

REFERENCES

- Adriaens, P., and Vogel, T. M. (1995). Biological treatment of chlorinated organics. Microbial Transformation and Degradation of Toxic organic chemical: 435 – 486.
- Bachmann, A. (1988). Biodegradation of Alpha-and Beta-Hexachlorocyclohexane in a soil slurry under different Redox Conditions. Environmental Microbiology 1: 143-149.
- Beck, W. (2003). Lipid [Online]. Available from <http://www.cem.msu.edu>
- Borden, R. C., Coulibaly, K., Jung, Y., Long, C. M., Harvin, A. S., and Lindow, N. L. (2003). Use of emulsified edible oil for in situ anaerobic bioremediation. Environmental alliance.
- Bouwer E. J., and McCarty, P. L. (1985). Utilization rates for trace halogenated organic compounds in acetate grown biofilms. Biotechnology and Bioengineering 27: 1564-1571.
- Bradley PM, Chapelle FH. (1996). Anaerobic mineralization of vinyl chloride in Fe(III)-reducing, aquifer sediments. Environmental Science and Technology 30: 2084-2086
- Chang, Y. C., Hatsu, M., Jung, K., Yoo, Y. S., and Takamizawa, K. (1998). Degradation of a variety of Halogenated Aliphatic Compounds by an aerobic mixed culture. Journal of fermentation and bioengineering 4: 410-412.
- DiStefano T. D., Gossett J. M., and Zinder, S. H. (1991). Reductive dechlorination of high concentrations of high chloroethene to ethene by an anaerobic enrichment

- culture in the absence of methanogenesis. Application Environmental Microbiology 57: 2287-2292.
- Doong, R. A., and Wu, S. C. (1995). Substrate effects on the enhanced biotransformation of polychlorinated hydrocarbons under anaerobic condition. Chemosphere8: 1499-1511.
- Ferguson, J. F., and Pietari, J. M. H. (1999). Anaerobic transformation and bioremediation of chlorinated solvents. Environmental Pollution 107: 209-215.
- Focht, D. D. (1994). Microbiological procedures for biodegradation research. In method of soil analysis, part 2. Microbiological and biochemical properties. (R. W. Weaver, J. S. Angle and P. S. Bottomly, eds.). Soil Science Society of America, Madison, WI.
- Fogel M. M., Teddeo A. R., And Fogel, S. (1986). Biodegradation of chlorinated ethenes by a methane utilizing culture. Appl. Environmental Microbiology 51: 720-724.
- Gao, J., Skeen, R. S., Hooker, B. S., and Quesenberry, R. D. (1997). Effects of several electron donors on tetrachloroethylene dechlorination in anaerobic soil microcosms. Water Research 10: 2479-2486.
- Haley J. L., Hanson, B., Enfield, C., and Glass, J. (1991). Evaluating the effectiveness of ground water extraction systems. Ground water Monitoring Review11: 119-124.
- Hara, J., and Ito, H. (2004). Kinetics of trichloroethene dechlorination with iron powder. Water Research 39: 1165-1173.

- He, W., Tina, W., Zhang, G., Chen, G. Q., and Zhang, Z. (1998). Production of novel polyhydroxyalkanoates by *Pseudomonas stutzeri* 1317 from glucose and soybean oil. FEMS Microbiology Letters 169: 45-49.
- Hinchee, R. (2002). Perchlorate bioremediation via anaerobic reduction.”\ Environmental alliance 2002.
- Holliger, C. (1995). The anaerobic microbiology and biotreatment of chlorinated ethenes. Biotechnology 6: 347-351.
- Hunt, J. R., Sitra, N., and Udell, K. S. (1988). Non aqueous phase liquid transport and clean up.1. Analysis of mechanisms. Water resource Research 24: 1247-1258.
- Jayaraj, J., Makkar, R. S., and Rockne, K. J. (2003). A new electron donor for reductive dechlorination of perchloroethylene. Available from <http://www.battelle.org/bookstore>.
- Kao, C. M., Chen, Y. L., Chen, S. C., The, T. Y., and Wu, W. S. (2003). Enhanced PCE dechlorination by biobarrier systems under different redox conditions. Water Research 37: 485-4894.
- Leahy, J. G., Byrne, A. M., and Olsen, R. H. (1996). Comparison of factors influencing trichloroethylene degradation by toluene-oxidizing bacteria. Application Environmental Microbiology 62: 825-833.
- Leahy, J. G., and Shreve, G. S. (2000). The effect of organic carbon on the sequential reductive dehalogenation of tetrachloroethylene in landfill leachates. Water Research 8: 2390-2396.
- Lee, M. D., Raymond, R. L., and Nehrig, C. A. (2003). Source area bioremediation of chlorinated solvents with edible oil emulsion. Solutions-IES industrial & Environmental Service.

