stabilizes, read the result.*

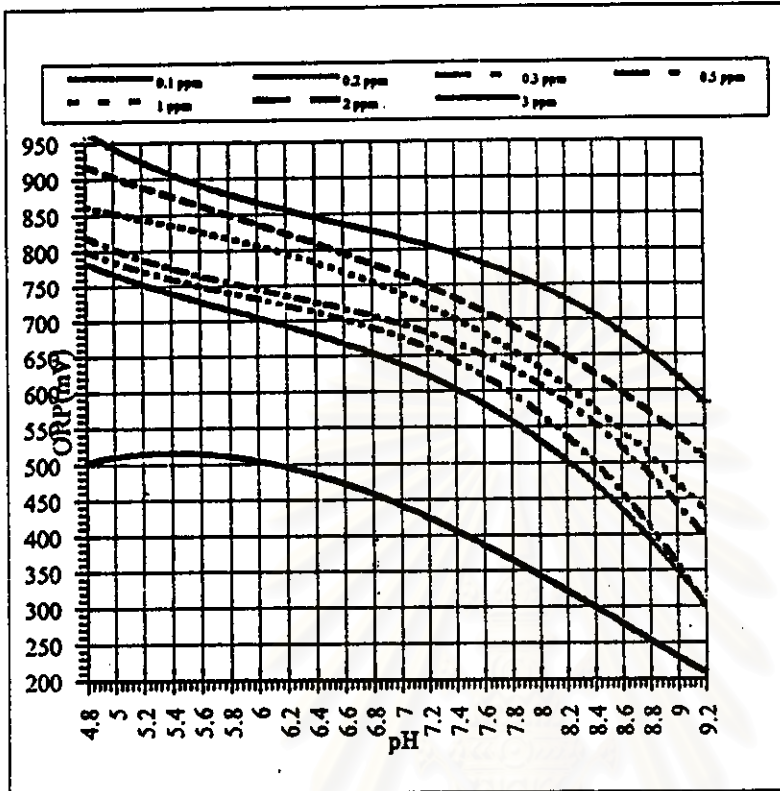
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## A2. Experimental Data

## 2. pH-ORP calibration data at each chlorine concentration

0.1 PPM		0.2 PPM		0.3 PPM		0.5 PPM		1 PPM		2 PPM		3 PPM	
pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP
4.94	510	4.96	782	4.98	775	4.97	826	4.96	863	4.98	899	4.94	892
5.06	532	5.03	776	5.01	781	4.98	778	4.99	848	4.98	903	5.04	903
5.18	552	5.15	769	5.18	777	5.17	813	5.18	856	5.15	890	5.17	900
5.23	490	5.24	781	5.18	788	5.24	767	5.18	838	5.18	895	5.18	890
5.40	510	5.37	750	5.43	759	5.39	790	5.40	827	5.35	872	5.37	893
5.44	498	5.40	760	5.43	766	5.45	757	5.42	844	5.43	885	5.37	896
5.55	492	5.55	751	5.59	746	5.60	750	5.55	814	5.62	859	5.60	889
5.62	526	5.57	740	5.62	768	5.64	772	5.60	830	5.62	871	5.78	892
5.76	495	5.74	744	5.76	742	5.79	763	5.78	810	5.74	858	5.83	853
5.79	491	5.86	726	5.85	758	5.81	777	5.82	807	5.78	845	5.98	840
5.98	550	5.95	709	5.98	730	5.96	731	6.01	819	6.01	822	6.00	860
6.06	400	6.18	691	6.00	708	6.05	748	6.21	808	6.02	835	6.20	847
6.23	478	6.40	650	6.16	720	6.17	740	6.40	799	6.18	820	6.20	850
6.28	539	6.40	680	6.24	700	6.20	728	6.58	781	6.19	818	6.40	840
6.35	492	6.58	649	6.38	708	6.39	738	6.82	760	6.36	814	6.41	820
6.44	522	6.62	667	6.47	706	6.41	723	7.00	751	6.44	806	6.58	823
6.58	439	6.77	648	6.55	704	6.55	717	7.18	746	6.59	797	6.64	615
6.58	528	6.77	650	6.65	697	6.61	704	7.38	736	6.63	790	6.64	768
6.79	504	6.99	644	6.79	689	6.73	711	7.60	690	6.79	785	6.79	754
6.82	455	7.01	631	6.82	693	6.76	718	7.81	675	6.83	779	6.79	818
7.03	459	7.15	634	6.95	675	6.96	683	7.99	640	7.00	766	6.99	797
7.03	499	7.17	633	6.97	680	7.03	700	6.59	738	7.04	760	7.01	761
7.13	469	7.39	626	7.17	670	7.18	681	6.98	722	7.21	754	7.21	763
7.17	432	7.43	613	7.25	669	7.19	687	7.18	668	7.22	753	7.22	794
7.21	355	7.58	623	7.36	651	7.38	672	7.22	708	7.39	739	7.38	725
7.45	312	7.60	598	7.46	637	7.46	660	7.60	687	7.42	734	7.42	768
7.45	399	7.76	576	7.56	635	7.59	662	8.02	630	7.57	724	7.59	736
7.75	320	7.78	587	7.62	619	7.61	640	8.21	596	7.58	714	7.64	695
7.83	342	8.01	530	7.79	613	7.76	632	8.23	589	7.78	700	7.80	720
7.97	317	8.05	523	7.80	604	7.78	638	8.42	565	7.79	694	7.98	700
8.14	343	8.16	546	8.00	570	7.99	603	8.45	565	7.94	679	8.02	910
8.16	318	8.23	524	8.08	552	8.06	585	8.57	537	8.07	670	8.13	669
8.21	380	8.40	484	8.17	572	8.15	608	8.57	537	8.15	660	8.17	694
8.38	304	8.40	486	8.23	507	8.22	587	8.74	531	8.19	637	8.36	677
8.38	340	8.60	441	8.36	455	8.36	562	8.82	486	8.38	599	8.38	668
8.58	282	8.61	438	8.41	526	8.43	552	8.96	511	8.39	643	8.56	632
8.65	293	8.76	412	8.54	481	8.56	528	9.00	461	8.56	570	8.76	589
8.78	261	8.85	400	8.57	419	8.57	530			8.56	616	8.78	590
8.85	220	8.94	380	8.75	435	8.78	500			8.75	563	8.97	574
8.93	227	8.99	379	8.76	406	8.80	454			8.78	586	9.11	560
8.95	235			8.96	361	8.95	482			8.95	540		
				8.99	392	8.97	427			8.95	562		

