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APPENDICES

Appendix A Plaster Test Section Mixing and Molding

Air often gets trapped inside the plaster test sections resulting in non-uniform dissolution of plaster as flow passes over it. From observing and trial-and-error experiments in order to reduce air bubbles inside the plaster test section, it was found that a vacuum pump and separator funnel similar to the system used in previous work had to be employed. However, the molding method was different, since a syringe was used to inject plaster in the liquid state to the acrylic mold to obtain a smoother plaster test section. The ratio between water and plaster was changed from 0.6 in previous work to 0.7 so as to cast a smoother plaster test section. Nevertheless, there was a problem in that the plaster broke easily when being removed from the mold. A releasing agent was used to coat the inside surface of the mold and the steel core but it did not work; in addition, a releasing agent can contaminate the plaster and influence the experiment. Therefore, another technique was used to remove the completed plaster test section instead of a using releasing agent; for example, removing the plaster while still wet after 20 minutes or totally dry after 2 days.

Table A.1 and A.2 shows some results and appearance of the plaster test section from trial and error for several times in each ratio; Figure A.1 shows the plaster test section features in the final step of casting.

Table A.1 The detail of noticeable appearance of plaster test section and procedures in different ratio without coating releasing agent.

R_o	M_{water} (g)	$M_{plaster}$ (g)	Detail (from naked eye)
0.6	300	500	- no well-mixed plaster and deionized water - difficult to inject the plaster liquid into the mold
0.75	300	400	- no smooth plaster - easiest to inject the plaster liquid into the mold
0.725	290	400	- more smooth plaster - easy to inject the plaster liquid into the mold
0.7	280	400	- get the most smooth plaster - easy to inject the plaster liquid into the mold

Notice : - The plaster test section in every case was broken while it was taken out from the acrylic mold.

- The smooth plaster means that the plaster surface has no air bubbles or holes inside.

Table A.2 The detail of noticeable appearance of plaster test section and procedures in different ratio with coating releasing agent.

R_o	M_{water} (g)	$M_{plaster}$ (g)	Detail (from naked eye)
0.75	300	400	- no smooth plaster - many air bubbles spreading surface
0.725	290	400	- more smooth plaster - still get cracking plaster sometime
0.7	280	400	- get the most smooth plaster, no air bubbles inside plaster - seems to take plaster out easily but sometime still get broken plaster

From the experience of molding plaster several times, it can be concluded that the plaster should be mixed with deionized water in a ratio of R_o = 0.7. The mixed plaster is injected to the acrylic mold which has a steel rod in the middle. After 20 minutes, the plaster conduit was removed from the mold while still wet. The smooth plaster conduit can be achieved without contamination by a releasing reagent.

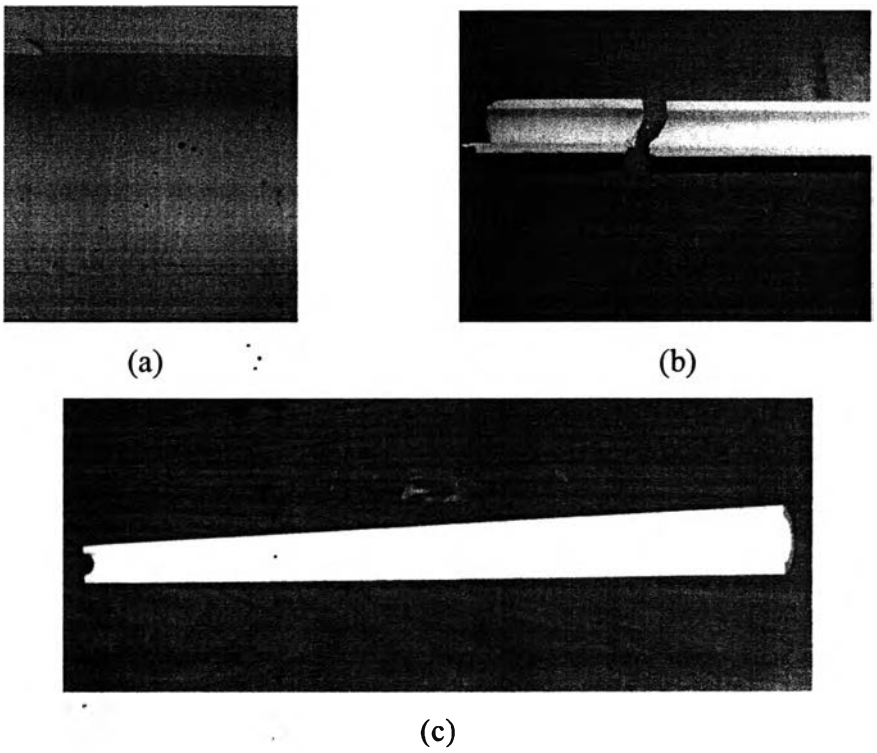

Figure A.1 The plaster test section after casting (a) air bubbles or holes on the surface (b) cracking plaster (c) complete plaster.

Appendix B Solubility of Gypsum

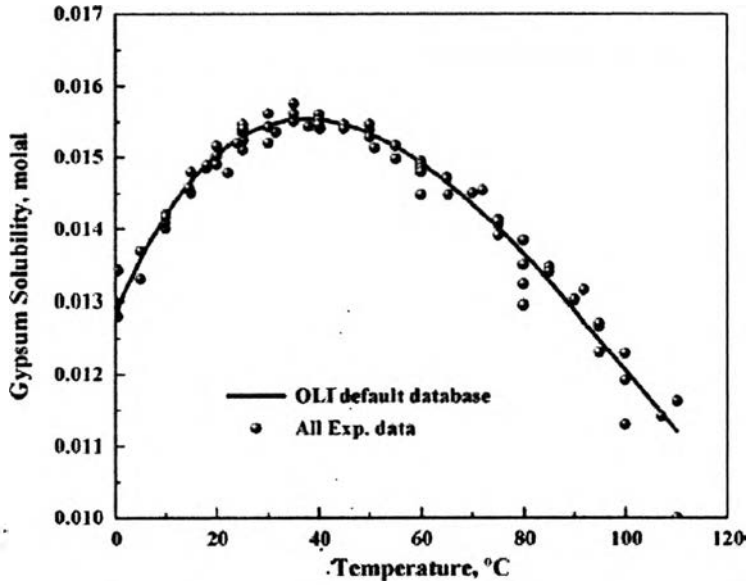

Figure B.1 Dihydrate solubility in H_2O vs. temperature. The curve is determined from the OLI default database (Azimi *et al.*, 2007)

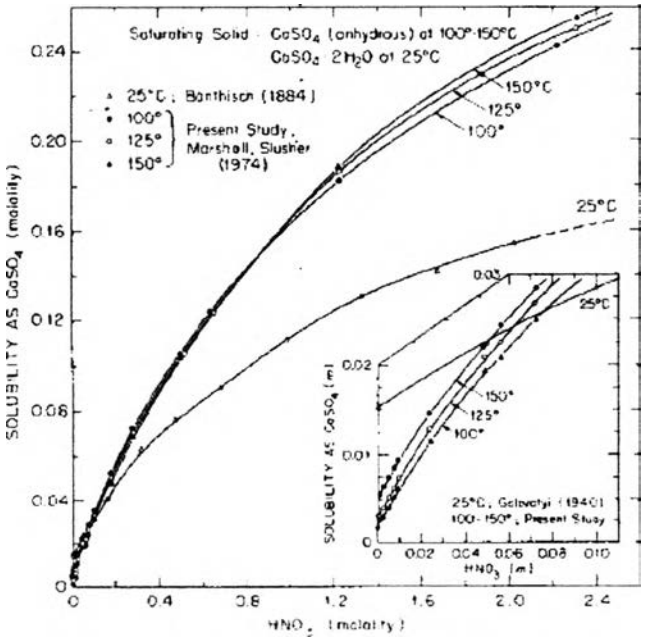

Figure B.2 Molal solubility of $CaSO_4 \cdot 2H_2O$ at 25°C and $CaSO_4$ (anhydrous) at 100-150°C in HNO_3-H_2O solutions, 0-2.4 molal (Marshall, *et al.* 1975)

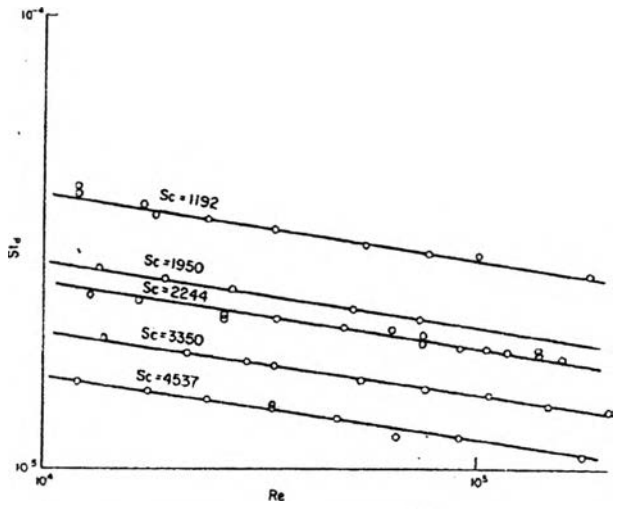

Figure B.3 Stanton number vs Reynolds number in fully developed flow (Schmidt number as parameter) (Berger *et al.*, 1977)

Table B.1 Properties of solutions at different NaOH concentrations and temperatures (Berger *et al.*, 1977)

NaOH (M)	Temp. (°C)	$\mu \times 10^3$ (kg·ms)	$\nu \times 10^6$ (m^2/s)	$D \times 10^{10}$ (m^2/s)	Sc	$\rho \times 10^{-3}$ (kg/m^3)
1.0	20.5	1.22	1.173	6.014	1950	1.04
1.0	30.5	0.97	0.9327	7.822	1192	1.04
2.0	25.5	1.345	1.245	5.548	2244	1.08
2.0	28.0	1.27	1.176	5.925	1985	1.08
2.0	40.0	0.995	0.9123	7.864	1160	1.08
4.0	24.5	2.26	1.948	3.291	5919	1.16
4.0	29.5	1.995	1.72	3.791	4837	1.16
4.0	35.0	1.73	1.491	4.451	3350	1.16

Appendix C Raw Data

This work measured the calcium concentration from AAS and analysed the characteristics of surfaces by taking the pictures. Moreover, runs were repeated at least twice in every condition of the experiment. The samples were measured for calcium concentration before the run, after the run and every 30 minutes. There are two different flow rates to test under each condition. The two repeating runs confirm the results in each flow rates. Samples were diluted from 10 ml to 250 ml in volumetric flask for initial samples and from 5 ml to 100 ml for other samples (10 samples every 30 minutes).

C.1 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 7 and 25°C

Table C.1 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 7 and 25°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.36	1.37	1.38	1.37	-	-	-
0, #2	1.38	1.38	1.39	1.38	-	-	-
average	1.37	1.38	1.39	1.38	34.42	0.00	-
1	1.74	1.78	1.79	1.77	35.40	0.98	0.84
2	1.73	1.78	1.78	1.76	35.27	0.85	0.72
3	1.74	1.77	1.77	1.76	35.20	0.78	0.67
4	1.77	1.78	1.79	1.78	35.60	1.18	1.00
5	1.76	1.79	1.78	1.78	35.53	1.12	0.95
6	1.77	1.78	1.79	1.78	35.60	1.18	1.00
7	1.77	1.76	1.79	1.77	35.47	1.05	0.89
8	1.80	1.80	1.79	1.80	35.93	1.52	1.29
9	1.80	1.80	1.78	1.79	35.87	1.45	1.23
10	1.80	1.79	1.79	1.79	35.87	1.45	1.23
average							0.98

Table C.2 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 7 and 25°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)			real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	Average			
0, #1	1.36	1.37	1.37	-	-	-
0, #2	1.37	1.37	1.37	-	-	-
average	1.37	1.37	1.37	34.19	0.00	-
1	1.76	1.76	1.76	35.20	1.01	0.86
2	1.77	1.74	1.76	35.10	0.91	0.77
3	1.76	1.76	1.76	35.20	1.01	0.86
4	1.77	1.75	1.76	35.20	1.01	0.86
5	1.76	1.75	1.76	35.10	0.91	0.77
6	1.79	1.76	1.78	35.50	1.31	1.11
7	1.78	1.76	1.77	35.40	1.21	1.03
8	1.77	1.77	1.77	35.40	1.21	1.03
9	1.78	1.77	1.78	35.50	1.31	1.11
10	1.78	1.77	1.78	35.50	1.31	1.11
average						0.95

Table C.3 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 7 and 25°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.45	1.36	1.37	1.39	-	-	-
0, #2	1.41	1.43	1.42	1.42	-	-	-
average	1.43	1.40	1.40	1.41	35.17	0.00	-
1	1.84	1.79	1.80	1.81	36.20	1.03	1.23
2	1.81	1.78	1.78	1.79	35.80	0.63	0.75
3	1.83	1.78	1.81	1.81	36.13	0.97	1.15
4	1.81	1.80	1.78	1.80	35.93	0.77	0.91
5	1.83	1.82	1.81	1.82	36.40	1.23	1.47
6	1.82	1.79	1.81	1.81	36.13	0.97	1.15
7	1.83	1.84	1.84	1.84	36.73	1.57	1.86
8	1.87	1.84	1.83	1.85	36.93	1.77	2.10
9	1.84	1.83	1.84	1.84	36.73	1.57	1.86
10	1.82	1.84	1.85	1.84	36.73	1.57	1.86
average							1.43

Table C.4 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 7 and 25°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.38	1.40	1.4	1.39	-	-	-
0, #2	1.39	1.41	1.42	1.41	-	-	-
average	1.39	1.41	1.41	1.40	35.00	0.00	-
1	1.78	1.81	1.82	1.80	36.07	1.07	1.27
2	1.78	1.83	1.82	1.81	36.20	1.20	1.43
3	1.77	1.82	1.82	1.80	36.07	1.07	1.27
4	1.78	1.82	1.84	1.81	36.27	1.27	1.51
5	1.79	1.82	1.83	1.81	36.27	1.27	1.51
6	1.79	1.82	1.82	1.81	36.20	1.20	1.43
7	1.81	1.82	1.82	1.82	36.33	1.33	1.59
8	1.80	1.82	1.84	1.82	36.40	1.40	1.66
9	1.82	1.84	1.84	1.83	36.67	1.67	1.98
10	1.82	1.83	1.84	1.83	36.60	1.60	1.90
average							1.55

C.2 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 3 and 25°C

Table C.5 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 3 and 25°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)			real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	Average			
0, #1	1.43	1.44	1.44	-	-	-
0, #2	1.43	1.44	1.44	-	-	-
average	1.43	1.44	1.44	35.88	0.00	-
1	1.86	1.86	1.86	37.20	1.33	1.13
2	1.83	1.83	1.83	36.60	0.73	0.62
3	1.84	1.84	1.84	36.80	0.92	0.79
4	1.85	1.84	1.85	36.90	1.03	0.87
5	1.86	1.86	1.86	37.20	1.33	1.13
6	1.87	1.86	1.87	37.30	1.43	1.21
7	1.87	1.86	1.87	37.30	1.43	1.21
8	1.86	1.87	1.87	37.30	1.43	1.21
9	1.87	1.87	1.87	37.40	1.53	1.30
10	1.87	1.87	1.87	37.40	1.53	1.30
average						1.07