- McCarty, P. L. (1993). In situ bioremediation of chlorinated solvents. Biotechnology 4: 323-330
- Nollet, H., Putte, I. V., Raskin, L., and Verstraete, W. (2005). Carbon/electron source dependence of polychlorinated biphenyl dechlorination pathways for anaerobic granules. Chemosphere 58: 299-310
- Prytula, M.T., and Pavlostathis, S. P. (1996). Extraction of sediment-bound chlorinated organic compounds: Implications on fate and hazard assessment. Water Science and Technology 30: 2669-2680
- Regenesis (2003). Hydrogen release compound. Advanced Technologies for Groundwater Resources Available from <http://www.regenesis.com>
- Saaty, R. P., Showalter, W. E., and Booth, S. R. (1995). Cost effectiveness of in situ bioremediation at Savannah River. In bioremediation of chlorinated solvents (Edited by Hincee R. E., Leeson, A., and Semprini, L.). Battelle Press, Columbus: 289-295.
- Skeen, R. S., Gao, J., and Hooker, B. S. (1995). Kinetics of chlorinated ethylene dehalogenation under methanogenic conditions. Biotechnology Bioengineering 48: 659-666.
- Sponza, D. (2001). Anaerobic granule formation and tetrachloroethylene(PCE) removal in an upflow anaerobic sludge blanket (UASB) reactor. Enzyme and Microbial Technology 29:417-427.
- Sponza, D. (2001). Toxicity and treatability of carbontetrachloride and tetrachloroethylene in anaerobic batch cultures. International biodeterioration and biodegradation 51: 119-127.

- Suthersan, S. (2001). Mechanism of reductive dechlorination. Natural and Enhanced Remediation Systems: 138 – 152.
- Suttinun, O., Lederman, P. B., and Luepromchai, E. (2004). Application of terpene-induced cell for enhancing biodegradation of TCE contaminated soil. Songklanakarin Journal of Science Technology 26: 131-142.
- Tae, H. (2002). Bioremediation of Trichloroethylene and Tetrachloroethylene. [Online] Available from <http://5host02.env.eng.osaka-u.ac.jp>
- Tchobanoglous, G., and Burton, F. L. (1991). Anaerobic digestion Wastewater engineering treatment, and disposal, and reuse. Metcalf and Eddy Inc., third edition: 420- 425.
- Tungmee, P. (2002). Anaerobic dechlorination of Hexachlorobenzene in contaminated sediment. Master's Thesis Inter-Departmental Program in Environmental Management, Graduate School, Chulalongkorn University.
- U.S. Department of Energy (2003). The advantage of in situ bioremediation. [Online] Available from <http://www.er.doe.gov>
- United States Sugar Corporation (2003). Molasses & Liquid Feeds Division Available from <http://www.suga-lik.com/molasses/blackstrap.molasses.html>
- Wikipedia (2006). Tetrachloroethylene, PCE properties. [Online] Available from <http://en.wikipedia.org/wiki/Tetrachloroethylene>
- Wu, W.-M., Kitakawa, M., Taniguchi, S., and Jain, M. K. (1998). Anaerobic dechlorination of perchloroethylene (PCE) in soil by a dechlorinating microbial consortium. Journal of Fermentation and Bioengineering 6: 588-594.

APPENDICES

APPENDIX A

Standard test methods for organic matter of peat and other organic soils

1. Apparatus

- 1.1 Oven, capable of being regulated to a constant temperature of $105 \pm 5^{\circ}\text{C}$.
- 1.2 Muffle Furnace, capable of producing constant temperature of 550°C and 750°C .
- 1.3 Evaporator Dishes, of high silica or porcelain of not less than 100mL capacity.
- 1.4 Blender, high speed.
- 1.5 Aluminum Foil, heavy-duty.
- 1.6 Porcelain Pan, Spoons, and equipment of the like.
- 1.7 Desiccators.

2. Moisture content

- 2.1 Record the nearest 0.01 g the mass of a high silica or porcelain evaporating dish fitted with a heavy-duty aluminum foil cover. The dish shall have a capacity of not less than 100 ml.
- 2.2 Mix thoroughly the representative sample and place a test specimen of at least 50 g in the container described in 2.1. Crush soft lumps with a spoon or spatula. The thickness of peat in the container should not exceed 3 cm.

- 2.3 Cover immediately with the aluminum foil cover and record the mass to the nearest 0.01 g.
- 2.4 Dry uncovered for at least 16 h at 105 °C or until there is no change in mass of the sample after further drying period in excess of 1 h. Remove from the oven, cover tightly, cool in a desiccator, and record the mass.

3. Calculation

Calculate the moisture content as follows:

$$\text{Moisture Content, \%} = [(A-B) \times 100]/A$$

Where:

A = mass of the as-received test specimen, g, and

B = mass of the oven-dried specimen, g.

4. Ash content

- 4.1 Determine the mass of a covered high-silica or porcelain dish.
- 4.2 Place a part of or all of the oven-dried test specimen from a moisture determination in the dish and determine the mass of the dish and specimen.
- 4.3 Remove the cover and place the dish in the muffle furnace. Gradually bring the temperature in the furnace to 550°C and hold until the specimen is completely ashed (no change of mass occurs after a further period of heating).

4.4 Cover with the retained aluminum foil cover, cool in the desiccators, and determine the mass.

4.5 This test method should use for all geotechnical and general classification purposes.

5. Calculation for Ash Content

$$\text{Ash content, \%} = (C \times 100) / B$$

Where:

C = ash, g, and

B = oven-dried test specimen, g.

6. Calculation for Organic matter

$$\text{Organic matter, \%} = 100.0 - D$$

Where:

D = ash content, %.

APPENDIX B

The mineral salts medium (MSM)

MSM used for isolation, degradation experiments and quantifying bacteria was consisted of the following components per liter.

