REFERENCE

American Public Health Association, "Standard Methods for the Examination of Water and Wastewater," 15th ed. American Public Health Association, Washington D.C., 1980.

Buswell, A.M., and H.F.Mueller, "Mechanisms of Methane Fermentation" Industrial and Engineering Chemistry, 44, 550-552, 1952.

Cail, R.G., and J.P. Barford, "The Development of Granulation in an Upflow Floc Digester and an Upflow Anaerobic Sludge Blanket Digester Treating Cane Juice Stillage," Biotech. Letters, 7(7), 493 - 498, 1985.

Chitcharoongkiat, N., "Residual Soy Bean Biogas Production by Upflow Anaerobic Sludge Blanket," Master's thesis, Department of Environmental Engineering, Graduate School, Chulalongkorn University, 1986.

Christensen, D.R., J.A. Gerick, and J.E.Eblen, "Design and Operation of an Upflow Anaerobic Sludge Blanket Reactor," JWPCF, 56(9), 1059 - 1062, 1984.

Cohen, A., R.J. Zoetemeyer, A. Van Deusen, and J.G. Van Andel, "Anaerobic Digestion of Glucose with Separated Acid Production and Methane Formation, "Water Res., 13, 571 - 580, 1979.

DiLallo, R., and O.E. Albertson, "Volatile Acids By Direct Titration," JWPCF, 33(4), 356 - 365, 1961.

Fernandes, X.A., A.D. Cantwell, and F.E. Mosey, " Anaerobic Biological Treatment of Sewage," J. Water Pollut. Control,

84(1), 99 - 110, 1985.

Ford, B.J., Microbiology And Food, pp. 108 - 109, Northwood Publications Ltd., London, 1971.

Guiot, S.R., and L. van den Berg, " Performance of an Upflow Anaerobic Reactor Combining a Sludge Blanket and a Filter Treating Sugar Waste," Biotech. & Bioeng., 27, 800 - 806, 1985.

Harbets, L.H.A., and J.H. Knelissen, "Application of the UASB Reactor for Anaerobic Treatment of Paper and Board Mill Effluent," Wat. Sci. Tech., 17, 61 - 75, 1985.

Heertjes, P.M., and L.J. Knijvenhoven, "Fluid Flow Pattern in Upflow Reactors for Anaerobic Treatment of Beet Sugar Factory Wastewater," Biotech. & Bioeng., 24, 443 - 459, 1982.

Heertjes, P.M., and R.R. van der Meer, "Dynamics of Liquid FLow in an Upflow Reactor used for Anaerobic Treatment of Wastewater," Biotech. & Bioeng., 20, 1577 - 1594, 1978.

Hulshoff Pol, L.W., W.J. de Zeeuw, C.T.M. Velzeboer, and G. Lettinga, "Granulation in UASB-Reactors," Wat. Sci. Tech., 15, 291 - 304, 1983.

Jeris, J.S., and P.L. McCarty, "Biochemistry of Methane Fermentation Using C_{14} Tracers," JWPCF, 37, 178 - 192, 1965.

Jewell, W.J.,W.W.JR.Eckenfelder, and M.E. Lavalier," The Use of Pure Oxygen for Biological Treatment of Brewery Wastewaster," Proceedings of Industrial Waste Conference, Purdue Univ. (J.M.Bell, ed.), pp.487-495, Ann Arbor Science Publisher Inc., Michigan, 1971.

Kirsch, E.G., and R.M. Sykes, "Anaerobic Digestion in Biological Waste Treatment," Progress in Industrial Microbiology, 9, 155

- 237, 1971.

Kobayashi, H.A., M.K. Stenstrom, and R.A. Mah, "Treatment of Low Strength Domestic Wastewater Using the Anaerobic Filter," Water Res., 17(8), 903 - 909, 1983.

Koster, Iman W., and Albertus Cramer, "Inhibition of Methanogenesis from Acetate in Granular Sludge by Long-Chain Fatty Acids," Applied and Environmental Microbiology, 53(2), 403 - 409, 1987.

Koster, I.W., and G. Lettinga, "Application of the Upflow Anaerobic Sludge Bed (UASB) Process for Treatment of Complex Wastewaters at Low Temperatures," Biotech. & Bioeng.,27, 1411 - 1417, 1985.

Kotze, J.P., P.G. Thiel, and W.H.J. Hattingh, "Anaerobic Digestion : Part II, The Characterization and Control of Anaerobic Digestion," Water Res., 3, 459 - 494, 1969.

Lettinga, G., and J.N. Vinken, "Feasibility of the process for the treatment of low strength wastes," Proceedings of the 35th Annual Industrial Waste Conference, Purdue Univ. (J.M. Bell, ed.), pp. 625 - 634, Ann Arbor Science Publishers Inc., Michigan, 1980 (a).