### A2.2 pH-ORP calibration Curve



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## A2.3 Batch adsorptionph-ORP results using ORP for chlorine analysis data

Time min.	CARBON MODEL PHO 8/30 IN 3 PPM CONC. CHLORINE SOLUTION 200 CC.															
	10 G				20 G				30 G				40 G			
	First		Second		First		Second		First		Second		First		Second	
	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP	pH	ORP
1	5.3	874	5.28	886	5.23	821	5.81	847	5.93	847	6.12	807	5.45	787	6.02	769
2	5.54	874	5.32	885	5.34	830	5.92	847	5.95	850	6.27	808	5.55	780	6.04	774
3	5.63	868	5.43	875	5.37	835	5.95	842	5.92	849	6.23	808	5.6	777	6.14	773
4	5.72	864	5.47	883	5.39	837	5.97	833	5.99	845	6.23	803	5.61	771	6.17	771
5	5.74	867	5.51	882	5.44	839	5.97	838	6.06	841	6.25	799	5.66	770	6.22	772
6	5.82	862	5.54	879	5.48	840	6.01	839	6.08	839	6.3	798	5.7	765	6.23	768
7	5.9	863	5.59	874	5.51	842	6.07	832			6.33	800	5.73	763	6.24	768
8	5.96	862	5.61	867	5.53	843	6.08	833			6.33	797	5.72	760	6.24	767
9	5.98	854	5.65	850	5.55	843	6.1	832	6.09	832	6.37	796	5.76	759	6.26	764
10	6.04	854	5.66	840	5.56	842	6.11	832	6.13	831	6.39	791	5.8	754	6.29	761
11	6.06	854	5.67	852	5.58	844	6.12	832	6.18	826	6.39	791	5.82	746	6.32	755
12	6.06	851	5.68	846	5.61	844	6.14	830	6.19	823	6.4	790	5.83	745	6.35	750
13	6.11	842	5.71	844	5.65	843	6.16	828	6.19	823	6.43	790	5.85	743	6.37	747
14	6.12	841	5.72	830	5.66	843	6.19	825	6.19	822	6.43	789	5.88	743	6.44	745
15	6.12	846	5.73	838	5.68	844	6.19	827	6.2	822	6.46	788	5.89	740	6.45	745
16	6.15	848	5.74	849	5.67	843	6.2	824	6.2	822	6.45	787	5.93	735	6.47	738
17	6.16	840	5.75	852	5.69	842	6.21	819	6.19	819	6.5	786	5.94	732	6.47	736
18	6.16	839	5.78	840	5.71	840	6.22	816	6.2	820	6.53	786	5.97	728	6.48	732
19	6.18	837	5.82	847	5.72	837	6.24	817	6.2	818	6.55	784	5.99	725	6.51	730
20	6.17	840	5.84	855	5.74	837	6.26	818	6.19	817	6.59	783	6.01	719	6.53	727
25	6.3	838	5.86	860	5.74	836	6.29	812	6.3	806	6.62	777	6.19	708	6.61	722
30	6.33	834	5.97	866	5.79	839	6.38	801	6.31	791	6.65	775	6.27	692	6.68	703
35			6.03	862	5.92	837	6.4	797	6.33	783	6.7	769	6.35	664	6.78	687
40	6.46	823	6.03	840	5.98	831	6.49	802	6.37	773	6.77	764	6.43	666	6.88	659
45	6.47	827	6.07	830	6.02	833	6.54	874	6.4	764	6.82	757	6.5	658	6.93	644
50			6.15	843			6.61	788	6.42	764	6.91	752	6.61	621	7	624
55					6.14	827	6.62	766	6.48	743	7.03	736	6.7	609	7.07	602
60	6.64	816	6.19	840			6.64	773	6.53	742	7.1	730	6.81	596	7.15	575
65													6.86	572	7.2	549
70													6.98	561	7.3	517
75													6.97	542	7.44	496
80													7.06	511	7.49	472
85					6.39	812							7.16	475	7.59	456
90	6.97	807	6.36	922			6.9	760	6.84	706	7.28	699	7.27	452	7.67	441
95													7.37	411	7.76	425
100													7.44	403	7.84	415
105													7.51	395	7.9	403
110													7.61	381		
115					6.52	808							7.63	381	8.02	371
120	7.1	798	6.73	807			7.13	749	7.16	660	7.58	649	7.71	369	8.07	365
125													7.76	359	8.11	356
130													7.83	353	8.17	353
135													7.85	346	8.23	346
140													7.9	340	8.24	339
145					6.7	795							7.92	332	8.25	333
150	7.23	774	6.81	810			7.34	717	7.46	630	7.88	593	7.94	328	8.29	329
155													7.97	324	8.33	324
160													7.99	317	8.34	319
165													8.05	313	8.38	313
170													8.09	311	8.4	309
175					6.84	777							8.13	306	8.41	306
180	7.36	771	6.96	792			7.53	693	7.76	593	8.06	574	8.14	303	8.43	301