Table B-1 Composition of MS medium used for this study

Stock solution	Additions, mL	Final concentration, mM
K ₂ HPO ₄ , 1M	10	10
NaH ₂ PO ₄ , 1M	3	3
(NH ₄) ₂ SO ₄ , 1M	10	10
MgSO ₄ , 1M	1	1
Ca(NO ₃) ₂ , 1M	0.1	0.1
Fe(NO ₃) ₃ , 1M	0.01	0.01
Trace minerals	1	
MnSO ₄	0.001	1
ZnSO ₄	0.001	1
CuSO ₄	0.001	1
NiSO ₄	0.0001	0.1
CoSO ₄	0.0001	0.1
Na ₂ MoO ₄	0.0001	0.1

Add about 0.9 L of distilled water before adding any of the solutions above, or precipitates will form, and then fill to volume. The trace mineral solution was made up with all chemical listed. The final pH of medium = 7.25. The MS medium was autoclaved 121°C for 15 min before use.

APPENDIX C

Table C-1 PCE and intermediate concentration (mg-PCE/kg-soil) at designated time with various concentrations of glucose and Soybean oil as carbon source.

Name	Day	PCE (Triplicate)		TCE (Triplicate)		DCE (Triplicate)	
		Average	S.D.	Average	S.D.	Average	S.D.
1.None	0	114.31	2.15	0	0	0	0
	6	60.25	2.57	6.16	0.36	0	0
	12	54.36	3.31	12.16	0.2	0	0
	18	54.4	0.67	6.8	1.6	0	0
	24	52.3	1.3	0	0	0	0
2.G:500	0	119.04	8.51	0	0	0	0
	6	11.33	2.4	8.69	1.37	0	0
	12	8.35	1.81	32.14	0.56	0	0
	18	2.72	0.86	4.34	2.73	0	0
	24	1	0.76	2.4	0.12	0	0
3.G:1,000	0	118.03	3.42	0	0	0	0
	6	5.46	0.57	6.56	0.38	0	0
	12	5.44	2.92	34.77	0.63	0	0
	18	6.77	1.76	14.2	0.19	0	0
	24	0.7	0.28	17.3	0.44	0	0
4.G:5,000	0	117.94	4.2	0	0	0	0
	6	8.41	1.5	8.78	0.11	0	0
	12	3.35	0.39	19.91	0.22	3.6	2.08
	18	1.54	0.8	25.5	1.59	0	0
	24	0.64	0.27	23.3	0.96	0	0

Name	Day	PCE (Triplicate)		TCE (Triplicate)		DCE (Triplicate)	
		Average	S.D.	Average	S.D.	Average	S.D.
5.G:10,000	0	124.16	7.21	0	0	0	0
	6	6.26	0.52	13.94	0.5	0	0
	12	3.68	0.13	24.67	0.74	18.77	1.08
	18	2.34	1.96	84.8	0.93	5.68	0.33
	24	0.66	0.14	1.54	0.49	0	0
6.S:500	0	116.85	5.76	0	0	0	0
	6	6.96	2.89	6.99	0.27	0	0
	12	6.43	2.36	46.13	3.16	4.53	0.28
	18	1.28	0.25	37.7	0.7	19.3	1.11
	24	1.22	0.55	29.8	1.17	0	0
7.S:1,000	0	117.55	4.7	0	0	0	0
	6	13.09	1.48	8.76	0.37	0	0
	12	7.49	2.45	39.6	0.04	0	0
	18	1.76	0.31	32.6	1.67	0	0
	24	1.38	0.23	3.4	0.85	0	0
8.S:5,000	0	115.24	6.7	0	0	0	0
	6	11.19	1.79	8.47	0.02	0	0
	12	4.72	1.09	71.12	1.54	8.938	0.51
	18	2.18	0.6	45.3	0.43	0	0
	24	1.09	0.65	27.8	0.54	0	0
9.S:10,000	0	95.74	7.2	0	0	0	0
	6	6.21	0.11	8.42	0.12	0	0
	12	1.5	0.36	45.58	1.34	0	0
	18	2.24	0.76	17.5	1	0	0
	24	1.65	0.16	5	0.13	0	0

Remark: None = no substrate addition, G = glucose and S = soybean oil

Table C-2 PCE reductive dechlorination (C/Co) and %decreasing of PCE/Day

Sample Name	C/Co					(%decrease of PCE/day)			
	0	6	12	18	24	(0 - 6)	(0-12)	(0-18)	(0-24)
1.None	100.0	52.70	4.76	4.76	4.58	7.88	4.37	2.91	2.26
2.G:500	100.0	9.50	7.00	2.30	0.80	15.08	7.75	5.43	4.13
3.G:1,000	100.0	4.60	4.60	5.70	0.60	15.90	7.95	5.24	4.14
4.G:5,000	100.0	7.10	2.80	1.30	0.50	15.48	8.10	5.48	4.14
5.G:10,000	100.0	5.00	3.00	1.90	0.50	15.83	8.09	5.45	4.15
6.S:500	100.0	6.00	5.50	1.10	1.00	15.67	7.88	5.50	4.12
7.S:1,000	100.0	11.10	6.40	1.50	1.20	14.81	7.80	5.47	4.12
8.S:5,000	100.0	9.70	4.10	1.90	0.90	15.05	7.99	5.45	4.13
9.S:10,000	100.0	6.50	1.60	2.30	1.70	15.59	8.20	5.43	4.10