Lettinga, G., A.F.M. van Velsen, S.W. Hobma, W.J. de Zeeuw, and A. Klapwijk, "Use of the Upflow Sludge Blanket (USB) reactor concept for biological wastewater treatment," Biotech. & Bioeng., 22, 699 - 734, 1980(b).

Lettinga, G., A.F.M. van Velsen, W.J. de Zeeuw, and S.W. Hobma, "The Application of Anaerobic Digestion to Industrial Pollution Treatment," Anaerobic Digestion (D.A. Stafford, B.I. Wheatly

and D.E. Hughes, eds), pp. 167 - 186, Applied Science Publishers, London, 1980(c).

Lettinga, G., L.W. Hulshoff Pol, I.W. Koster, W.M. Wiegant, W.J. de Zeeuw, P.C. Grin, and R.E. Roersma, and S.W. Hobma, "High-Rate Anaerobic Waste-Water Treatment Using the UASB Reactor Under a Wide Range of Temperature Conditions," Biotech. & Genetic Eng. Reviews, 2, 253 - 284, 1984.

Lettinga, G., P.C. Grin, and R.E. Roersma, " Anaerobic Treatment of Raw Domestic Sewage at Ambient Temperature Using a Granular Sludge Bed UASB Reactors, " Biotech. & Bioeng., 24, 1701 - 1724, 1983.

Lettinga, G., W.J. de Zeeuw, L.W. Hulshoff Pol, W.M. Wiegant, and A.Rinzema, "Anaerobic Wastewater Treatment Based on Biomass Retention with Emphasis on the UASB-process," Anaerobic Digestion 1985(China State Biogas Association, ed.), pp. 279-301, 1985.

Lovan, C.R., and E.G. Foree, "The Anaerobic Filter for the Treatment of Brewery Press Liquor Waste," Proceedings of the 26th Annual Industrial Waste Conference, Purdue Univ. (J.M. Bell, ed.), pp. 1074 - 1086, Ann Arbor Science Publishers Inc., Michigan, 1974.

McCarty, P.L., "Anaerobic Waste Treatment Fundamentals Part I - III," J. Public Works, September - November, 1964.

McInerney, M.J., M.P.Bryant, and D.A. Stafford, "Metabolic Stages and Energetics of Microbial Anaerobic Digestion," Anaerobic Digestion (D.A. Stafford, B.I. Wheatley and D.E. Hughes, eds.), pp. 97, Applied Science Publishers, London, 1980.

Meer, R.R. van der, and R. de Vletter, " Anaerobic Treatment of Wastewater : The Gas - Liquid Sludge Separator," JWPCF, 54(11), 1482 - 1492, 1982.

Meyer Hakan, "Pollution Problems in Brewing," European Brewery Convention; Proceedings of 14th Congress Salzburg 1973, pp. 429 - 442, Elsevier Scientific Publishing Company, Amsterdam London New York, 1974.

Mosey, F.E., "New Development in the Anaerobic Treatment of Industrial Wastes," J. Water Pollut. Control, 550 - 552, 1982.

Opasawatchai, S., "Anaerobic Digestion and Biogas Production of Garbage by Thermophilic Bacteria," Master's thesis, Department of Environmental Engineering, Graduate School, Chulalongkorn University, 1983.

Pang, K., "Upflow Anaerobic Sludge Blanket Reactor with Inclined Tube Settlers," Master's thesis, Division of Environmental Engineering, Asian Institute of Technology, 1988.

Parkin, G.F., and R.E. Speece, "Attached vs Suspended Growth Anaerobic Reactors Response to Toxic Substances," Wat. Sci. Tech., 15, 261 - 289, 1983.

Pederson, C.H., Microbiology of Food Fermentations, pp. 270, The AVI Publishing Company, Inc., Connecticut, 1971.

Pette, K.C., and A.I. Versprille, "Application of the UASB-Concept for Wastewater Treatment," Anaerobic Digestion 1981 (Hughes *et al.*, eds.), pp. 121-133, Elsevier Biomedical Press, Amsterdam, 1981.

Pette, K.C., R. de Vletter, E. Wind, and W. van Gils, "Full-Scale

Anaerobic Treatment of Beet-Sugar Wastewater," Proceedings of the 35th Annual Industrial Waste Conference, Purdue Univ. (J.M. Bell, ed.), pp. 39-47, Ann Arbor Science Publishers Inc., Michigan, 1980.

Pfeffer, J.T., "Temperature Effects on Anaerobic Fermentation of Domestic Refuse,"Biotech. & Bioeng., 16, 771, 1974.

Pittayathorn, P., "Treatment of Low-Strength Wastewater by UASB Process," Master's thesis, Department of Environmental Engineering, Graduate School, Chulalongkorn University, 1986.