Table A2.4 Batch adsorption using ORP for chlorine content analysis

Time (min)	Clorine Concentration (ppm)							
	10 g		20 g		30g		40 g	
	First	Second	First	Second	First	Second	First	Second
0	3	3	3	3	3	3	3	3
1	1.20	2.13	0.80	1.89	2.19	1.25	0.62	0.71
2	2.25	2.13	0.94	2.25	2.25	1.44	0.60	0.74
3	2.25	2.38	0.97	2.13	2.25	1.50	0.60	0.76
4	2.25	2.38	1.00	1.88	2.29	1.38	0.54	0.78
5	2.50	2.38	1.18	1.88	2.29	1.25	0.57	0.78
6	2.50	2.38	1.23	1.88	2.25	1.38	0.54	0.78
7	2.75	2.38	1.27	2.00		1.50	0.54	0.78
8	2.75	2.14	1.40	2.06		1.38	0.53	0.78
9	2.63	1.78	1.45	2.06	2.11	1.38	0.53	0.75
10	2.63	1.50	1.40	2.06	2.06	1.25	0.50	0.78
11	2.75	1.80	1.50	2.06	1.75	1.25	0.40	0.75
12	2.63	1.67	1.50	2.11	1.88	1.38	0.40	0.69
13	2.63	1.67	1.50	2.11	1.88	1.38	0.38	0.66
14	2.50	1.33	1.50	2.00	1.88	1.38	0.40	0.67
15	2.63	1.56	1.50	2.11	1.88	1.38	0.35	0.63
16	2.75	1.89	1.50	2.00	1.88	1.38	0.35	0.60
17	2.50	2.00	1.50	2.00	1.88	1.38	0.29	0.57
18	2.50	1.67	1.50	1.88	1.88	1.38	0.28	0.57
19	2.50	2.00	1.50	1.88	1.88	1.47	0.27	0.57
20	2.50	2.25	1.50	1.88	1.88	1.53	0.28	0.57
25	2.61	2.50	1.50	1.86	1.63	1.36	0.25	0.57
30	2.61	2.88	1.67	1.63	1.38	1.40	0.21	0.38
35			1.83	1.50	1.13	1.29	0.19	0.29
40	2.50	2.25	1.81	2.00	0.88	1.27	0.19	0.23
45	2.60	2.00	2.00		0.84	1.21	0.19	0.20
50				1.71	0.87	1.29	0.18	0.19
55			2.11	1.29	0.70	1.00	0.17	0.18
60	2.64	2.50		1.29	0.70	1.00	0.17	0.17
65							0.16	0.16
70							0.15	0.15
75							0.15	0.15
80							0.14	0.14
85			2.10				0.12	0.14
90	2.50	2.30		1.57	0.52	0.85	0.12	0.13
95							0.10	0.13
100							0.10	0.13
105							0.10	0.13
110							0.10	0.12
115			2.18					
120	2.73	2.50		1.86	0.29	0.50	0.10	0.11
125							0.10	0.12
130							0.10	0.11
135							0.10	0.12
140							0.10	0.11
145			2.17				0.09	0.11
150	2.47	2.68		1.38	0.28	0.34	0.09	0.11
155							0.09	0.11
160							0.09	0.11
165							0.09	0.11
170							0.09	0.11
175			2.00				0.09	0.10
180	2.56	2.50		1.13	0.28	0.38	0.09	0.11



## A 2.5 Batch adsorption isotherm using ORP for chlorine content analysis

Sol. Vol. (ml)	m, Weight of Carbon (mg.)	x Wt. of chlorine adsorbed(mg)		C Chlorine conc.(mg/l)			x/m (mg/g)
				First	Second	Average	
200	10000	0.13		2.59	2.07	2.33	0.0134
200	20000	0.25		1.70	1.79	1.75	0.0126
200	30000	0.35		1.31	1.17	1.24	0.0117
200	40000	0.55		0.19	0.29	0.24	0.0138

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**A2.6 Batch adsorption using spectrophotometer for chlorine analysis data  
using activated carbon model DEO 8/30 250 mg in chlorinated water 175 cc.**

**A2.6.1 Chlorine 2 ppm concentration**

Time (min)	First Test				Second Test			
	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>t</sub> /C <sub>∞</sub>	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>t</sub> /C <sub>∞</sub>
10	24.5	2.03	1.86	0.92	27.5	1.88	1.64	0.87
20	24.5	2.00	1.73	0.87	27.5	1.90	1.51	0.79
30	24.8	2.05	1.58	0.77	27.7	1.89	1.28	0.68
40					28.0	1.88	1.15	0.61
50	28.1	1.89	1.10	0.58	28.1	1.87	1.19	0.64
60	28.5	1.91	0.97	0.51	28.5	1.90	1.11	0.58
70	28.9	1.92	0.85	0.44	29.0	1.92	0.93	0.48
80	29.2	1.90	0.70	0.37	29.2	1.88	0.85	0.45
90	25.7	1.95	0.68	0.35	29.2	1.91	0.83	0.43
100	26.3	1.99	0.78	0.39	30.0	1.92	0.82	0.43
110	26.9	1.97	0.86	0.44	22.9	1.93	0.97	0.50
120	28.4	1.99	0.99	0.50	22.5	1.98	0.83	0.42
130	27.0	1.99	0.68	0.34	24.5	1.79	0.61	0.34
140	27.5	2.00	0.59	0.30	22.0	1.96	0.90	0.46
150	26.1	1.91	0.64	0.34	25.2	1.82	0.60	0.33
160	26.1	1.87	0.77	0.41	26.5	1.84	0.84	0.46
170	26.3	1.91	0.67	0.35	27.5	1.80	0.44	0.24
180	26.5	1.94	0.63	0.32	21.0	1.82	0.74	0.41
200	25.3	1.93	0.58	0.30	25.0	1.97	0.61	0.31
220	26.0	1.91	0.60	0.31	21.0	1.85	0.67	0.36
Average	26.7	1.95			26.1	1.89		

### A2.6.2 Chlorine3 ppm concentration

Time (min)	First Test				Second Test			
	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>∞</sub> /C <sub>∞</sub>	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>∞</sub> /C <sub>∞</sub>
20	26.5	3.18	2.74	0.86	27.0	2.58	2.22	0.86
30	26.0	3.28	2.62	0.80				
40	26.7	3.16	2.60	0.82	27.0	2.78	1.92	0.69
60	25.5	3.06	2.48	0.81	27.5	2.84	1.83	0.64
90	26.8	3.50	1.92	0.55	28.5	3.04	1.45	0.48
120	29.5	2.44	1.25	0.51	28.0	2.52	1.09	0.43
160	30.0	2.58	1.00	0.39	28.0	2.52	0.89	0.35
200	30.0	3.14	0.97	0.31	28.0	2.56	0.66	0.26
Average	27.6	3.04			27.7	2.69		

### A2.6.3 Chlorine4 ppm concentration

Time (min)	First Test				Second Test			
	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>∞</sub> /C <sub>∞</sub>	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>∞</sub> /C <sub>∞</sub>
20	29.5	3.88	2.22	0.57	29.5	3.82	3.44	0.90
40	30.0	4.00	1.92	0.48	29.5	3.90	2.38	0.61
60	30.0	3.90	1.83	0.47	29.5	3.90	2.68	0.69
80	30.0	3.82	1.45	0.38	29	3.98	2.52	0.63
100	30.0	3.78	1.45	0.38	29.5	3.74	1.86	0.50
120	29.8	4.04	1.09	0.27	29	3.96	1.96	0.49
160	30.0	3.82	1.5	0.39	29	3.82	1.42	0.37
200	30.0	3.98	0.66	0.17	29.5	3.4	0.825	0.24
Average	29.9	3.90			29.3	3.82		