Remark: G = Glucose, S = Soybean oil

Table C-3 Percent PCE removal

Name	Triplicate of PCE removal efficiency, % (Average \pm S.D.)				
	0	6	12	18	24
1.None	0 \pm 2.15	47.29 \pm 2.57	52.45 \pm 3.31	52.38 \pm 0.67	54.24 \pm 1.30
2.G:500	0 \pm 8.51	90.48 \pm 2.40	92.99 \pm 1.81	97.72 \pm 0.86	99.16 \pm 0.76
3.G:1,000	0 \pm 3.42	95.37 \pm 0.57	95.39 \pm 2.92	94.26 \pm 1.76	99.41 \pm 0.28
4.G:5,000	0 \pm 4.20	92.87 \pm 1.50	97.16 \pm 0.39	98.69 \pm 0.80	99.46 \pm 0.27
5.G:10,000	0 \pm 7.21	94.96 \pm 0.52	97.04 \pm 0.13	98.12 \pm 1.96	99.47 \pm 0.14
6.S:500	0 \pm 5.76	94.45 \pm 2.89	94.45 \pm 2.36	98.90 \pm 0.25	98.96 \pm 0.55
7.S:1,000	0 \pm 4.70	88.86 \pm 1.48	93.63 \pm 2.45	98.50 \pm 0.31	98.83 \pm 0.23
8.S:5,000	0 \pm 6.70	90.29 \pm 1.79	95.9 \pm 1.09	98.11 \pm 0.60	99.05 \pm 0.65
9.S:10,000	0 \pm 7.20	93.51 \pm 0.11	98.43 \pm 0.36	97.66 \pm 0.76	98.28 \pm 0.16

Remark: G = Glucose, S = Soybean oil

Table C-4 pH, Chloride accumulation and gas production

Sample	pH (average)				
	Times(Days)				
	0	6	12	18	24
1.None	7.61	7.16	7.85	7.44	7.26
2.G:500	7.56	7.29	7.60	7.47	7.42
3.G:1,000	6.88	7.40	7.76	7.95	7.44
4.G:5,000	7.05	7.25	7.74	7.36	7.29
5.G:10,000	7.58	7.06	7.61	7.53	7.43
6.S:500	7.04	7.31	7.80	7.68	7.15
7.S:1,000	8.06	7.28	7.86	7.90	7.40
8.S:5,000	7.56	7.18	7.70	7.59	7.32
9.S:10,000	6.85	7.26	7.61	7.47	7.50

Sample	Triplicate of Chloride production (mg/kg-soil)				
	(Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.None	0 \pm 1.23	9.66 \pm 1.28	10.14 \pm 0.91	11.13 \pm 1.27	12.78 \pm 0.88
2.G:500	0 \pm 0.94	49.76 \pm 1.17	54.60 \pm 1.13	61.81 \pm 0.89	67.01 \pm 0.94
3.G:1,000	0 \pm 1.11	45.66 \pm 1.24	50.06 \pm 1.26	58.92 \pm 1.17	64.82 \pm 0.79
4.G:5,000	0 \pm 1.07	54.93 \pm 0.86	61.73 \pm 1.31	67.64 \pm 0.93	73.18 \pm 0.81
5.G:10,000	0 \pm 0.91	57.27 \pm 0.95	65.00 \pm 1.18	71.85 \pm 0.91	79.81 \pm 0.90
6.S:500	0 \pm 1.16	52.35 \pm 1.09	60.85 \pm 1.26	68.90 \pm 1.10	74.56 \pm 1.10
7.S:1,000	0 \pm 1.05	47.16 \pm 1.11	52.17 \pm 1.33	63.00 \pm 1.16	68.19 \pm 1.06
8.S:5,000	0 \pm 0.89	53.76 \pm 1.18	58.28 \pm 1.29	65.78 \pm 1.07	72.18 \pm 1.21
9.S:10,000	0 \pm 1.21	41.57 \pm 1.24	47.37 \pm 0.91	54.62 \pm 0.88	63.66 \pm 1.32

Sample	Triplicate of Gas production (ml)				
	(Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.None	0	1.5 \pm 0.1	1.8 \pm .2	1.4 \pm 0.1	0.8 \pm 0.2
2.G:500	0	2.6 \pm 0.1	3.2 \pm 0.1	3.6 \pm 0.2	3.4 \pm 0.1
3.G:1,000	0	3.8 \pm 0.2	5.3 \pm 0.1	3.8 \pm 0.1	3.6 \pm 0.2
4.G:5,000	0	3.2 \pm 0.1	5.8 \pm 0.2	4.6 \pm 0.1	4.0 \pm 0.2
5.G:10,000	0	4.2 \pm 0.1	6.2 \pm 0.1	6.0 \pm 0.1	5.8 \pm 0.1
6.S:500	0	3.8 \pm 0.2	4.6 \pm 0.1	4.8 \pm 0.2	4.4 \pm 0.1
7.S:1,000	0	1.8 \pm 0.1	3.6 \pm 0.1	3.0 \pm 0.2	3.0 \pm 0.2
8.S:5,000	0	2.8 \pm 0.1	4.8 \pm 0.1	5.0 \pm 0.1	4.6 \pm 0.1
9.S:10,000	0	3.6 \pm 0.2	4.2 \pm 0.1	4.4 \pm 0.1	4.2 \pm 0.1

Remark: G = Glucose, S = Soybean oil

Table C-5 Reduced PCE and increasing intermediate at designated time with various concentrations of wastes as carbon source.