Pohland, F.G., and D.E. Bloodgood, "Laboratory Studies on Mesophilic and Thermophilic Anaerobic Sludge Digestion," JWPCF, 35(1), 11 - 42, 1963.

Pohland, F.G., "High-Rate Digestion Control III - Acid-Base Equilibrium and Buffer Capacity," Proceedings of the 23rd Annual Industrial Waste Conference, Purdue Univ. (J.M. Bell, ed.), pp. 275 - 284, Ann Arbor Science Publishers Inc., Michigan, 1968.

Polprasert, C., and N.C. Thanh, "Biogas Systems in Asia," Second Regional Seminar on Solid Waste Management (Thanh, N.C., *et al.*, eds.), pp.213 - 243, AIT, Bangkok, 1979.

Sawyer, C.N., P.L. McCarty, Chemistry for Environmental Engineering, McGraw-Hill Book Co., New York, 3rd ed., 1978.

Sayed, Sameh, W. de Zeeuw, and G. Lettinga, "Anaerobic Treating of Slaughterhouse Waste Using a Flocculant Sludge UASB Reactor," Agricultural Wastes, 11, 197 - 226,1984.

Speece, R.E., and P.L. McCarty, "Nutrient Requirements and Biological Solid Accumulation in Anaerobic Digestion,"

Advanced in Water Pollution Research (W.W. Eckenfelder, ed.), Vol.2, pp. 305 - 322, Pergamon Press, New York, 1964.

Speece, R.E. "Toxicity in Anaerobic Digestion," Anaerobic Digestion 1985 (China State Biogas Association, ed.), pp. 515-523, 1985.

Tebbutt, T.H.Y., Principles of Water Quality Control, pp. 130 - 132, Pergamon Press Ltd., Glasgow, 1st ed., 1971.

Technological Practice Commitee-Subcommitee on Sludge Digestion, "Anaerobic Sludge Digestion," WPCF's Manual of Practice No.16, JWPCF, 38, 1683 - 1702, 1966.

Toerien, D.F., and W.H.J. Hattingh, "Anaerobic Digestion : Part I, The Microbiology of Anaerobic Digestion," Water Res., 3, 385, 1969.

Van den Berg, J.G., "Effect of Temperature on Growth and Activity of a Methanogenic Culture Utilizing Acetate," Can. J. Microbiol, 23,898 - 902, 1977.

Van Velsen, A.F.M., and G. Lettinga, "Effect of Feed Composition on Digester Performance," Anaerobic Digestion (D.A. Stafford, B.I. Wheatley and D.E. Hughes, eds.), pp. 128 - 129, Applied Science Publishers, London, 1980.

Verink, J. *et al.*, "Pilot-Scale Research for Distillery Wastewater Treatment," Paper presented in the Seminar on Biotechnology for Agro-Industrial Waste Management, 5 - 6 February, Bangkok, Thailand, 1990.

Wheatley, B.I., "The Gaseous Products of Anaerobic Digestion - Biogas," Anaerobic Digestion (D.A. Stafford, B.I. Wheatley and D.E. Hughes, eds.), pp. 416, Applied Science Publishers,

London, 1980.

Wiegant, W.M., and A.W. de Man, "Granulation of Biomass in Thermopilic Upflow Anaerobic Sludge Blanket Reactors Treating Acidified Wastewater," Biotech. & Bioeng., 28, 718 - 727, 1986.

Wiegant, W.M., and G. Lettinga, "Thermophilic Anaerobic Digestion of Sugars in Upflow Anaerobic Sludge Blanket Reactors," Biotech. & Bioeng., 27, 1603 - 1607, 1985.

Williams, Richard T., Ronald L. Crawford, "Methanogenic Bacteria, Including and Acid - Tolerant Strain, from Peatlands," Applied and Environmental Microbiology, 50(6), 1542 - 1544, 1985.

Wu Wei-min, Hu Ji-cui, and Gu Xia-sheng, "Properties of Granular Sludge in Upflow Sludge Blanket (UASB) Reactor and Its Formation," Anaerobic Digestion 1985(China State Biogas Association, ed.), pp. 339-351, 1985.

Zeeuw, W.J. de, and G. Lettinga "Acclimation of Digested Sewage Sludge during Start-up of an Anaerobic Sludge Blanket (UASB)Reactor," Proceedings of the 35th Annual Industrial Waste Conference, Purdue Univ.(J.M.Bell,ed.), pp. 39-47, Ann Arbor Science Publishers Inc.,Michigan, 1981.

Zeevalkink, J.A., and W. Maahkant, "Biogas from Effluents of Starch Industries by Anaerobic Treatment," Starch/Stärke, 36, Nr.4, s, 131-135, 1984.

Zeikus, J.G., "Microbial Populations in Digesters," Anaerobic Digestion (D.A. Stafford, B.I. Wheatley and D.E. Hughes, eds.), pp. 63, Applied Science Publishers, London, 1980.