Table C.6 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 3 and 25°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.37	1.36	1.33	1.35	-	-	-
0, #2	1.39	1.38	1.32	1.36	-	-	-
average	1.38	1.37	1.33	1.36	33.96	0.00	-
1	1.78	1.76	1.75	1.76	35.27	1.31	1.11
2	1.76	1.73	1.74	1.74	34.87	0.91	0.77
3	1.76	1.74	1.74	1.75	34.93	0.98	0.83
4	1.78	1.74	1.72	1.75	34.93	0.98	0.83
5	1.78	1.76	1.72	1.75	35.07	1.11	0.94
6	1.78	1.77	1.72	1.76	35.13	1.18	1.00
7	1.82	1.79	1.74	1.78	35.67	1.71	1.45
8	1.81	1.80	1.74	1.78	35.67	1.71	1.45
9	1.79	1.79	1.75	1.78	35.53	1.58	1.34
10	1.80	1.80	1.75	1.78	35.67	1.71	1.45
average							1.12

Table C.7 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 3 and 25°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)			real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	Average			
0, #1	1.39	1.36	1.38	-	-	-
0, #2	1.38	1.39	1.39	-	-	-
average	1.39	1.38	1.38	34.50	0.00	-
1	1.80	1.78	1.79	35.80	1.30	1.55
2	1.78	1.77	1.78	35.50	1.00	1.19
3	1.78	1.77	1.78	35.50	1.00	1.19
4	1.78	1.78	1.78	35.60	1.10	1.31
5	1.79	1.77	1.78	35.60	1.10	1.31
6	1.80	1.79	1.80	35.90	1.40	1.66
7	1.81	1.8	1.81	36.10	1.60	1.90
8	1.80	1.8	1.80	36.00	1.50	1.78
9	1.80	1.8	1.80	36.00	1.50	1.78
10	1.81	1.8	1.81	36.10	1.60	1.90
average						1.56

Table C.8 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 3 and 25°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.41	1.45	1.45	1.44	-	-	-
0, #2	1.44	1.45	1.45	1.45	-	-	-
average	1.43	1.45	1.45	1.44	36.04	0.00	-
1	1.84	1.88	1.88	1.87	37.33	1.29	1.54
2	1.80	1.85	1.84	1.83	36.73	0.69	0.82
3	1.81	1.83	1.83	1.82	36.60	0.56	0.66
4	1.81	1.83	1.83	1.82	36.60	0.56	0.66
5	1.81	1.87	1.87	1.85	37.00	0.96	1.14
6	1.84	1.91	1.91	1.89	37.67	1.63	1.93
7	1.87	1.90	1.91	1.89	37.80	1.76	2.09
8	1.87	1.90	1.92	1.90	37.93	1.89	2.25
9	1.91	1.91	1.92	1.91	38.07	2.03	2.41
10	1.90	1.90	1.91	1.90	38.00	1.96	2.33
average							1.58

C.3 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 10 and 25°C

Table C.9 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 10 and 25°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)	real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
0, #1	0.76	-	-	-
0, #2	0.74	-	-	-
average	0.75	18.70	0.00	-
1	1.04	20.80	2.10	1.78
2	0.98	19.60	0.90	0.76
3	0.98	19.60	0.90	0.76
4	0.97	19.40	0.70	0.59
5	0.97	19.40	0.70	0.59
6	0.96	19.20	0.50	0.42
7	0.96	19.20	0.50	0.42
8	0.98	19.60	0.90	0.76
9	0.96	19.20	0.50	0.42
10	0.98	19.60	0.90	0.76
average				0.73

Table C.10 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 10 and 25°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	0.68	0.68	0.65	0.67	-	-	-
0, #2	0.66	0.68	0.63	0.66	-	-	-
average	0.67	0.68	0.64	0.66	16.58	0.00	-
1	0.96	0.97	0.96	0.96	19.27	2.68	2.28
2	0.94	0.95	0.93	0.94	18.80	2.22	1.88
3	0.85	0.85	0.83	0.84	16.87	0.28	0.24
4	0.84	0.83	0.84	0.84	16.73	0.15	0.13
5	0.84	0.84	0.83	0.84	16.73	0.15	0.13
6	0.84	0.86	0.82	0.84	16.80	0.22	0.18
7	0.87	0.86	0.84	0.86	17.13	0.55	0.47
8	0.88	0.87	0.85	0.87	17.33	0.75	0.64
9	0.85	0.85	0.85	0.85	17.00	0.42	0.35
10	0.85	0.86	0.85	0.85	17.07	0.48	0.41
average							0.67

Table C.11 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 10 and 25°C

Sample (No.)	Calcium concentration from AAS (mg/l)			real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	Average			
0, #1	0.66	0.67	0.67	-	-	-
0, #2	0.65	0.66	0.66	-	-	-
average	0.66	0.67	0.66	16.60	0.00	-
1	0.95	0.94	0.95	18.90	2.30	2.73
2	0.92	0.92	0.92	18.40	1.80	2.14
3	0.87	0.89	0.88	17.60	1.00	1.19
4	0.88	0.89	0.89	17.70	1.10	1.31
5	0.88	0.87	0.88	17.50	0.90	1.07
6	0.88	0.89	0.89	17.70	1.10	1.31
7	0.87	0.87	0.87	17.40	0.80	0.95
8	0.88	0.86	0.87	17.40	0.80	0.95
9	0.88	0.87	0.88	17.50	0.90	1.07
10	0.87	0.89	0.88	17.60	1.00	1.19
average						1.39

C.4 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 7 and 10°C

Table C.12 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 7 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.23	1.25	1.26	1.25	-	-	-
0, #2	1.25	1.26	1.25	1.25	-	-	-
average	1.24	1.26	1.26	1.25	31.25	0.00	-
1	1.59	1.59	1.60	1.59	31.87	0.62	0.52
2	1.58	1.59	1.60	1.59	31.80	0.55	0.47
3	1.61	1.58	1.59	1.59	31.87	0.62	0.52
4	1.62	1.59	1.59	1.60	32.00	0.75	0.64
5	1.59	1.58	1.59	1.59	31.73	0.48	0.41
6	1.59	1.59	1.60	1.59	31.87	0.62	0.52
7	1.62	1.61	1.60	1.61	32.20	0.95	0.81
8	1.59	1.59	1.59	1.59	31.80	0.55	0.47
9	1.58	1.59	1.59	1.59	31.73	0.48	0.41
10	1.62	1.58	1.59	1.60	31.93	0.68	0.58
average							0.54

Table C.13 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 7 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.36	1.34	1.34	1.35	-	-	-
0, #2	1.35	1.35	1.34	1.35	-	-	-
average	1.36	1.35	1.34	1.35	33.67	0.00	-
1	1.72	1.73	1.71	1.72	34.40	0.73	0.62
2	1.71	1.71	1.71	1.71	34.20	0.53	0.45
3	1.71	1.71	1.71	1.71	34.20	0.53	0.45
4	1.72	1.71	1.71	1.71	34.27	0.60	0.51
5	1.72	1.72	1.72	1.72	34.40	0.73	0.62
6	1.73	1.72	1.71	1.72	34.40	0.73	0.62
7	1.73	1.70	1.71	1.71	34.27	0.60	0.51
8	1.73	1.70	1.71	1.71	34.27	0.60	0.51
9	1.73	1.71	1.72	1.72	34.40	0.73	0.62
10	1.73	1.70	1.71	1.71	34.27	0.60	0.51
average							0.54

Table C.14 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 7 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)			real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	Average			
0, #1	1.36	1.36	1.36	-	-	-
0, #2	1.36	1.35	1.36	-	-	-
average	1.36	1.36	1.36	33.94	0.00	-
1	1.72	1.72	1.72	34.40	0.46	0.55
2	1.71	1.72	1.72	34.30	0.36	0.43
3	1.72	1.73	1.73	34.50	0.56	0.67
4	1.72	1.72	1.72	34.40	0.46	0.55
5	1.73	1.72	1.73	34.50	0.56	0.67
6	1.73	1.73	1.73	34.60	0.66	0.79
7	1.73	1.73	1.73	34.60	0.66	0.79
8	1.73	1.74	1.74	34.70	0.76	0.91
9	1.74	1.74	1.74	34.80	0.86	1.03
10	1.73	1.74	1.74	34.70	0.76	0.91
average						0.73

Table C.15 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 7 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.39	1.38	1.29	1.35	-	-	-
0, #2	1.30	1.39	1.30	1.33	-	-	-
average	1.35	1.39	1.30	1.34	33.54	0.00	-
1	1.72	1.73	1.65	1.70	34.00	0.46	0.54
2	1.71	1.74	1.66	1.70	34.07	0.52	0.62
3	1.71	1.72	1.65	1.69	33.87	0.32	0.39
4	1.72	1.71	1.65	1.69	33.87	0.32	0.39
5	1.71	1.75	1.66	1.71	34.13	0.59	0.70
6	1.73	1.75	1.67	1.72	34.33	0.79	0.94
7	1.73	1.74	1.67	1.71	34.27	0.72	0.86
8	1.74	1.74	1.68	1.72	34.40	0.86	1.02
9	1.72	1.75	1.68	1.72	34.33	0.79	0.94
10	1.72	1.75	1.69	1.72	34.40	0.86	1.02
average							0.74

C.5 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 3 and 10°C

Table C.16 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 3 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.37	1.36	1.38	1.37	-	-	-
0, #2	1.38	1.36	1.37	1.37	-	-	-
average	1.38	1.36	1.38	1.37	34.25	0.00	-
1	1.76	1.77	1.77	1.77	35.33	1.08	0.92
2	1.75	1.76	1.75	1.75	35.07	0.82	0.69
3	1.74	1.75	1.75	1.75	34.93	0.68	0.58
4	1.74	1.74	1.75	1.74	34.87	0.62	0.52
5	1.75	1.74	1.75	1.75	34.93	0.68	0.58
6	1.74	1.74	1.75	1.74	34.87	0.62	0.52
7	1.75	1.75	1.76	1.75	35.07	0.82	0.69
8	1.74	1.74	1.75	1.74	34.87	0.62	0.52
9	1.74	1.74	1.75	1.74	34.87	0.62	0.52
10	1.74	1.75	1.76	1.75	35.00	0.75	0.64
average							0.62

Table C.17 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 3 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)					real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	#4	Average			
0, #1	1.36	1.36	1.35	1.37	1.36	-	-	-
0, #2	1.39	1.37	1.37	1.35	1.37	-	-	-
average	1.38	1.37	1.36	1.36	1.37	34.17	0.00	-
1	1.75	1.75	1.75	1.75	1.75	35.00	0.83	0.71
2	1.73	1.72	1.73	1.74	1.73	34.60	0.43	0.37
3	1.74	1.73	1.73	1.73	1.73	34.65	0.48	0.41
4	1.76	1.73	1.73	1.74	1.74	34.80	0.63	0.54
5	1.74	1.76	1.75	1.75	1.75	35.00	0.83	0.71
6	1.75	1.75	1.76	1.75	1.75	35.05	0.88	0.75
7	1.76	1.74	1.75	1.75	1.75	35.00	0.83	0.71
8	1.75	1.74	1.75	1.76	1.75	35.00	0.83	0.71
9	1.75	1.74	1.75	1.75	1.75	34.95	0.78	0.67
10	1.76	1.75	1.76	1.75	1.76	35.10	0.93	0.79
average								0.64

Table C.18 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 3 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.46	1.46	1.44	1.45	-	-	-
0, #2	1.48	1.44	1.44	1.45	-	-	-
average	1.47	1.45	1.44	1.45	36.33	0.00	-
1	1.87	1.86	1.86	1.86	37.27	0.93	1.11
2	1.84	1.84	1.83	1.84	36.73	0.40	0.48
3	1.85	1.84	1.83	1.84	36.80	0.47	0.55
4	1.87	1.84	1.84	1.85	37.00	0.67	0.79
5	1.86	1.84	1.84	1.85	36.93	0.60	0.71
6	1.86	1.85	1.84	1.85	37.00	0.67	0.79
7	1.86	1.85	1.84	1.85	37.00	0.67	0.79
8	1.86	1.86	1.86	1.86	37.20	0.87	1.03
9	1.86	1.86	1.85	1.86	37.13	0.80	0.95
10	1.86	1.86	1.86	1.86	37.20	0.87	1.03
average							0.82

Table C.19 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 3 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	1.38	1.38	1.37	1.38	-	-	-
0, #2	1.38	1.37	1.37	1.37	-	-	-
average	1.38	1.38	1.37	1.38	34.38	0.00	-
1	1.41	1.42	1.41	1.41	35.33	0.96	1.14
2	1.40	1.39	1.39	1.39	34.83	0.46	0.54
3	1.41	1.40	1.39	1.40	35.00	0.62	0.74
4	1.41	1.39	1.40	1.40	35.00	0.62	0.74
5	1.41	1.41	1.40	1.41	35.17	0.79	0.94
6	1.41	1.40	1.40	1.40	35.08	0.71	0.84
7	1.40	1.41	1.40	1.40	35.08	0.71	0.84
8	1.41	1.41	1.40	1.41	35.17	0.79	0.94
9	1.41	1.42	1.40	1.41	35.25	0.88	1.04
10	1.42	1.41	1.40	1.41	35.25	0.88	1.04
average							0.88

C.6 The Raw Data for Run Experiment under Condition, $pH_{25°C}$ 10 and 10°C

Table C.20 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 10 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	0.58	0.59	0.59	0.59	-	-	-
0, #2	0.59	0.59	0.59	0.59	-	-	-
average	0.59	0.59	0.59	0.59	14.71	0.00	-
1	0.79	0.79	0.78	0.79	15.73	1.03	0.87
2	0.76	0.77	0.77	0.77	15.33	0.63	0.53
3	0.78	0.78	0.78	0.78	15.60	0.89	0.76
4	0.77	0.77	0.77	0.77	15.40	0.69	0.59
5	0.77	0.77	0.77	0.77	15.40	0.69	0.59
6	0.75	0.75	0.76	0.75	15.07	0.36	0.30
7	0.76	0.76	0.75	0.76	15.13	0.43	0.36
8	0.76	0.77	0.76	0.76	15.27	0.56	0.47
9	0.77	0.76	0.76	0.76	15.27	0.56	0.47
10	0.77	0.77	0.76	0.77	15.33	0.63	0.53
average							0.55

Table C.21 Raw data for run at flow rate 25 LPM, $pH_{25°C}$ 10 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)				real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	Average			
0, #1	0.58	0.58	0.59	0.58	-	-	-
0, #2	0.59	0.59	0.57	0.58	-	-	-
average	0.59	0.59	0.58	0.58	14.58	0.00	-
1	0.79	0.79	0.79	0.79	15.80	1.22	1.03
2	0.77	0.77	0.76	0.77	15.33	0.75	0.64
3	0.77	0.77	0.75	0.76	15.27	0.68	0.58
4	0.76	0.76	0.74	0.75	15.07	0.48	0.41
5	0.75	0.75	0.75	0.75	15.00	0.42	0.35
6	0.76	0.76	0.74	0.75	15.07	0.48	0.41
7	0.76	0.75	0.74	0.75	15.00	0.42	0.35
8	0.75	0.76	0.74	0.75	15.00	0.42	0.35
9	0.77	0.76	0.75	0.76	15.20	0.62	0.52
10	0.77	0.76	0.76	0.76	15.27	0.68	0.58
average							0.52

Table C.22 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 10 and 10°C (the first run)