Sample Name	Day	PCE (Triplicate)		TCE (Triplicate)		DCE (Triplicate)	
		Average	S.D.	Average	S.D.	Average	S.D.
1.M:5,000	0	125.86	13.26	0	0	0	0
	6	28.07	12.97	5.54	0.32	0	0
	12	10.31	2.56	12.43	0.72	0	0
	18	4.75	2	16.81	0.45	0	0
	24	1.49	0.84	7.47	0.16	0	0
2.M:10,000	0	117.69	23.74	0	0	0	0
	6	13.6	6.54	0	0	0	0
	12	10.6	1.91	15	0.55	0	0
	18	3.07	0.74	10.81	0.84	0	0
	24	2.98	1.34	0	0	0	0
3.C1:500	0	115.83	11.18	0	0	0	0
	6	14.27	3.1	0	0	0	0
	12	9.16	1.62	18.96	1.1	0	0
	18	4.76	1.88	16.59	0.38	0	0
	24	0.68	0.65	7.19	0.42	0	0
4.C2:500	0	120.04	8.52	0	0	0	0
	6	20.17	6.35	0	0	0	0
	12	11.66	1.74	0	0	0	0
	18	5.48	3.88	14.52	1.99	0	0
	24	1.08	0.51	12.9	0.25	0	0
5.C3:500	0	125.74	4.4	0	0	0	0
	6	32.98	2.83	5.66	0.4	0	0
	12	15.82	1.43	8.05	6.73	0	0
	18	1.99	0.27	3.68	2.16	0	0
	24	1.26	0.69	6.95	2.02	2.26	0.42

Sample Name	Day	PCE (TriPLICATE)		TCE (TriPLICATE)		DCE (TriPLICATE)	
		Average	S.D.	Average	S.D.	Average	S.D.
6.C1:5,000	0	124.82	9.41	0	0	0	0
	6	12.44	2.34	0	0	0	0
	12	9.63	2.83	1.08	0.59	1	0
	18	4.7	2.16	11.68	0.82	0	0
	24	2.33	1.65	3.71	0.21	0	0
7.C2:5,000	0	117.65	5.86	0	0	0	0
	6	17.62	2.58	0	0	0	0
	12	12.64	3.7	0	0	0	0
	18	1.74	1.05	22.06	0.73	0	0
	24	0.63	0.26	21.08	1.5	0	0
8.C3:5,000	0	112.89	9.81	0	0	0	0
	6	30.05	3.16	1.12	0.57	0	0
	12	16.36	5.27	28.65	11	0	0
	18	5.88	1.4	31.28	11.85	0	0
	24	0.61	0.74	14.83	0.41	3.3	0.53

Remark: M = Molasses, C1 = Used lard, C2 = Used soybean oil and C3 = Oil waste

Table C-6 PCE reductive dechlorination (C/Co) and %decreasing of PCE/Day

Name	% PCE residual					(%decrease of PCE/day)			
	0	6	12	18	24	(0 - 6)	(0-12)	(0-18)	(0-24)
1.M:5,000	100.0	22.30	8.19	3.77	1.18	12.95	7.65	5.35	4.12
2.M:10,000	100.0	11.56	9.01	2.61	2.53	14.74	7.58	5.41	4.06
3.C1:500	100.0	12.32	7.91	4.11	0.59	14.61	7.67	5.33	4.14
4.C2:500	100.0	16.80	9.71	4.57	0.90	13.87	7.52	5.30	4.13
5.C3:500	100.0	26.23	12.58	1.58	1.00	12.30	7.28	5.47	4.12
6.C1:5,000	100.0	9.97	7.72	3.70	1.87	15.01	7.70	5.35	4.09
7.C2:5,000	100.0	14.98	10.74	1.48	0.54	14.17	7.44	5.47	4.14
8.C3:5,000	100.0	26.62	14.49	5.21	0.54	12.23	7.13	5.27	4.14

Remark: M = Molasses, C1 = Lard, C2 = Used soybean oil and C3 = Oil waste from Leo Food Industry

Table C-7 Percent PCE removal

Name	Triplicate of PCE removal efficiency,%				
	(Average \pm S.D.)				
	0	6	12	18	24
1.M:5,000	0 \pm 13.26	77.70 \pm 12.97	91.81 \pm 2.56	96.23 \pm 2.00	98.82 \pm 0.84
2.M:10,000	0 \pm 23.74	88.44 \pm 6.54	90.99 \pm 1.91	97.39 \pm 0.74	97.47 \pm 1.34
3.C1:500	0 \pm 11.18	87.68 \pm 3.10	92.09 \pm 1.62	95.89 \pm 1.88	94.10 \pm 0.65
4.C2:500	0 \pm 8.520	83.19 \pm 6.35	90.29 \pm 1.74	95.43 \pm 3.88	99.10 \pm 0.51
5.C3:500	0 \pm 4.400	73.77 \pm 2.83	87.42 \pm 1.43	98.42 \pm 0.27	99.00 \pm 0.69
6.C1:5,000	0 \pm 9.410	90.03 \pm 2.34	92.28 \pm 2.83	96.23 \pm 2.16	98.13 \pm 1.65
7.C2:5,000	0 \pm 5.860	85.02 \pm 2.58	89.26 \pm 3.70	98.52 \pm 1.05	99.46 \pm 0.26
8.C3:5,000	0 \pm 9.810	73.38 \pm 3.16	85.51 \pm 5.27	94.79 \pm 1.40	99.46 \pm 0.74