#### A2.6.4 Chlorine5 ppm concentration

Time (min)	First Test				Second Test			
	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>t</sub> /C <sub>∞</sub>	Temp (°C)	C <sub>∞</sub> (mg/l)	Cat (mg/l)	C <sub>t</sub> /C <sub>∞</sub>
20	29.5	4.78	4.35	0.91	29.5	4.95	4.28	0.86
40	29.5	4.95	4.05	0.82	29.5	4.90	3.63	0.74
60	29.5	4.93	3.45	0.70	30.0	5.25	3.85	0.73
80	29.0	5.00	2.93	0.59	30.0	5.05	3.23	0.64
100	29.5	4.85	2.95	0.61	30.0	4.95	2.55	0.52
120	29.0	5.00	2.16	0.43	30.0	4.98	2.75	0.55
160	29.0	4.95	2.26	0.46	30.0	4.93	2.33	0.47
200	29.5	4.98	2.00	0.40	30.0	4.75	1.55	0.33
Average	29.3	4.92			29.9	4.97		

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A2.7 Relation between  $C_A/C_{A0}$  and  $t$  at each chlorine solution concentration

175 cc after adsorbed by 250 mg of activated carbon model DEO 8/30

$C_{A0}$ (ppm)			$C_A/C_{A0}$		$d(C_A/C_{A0})/dt$	
First	Second	Avg.	First	Second	First	Second
1.95	1.89	1.92	$2.5402t^{-0.3956}$	$2.1955t^{-0.3498}$	$-1.0049t^{-1.3956}$	$-0.7680t^{-1.3498}$
3.04	2.69	2.87	$3.7902t^{-0.4382}$	$4.2369t^{-0.4941}$	$-1.6609t^{-1.4382}$	$-2.0934t^{-1.4941}$
3.9	3.82	3.86	$2.2499t^{-0.4153}$	$4.1574t^{-0.4765}$	$-0.9344t^{-1.4153}$	$-1.9810t^{-1.4765}$
4.93	4.97	4.95	$3.1052t^{-0.3804}$	$2.9808t^{-0.3742}$	$-1.1812t^{-1.3804}$	$-1.1154t^{-1.3742}$

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A2.8 Approximated slope of the variation of chlorine content with time

t(min)	[d(C <sub>1</sub> /C <sub>∞</sub> )/dt at t(n+1)]/[d(CA/CA <sub>0</sub> )/dt at tn]*100 (%)															
	CA <sub>0</sub> =1.92 ppm				CA <sub>0</sub> =2.87ppm				CA <sub>0</sub> =3.86 ppm				CA <sub>0</sub> =4.95 ppm			
	First		Second		First		Second		First		Second		First		Second	
	d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt		d(C <sub>1</sub> /C <sub>∞</sub> )/dt	
20	-0.0154	-0.013	%	-0.013	-0.022	%	-0.0238	%	-0.0135	%	-0.0238	%	-0.019	%	-0.0182	%
40	-0.0058	-0.005	39	-0.008	37	-0.0085	36	-0.0050	37	-0.0085	36	-0.007	38	-0.007	39	39
60	-0.0033	-0.003	58	-0.005	56	-0.0046	55	-0.0028	56	-0.0047	55	-0.004	57	-0.004	57	57
80	-0.0022	-0.002	68	-0.0030	66	-0.0030	65	-0.0019	67	-0.0031	65	-0.003	67	-0.0027	67	67
100	-0.0016	-0.002	74	-0.002	73	-0.0022	72	-0.0014	73	-0.0022	72	-0.002	73	-0.002	74	74
120	-0.0013	-0.001	78	-0.002	77	-0.0016	76	-0.0011	77	-0.0017	76	-0.002	78	-0.0015	78	78
140	-0.0010	-0.0010	81	-0.001	80	-0.0013	79	-0.0009	80	-0.0013	80	-0.001	81	-0.0013	81	81
160	-0.0008	-8E-04	84	-0.001	83	-0.0011	82	-0.0007	83	-0.0011	82	-0.001	83	-0.0010	83	83
180	-0.0007	-7E-04	85	-9E-04	84	-0.0009	84	-0.0006	85	-0.0009	84	-9E-04	85	-0.0009	85	85
200	-0.0006	-6E-04	87	-8E-04	86	-0.0008	85	-0.0005	86	-0.0008	86	-8E-04	86	-0.0008	87	87



### A.2.9 Batch adsorption analysis of activated carbon model DEO 8/30

250 mg in 5 concentration chlorine solution

Chlorine Conc.(mg/l)						x(mg)	x/m (mg/g)	
C <sub>t</sub> /CA <sub>0</sub> (ppm)			CA <sub>0</sub> (ppm)					CA <sub>t</sub> (ppm)
First	Second	Avg.	First	Second	Avg.			
0.31	0.34	0.33	1.95	1.89	1.92	0.63	0.23	0.92
0.37	0.31	0.34	3.04	2.69	2.87	0.98	0.33	1.32
0.25	0.33	0.29	3.9	3.82	3.86	1.26	0.46	1.84
0.41	0.41	0.41	4.93	4.97	4.95	2.04	0.51	2.04

### A2.10 Breakthrough curve data

#### A2.10.1 Experiment 4 data: Effluent chlorine concentration

at each resident from 1" bed depth

##### A2.10.1.1 activated carbon model DEO 8/30

Time(hr)	Influent Conc.(ppm)	Effluent Conc.(ppm)				
		4 min	3 min	2 min	1 min	0.5 min
0.02	4.00	0.50	0.75	0.45	1.30	1.70
0.17	4.00	0.38	0.40	0.40	1.30	1.50
0.33	4.00	0.35	0.40	0.34	1.30	1.75
0.50	4.00	0.50	0.45	0.60	1.45	1.70
1.00	4.00	0.60	0.55	0.84	1.70	2.05
1.50	4.00	0.85	0.45	0.92	1.85	2.10
2.00	4.00	0.60	0.65	1.04	1.65	2.60
2.50	4.00	0.60	0.60	1.11	1.80	2.45
3.00	4.00	0.55	0.70	1.00	1.85	2.30
Average	4.00	0.55	0.55	0.74	1.58	2.02

## A2.10.1.2 activated carbon modelPHO 8/30

Time(hr)	Influent Conc.(ppm)	Effluent Conc.(ppm)				
		4 min	3 min	2 min	1 min	0.5 min
0.02	4.00	0.29	0.33	0.84	0.95	1.17
0.17	4.00	0.55	0.84	0.91	1.04	1.42
0.33	4.00	0.63	1.17	1.26	1.07	1.46
0.50	4.00	0.57	1.32	1.34	1.19	1.46
1.00	4.00	0.70	1.44	1.41	1.30	1.42
1.50	4.00	0.75	1.42	1.36	1.36	1.52
2.00	4.00	0.73	0.91	1.26	1.42	1.50
2.50	4.00	0.75	1.03	1.23	1.52	1.49
3.00	4.00	0.72	1.07	1.21	1.40	1.40
<b>Average</b>	<b>4.00</b>	<b>0.66</b>	<b>1.06</b>	<b>1.20</b>	<b>1.25</b>	<b>1.43</b>