Sample (No.)	Calcium concentration from AAS (mg/l)					real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	#4	Average			
0, #1	0.63	0.62	0.63	0.63	0.63	-	-	-
0, #2	0.63	0.64	0.63	0.63	0.63	-	-	-
average	0.63	0.63	0.63	0.63	0.63	15.75	0.00	-
1	0.85	0.83	0.84	0.85	0.84	16.85	1.10	1.31
2	0.82	0.80	0.81	0.82	0.81	16.25	0.50	0.59
3	0.82	0.80	0.80	0.81	0.81	16.15	0.40	0.48
4	0.83	0.81	0.81	0.82	0.82	16.35	0.60	0.71
5	0.83	0.80	0.82	0.81	0.82	16.30	0.55	0.65
6	0.84	0.81	0.81	0.82	0.82	16.40	0.65	0.77
7	0.82	0.80	0.81	0.82	0.81	16.25	0.50	0.59
8	0.84	0.81	0.82	0.82	0.82	16.45	0.70	0.83
9	0.83	0.80	0.81	0.82	0.82	16.30	0.55	0.65
10	0.83	0.81	0.82	0.82	0.82	16.40	0.65	0.77
average								0.74

Table C.23 Raw data for run at flow rate 35 LPM, $pH_{25°C}$ 10 and 10°C (the second run)

Sample (No.)	Calcium concentration from AAS (mg/l)					real Ca conc. (mg/l)	Difference in Ca conc. (mg/l)	Dissolution Rate ($g/m^2 \cdot min$)
	#1	#2	#3	#4	Average			
0, #1	0.63	0.61	0.61	0.58	0.61	-	-	-
0, #2	0.61	0.61	0.61	0.58	0.60	-	-	-
average	0.62	0.61	0.61	0.58	0.61	15.13	0.00	-
1	0.80	0.82	0.81	0.79	0.81	16.10	0.98	1.16
2	0.79	0.80	0.80	0.77	0.79	15.80	0.68	0.80
3	0.79	0.80	0.79	0.78	0.79	15.80	0.68	0.80
4	0.78	0.80	0.80	0.77	0.79	15.75	0.63	0.74
5	0.78	0.80	0.79	0.77	0.79	15.70	0.57	0.68
6	0.78	0.80	0.79	0.77	0.79	15.70	0.57	0.68
7	0.77	0.78	0.78	0.77	0.78	15.50	0.38	0.45
8	0.78	0.79	0.78	0.76	0.78	15.55	0.43	0.51
9	0.79	0.79	0.78	0.78	0.79	15.70	0.58	0.68
10	0.78	0.80	0.78	0.78	0.79	15.70	0.58	0.68
average								0.72

Appendix D The Development of Scallops with Time

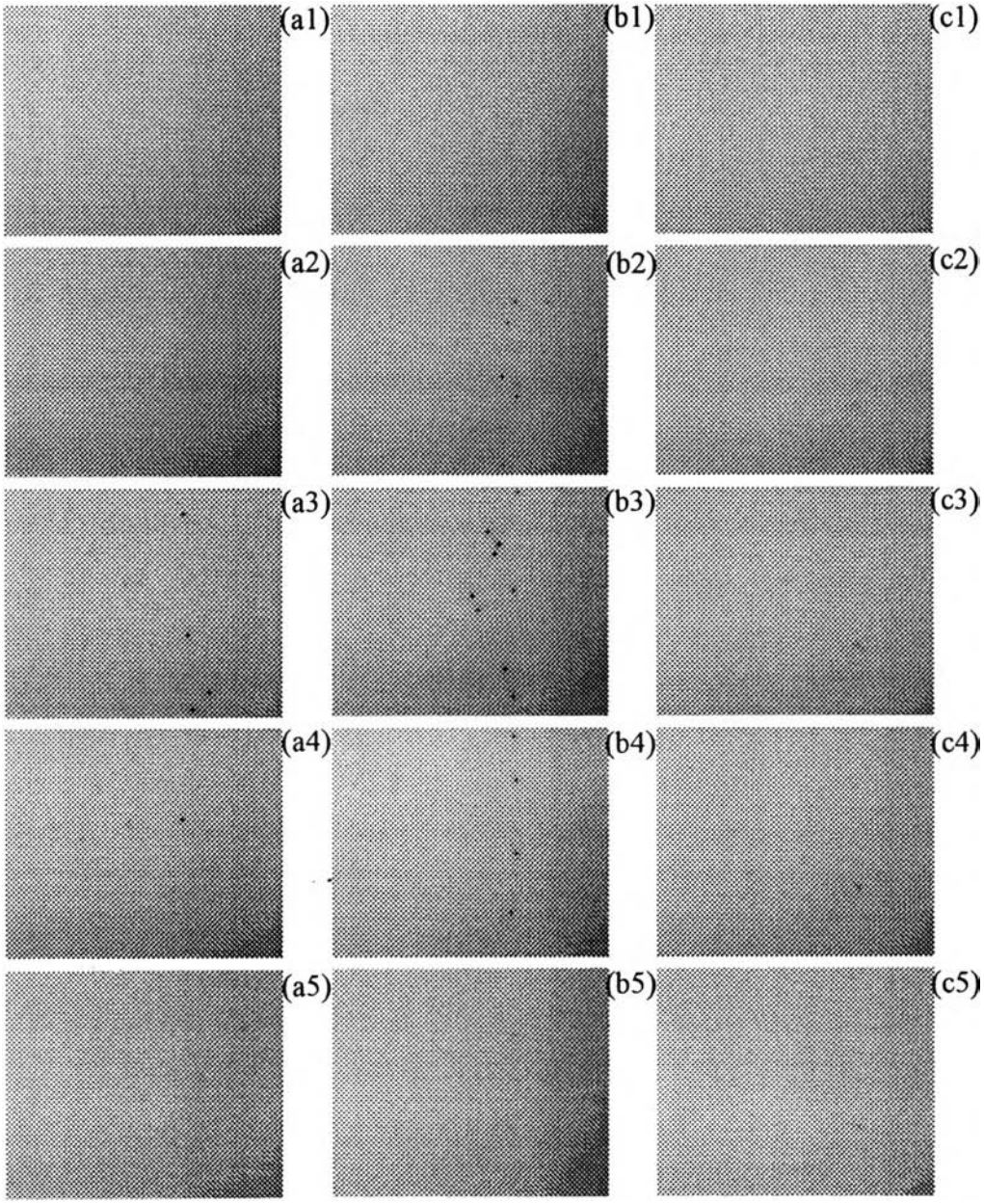

Figure D.1 The scallop surface development at every hour at 25 LPM and 10°C under different conditions: (a1-5) $pH_{25°C}$ 3, (b1-5) $pH_{25°C}$ 7 and (c1-5) $pH_{25°C}$ 10

Appendix E The Results from SEM/EDX

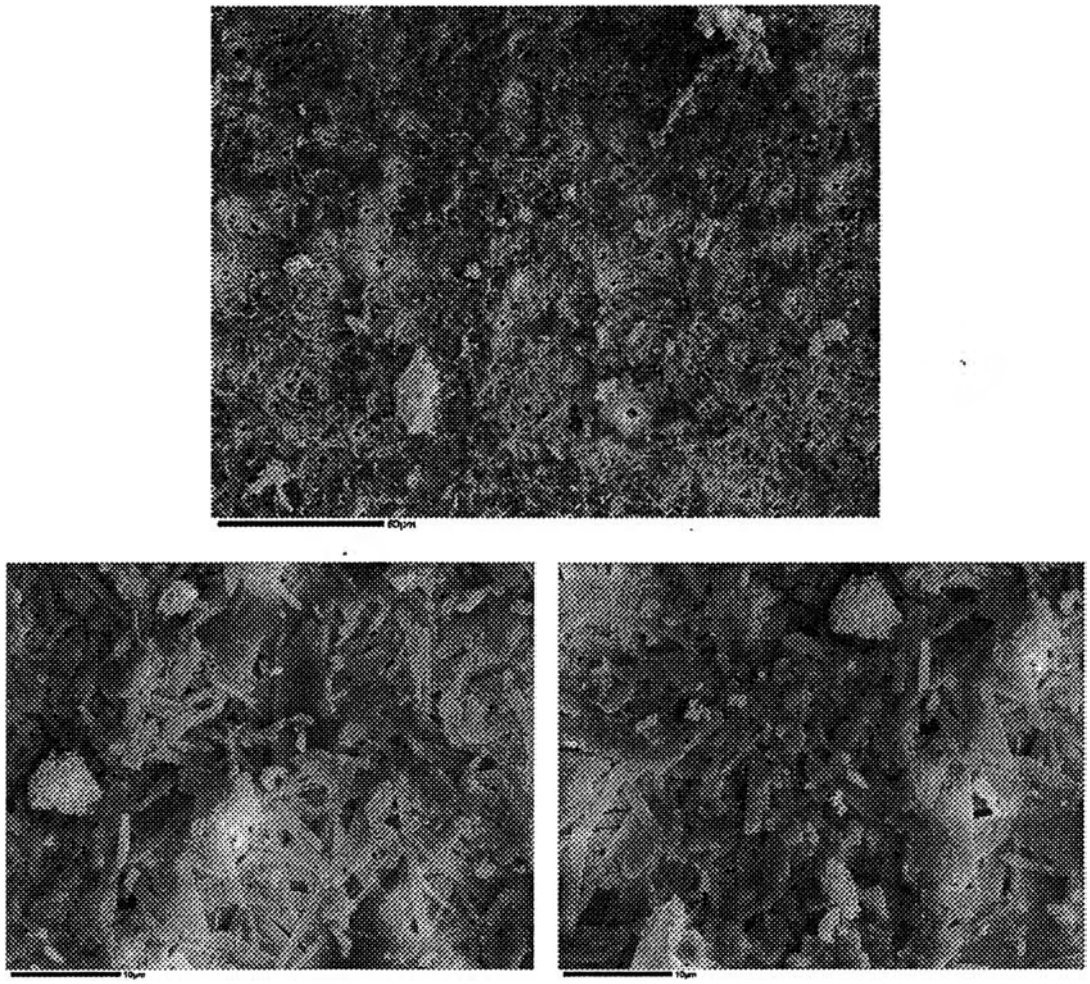

Figure E.1 The SEM images for the plaster conduit before run

Table E.1 The composition of plaster before run

Test Area	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	ClO_0	K_2O	CaO	FeO	Total
1	0.17	0.19	0.79	0.28	44.71	0.24	0.09	32.83	0.83	80.13
2	0.09	0.07	0.14	0.29	47.52	0.15	0.05	34.37	0	82.68
3	4.08	0.71	12.5	0.62	16.85	3.36	0.07	31.04	13.4	82.61
Ave.	1.45	0.32	4.49	0.40	36.36	1.25	0.07	32.75	4.73	81.81

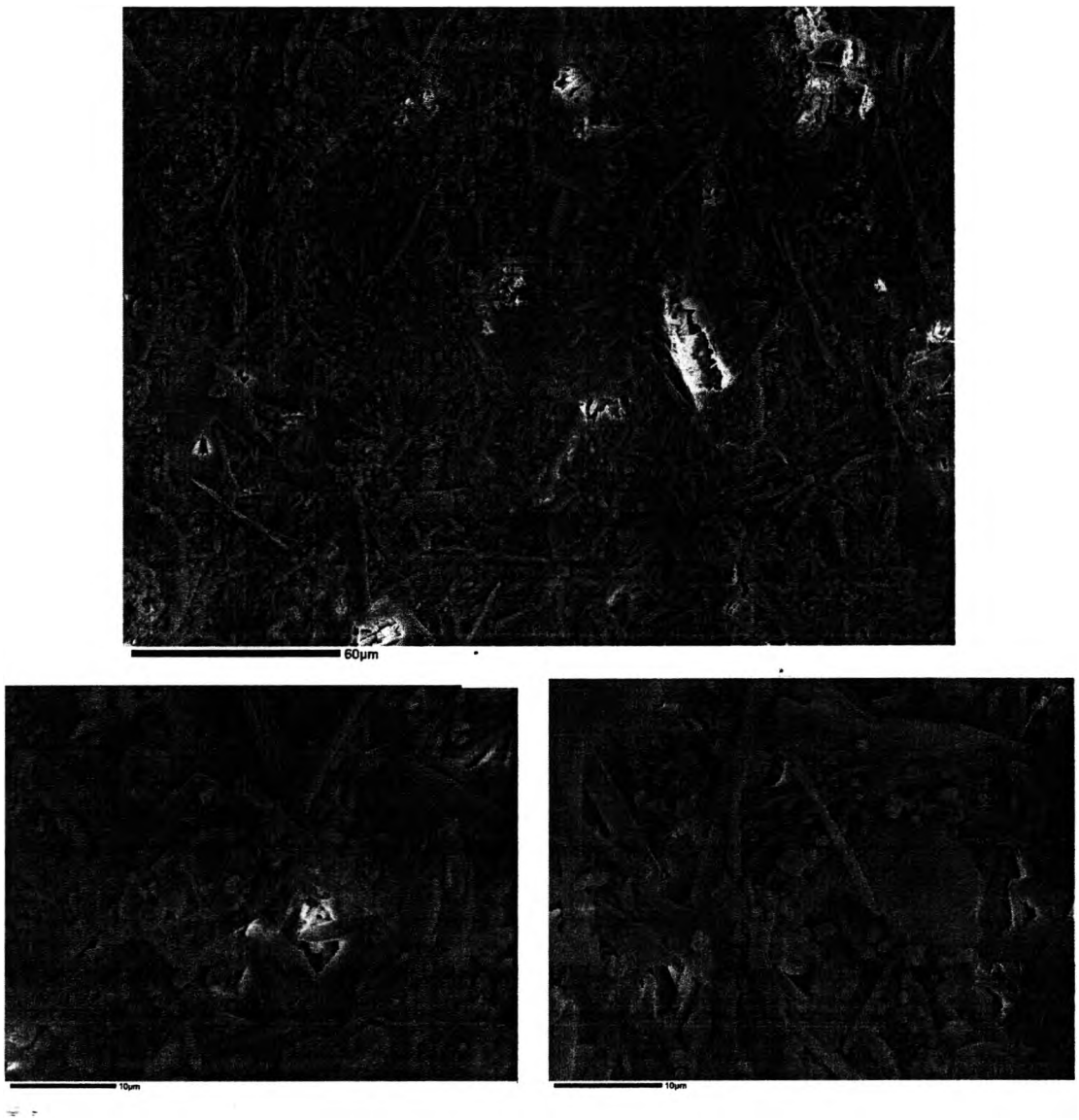

Figure E.2 The SEM images for the plaster conduit after run under 25 LPM, $pH_{25°C}$ 10 and 25°C

Table E.2 The composition of plaster after run under 25 LPM, $pH_{25°C}$ 10 and 25°C

Test Area	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	ClO_0	K_2O	CaO	FeO	Total
1	0.2	7.99	0.97	2.32	18.19	0.02	0.39	31.81	0.65	62.52
2	0.1	1.21	0.74	1.59	37.6	0	0.21	30.33	0.07	71.84
Ave.	0.15	4.60	0.86	1.96	27.90	0.01	0.30	31.07	0.36	67.18