Zheng Yan-jin, and Wu Wei-guo, "A Study of Meat Packing Plant

Wastewater Treatment with Upflow Anaerobic Sludge Blanket Process, "Anaerobic Digestion 1985(China State Biogas Association, ed.), pp. 327-337, 1985.

APPENDIX

1. Calculation of Biogas at STP

In this study the total pressure of biogas collected on the top of the UASB reactor operating under 15 cm. water pressure was 780.6 mm Hg. The collecting of biogas was made over water of 38°C and the temperature of biogas was 40°C in average.

The calculation was based on the Gas Law as

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

or $$V_2 = V_1\left(\frac{P_1}{P_2}\right)\left(\frac{T_2}{T_1}\right)$$

where V_1 = volume of biogas collected

V_2 = final volume of gas at STP

P_1 = pressure of biogas collected

P_2 = standard pressure = 760 mm Hg

T_1 = temperature of biogas collected (°K)

T_2 = standard temperature = 273°K

The biogas collected was estimaated to compose of CH_4 & CO_2 (ignoring traces of N_2, H_2S, and NH_3) and water vapor. The partial pressure of water vapor at 38°C is 49.7 mm Hg (see Table I).

Table I

Vapor pressure of water of various temperatures

Temperature (°C)	30	35	38	40	50	60
Vapor Pressure (mm Hg)	31.8	42.2	49.7	55.3	92.5	149.4

Source : *Handbook of Chemistry and Physics, 40th ed., CRC Publishing Co.*

Hence the partial pressure of the biogas is the total pressure less 49.7 mm Hg.

Pressure of dry biogas = total pressure - vapor pressure of water

= 780.6 mm Hg - 49.7 mm Hg

= 730.9 (or 731 mm Hg)

Example

Exactly 300 l of biogas is collected per day from the UASB reactor. Compute the standard volume of the dry biogas.

$$\text{Volume of biogas at STP } (V_2) = 300 \text{ l} \times \frac{731 \text{ mm Hg}}{760 \text{ mm Hg}} \times \frac{273^\circ\text{K}}{273+40^\circ\text{K}}$$

$$= 251.7 \text{ l/d}$$

2. Calculation of CO_2 Solubility

The solubility of CO_2 is based on Henry's Law as

$$X = \frac{P}{K}$$

where X = mole fraction of CO_2

P = partial pressure of CO_2 (mm Hg)

K = Henry's Constant for CO_2

In this study, the UASB reactor was always found in a normal performance. Hence the given CO_2 and CH_4 containing in the biogas collected were 25% and 75% by volume, respectively.

With the above pressure of dry biogas computed (in item 1), it equals to 731 mm Hg; the partial pressure of CO_2 and CH_4 are therefore asd follow :

$$\text{Partial pressure of } CO_2 = 731 \times \frac{25}{100} = 182.75 \text{ mm Hg}$$

$$\text{Partial pressure of } CH_4 = 731 \times \frac{75}{100} = 548.25 \text{ mm Hg}$$

And Henry's Constant for carbon dioxide at various temperature are listed in Table II.

Table II

Henry's Constant for carbon dioxide at various temperatures

Temperature (°C)	30	38	40	50	60
K x 10^{-7}	0.139	0.168	0.173	0.217	0.258

Source : *Handbook of Chemistry and Physics, 40th ed., CRC Publishing Co.*

We can find CO_2 solubility in water 1 liter from Henry's Law as

$$X_{CO_2} = \frac{P_{CO_2}}{K_{CO_2(38°C)}} = \frac{\text{moles of } CO_2}{\text{moles of } CO_2 + \text{moles of } H_2O + \text{moles of } CH_4}$$

where moles of $H_2O = \frac{1000g}{18.02g} = 55.49$

moles of CO_2, moles of CH_4 <<< moles of H_2O .·. neglected

Hence moles of CO_2 = $\frac{182.75 \text{ mm Hg} \times 55.49}{0.168 \times 10^7}$

= 6.04×10^{-3}

Molecular Weight of CO_2 1M = 44 g

Volume of CO_2 1M = 22.4 l

.·. The CO_2 solubility = $6.04 \times 10^{-3} \times 44$ = 0.26 g/l

or = $0.04 \times 10^{-3} \times 22.4$ = 0.14 l/l

VITA

The author, Ms. Arunee Wajanavijai, was born on October 21, 1960 here in Bangkok, Thailand. She received a bachelor degree in general science from Chulalongkorn University in the education year 1982. She then worked as a staff of the Boon Rawd Brewery Co., Ltd ever since the year 1983. After 4 years working, she was sent to further her postgraduate study in Environmental Science at Graduate School, Chulalongkorn University. At present, she is now in charge of chief of wastewater analysis laboratory which is a unit in the Boon Rawd Brewery Wastewater Treatment Section.