Remark: M = Molasses, C1 = Lard, C2 = Used soybean oil and C3 = Oil waste from Leo Food Industry

Table C-8 pH, Chloride accumulation and gas production

Sample	pH (average)				
	Times(Days)				
	0	6	12	18	24
1.M:5,000	8.69	7.55	7.26	7.31	7.06
2.M:10,000	9.07	7.28	7.61	7.80	7.61
3.C1:500	8.59	7.55	7.47	7.68	7.53
4.C2:500	8.67	7.75	7.50	7.15	7.43
5.C3:500	8.79	7.88	7.32	7.40	7.29
6.C1:5,000	8.35	7.26	7.59	7.90	7.36
7.C2:5,000	8.55	7.46	7.70	7.86	7.74
8.C3:5,000	8.72	7.32	7.18	7.28	7.25

Sample	Triplicate of Chloride production (mg/kg-soil)				
	(Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.M:5,000	0 \pm 1.30	19.61 \pm 1.08	25.72 \pm 0.91	32.18 \pm 1.17	38.16 \pm 0.86
2.M:10,000	0 \pm 1.31	15.18 \pm 1.17	21.42 \pm 0.88	28.66 \pm 1.24	35.11 \pm 1.06
3.C1:500	0 \pm 1.24	22.14 \pm 1.13	28.00 \pm 1.06	37.67 \pm 1.20	53.00 \pm 0.94
4.C2:500	0 \pm 1.18	11.68 \pm 1.07	19.22 \pm 1.18	23.15 \pm 1.18	28.22 \pm 1.12
5.C3:500	0 \pm 1.14	15.37 \pm 1.19	24.19 \pm 0.95	31.81 \pm 1.14	37.18 \pm 1.26
6.C1:5,000	0 \pm 1.25	20.01 \pm 1.23	24.16 \pm 1.07	35.62 \pm 0.86	40.16 \pm 0.92
7.C2:5,000	0 \pm 1.31	21.11 \pm 1.15	29.22 \pm 1.19	37.44 \pm 0.88	43.62 \pm 1.15
8.C3:5,000	0 \pm 1.15	20.00 \pm 1.09	25.17 \pm 1.04	33.65 \pm 0.92	40.26 \pm 1.11

Sample	Triplicate of Gas production (ml)				
	(Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.M:5,000	0 \pm 0.1	0.8 \pm 0.1	1.8 \pm 0.1	1.9 \pm 0.1	2.1 \pm 0.1
2.M:10,000	0 \pm 0.1	1.6 \pm 0.1	1.8 \pm 0.1	2.0 \pm 0.1	2.0 \pm 0.1
3.C1:500	0 \pm 0.1	1.6 \pm 0.1	2.2 \pm 0.1	2.8 \pm 0.1	2.6 \pm 0.1
4.C2:500	0 \pm 0.1	1.2 \pm 0.1	1.6 \pm 0.1	1.8 \pm 0.1	1.8 \pm 0.1
5.C3:500	0 \pm 0.1	0.5 \pm 0.1	1.4 \pm 0.1	1.8 \pm 0.1	2.1 \pm 0.1
6.C1:5,000	0 \pm 0.1	1.8 \pm 0.1	2.0 \pm 0.1	2.2 \pm 0.1	2.0 \pm 0.1
7.C2:5,000	0 \pm 0.1	1.4 \pm 0.1	1.8 \pm 0.1	2.4 \pm 0.1	2.4 \pm 0.1
8.C3:5,000	0 \pm 0.1	0.5 \pm 0.1	2.2 \pm 0.1	2.4 \pm 0.1	2.2 \pm 0.1

Remark: M = Molasses, C1 = Lard, C2 = Used soybean oil and C3 = Oil waste from

Leo Food Industry

Table C-9 Reduced PCE and increasing intermediates using Lard 500 mg/kg-sludge as carbon source

PCE Concentration (mg/kg-soil)	VOC	Triplicate of PCE Dechlorination (mg/kg-soil) (Average \pm S.D.)		
		0	12	24
1. 100	PCE	115.83 \pm 1.90	14.27 \pm 2.17	1.05 \pm 2.16
	TCE	0.00	18.96 \pm 1.09	7.190 \pm 1.47
	DCE	0.00	0.000	0.000
2. 150	PCE	150.40 \pm 2.14	37.09 \pm 1.33	17.00 \pm 2.11
	TCE	0.00	18.12 \pm 5.30	7.76 \pm 4.31
	DCE	0.00	0.000	0.000
3. 200	PCE	216.10 \pm 2.26	56.28 \pm 2.16	26.09 \pm 1.98
	TCE	0.00	7.39 \pm 1.91	4.09 \pm 2.15
	DCE	0.00	0.000	0.000
4. 250	PCE	239.70 \pm 2.10	67.71 \pm 2.06	46.32 \pm 1.51
	TCE	0.00	3.41 \pm 2.40	1.60 \pm 1.48
	DCE	0.00	0.000	0.000
5. 500	PCE	465.60 \pm 1.86	400.38 \pm 2.05	291.91 \pm 2.12
	TCE	0.00	0.79 \pm 0.96	4.94 \pm 2.02
	DCE	0.00	0.000	0.000