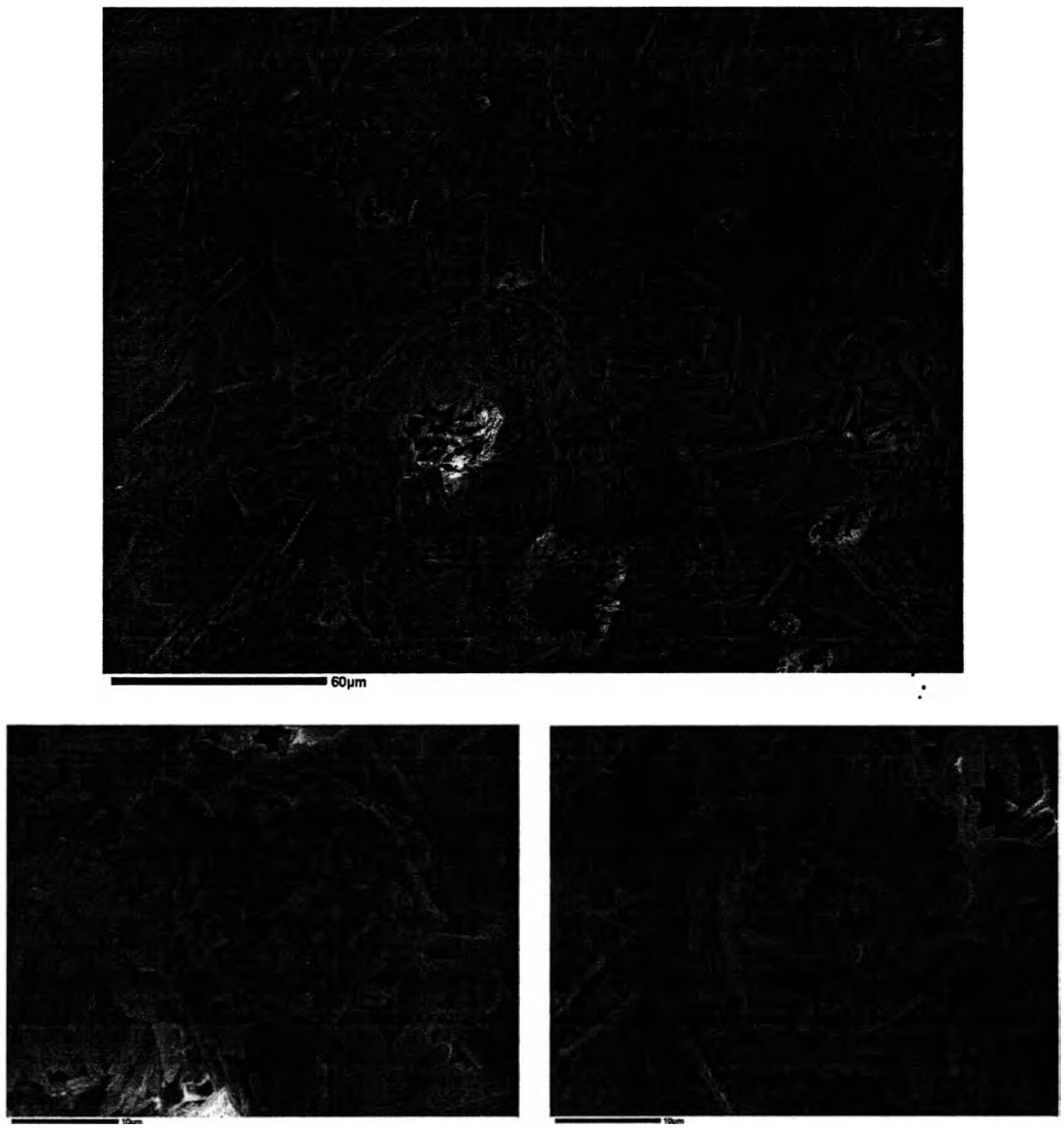

Figure E.3 The SEM images for the plaster conduit after run under 35 LPM, $pH_{25°C}$ 7 and 25°C

Table E.3 The composition of plaster after run under 35 LPM, $pH_{25°C}$ 7 and 25°C

Test Area	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	ClO_0	K_2O	CaO	FeO	Total
1	0.09	2.88	1.5	9.68	22.94	0.05	0.47	23.76	1.34	62.73
2	0.45	14.71	9.44	14.75	1.28	0.15	2.16	24.33	0.76	68.04
3	0.48	26.36	0.58	1.05	0.76	0.03	0.05	33.26	0.05	62.62
Ave.	0.34	14.65	3.84	8.49	8.33	0.08	0.89	27.12	0.72	64.46

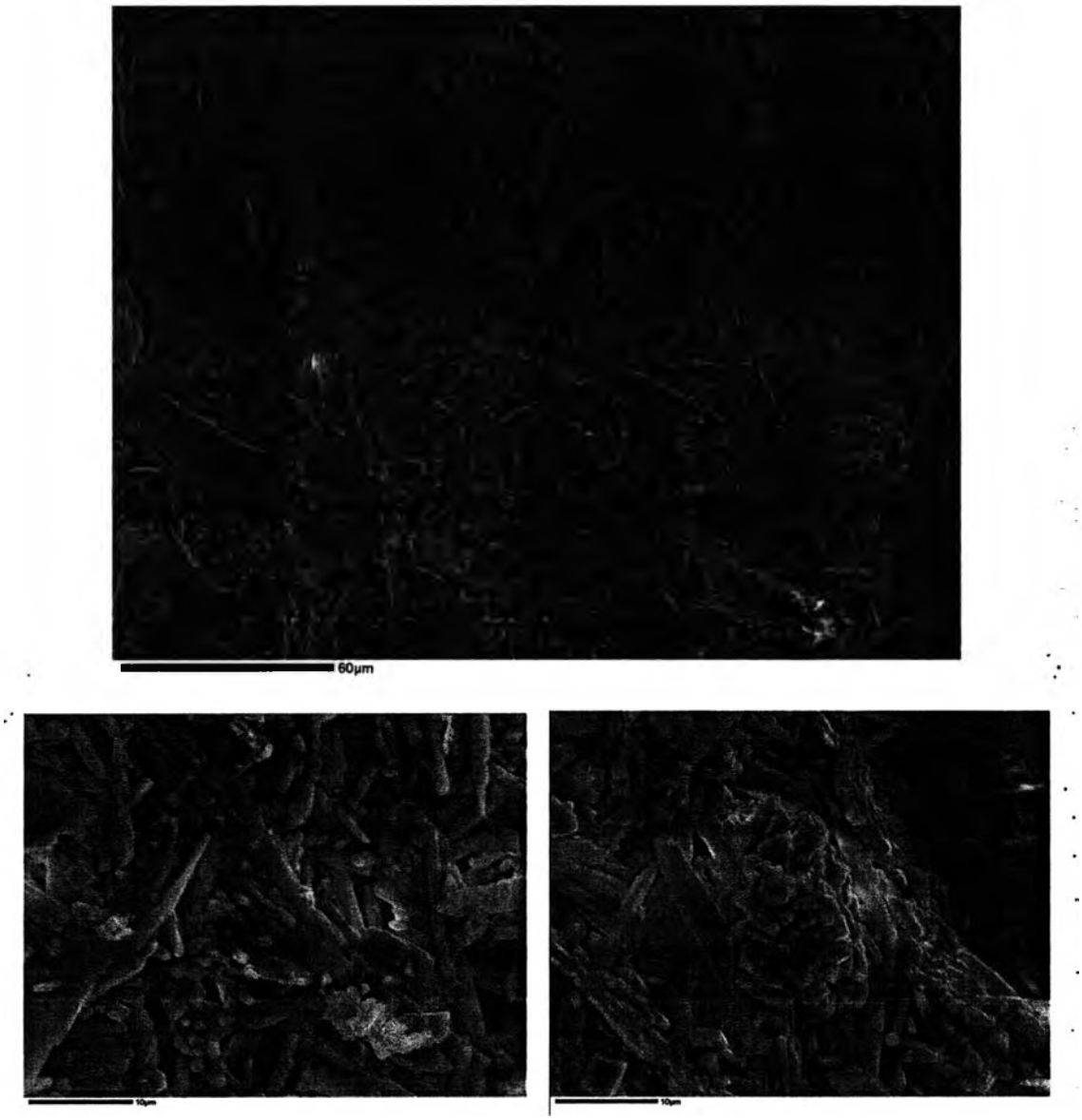

Figure E.4 The SEM images for the plaster conduit after run under 25 LPM, $pH_{25°C}$ 3 and 25°C

Table E.4 The composition of plaster after run under 25 LPM, $pH_{25°C}$ 3 and 25°C

Test Area	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	ClO_0	K_2O	CaO	FeO	Total
1	0.09	1.6	0.98	2.54	30.1	0	0.30	26.2	0.41	62.2
2	0.09	2.46	1.21	2.85	35.3	0	0.35	28.5	0.17	71.0
3	0.03	4.46	0.78	1.81	26.6	0.02	0.27	28.4	0	62.4
Ave.	0.07	2.84	0.99	2.40	30.69	0.01	0.31	27.69	0.19	65.19

Appendix F Dissolution Rate Along the Pipe and Dissolution Coefficient

F.1 Dissolution Rate Along the Pipe

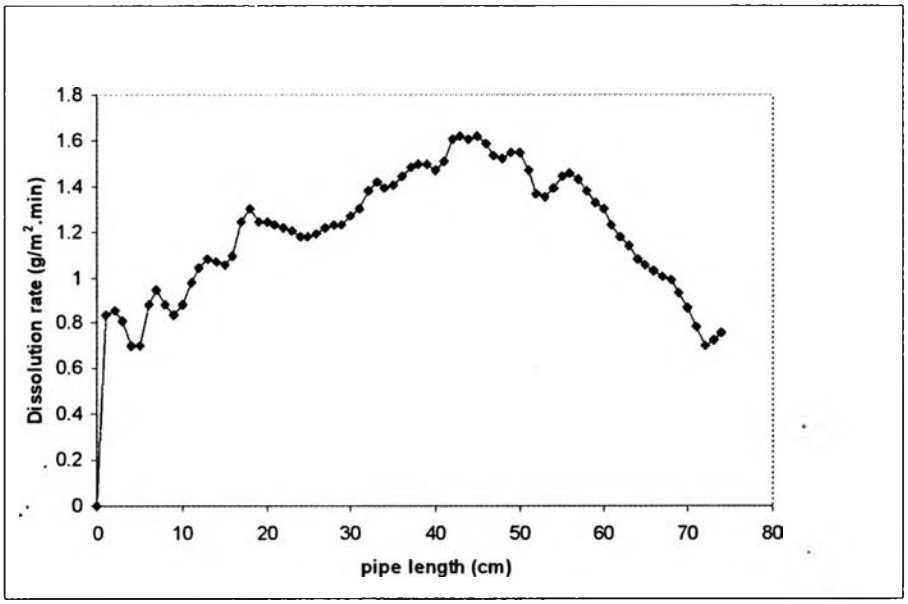

Figure F.1 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 25°C and 25 LPM (the second run)

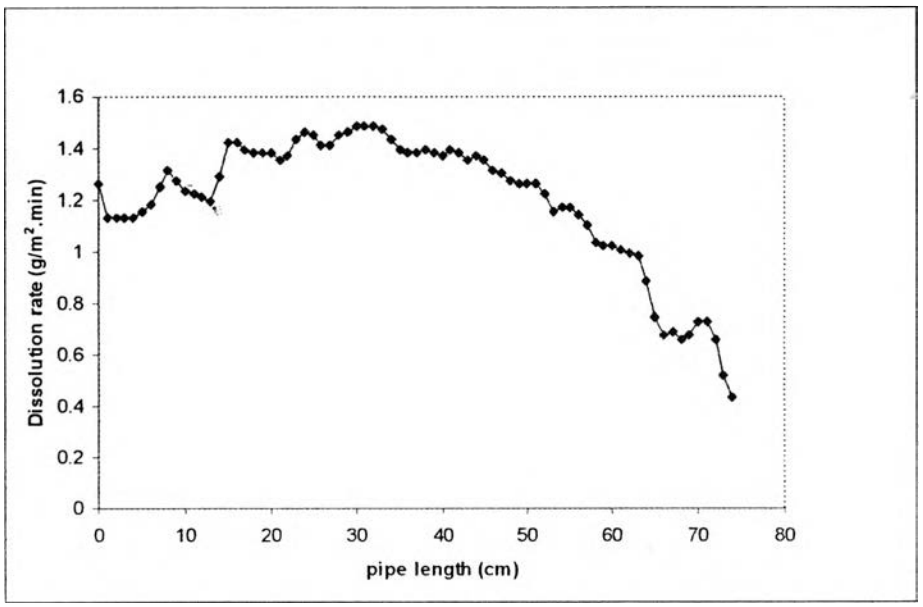

Figure F.2 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 7, 25°C and 25 LPM (the second run)

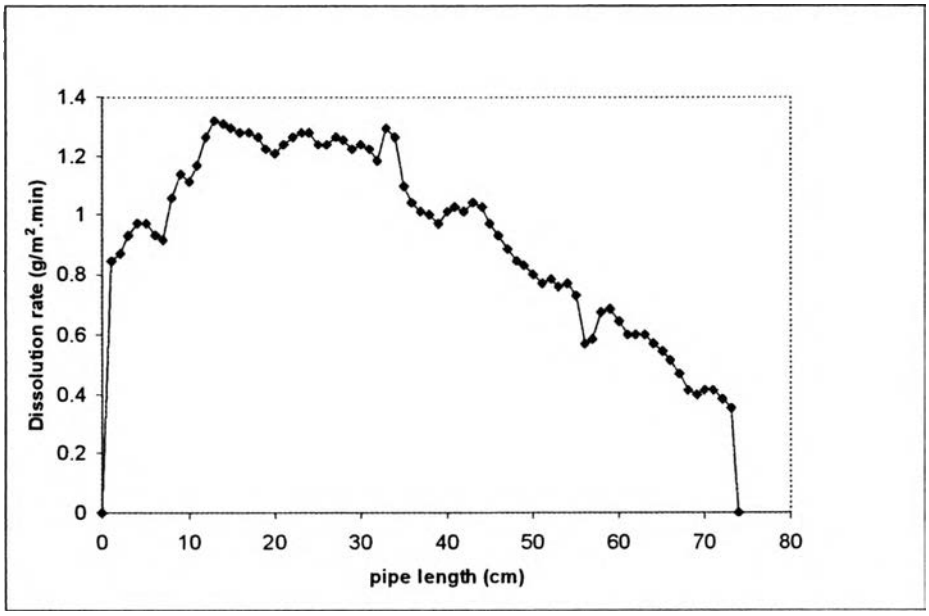

Figure F.3 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 25°C and 25 LPM (the second run)

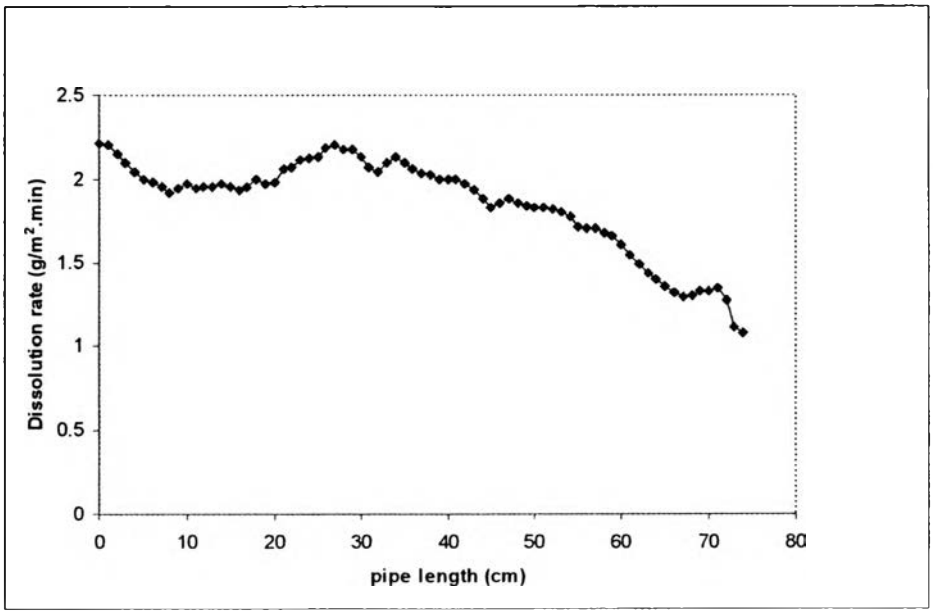

Figure F.4 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 25°C and 35 LPM (the first run)