## A2.10.1.3 activated carbon model HRO 8/30

Time(hr)	Influent Conc.(ppm)	Effluent Conc.(ppm)				
		4 min	3 min	2 min	1 min	0.5 min
0.02	4.00	0.19	0.51	0.84	1.78	1.04
0.17	4.00	0.77	1.07	1.82	2.12	1.31
0.33	4.00	1.20	1.07	1.69	2.20	1.48
0.50	4.00	1.35	1.11	1.67	2.30	1.35
1.00	4.00	1.50	1.08	1.81	2.10	1.24
1.50	4.00	1.52	1.04	1.77	1.90	1.27
2.00	4.00	1.49	1.01	1.55	1.30	1.40
2.50	4.00	1.45	1.29	1.68	1.24	1.37
3.00	4.00	1.44	1.27	1.75	1.33	1.29
<b>Average</b>	<b>4.00</b>	<b>1.34</b>	<b>1.06</b>	<b>1.62</b>	<b>1.81</b>	<b>1.31</b>

### A2.10.2 Experiment 5 data: Effluent chlorine concentration

at each residence time from 1" to 5" bed depth

#### A2.10.2.1 activated carbon model DEO 8/30

Time (hr)	Influent Conc. (ppm)	CA <sub>t</sub> (ppm)				
		1 min	2 min	3 min	4 min	5 min
		1"	2"	3"	4"	5"
0.03	4.00	1.30	0.60	0.35	0.50	0.60
0.17	4.00	1.30	0.45	0.25	0.20	0.30
0.33	4.00	1.30	0.45	0.25	0.08	0.25
0.50	4.00	1.45	0.45	0.20	0.10	0.20
1.00	4.00	1.70	0.60	0.20	0.13	0.05
1.50	4.00	1.85	0.45	0.25	0.13	0.05
2.00	4.00	1.65	0.45	0.25	0.13	0.04
2.50	4.00	1.80	0.50	0.25	0.13	0.04
3.00	4.00	1.85	0.65	0.30	0.15	0.04
<b>Average</b>	<b>4.00</b>	<b>1.58</b>	<b>0.51</b>	<b>0.26</b>	<b>0.13</b>	<b>0.12</b>

#### A2.10.2.2 activated carbon model PHO 8/30

Time (hr)	Influent Conc. (ppm)	CA <sub>t</sub> (ppm)				
		1 min	2 min	3 min	4 min	5 min
		1"	2"	3"	4"	5"
0.33	4.00	1.07	0.20	0.12	0.11	0.12
0.50	4.00	1.19	0.22	0.11	0.12	0.13
1.00	4.00	1.30	0.24	0.12	0.13	0.12
1.50	4.00	1.36	0.28	0.14	0.13	0.12
2.00	4.00	1.42	0.26	0.15	0.14	0.12
2.50	4.00	1.52	0.27	0.15	0.14	0.12
3.00	4.00	1.40	0.29	0.15	0.15	0.12
<b>Average</b>	<b>4.00</b>	<b>1.08</b>	<b>0.20</b>	<b>0.10</b>	<b>0.10</b>	<b>0.09</b>

### A2.10.2.3 activated carbon model HRO 8/30

Time (hr)	Influent Conc. (ppm)	CAI(ppm)				
		1 min	2 min	3 min	4 min	5 min
		1"	2"	3"	4"	5"
	4.00	1.78	0.12	0.15	0.13	0.15
0.17	4.00	2.12	0.19	0.12	0.10	0.10
0.33	4.00	2.20	0.19	0.15	0.10	0.11
0.50	4.00	2.30	0.22	0.14	0.12	0.11
1.00	4.00	2.10	0.23	0.16	0.13	0.14
1.50	4.00	1.90	0.26	0.19	0.14	0.13
2.00	4.00	1.30	0.26	0.20	0.15	0.14
2.50	4.00	1.24	0.26	0.21	0.18	0.16
3.00	4.00	1.33	0.25	0.21	0.15	0.17
<b>Average</b>	<b>4.00</b>	<b>1.81</b>	<b>0.22</b>	<b>0.17</b>	<b>0.13</b>	<b>0.13</b>

### A2.10.3 Experiment 6 data: Effluent chlorine concentration at each residence time from 1" to 5" bed depth

#### A2.10.3.1 activated carbon model DEO 8/30

Time (hr)	Influent Conc. (ppm)	CAI(ppm)				
		0.5 min	1 min	1.5 min	2 min	2.5 min
		1"	2"	3"	4"	5"
0.03	4.00	1.70	0.80	0.70	0.30	0.21
0.17	4.00	1.50	0.60	0.30	0.10	0.07
0.33	4.00	1.75	0.54	0.23	0.10	0.06
0.50	4.00	1.70	0.64	0.33	0.10	0.07
1.00	4.00	2.05	0.52	0.22	0.12	0.07
1.50	4.00	2.10	0.53	0.24	0.11	0.07
2.00	4.00	2.60	0.58	0.25	0.13	0.07
2.50	4.00	2.45	0.60	0.26	0.13	0.06
3.00	4.00	2.30	0.61	0.27	0.13	0.09
<b>Average</b>	<b>4.00</b>	<b>2.06</b>	<b>0.58</b>	<b>0.26</b>	<b>0.12</b>	<b>0.07</b>

### A2.10.3.2 activated carbon model PHO 8/30

Time (hr)	Influent Conc. (ppm)	CA <sub>t</sub> (ppm)				
		0.5 min	1 min	1.5 min	2 min	2.5 min
		1"	2"	3"	4"	5"
0.03	4.00	1.17	0.28	0.22	0.13	0.12
0.17	4.00	1.42	0.43	0.20	0.13	0.11
0.33	4.00	1.46	0.54	0.28	0.11	0.12
0.50	4.00	1.46	0.55	0.28	0.13	0.14
1.00	4.00	1.42	0.65	0.31	0.13	0.15
1.50	4.00	1.52	0.71	0.35	0.13	0.12
2.00	4.00	1.50	0.76	0.37	0.13	0.13
2.50	4.00	1.49	0.74	0.38	0.16	0.13
3.00	4.00	1.40	0.74	0.39	0.16	0.14
<b>Average</b>	<b>4.00</b>	<b>1.49</b>	<b>0.60</b>	<b>0.31</b>	<b>0.13</b>	<b>0.13</b>