Table C-10 PCE reductive dechlorination (C/Co) and %decreasing of PCE/Day

PCE Concentration (mg/kg-soil)	C/Co (%)			PCE decreasing per day	
	0	12	24	sampling time1	sampling time2
1.100	100	12.322	0.904	7.301	0.952
2.150	100	24.663	11.305	6.278	1.113
3.200	100	26.045	12.072	6.163	1.164
4.250	100	28.249	19.324	5.979	0.744
5.500	100	85.992	62.695	1.167	1.941

Table C-11 Percent PCE removal

PCE concentration (mg/kg-soil)	TriPLICATE of PCE removal (%) (Average \pm S.D.)		
	Time (days)		
	0	12	24
1. 100	0 \pm 1.90	87.68 \pm 2.17	99.10 \pm 2.16
2. 150	0 \pm 2.14	75.34 \pm 1.33	88.70 \pm 2.11
3. 200	0 \pm 2.26	73.96 \pm 2.16	87.93 \pm 1.98
4. 250	0 \pm 2.10	71.75 \pm 2.06	80.68 \pm 1.55
5. 500	0 \pm 1.86	14.01 \pm 2.05	37.30 \pm 2.12

Table C-12 pH, Chloride accumulation and gas production

PCE Concentration (mg/kg-soil)	pH (average)				
	Times(Days)				
	0	6	12	18	24
1.100	8.67	-	7.41	-	7.05
2.150	8.93	-	7.59	-	7.11
3.200	8.45	-	7.02	-	7.24
4.250	8.72	-	7.76	-	7.31
5.500	8.16	-	6.89	-	7.23

PCE Concentration (mg/kg-soil)	TriPLICATE of Chloride production (mg/kg-soil) (Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.100	0 \pm 1.24	-	28.0 \pm 1.06	-	53.0 \pm 1.18
2.150	0 \pm 1.08	-	36.2 \pm 1.18	-	71.3 \pm 1.12
3.200	0 \pm 1.12	-	42.1 \pm 1.20	-	76.8 \pm 1.24
4.250	0 \pm 1.20	-	49.8 \pm 1.07	-	86.3 \pm 1.20
5.500	0 \pm 1.14	-	83.2 \pm 1.26	-	112.6 \pm 1.09

PCE Concentration (mg/kg-soil)	Triplicate of Gas production (ml) (Average \pm S.D.)				
	Times(Days)				
	0	6	12	18	24
1.100	0 \pm 0.1	-	2.2 \pm 0.1	-	2.6 \pm 0.1
2.150	0 \pm 0.1	-	0.7 \pm 0.1	-	1.0 \pm 0.1
3.200	0 \pm 0.1	-	0.4 \pm 0.1	-	0.6 \pm 0.1
4.250	0 \pm 0.1	-	0.5 \pm 0.1	-	0.7 \pm 0.1
5.500	0 \pm 0.1	-	0.2 \pm 0.1	-	0.4 \pm 0.1

APPENDIX D

The Extraction Efficiency

Recovery rates were consistent for all samples. LeBoeuf E. J, see Table 4.4, has been working on the understanding of how contaminants interact with organic matter in soil and sediment. Organic contaminants such as chlorinated hydrocarbon are attracted to organic matter present in soil. Many clues are still unknown with the point to controlling behavior of contaminant molecule work their way into organic matter. For example, how strongly the contaminant will be bound to the organic matter in soil, how long it will take to diffuse into soil or how fast it will be released back into the environment. He observed that when organic matter is in a glassy state, it has multiple pores and holds and thus poses a higher sorption capacity then when it is in a rubbery state. It was expected that the contaminants may leach from soil do not reach significant levels.

Table D-1 Recovery efficiency of the chlorinated hydrocarbon using hexane for extraction from different matrix.

Matrix	% Recovery
Water	70-80
Soil or sediment	15-35

However, extraction of wet sediment achieved nearly 100% had been done via sequential solvent extraction. PCE extraction and analysis procedure was modified from Leahy *et al.* (1996) and Suttinun (2004). The extraction efficiency during this experiment in slurry was $95 \pm 10\%$ (Table D-2). Recovery rates were consistent for all samples.

Table D-2 PCE extract concentration (mg/kg-soil) and % Recovery of PCE from slurry contaminated with PCE 100 mg/kg-soil, using extraction method from section 3.5

Sample	Triplicate			Average	S.D.
	1	2	3		
1	104.56	92.65	96.01	97.74	6.14
2	87.65	93.67	85.11	88.81	4.40
3	106.13	100.02	108.51	104.89	4.38
4	90.74	95.73	88.42	91.63	3.74
5	93.26	97.53	91.04	93.94	3.30
6	100.05	97.81	102.97	100.28	2.59
7	88.06	91.39	89	89.48	1.72
8	94.03	97.88	95.02	95.64	2.00
9	92.12	98.05	94.27	94.81	3.00
10	98.07	102.01	99.09	99.72	2.04
% Recovery				95 ± 10	4 ± 2.5