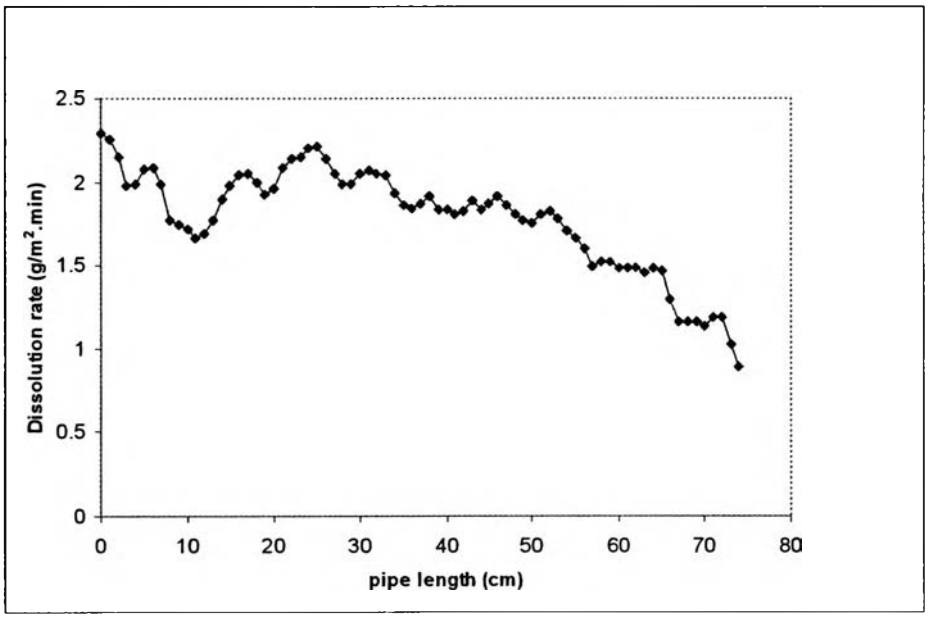

Figure F.5 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 25°C and 35 LPM (the second run)

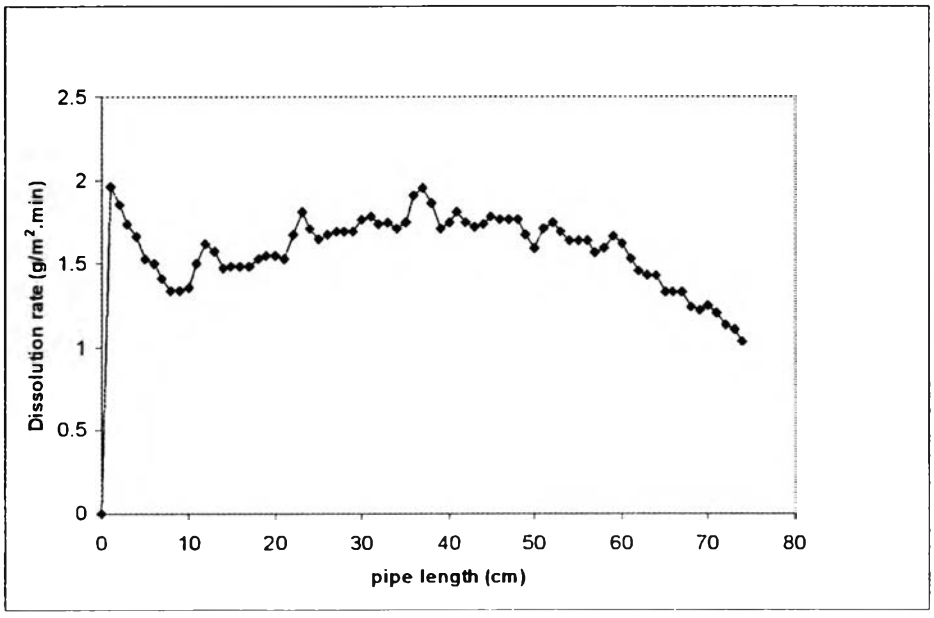

Figure F.6 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 7, 25°C and 35 LPM (the first run)

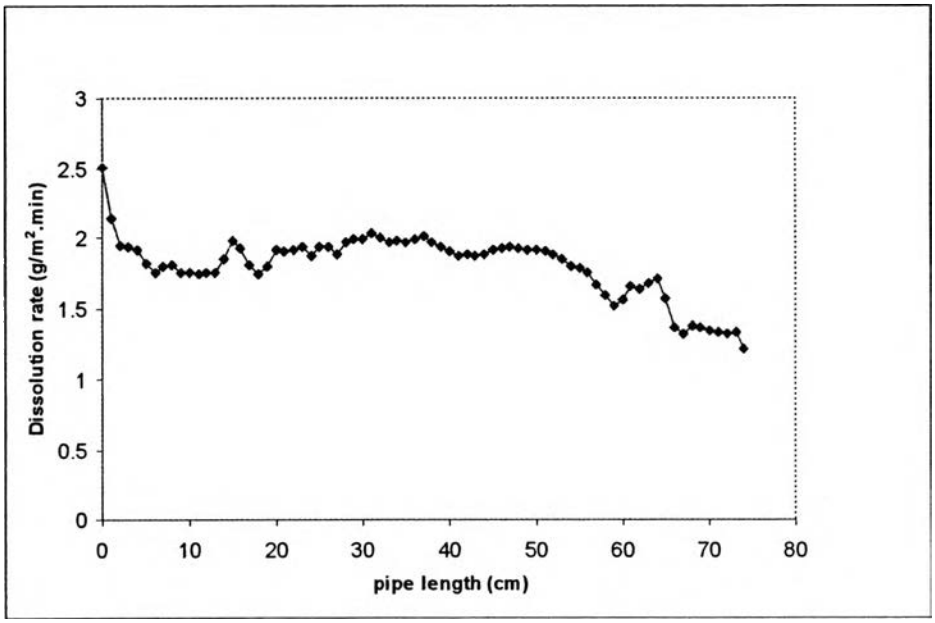

Figure F.7 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 7, 25°C and 35 LPM (the second run)

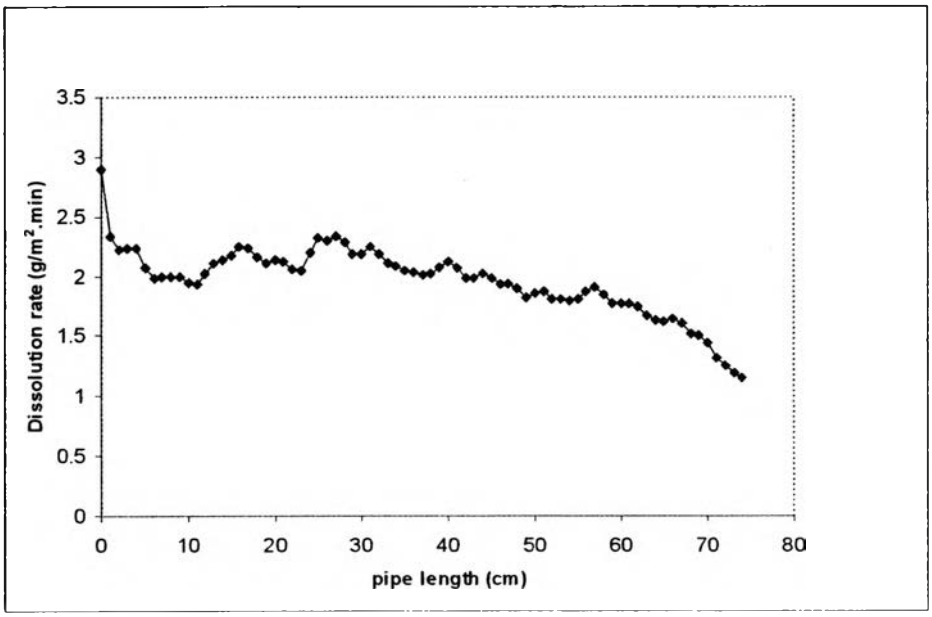

Figure F.8 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 25°C and 35 LPM (the first run)

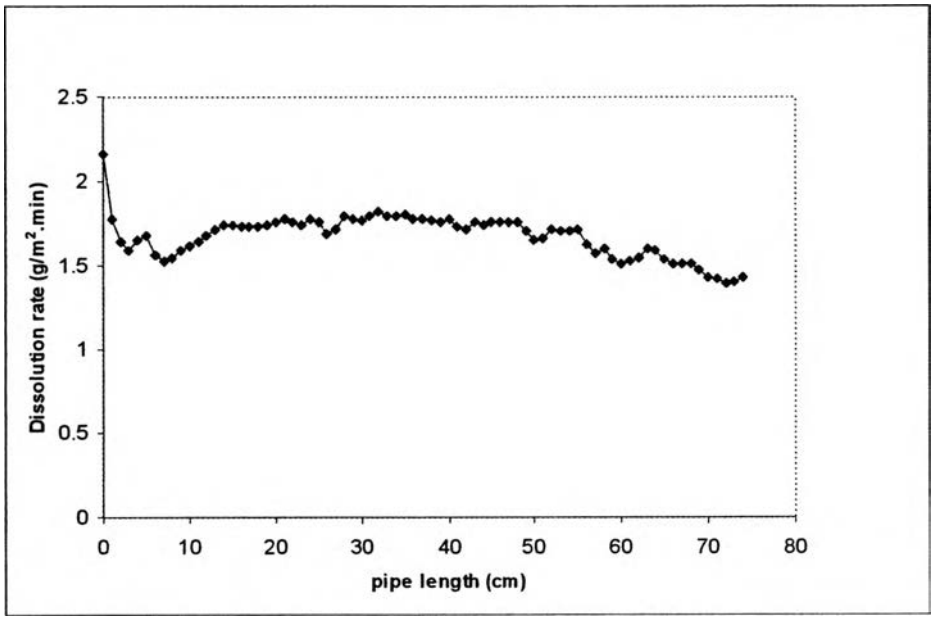

Figure F.9 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 25°C and 35 LPM (the second run)

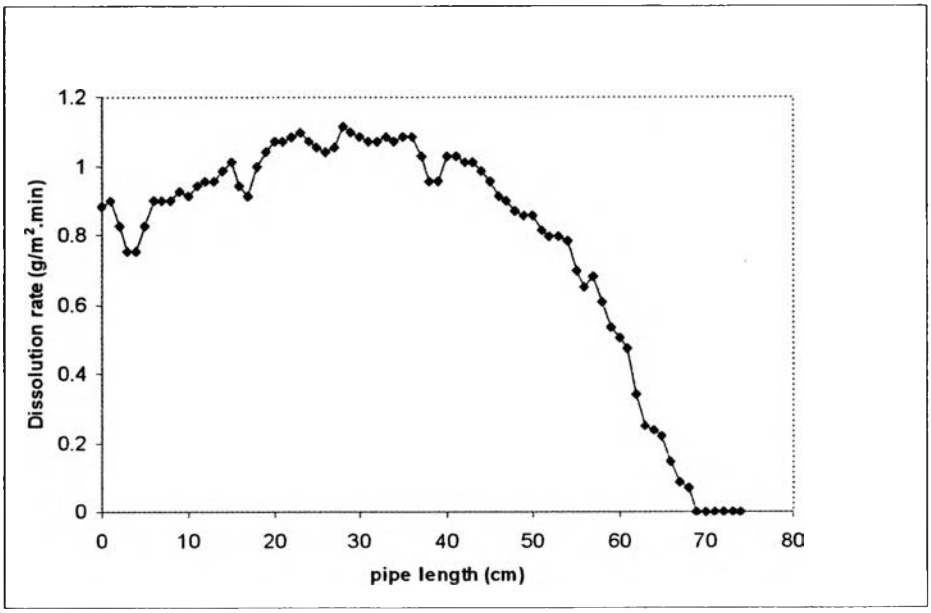

Figure F.10 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 10°C and 25 LPM (the second run)

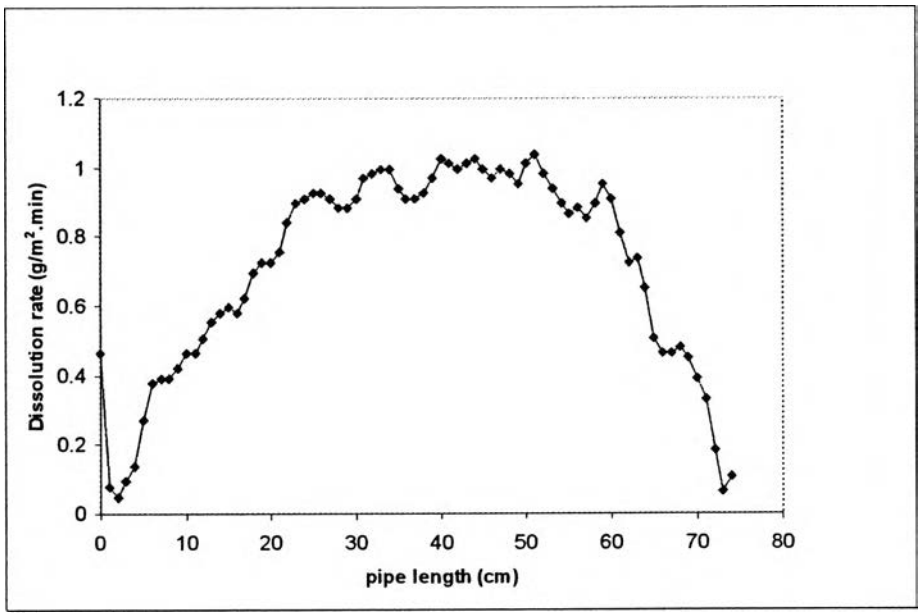

Figure F.11 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 7, 10°C and 25 LPM (the second run)

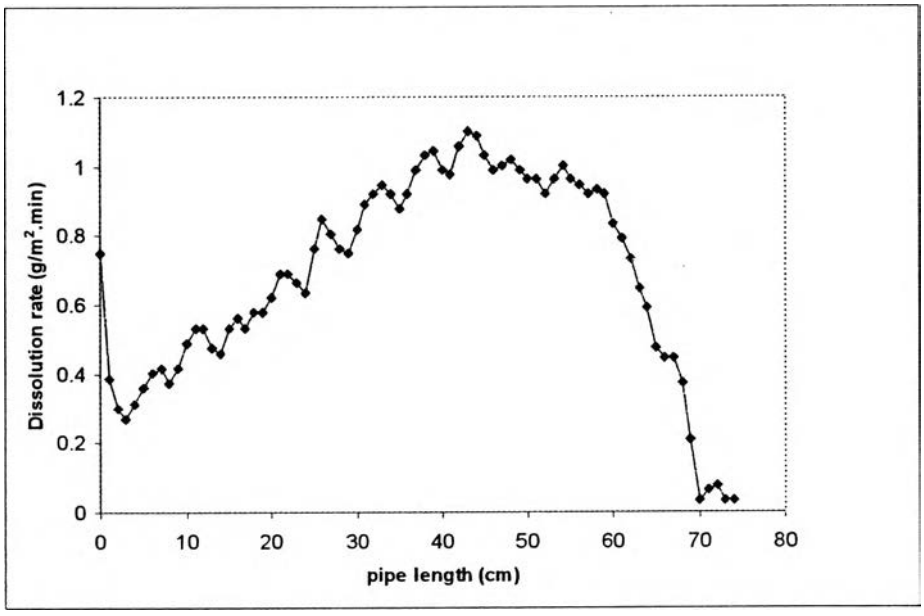

Figure F.12 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 10°C and 25 LPM (the second run)