### A2.10.3.3 activated carbon model HRO 8/30

Time (hr)	Influent Conc. (ppm)	CA <sub>t</sub> (ppm)				
		0.5 min	1 min	1.5 min	2 min	2.5 min
		1"	2"	3"	4"	5"
0.03	4.00	1.04	0.36	0.26	0.16	0.10
0.17	4.00	1.31	0.44	0.29	0.25	0.08
0.33	4.00	1.48	0.49	0.30	0.28	0.09
0.50	4.00	1.35	0.52	0.32	0.30	0.10
1.00	4.00	1.24	0.57	0.38	0.32	0.10
1.50	4.00	1.27	0.59	0.39	0.33	0.11
2.00	4.00	1.40	0.63	0.40	0.38	0.13
2.50	4.00	1.37	0.63	0.39	0.42	0.13
3.00	4.00	1.29	0.65	0.38	0.40	0.12
<b>Average</b>	<b>4.00</b>	<b>1.31</b>	<b>0.54</b>	<b>0.35</b>	<b>0.32</b>	<b>0.11</b>

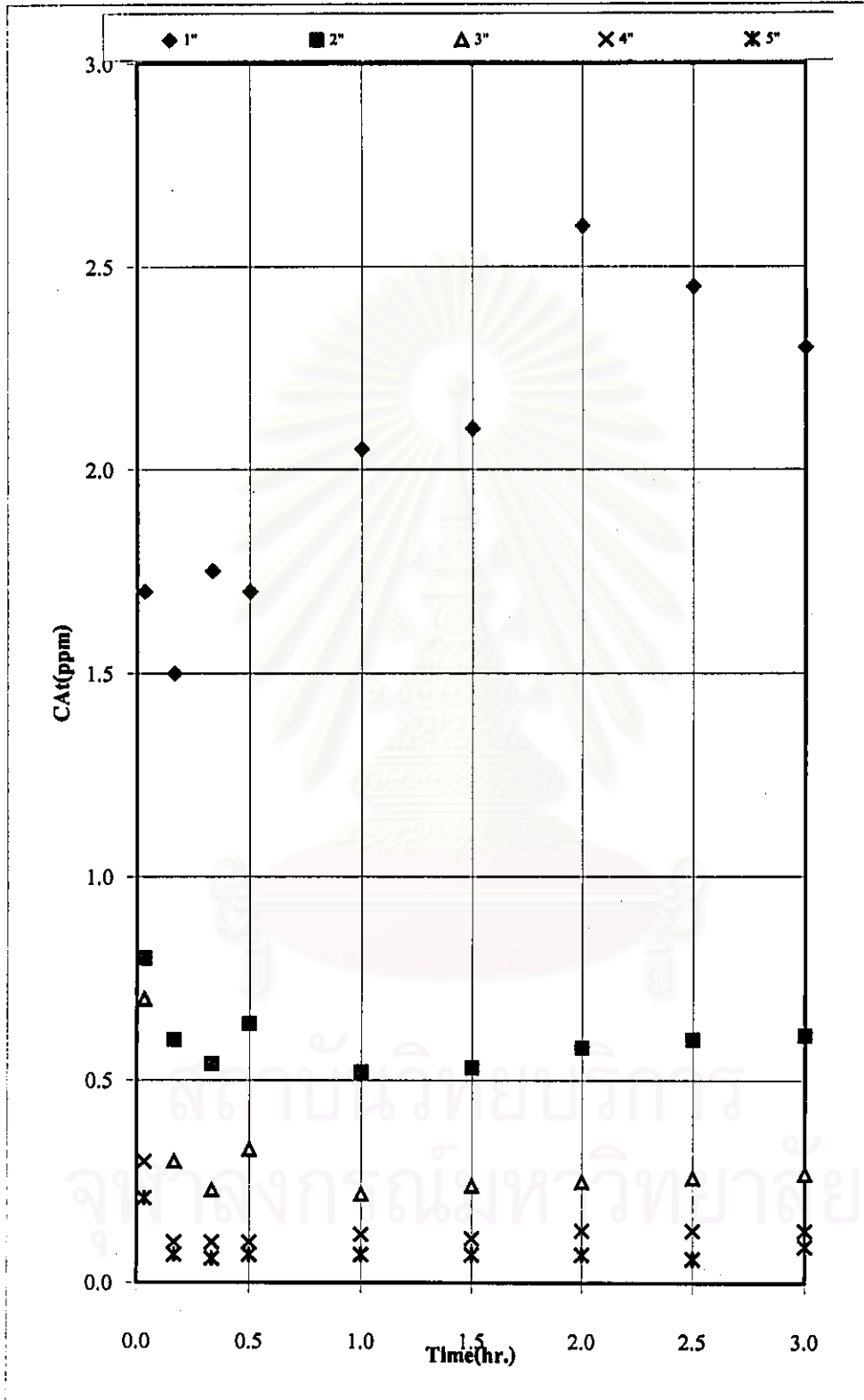
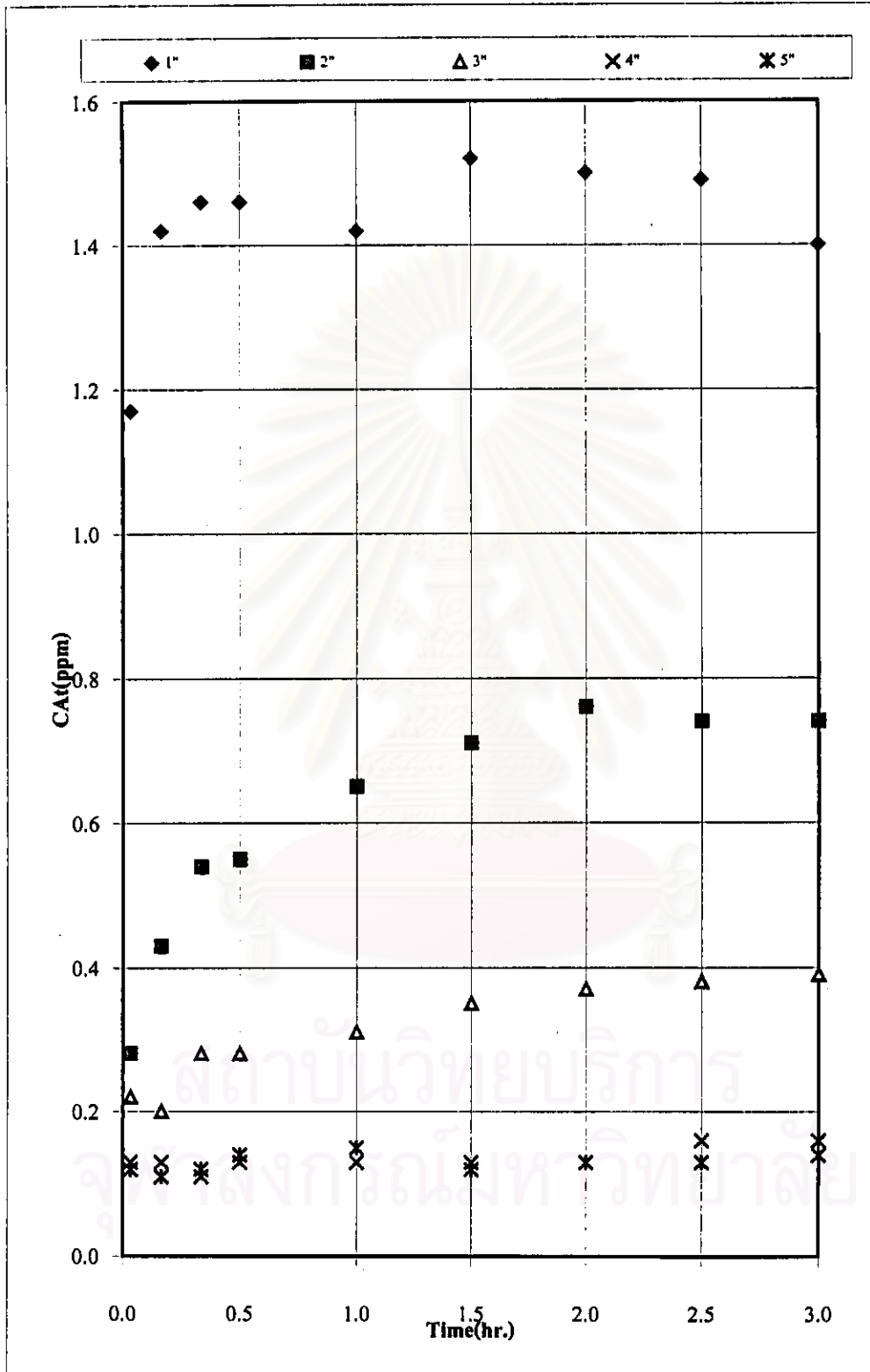