APPENDIX E

Table E-1 The properties of soil

Sample	Initial PCE (mg/kg-soil)	pH	OM g/100g	Sand %	Silt %	Clay %	Texture	Moisture %
Soil	0	6.25	2.15	85.30	11.60	3.10	Loamy sand	2.51

Table E-2 The properties of sludge

Sample	Initial PCE (mg/kg-soil)	pH	OM g/100g	OC g/100g	VSS mg/L
Sludge	0	6.39	0.99	0.58	1.96

Sample analysis Report

By

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APPENDIX F

Table F-1 Direct Reaction of Soybean Oil, Used Oil (Lard & Used Soybean Oil), Molasses with PCE

Sample	Triplicate of PCE Concentration (mg/kg-soil) (Average \pm S.D.)				
	0	6	12	18	24
Soybean Oil	113.5 \pm 0.54	111.1 \pm 1.03	109.9 \pm 0.87	109.7 \pm 0.93	109.0 \pm 0.55
Lard	115.8 \pm 0.43	113.6 \pm 0.67	109.9 \pm 0.54	109.6 \pm 1.10	109.1 \pm 0.32
Used Soybean Oil	112.0 \pm 0.67	111.5 \pm 0.98	109.4 \pm 0.73	108.1 \pm 1.06	107.0 \pm 0.71
Molasses	114.8 \pm 0.27	113.2 \pm 0.37	110.3 \pm 0.28	109.6 \pm 0.57	109.5 \pm 0.48

APPENDIX G

Table G-1 Effect of sludge on PCE reductive dechlorination

Sample name (PCE150 mg/kg-soil)	Parameters (average)	Time (days)					C/Co (%)				
		0	6	12	18	24	0	6	12	18	24
1. sludge	PCE, mg/kg-soil	140.5	133.54	127.67	114.6	110.44	100	95.05	90.89	81.57	78.60
	TCE, mg/kg-soil	0	0.34	3.18	7.45	6.78					
	DCE, mg/kg-soil	0	0	0	0	0					
	Gas production, ml	0	0.4	0.9	0.8	0.6					
	Chloride, mg/kg-soil	0	0.23	1.7	2.6	2.8					

Table G-2 Effect of nutrient on PCE reductive dechlorination

Sample name (PCE150 mg/kg-soil)	Parameters (average)	Time (days)					C/Co (%)				
		0	6	12	18	24	0	6	12	18	24
1. Nutrient	PCE, mg/kg-soil	151.8	149.2	146.9	133.9	125.7	100	98.29	96.77	88.21	82.81
	TCE, mg/kg-soil	0	1.34	2.38	4.06	1.39					
	DCE, mg/kg-soil	0	0	0	0	0					
	Gas production, ml	0	0.2	0.3	0.4	0.4					
	Chloride, mg/kg-soil	0	0.50	0.82	1.45	2.56					

Table G-3 Effect of sludge and nutrient on PCE reductive dechlorination

Sample name (PCE150 mg/kg-soil)	Parameters (average)	Time (days)					C/Co (%)				
		0	6	12	18	24	0	6	12	18	24
1. Sludge and Nutrient	PCE, mg/kg-soil	145.7	105.93	98.52	98.42	84.15	100	72.71	67.62	67.55	57.76
	TCE, mg/kg-soil	0	2.57	4.21	4.72	3.89					
	DCE, mg/kg-soil	0	0	0	0	0					
	Gas production, ml	0	1.2	1.5	1.6	1.4					
	Chloride, mg/kg-soil	0	7.642	8.215	8.976	9.147					

Table G-4 Effect of nothing added on PCE reductive dechlorination

Sample name (PCE150 mg/kg-soil)	Parameters (average)	Time (days)					C/Co (%)				
		0	6	12	18	24	0	6	12	18	24
1. Nothing added	PCE, mg/kg-soil	152.7	152.47	151.84	152.15	152.29	0	99.85	99.44	99.64	99.73
	TCE, mg/kg-soil	0	0	0	0	0					
	DCE, mg/kg-soil	0	0	0	0	0					
	Gas production, ml	0	0	0	0	0					
	Chloride, mg/kg-soil	0	0	0	0	0					

Table G-5 Effect of carbon source, sludge and nutrient on PCE reductive dechlorination

Sample name (PCE150 mg/kg-soil)	Parameters (average)	Time (days)					C/Co (%)				
		0	6	12	18	24	0	6	12	18	24
1. C-source, sludge and nutrient	PCE, mg/kg-soil	149.6		36.89		16.90	0		24.66		11.30
	TCE, mg/kg-soil	0		15.34		5.68					
	DCE, mg/kg-soil	0		0		0					
	Gas production, ml	0		0.4		0.8					
	Chloride, mg/kg-soil	0		31.60		65.10					

BIOGRAPHY

Miss Sunisa Nortem was born on December 5, 1981 in Chiang Mai, Thailand. She attended Sanpatong Wittayakom School in Chiang Mai and graduated 2000. She received her Bachelor's Degree in Environmental Engineering from Faculty of Engineering, Chiang Mai University in 2004. She pursued her Master Degree study in the International Postgraduate Programs in Environmental Management, Inter-Department of Environmental Management, Chulalongkorn University, and Bangkok, Thailand in May 2004. She was awarded Master degree of Science in Environmental Management in April 2006.