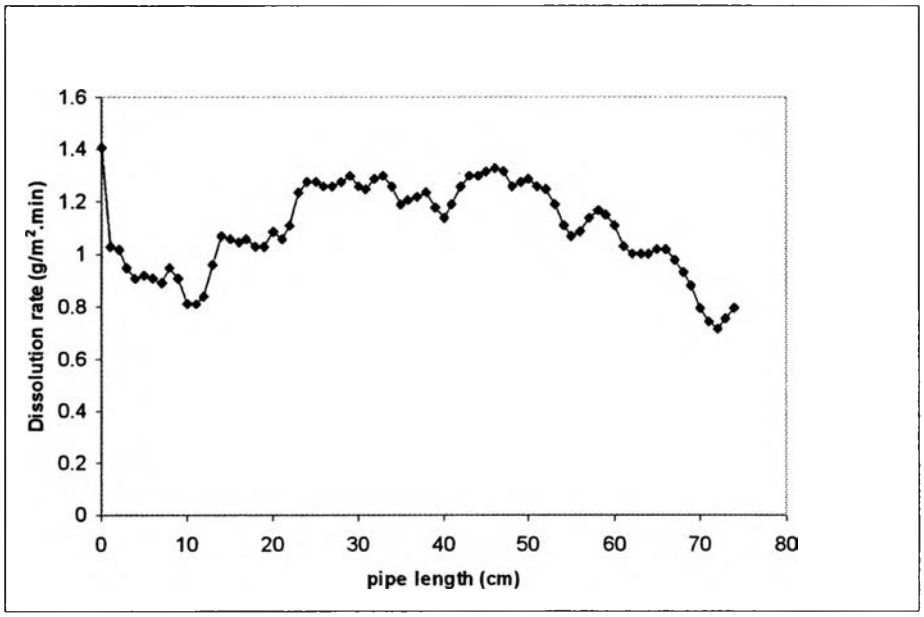

Figure F.13 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 10°C and 35 LPM (the first run)

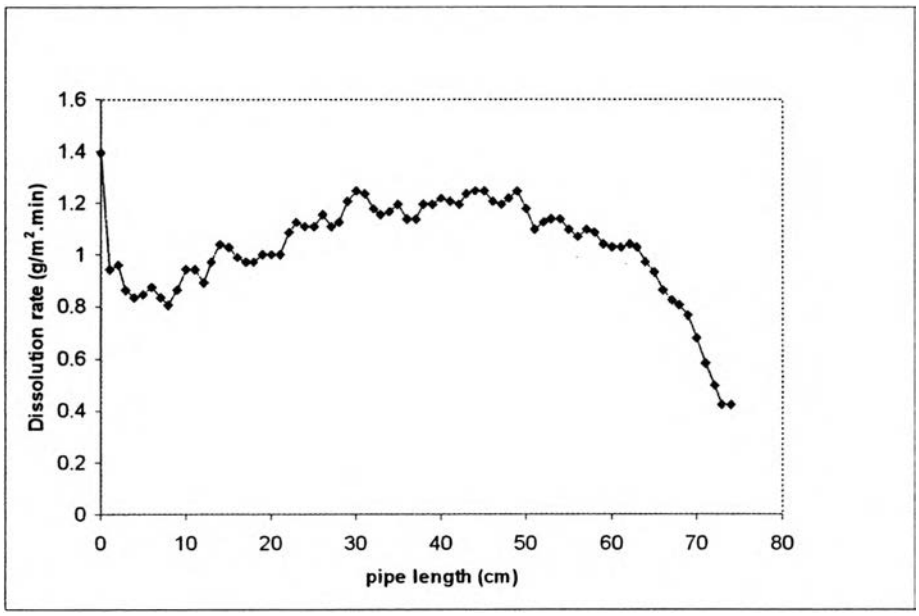

Figure F.14 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 3, 10°C and 35 LPM (the second run)

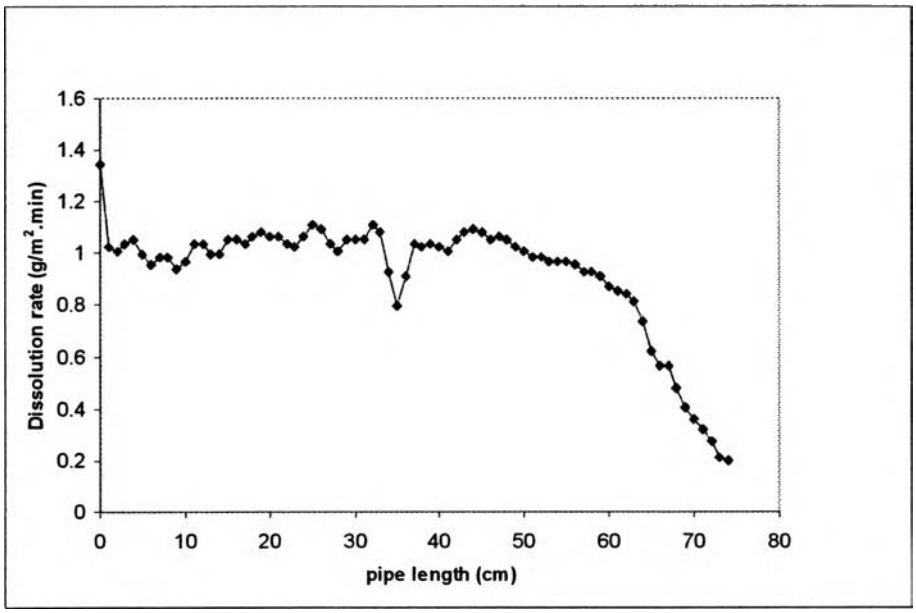

Figure F.15 The dissolution rate profile along the pipe under condition $pH_{25^{\circ}C}$ 7, 10°C and 35 LPM (the first run)

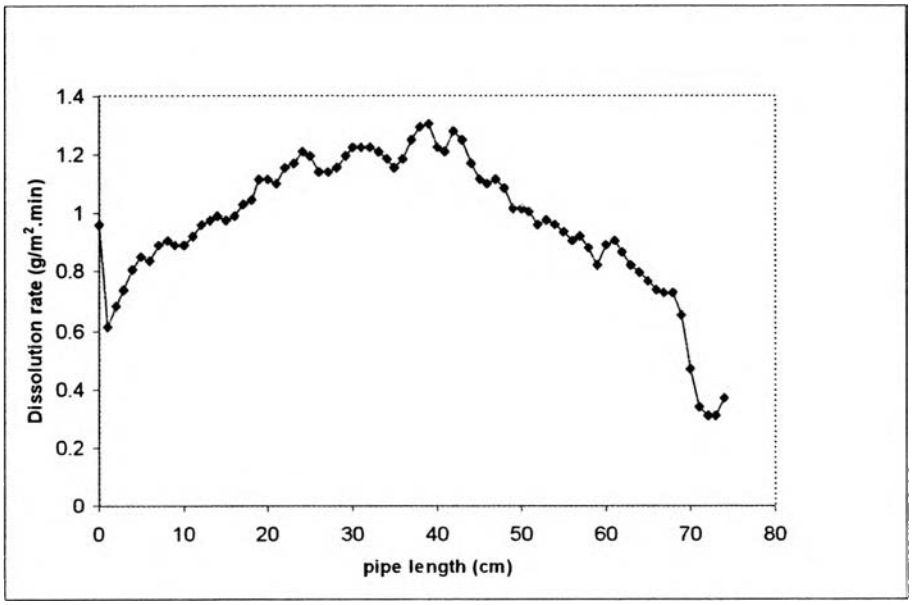

Figure F.16 The dissolution rate profile along the pipe under condition $pH_{25^{\circ}C}$ 7, 10°C and 35 LPM (the second run)

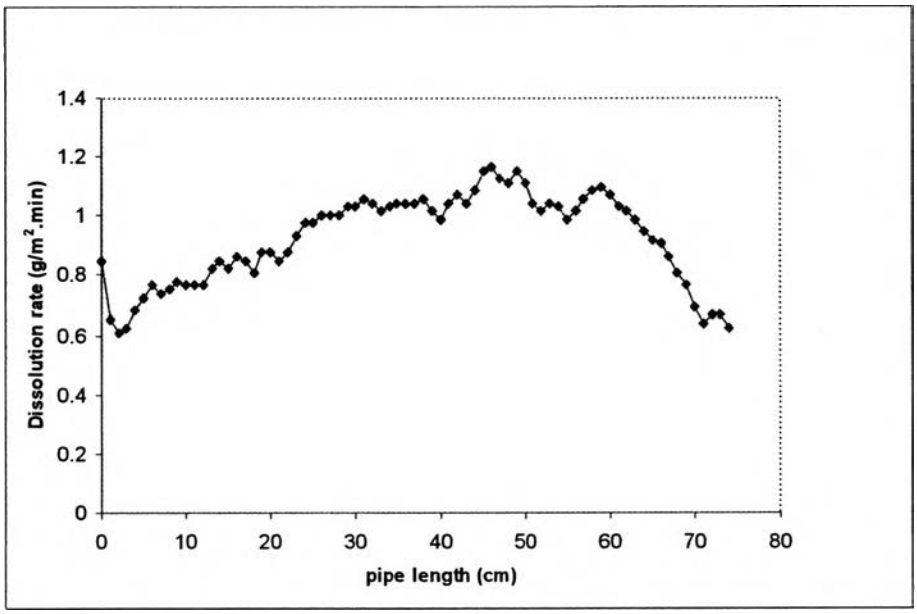

Figure F.17 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 10°C and 35 LPM (the first run)

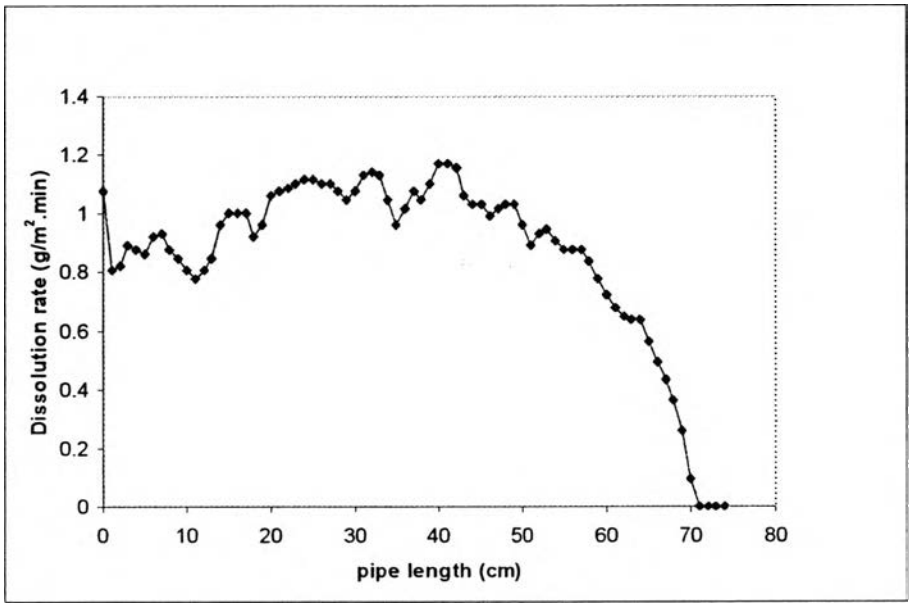

Figure F.18 The dissolution rate profile along the pipe under condition $pH_{25°C}$ 10, 10°C and 35 LPM (the second run)

F.2 Dissolution Coefficient Along the Pipe and Mass Transfer Coefficient

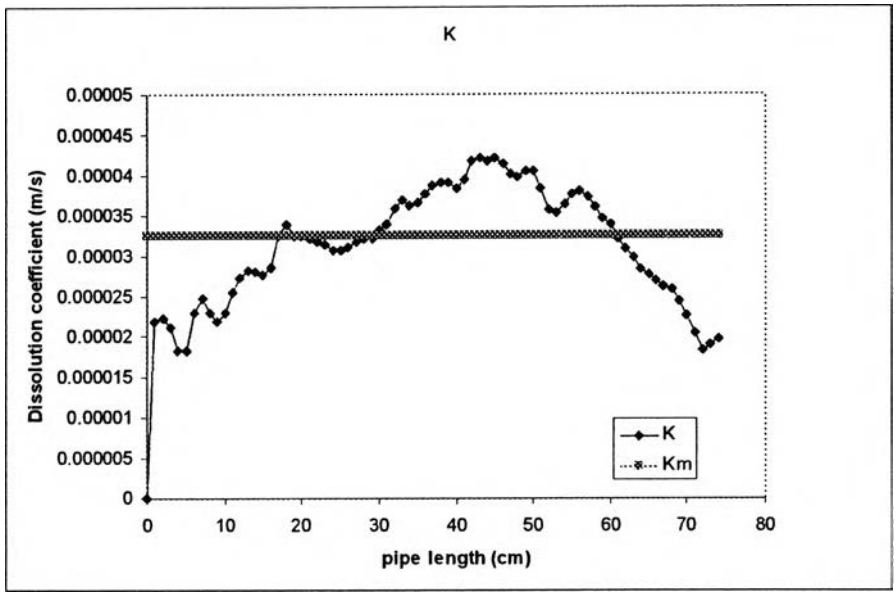

Figure F.19 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 25°C and 25 LPM (the second run)

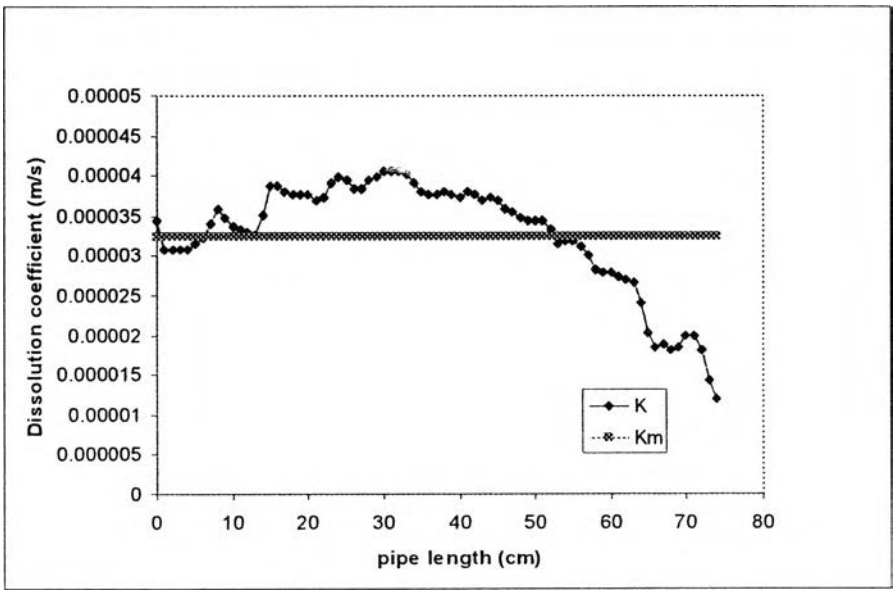

Figure F.20 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 25°C and 25 LPM (the second run)