Figure A1 Effluent chlorine concentration

of activated carbon model DEO 8/30 for service flow rate 1.256 gal/min/ft<sup>2</sup>





FigureA2 Effluent chlorine concentration

of activated carbon model PHO 8/30 for service flow rate  $1.256 \text{ gal/min/ft}^2$

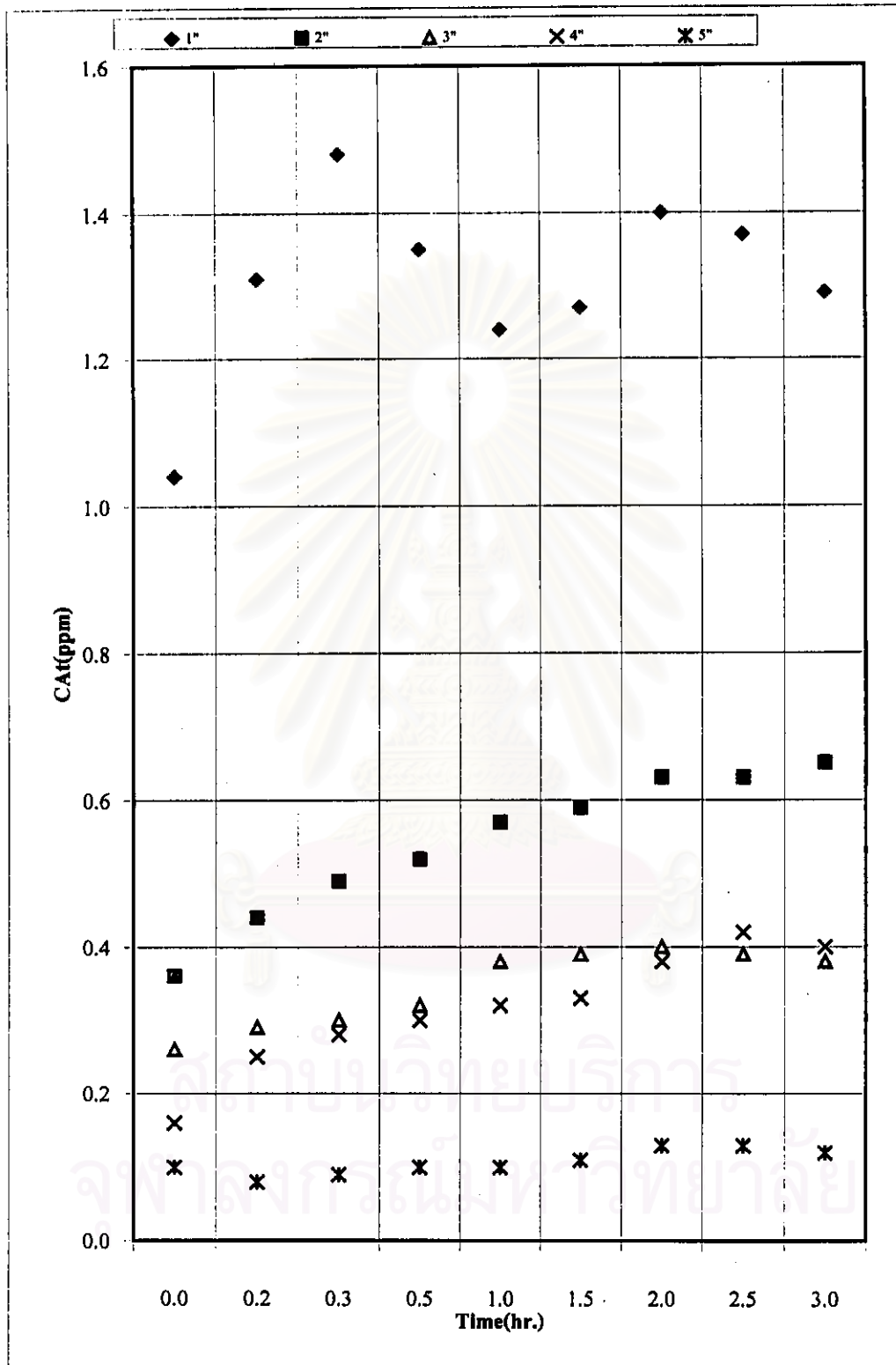


Figure A3 Effluent chlorine concentration

of activated carbon model HRO 8/30 for service flow rate  $1.256 \text{ gal/min/ft}^2$

**A2.10.4 Comparison Experiment 5 & 6 data: Average effluent chlorine concentration at each residence time from 1" to 5" bed depth**

**A2.10.4.1 activated carbon model DEO 8/30**

Bed	0.622 gal/min/ft <sup>2</sup>		1.256 gal/min/ft <sup>2</sup>	
	Resident Time(min)	Conc.(ppm)	Resident Time(min)	Conc.(ppm)
1	1	1.58	0.5	2.06
2	2	0.51	1	0.58
3	3	0.26	1.5	0.26
4	4	0.13	2	0.12
5	5	0.12	2.5	0.07

**A2.10.4.2 activated carbon model PHO 8/30**

Bed	0.622 gal/min/ft <sup>2</sup>		1.256 gal/min/ft <sup>2</sup>	
	Resident Time(min)	Conc.(ppm)	Resident Time(min)	Conc.(ppm)
1	1	1.26	0.5	1.43
2	2	0.35	1	0.6
3	3	0.13	1.5	0.31
4	4	0.13	2	0.13
5	5	0.12	2.5	0.13

**A2.10.4.3 activated carbon model HRO 8/30**

Bed	0.622 gal/min/ft <sup>2</sup>		1.256 gal/min/ft <sup>2</sup>	
	Resident Time(min)	Conc.(ppm)	Resident Time(min)	Conc.(ppm)
1	1	1.81	0.5	1.31
2	2	0.22	1	0.54
3	3	0.17	1.5	0.35
4	4	0.13	2	0.32
5	5	0.13	2.5	0.11

**A2.10.5 Experiment 7 data: effluent chlorine concentration from 4" bed depth**

**A2.10.5.1 activated carbon model PHO 8/30**

Time(Hr.)	CAo(ppm)	CAi(ppm)
0.03	4.00	0.21
0.17	4.00	0.23
0.33	4.00	0.24
0.50	4.00	0.27
1.00	4.00	0.28
1.50	4.00	0.34
2.00	4.00	0.34
2.50	4.00	0.39
3.00	4.00	0.41
<b>Average</b>	<b>4.00</b>	<b>0.30</b>

**A2.10.5.2 activated carbon model HRO 8/30**

Time(Hr.)	CAo(ppm)	CAi(ppm)
0.03	4.00	0.23
0.17	4.00	0.31
0.33	4.00	0.33
0.50	4.00	0.36
1.00	4.00	0.39
1.50	4.00	0.40
2.00	4.00	0.53
2.50	4.00	0.45
3.00	4.00	0.5
<b>Average</b>	<b>4.00</b>	<b>0.39</b>

**A2.10.6 Comparison experiment 5,6 & 7 data: average effluent chlorine concentration at each service flow rate from 4" bed depth**

Service flow rates (gal/min/sq.ft.)	Effluent concentration(ppm)		
	DEO8/30	PHO 8/30	HRO 8/30
0.622	0.12	0.13	0.13
1.256	0.12	0.13	0.32
2.512		0.3	0.39

**A2.10.7 Comparison of experiment 4 & 5 data: average effluent chlorine concentration same residence time with different bed depth**

**A2.10.7.1 Activated carbon model DEO 8/30**

Time (min)	Effluent Conc. (ppm)				
	1"	2"	3"	4"	5"
1	1.58				
2	0.74	0.51			
3	0.55		0.26		
4	0.55			0.13	
5					0.12

**A2.10.7.2 Activated carbon model PHO 8/30**

Time (min)	Effluent Conc. (ppm)				
	1"	2"	3"	4"	5"
1	1.25				
2	1.2	0.35			
3	1.06		0.13		
4	0.63			0.13	
5					0.12

**A2.10.7.3 Activated carbon model HRO 8/30**

Time (min)	Effluent Conc. (ppm)				
	1"	2"	3"	4"	5"
1	1.81				
2	1.62	0.22			
3	1.05		0.17		
4	1.34			0.13	
5					0.13

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### A3 Example of a Design of an Adsorption Unit by Using Data from laboratory Results

Example: A laboratory adsorption column, 4 in. in diameter and 12 feet depth, is found to produce good results when operated at a flow of 10 gal/hr. Calculate the following:

1. The service flow rate in gal/min/ft<sup>2</sup>.
2. The residence time, t, in the column.
3. The volumetric flow rate, V<sub>b</sub>, in bed volumes per hour, associated with this residence time.
4. The service flow rate that would yield the same residence time in a production column that was 10 ft in diameter and 30 ft tall.

Solution:

1. The service flow rate in gal/min/ft<sup>2</sup>:

$$\text{column area} = \frac{\pi(4)^2}{4} = 12.57 \text{ in.}^2 = .087 \text{ ft}^2$$

$$\text{Service flow rate} = \frac{10 \text{ gal/hr}}{60 \text{ min/hr} \times .087 \text{ ft}^2} = 1.915 \text{ gal/min/ft}^2$$

2. The residence time, t, in the column:

$$\text{linear velocity} = \frac{1.915 \text{ gpm/ft}^2}{7.48 \text{ gal/ft}^3} = .256 \text{ ft/min}$$

$$t = \frac{12 \text{ ft}}{.256 \text{ ft/min}} = 46.87 \text{ min}$$

3. The volumetric flow rate, V<sub>b</sub>, in bed volumes per hour:

$$V_b = \frac{10 \text{ gal/hr}}{7.48 \text{ gal/ft}^3} \cdot \frac{1 \text{ ft}^3}{.087 \text{ ft}^2} \cdot \frac{1}{4/12 \text{ ft}} = 46 \text{ Vb/hr}$$

4. The service flow rate for a 10 ft diameter by 30 ft deep column to give the same residence time as in the laboratory column :

$$\begin{aligned}\text{required liner velocity} &= \frac{30 \text{ ft}}{46.87 \text{ min}} = .640 \text{ ft/min} \\ \text{application rate} &= .640 \frac{\text{ft}}{\text{min}} \times 7.48 \frac{\text{gal}}{\text{ft}^3} = 4.707 \frac{\text{gpm}}{\text{ft}^2}\end{aligned}$$



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## Biography

Miss Orapat Phrudthaparmoke was born on June 7, 1970, in Phatthalung, Thailand. She graduated with a Bachelor Degree of Engineering in Chemical Engineering from Prince of Songkla University in 1993.



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