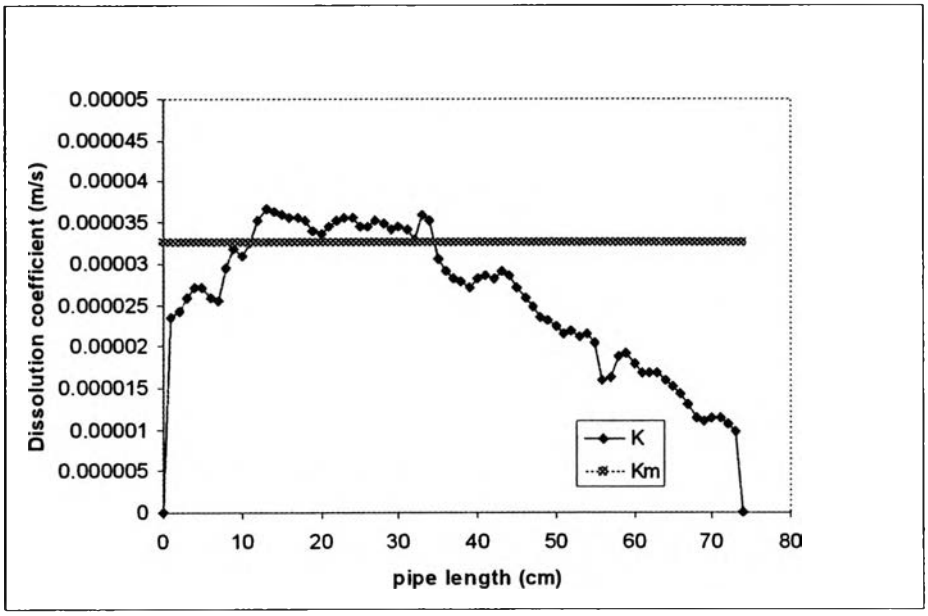

Figure F.21 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 25°C and 25 LPM (the second run)

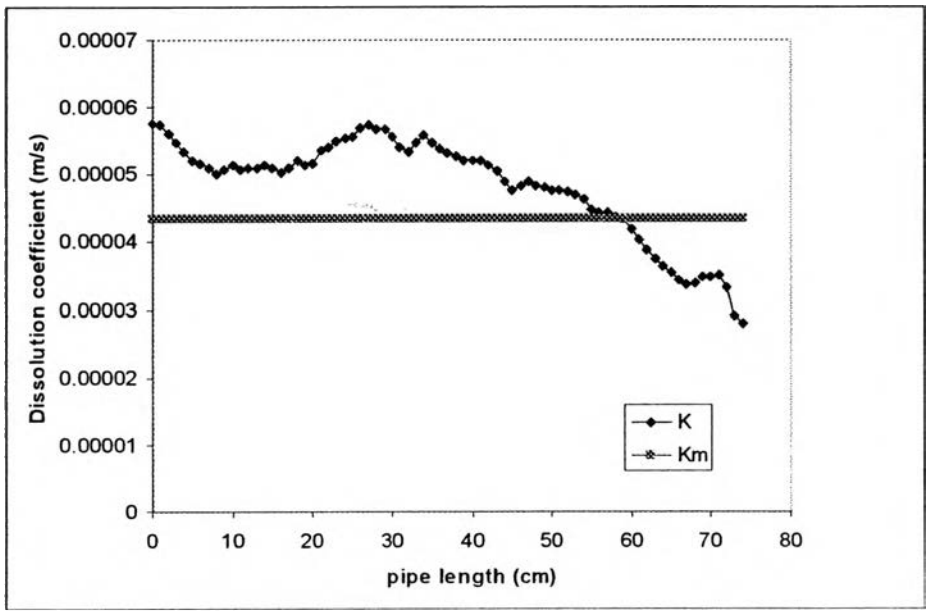

Figure F.22 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 25°C and 35 LPM (the first run)

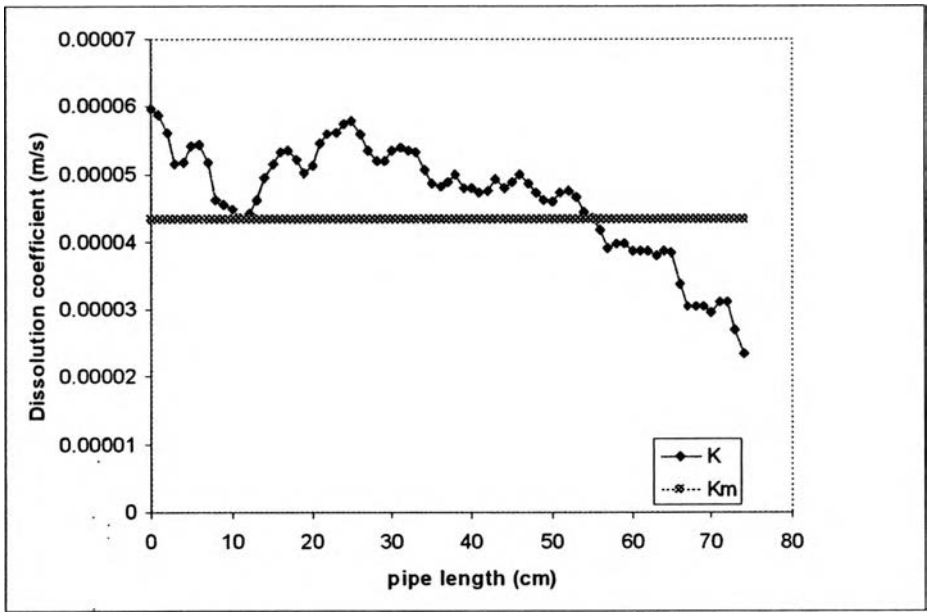

Figure F.23 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 25°C and 35 LPM (the second run)

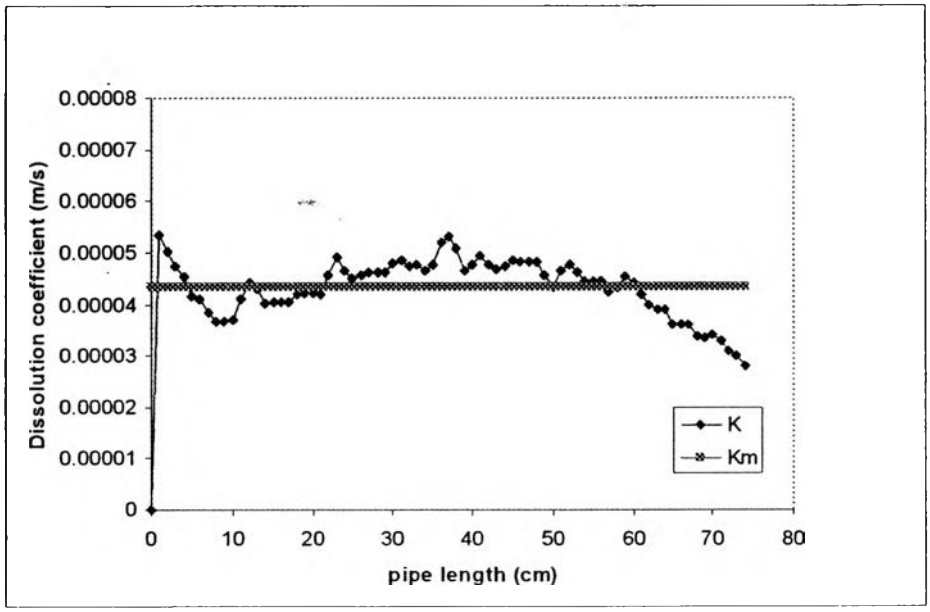

Figure F.24 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 25°C and 35 LPM (the first run)

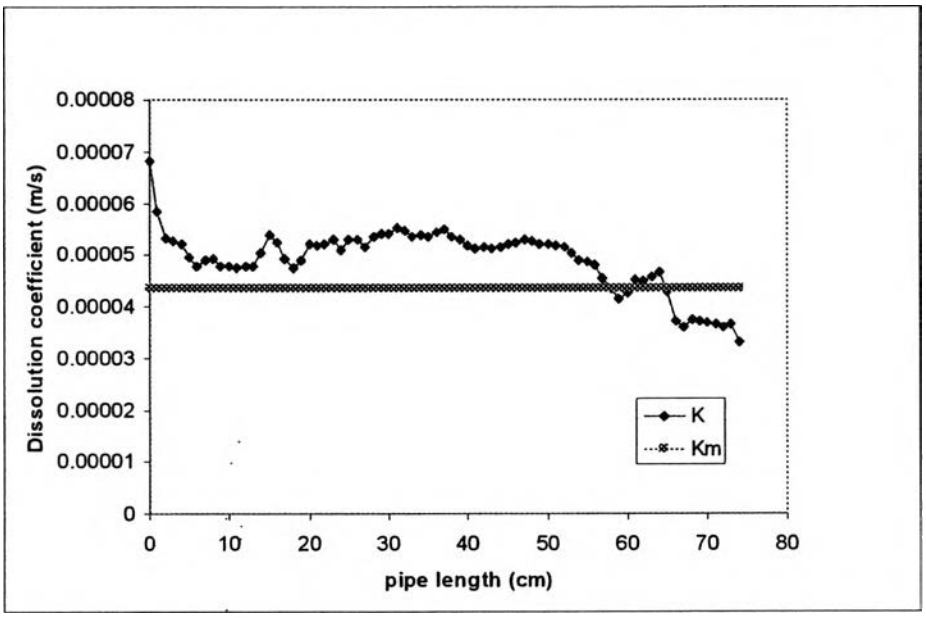

Figure F.25 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 25°C and 35 LPM (the second run)

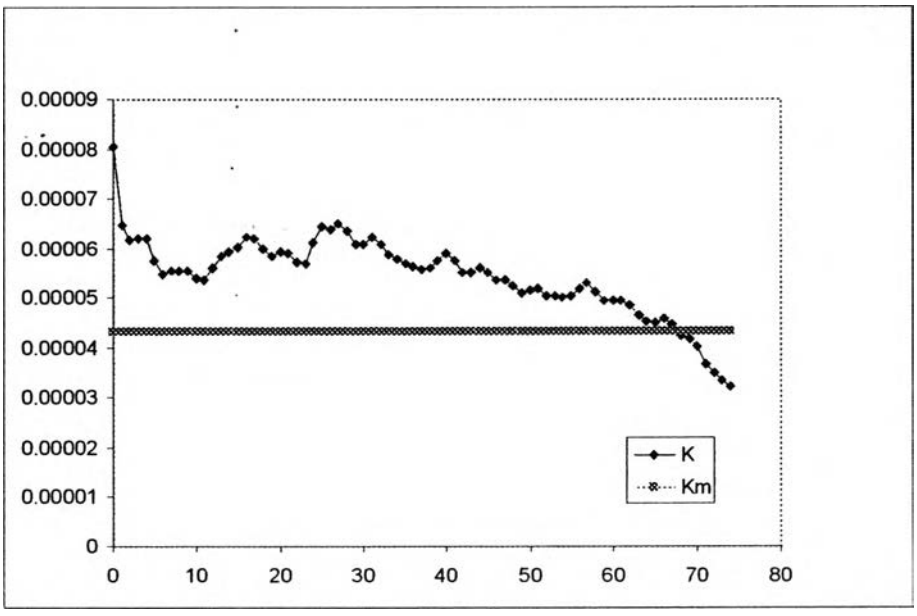

Figure F.26 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 25°C and 35 LPM (the first run)

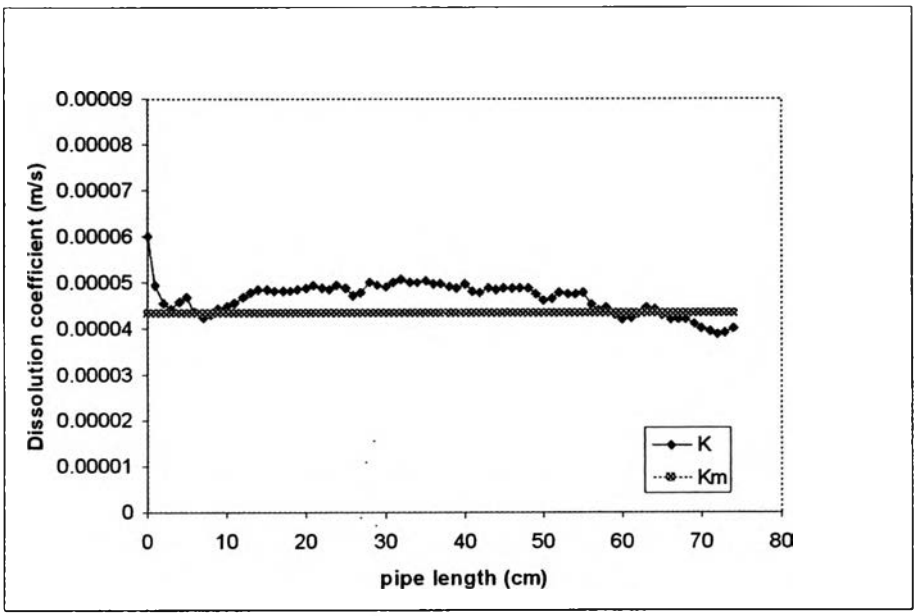

Figure F.27 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 25°C and 35 LPM (the second run)

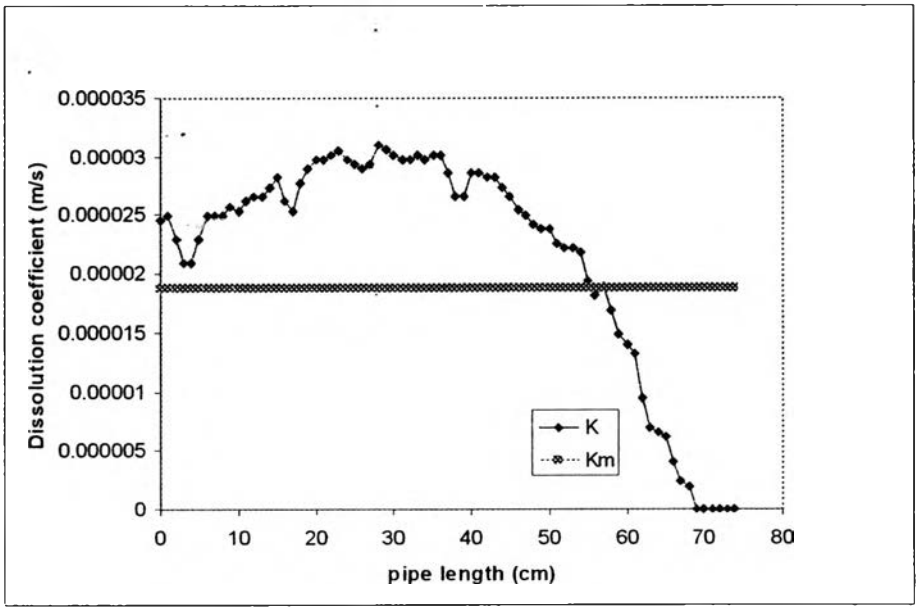

Figure F.28 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 10°C and 25 LPM (the second run)

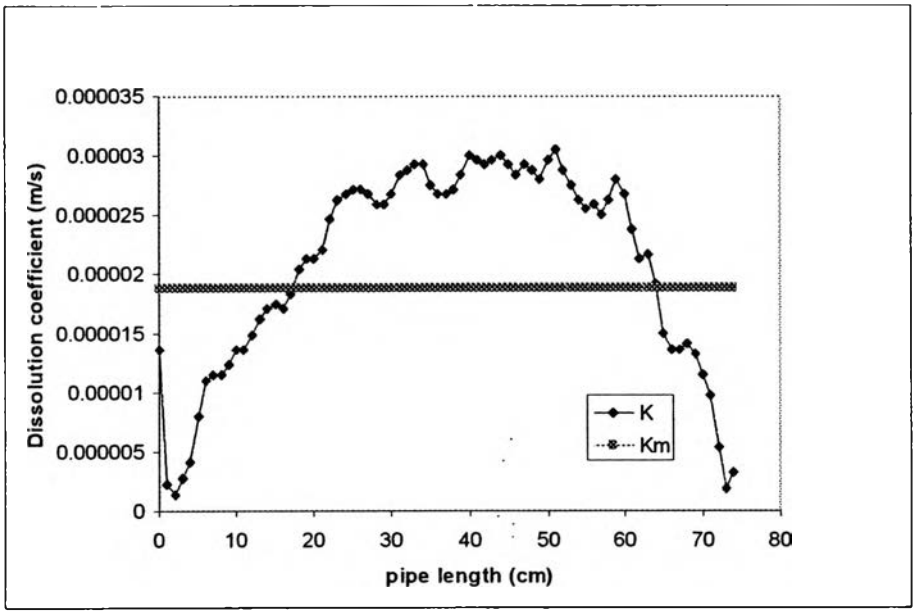

Figure F.29 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 10°C and 25 LPM (the second run)

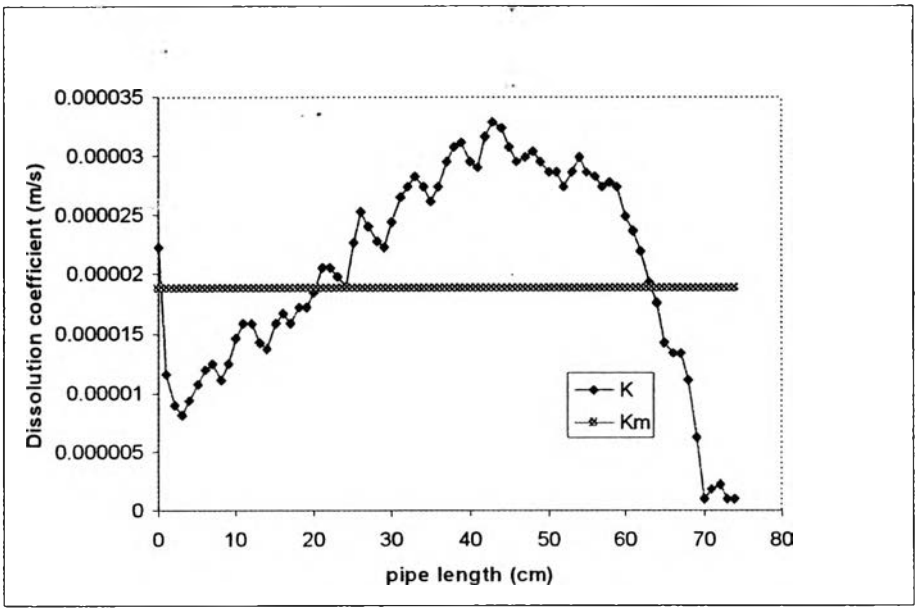

Figure F.30 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 10°C and 25 LPM (the second run)

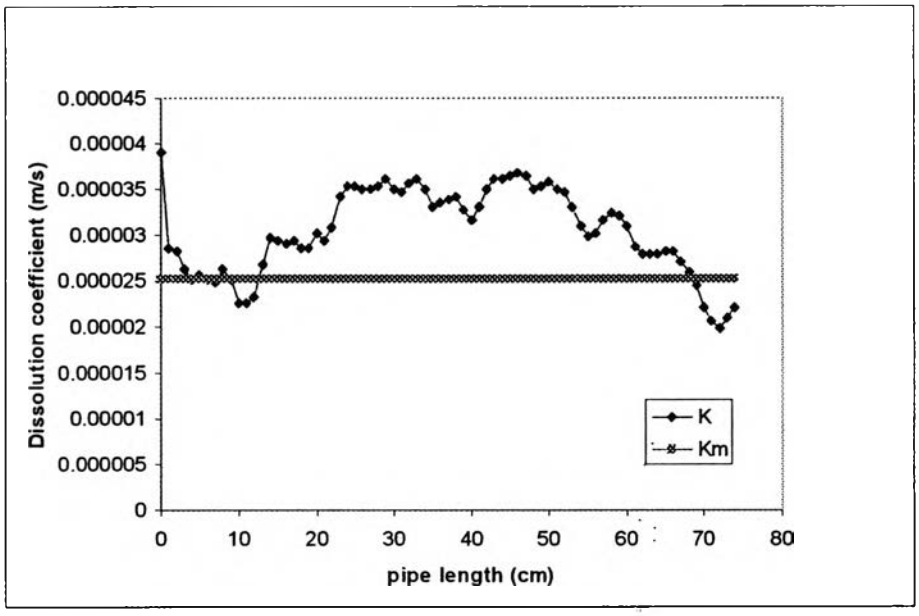

Figure F.31 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 10°C and 35 LPM (the first run)

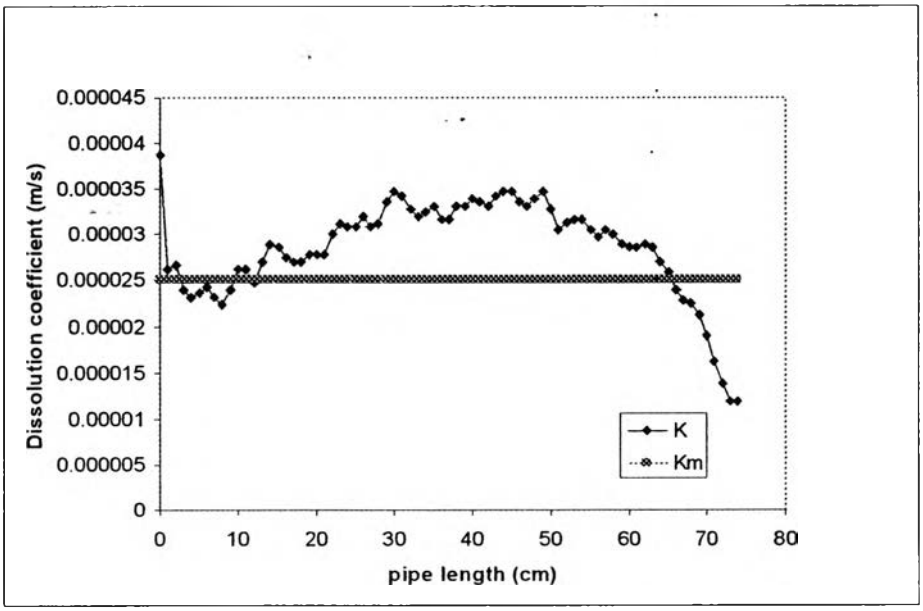

Figure F.32 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 3, 10°C and 35 LPM (the second run)

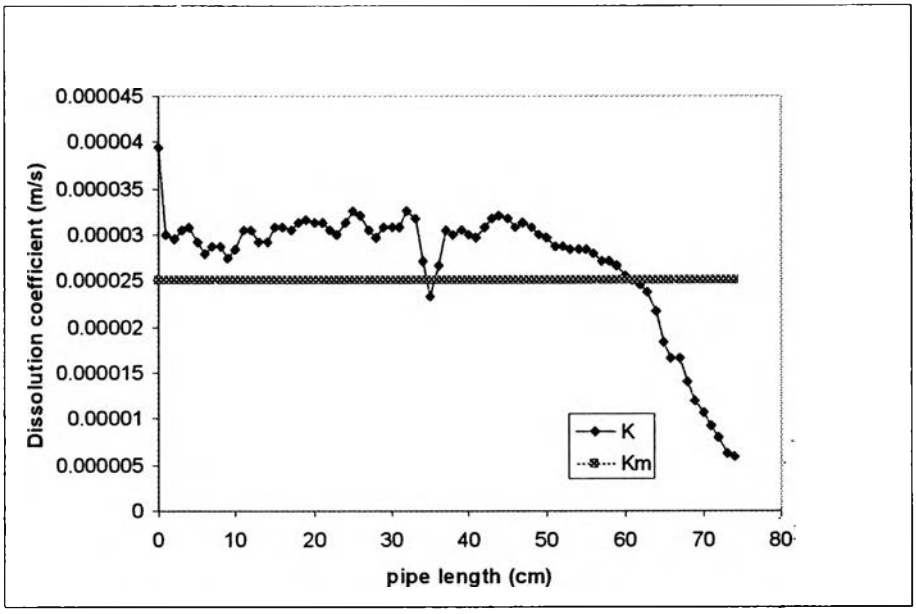

Figure F.33 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 10°C and 35 LPM (the first run)

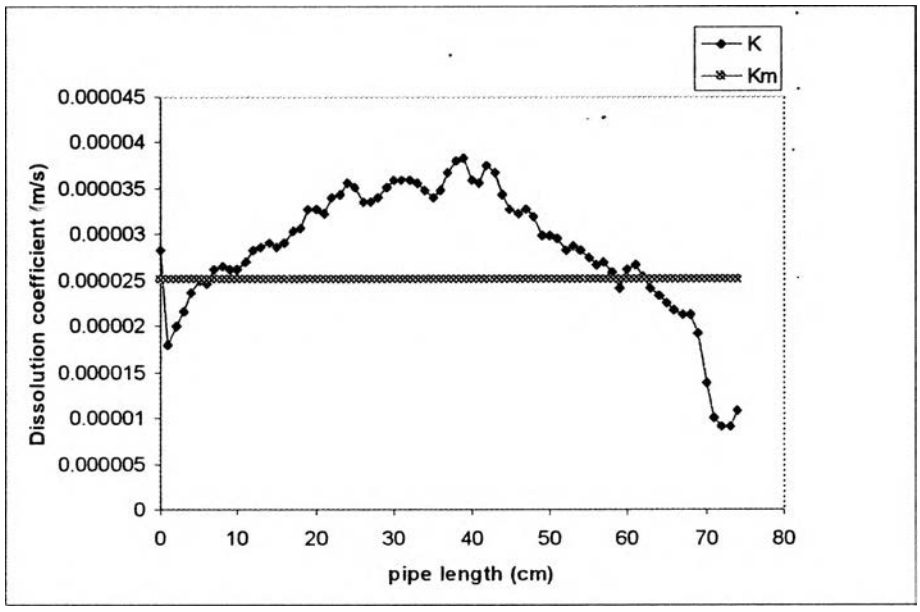

Figure F.34 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 7, 10°C and 35 LPM (the second run)

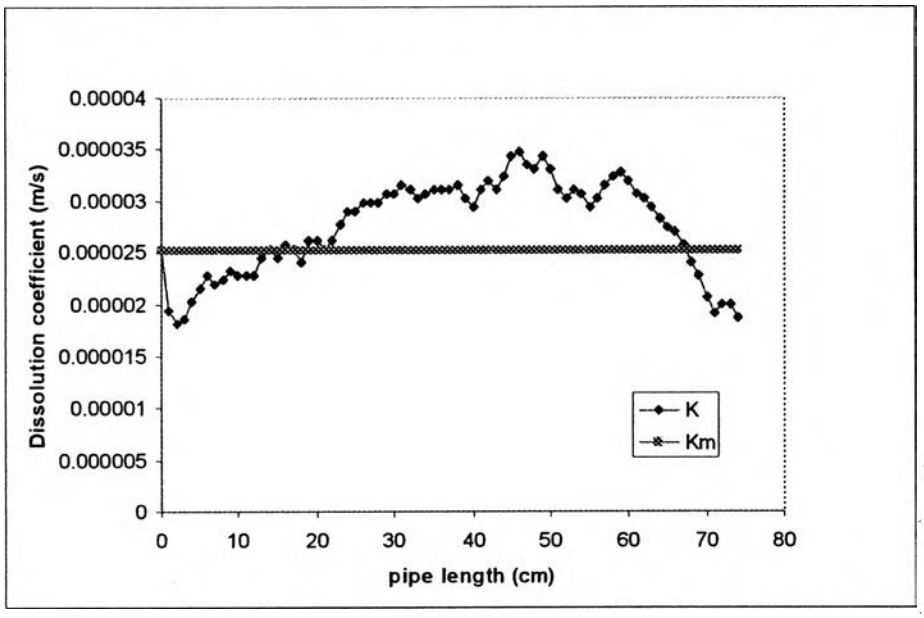

Figure F.35 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 10°C and 35 LPM (the first run)

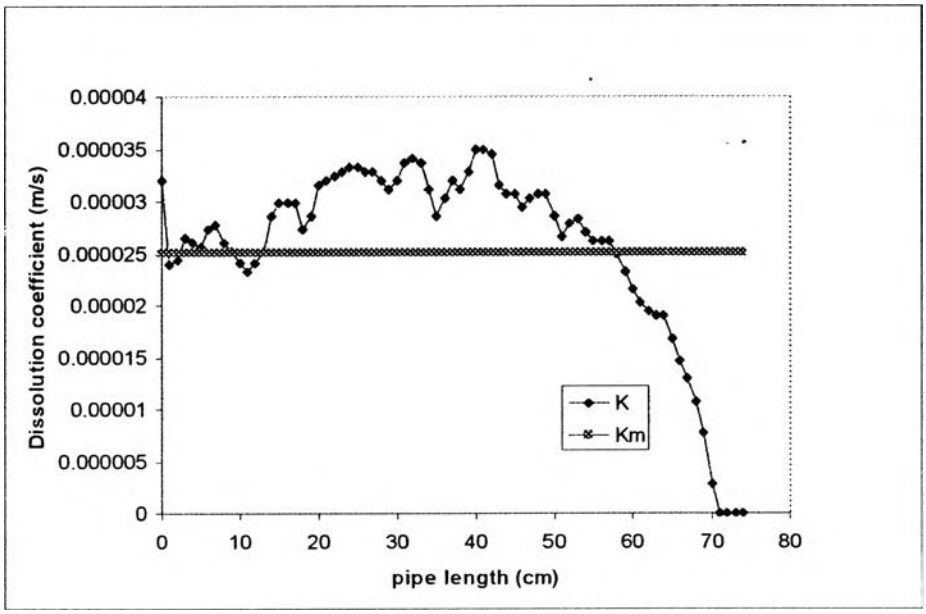

Figure F.36 The dissolution coefficient (K) compared with the mass transfer coefficient (K_m) along the pipe under condition $pH_{25°C}$ 10, 10°C and 35 LPM (the second run)

Note: The dissolution rate or dissolution coefficient is zero value because the plaster tubes were cut for SEM analysis before measuring the thickness. Therefore, the thickness data at that position could not be found out.

CURRICULUM VITAE

Name: Ms. Suphanan Sinthuphan

Date of Birth: May 26, 1984

Nationality: Thai

University Education:

2002-2005 Bachelor Degree of Chemical Engineering, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

Working Experience:

2005	Position:	Process Engineer Intern Student
	Company name:	Mitr Phol Sugar Corp., Ltd., Suphanburi, Thailand

Proceeding:

1. Sinthuphan, S., Rirksomboon, T., Lister, D.H. and Steward, F.R. (2008, April 23rd) Effects of Dissolution Rate and Flow Characteristics on Scalloping of Pipe Surfaces. Proceedings of The 14th PPC Symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand