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APPENDICES

APPENDIX A

Research Report To
The International DAAD - granted Exchange Project

Name :

Mrs. Arunee Supasinsathit Ph.D Student of Inter-department of Environmental Science, Chulalongkorn University, Bangkok Thailand

Duration of Stay :

September 29 – October 30, 2005 at the Bauhaus-Universität Weimar

Supervisor :

Jun.-Prof. Dr.- Ing. Eckard Kraft

Address :

Department of Waste Management, Bauhaus-Universität Weimar, Coudraystrasse 7, 99423 Weimar, Germany

Acadamic Activity :

Feasibility Study of Trend to Get Hydrogen Production from the Residue of Brewing Process by Using 2 types of Seed Sludge as follow :

1) Anaerobic Digestion Sludge taken from the laboratory of Waste Management of Bauhaus-Universität Weimar, Germany (let's say Inoculum I)
2) Anaerobic Digestion Sludge taken from the UASB reactor of Boonrawd Brewery Co., Ltd. Bangkok, Thailand (let's say Inoculum II)

Methodology

The sample of residue from brewing process (spent malt or used grain) was taken from the Ehringsdorfer Brewery in Weimar, Germany (Address: Brauerei Weimar-Ehringsdorf, Hainweg 13, 99425 Weimar-Ehringsdorf). The batch test was carried out in vol. of 8 l and 10 l reactor, respectively (without stirrer). Each reactor was determined by mixing 300 g of spent malt (wet weight) with tap water nearly up to full of the reactors. The aim in doing so was to have a small head space gas left in the least. Due to the mixture of CO_2/CH_4 gas used to flush the head space was not available in the laboratory at that moment. Two seed sludge of anaerobic digester were boiled for 30 min to inactivated hydrogen consumer and to harvest spore-forming anaerobic bacteria. The 432 ml of Inoculum I and 290 ml of Inoculum II were added to individual reactor. A small amount of used yeast from the Brewery and $NaHCO_3$ were also added to the reactors so as to be a nutrient and as a buffer capacity. Two reactors were kept under mesophyllic condition (36 deg. C). The pH value of each reactor during start-up period was approx. 6.0. The process reaction was evaluated based on the parameters: amount of gas, content of methane, carbondioxide, hydrogen , hydrogen sulfide and pH-values. By using bag collecting gas sample and then fed in the gas analyser.

Analytical Method

- The percentage of H_2 in biogas can not be detected directly in this experiment. Because the gas analyser available here in the laboratory has been geared to the investigation of CH_4&CO_2 (infrared sensors) and H_2&H_2S (electrochemical sensors). And also the H_2&H_2S content analysis can be measured only in the range from 0-2000 ppm. To solve this problem, supposing CH_4 gas was not found in the measurement. Let's say that the rest should be CO_2, H_2 and N_2 gas.

- The amount of gas production was measured by using Ritter Milligascounter, type MGC-1 as shown in the appendix.

- The pH-value was determined by a WTW pH 330 pH meter equipped with a EGA 173 probe.

Result & Discussion

Date / Time	Reactor A				Reactor J		
	Gas Production (ml/d)	Content	pH		Gas Production (ml/d)	Content	pH
07.10.2005 17:30	8458,24	%CH4= 0 %CO2=59,4 H2 = 2000 ppm H2S = 0 ppm	5.7		4311,24	%CH4 = 1.4 %CO2 = 48,6 H2 = 2000 ppm H2S = 0 ppm	6.1
08.10.2005 17:30	6521.76	%CH4= 0 %CO2 = 75,1 H2 = 2000 ppm H2S = 0 ppm	4,9		6906.42	%CH4 = 0 %CO2 = 81,7 H2 = 2000 ppm H2S = 0 ppm	5.4
09.10.2005 17:30	3599,68	%CH4= 0 %CO2 = 83,7 H2 = 2000 ppm H2S = 0 ppm	4.7		5491.17	%CH4 = 0 %CO2 = 77,7 H2 = 2000 ppm H2S = 0 ppm	5.2
10.10.2005 17:30	2048,32	%CH4= 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	4,6		3891.17	%CH4 = 0 %CO2 = 70,3 H2 = 2000 ppm H2S = 0 ppm	5,1
11.10.2005 17:30	1209.76	%CH4= 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	4,5		1818.67	%CH4 = 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	5.1
1[illegible].10.2005 [illegible]7:30	182.24	%CH4= 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	4.5		321.33	%CH4 = 0 %CO2 - H2 = 2000 ppm H2S = 0 ppm	5
1[illegible].10.2005 [illegible]7:30	0	%CH4= 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	4.5		107	%CH4 = 0 %CO2 = H2 = 2000 ppm H2S = 0 ppm	5

Batch Trial I : From Table, it can be seen that the digester sludge in both reactors can work suddenly since the start-up period. No need to wait for 2-3 days incubation for gas production like the other experiments (e.g., O.Mizuno *et al.*, 2000), by observation of the amount of gas production. In this study, the result of the gas content in the first day should be neglected because there may be some N_2 gas mixed in the head space of the reactor from the atmosphere before each reactor was closed on the top side. However it can be seen that gas production of the reactor J increase in a more fraction when compare to the reactor A. By observation of the performance of the reactor J, a gradual decreasing in $\%CO_2$ was shown, together with the amount of gas occurred and the stable of pH-value. This implied that $\%H_2$ may be increasing gradually in the reactor J and also the process operation seemed to be entered the steady state condition which was better than those of the reactor A. It may be because of the pH-value in the reactor A was dropped below 5 despite the fact that buffer solution was added equally in each reactor. Normally the optimum pH for H_2 production should be kept between 5-6 (J.J. Lay *et al*,1999). As seen from the table, the content of gas production could not detected at all since the day 3rd . There are 2 reasons from the limitation in this study as follows :

1) If the gas collected in a bag was not higher than 2000 ml/d, it could not be detected by gas analyser because of too less gas.
2) After the day 3[rd] gas production begin to decrease in both reactors, maybe because of lacking of stirrer to mix inside the reactor which lead to the accumulation of organic acid production. This will make the pressure in the reactor too low. As a result, a polymer or oil inside the gasmeter device was suck back to the reactor. Thus the gas produced could not come out from the reactor. That's why it can be seen that gas production in each reactor was dropped so quickly.

Batch Trial II : Another batch test has been done later on (October 20,2005). Eventhough the result of the 1[st] day could not detected (arising from some mistaken techniques). However, the result of the day 2[nd] (as shown in the table below) could be used as a supporting data.

Date	Reactor J					Reactor A				
21/10/2005	Gas Production (ml/d)	CH_4 (%)	CO_2 (%)	H_2 (ppm)	H_2S (ppm)	Gas Production (ml/d)	CH_4 (%)	CO_2 (%)	H_2 (ppm)	H_2S (ppm)
	> 8000	0	50.9	2000	0	4131.60	0	78.1	2000	0

It indicated a better performance of the reactor J, particularly %CO_2 of 50.9 which implied that H_2 content may be reached to 50-60% similarly to the other experiments (S.H. Kim *et al*, 2004)

Conclusion

In this study, residue of the brewery has a good trend to give H_2 gas production, particularly by using a H_2-producing mixed culture from the laboratory of Waste Management of Bauhaus-Universität Weimar.

References

1) S.-H. Kim, S.-K. Han and H.-S. Shin. 2004. Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge. International Journal of Hydrogen Energy.29:1607-1616.
2) J.-J. Lay, Y.-J. Lee and T. Noike. 1999. Feasibility of biological hydrogen production from organic fraction of municipal solid waste. Wat.Res. vol. 33, No.11. 2579-2586.
3) O. Mizuno, R. Dinsdale, F.R. Hawkes and T. Noike. 2000. Bioresource Technology 73: 59-65.

Comment

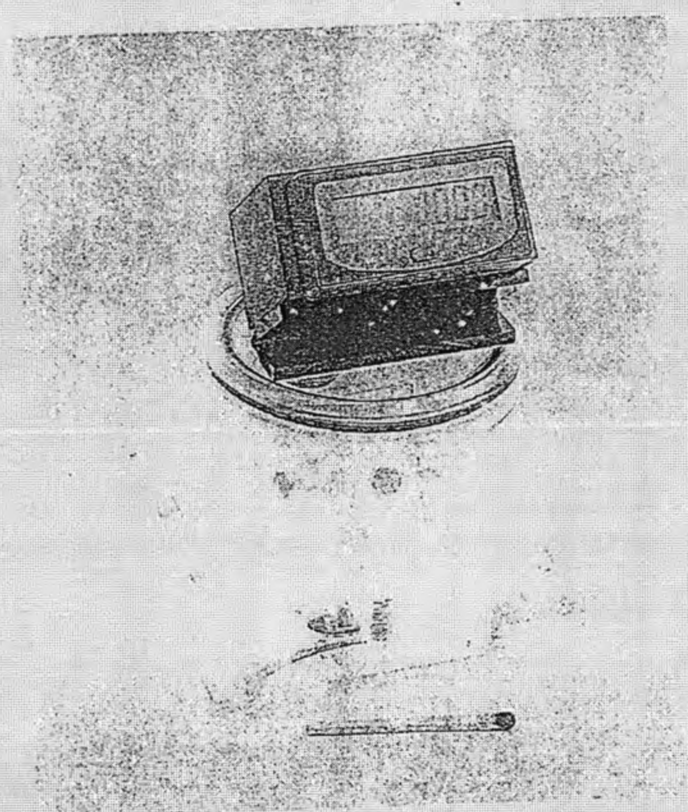
I would like to express my sincerely thanks to Jun.-Prof. Dr.-Ing. Eckhard Kraft for being my host scientist and his very warm hospitality during my stay. Special thanks to Dipl.-Ing. Thomas Haupt and Dipl.-Ing. Jan Liebetrau for their kindly advice, assistance and all facilitation providing in my experimental work.

Acknowledgement

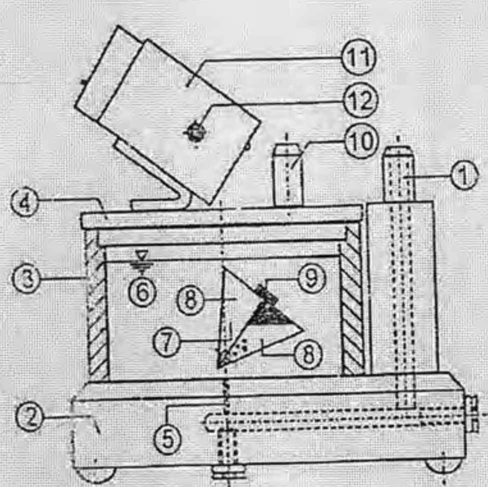
I would like to express my gratitude to the International DAAD-granted Exchange Project for the financial support on this visit.

Appendix

Ritter	MILLIGASCOUNTER®[1]	05.01 V 2.4 Rev. 04/05



[1] Eingetragenes Warenzeichen. Der MilliGascounter wurde an der Hochschule für Angewandte Wissenschaften Hamburg unter der Leitung von Prof. Dr. Paul Scherer entwickelt.



Gehäuse-Komponenten

(1) Gaseingangsstutzen
(2) Basisplatte
(3) Flüssigkeits-Behälter
(4) Behälterdeckel
(5) Mikrokapillare
(6) Sperrflüssigkeit
(7) Messzelle (Kippkörper)
(8) zwei Messkammern
(9) Dauermagnet
(10) Gasausgangsstutzen
(11) Zählwerk mit LCD-Anzeige
(12) Ausgangsbuchse Reed-Kontakt

2. Inbetriebnahme

2.1. Nach dem Erhalt

a) Jeder MilliGascounter wurde einzeln aufwendig kalibriert und ist damit ein Präzisionsmessgerät. Lesen Sie daher bitte sorgfältig diese Bedienungsanleitung, um einen langen, störungsfreien Betrieb zu gewährleisten.

b) Bitte den MilliGascounter vorsichtig auspacken. Die Packung enthält:

- 1 MilliGascounter
- 1 Flasche Sperrflüssigkeit (100ml)
- 1,5 m Anschlussschlauch
- 1 Deckel-Öffner (PMMA-Block mit abgerundeten Kanten)
- 1 Reinigungsstab für die Mikrokapillare

c) **Als Transportschutz ist die Messzelle (7) durch ein Stück Schaumstoff blockiert, das entfernt werden muss.** Nehmen Sie hierzu den Deckel (4) des Flüssigkeitsbehälters inklusive Zählwerk (11) herunter unter Beachtung der Anweisungen in Ziffer 2.2. **Bitte fassen Sie die Deckel hierbei nicht am Zählwerk an, da dieses abbrechen könnte.**

Entfernen Sie den Schaumstoff **vorsichtig** ohne die zerbrechliche Messzelle (7) zu beschädigen.

Empfehlung: Nach Abnahme des Deckels kann der Behälter auch mit der Sperrflüssigkeit entsprechend Ziffer 2.3 gefüllt werden. Führen Sie die Inbetriebnahme nach dem Befüllen mit dem folgenden Absatz weiter durch.

Bitte beachten Sie: Die korrekte Position (in Rotationsrichtung) des Deckels relativ zum Behälter ist sehr wichtig! Zur ersten Grob-Orientierung muss sich der Gaseingangs-Stutzen (1) direkt neben dem Gasausgangs-Stutzen (10) befinden. Zur Feinjustierung müssen die Ritzmarkierungen an der Oberseite der beiden Stutzen in einer Linie fluchten. **Eine falsche Position des Behälterdeckels kann zu fehlerhaften Mes-**

Figure A-1 Photo of the parallel experiments carried out using two types of seed sludge; inoculum I and inoculum II, in the temperature control room at 37° C.

APPENDIX B

Anaerobic digestion

Anaerobic digestion is the complex process involving several classes of microbes and many intermediate products. Methane production by anaerobic degradation occurs in a series of 3 steps: the complex organic compounds are hydrolyzed to their monomer units by microbial external enzymes, which are then transformed into volatile acids by acidogens, and gases mainly methane by methanogens from which methane is generated.

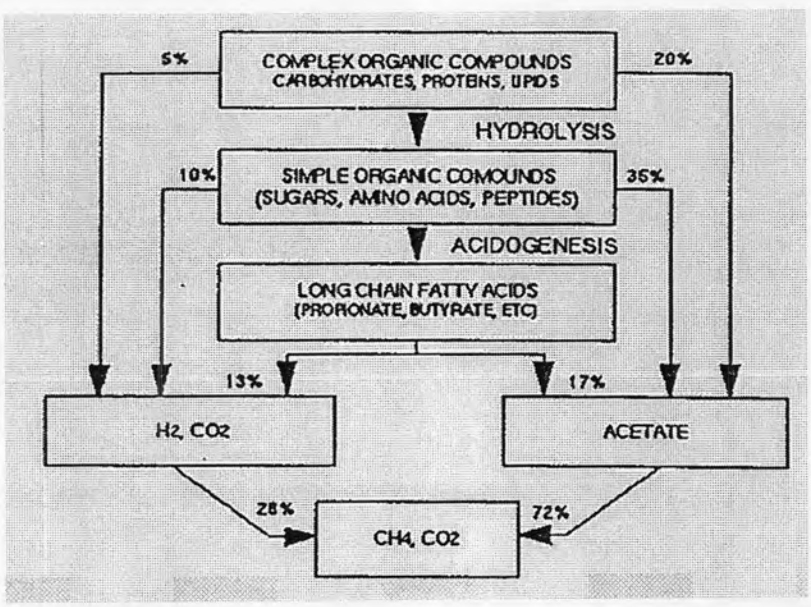


Figure B-1 Metabolism resulting in methanogenesis (Carty and Smith, 1986)

Calculation of Biogas at STP

In this study the total pressure of biogas collected on the top of the CSRT reactor operating under normal pressure. The collecting of biogas was made over the temperature of bio gas was 30 ℃ 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 = 273.15 °K

The biogas collected was estimated to compose of H_2 & CO_2 (ignoring traces of N_2. H_2S, and NH_3) and water vapor.

Example

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

Volume of biogas at STP (V_2) $= 300l \times \dfrac{273.15°K}{273.15 + 30°K}$

$= 270.31$ l/d

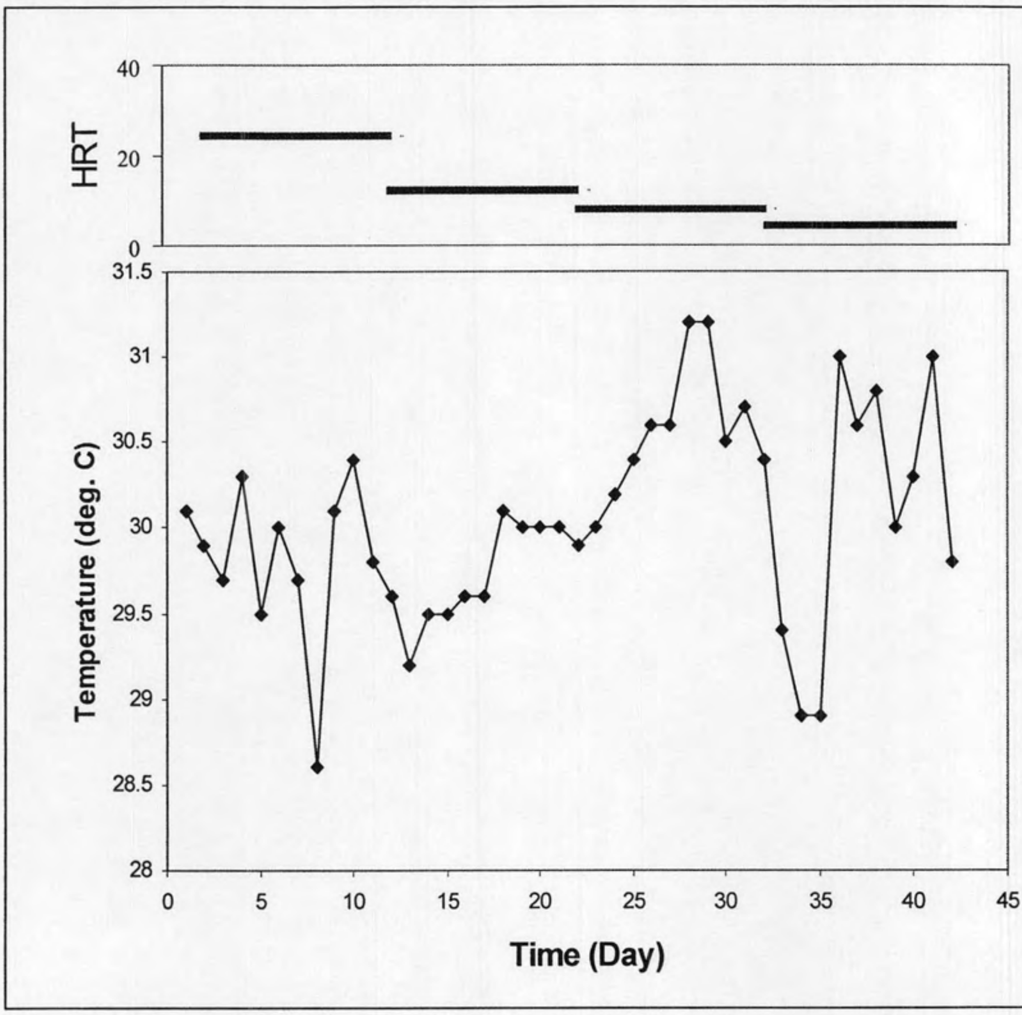


Figure B-2 Temperature during continuous experiment

APPENDIX C

Beer Production Process

Beer brewing is the largest biotechnological industry in the world. This production of beer in the world and per capital consumption are shown in table C-1 The world beer production in 1990 as approximately 1,141 x 10^2 megaliters. Beer can legally be defined as a malt beverage resulting from alcoholic fermentation of the aqueous extract of malted barley flavored with hops with or without other cereal grains. Most beer is made from malt, hops, yeasts, water, and malt adjuncts, Adjuncts are nonmalted carbohydrate-containing materials that beneficially supplement or attenuate malt barley. The quantity of dry adjuncts such as corn, rice, sorghum, and wheat may vary from 10% to 50% of the total. The choice depends on the individual brewer and on the availability of the cereals to regulated the composition of the resulting wort and to save costs. The starch of these adjuncts is in its native form and is not susceptible to enzymatic hydrolysis during mashing. Thus, these adjuncts are normally boiled in a cooker mash to solubilize and gelatinize in starch granules. Today, liquid adjuncts, which are clean, noncrystallizing mixtures of fermentable sugars and dextrins, are available to achieve a better runoff wort and to control over the kettle operation. The significant difference between the beer, whiskey, and the wine industries is the composition of the raw material. Beer production involves three distinct but interrelated malt steps (Figure C-1). The first step in brewing is the malting process, which is the production of a soluble malt extract, so-called wort.

Table C-1 World beer production (1990) in different countries

Area of Consumption	Production (x 1000 hL)
The Americas	
United States	238,997
Brazil	58,000
Mexico	39,743
Canada	22,565
Colombia	17,500
Venezuela	11,000
Others	31,266
Total	419,071
Europe	
Germany (included East)	104,271
U.S.S.R	50,000
United Kingdom	59,653
Spain	27,315
Czechoslovakia	23,537
France	21,398
Netherlands	20,047
Romania	13,100
Belgium	14,141
Poland	12,240
Yugoslavia	13,540
Italy	11,067
Austria	9,600
Denmark	8,510
Ireland	6,500
Luxemburg	600
Others	58,469
Total	453,978
Africa	
South Africa	22,500
Nigeria	8,000
Cameroon	4,505
Kenya	3,700
Zaire	2,918
Zimbabwe	2,700
Ivory Coast	1,095
Others	13,305
Total	58,723
Asia	
Japan	65,617
China	70,000
Philippines	15,000
South Korea	12,690
Others	22,295
Total	185,602
South Pacific	
Australia	19,548
New Zealand	3,858
Others	953
Total	24,359
Grand Total	1,141,733

Source: Lee (1996)

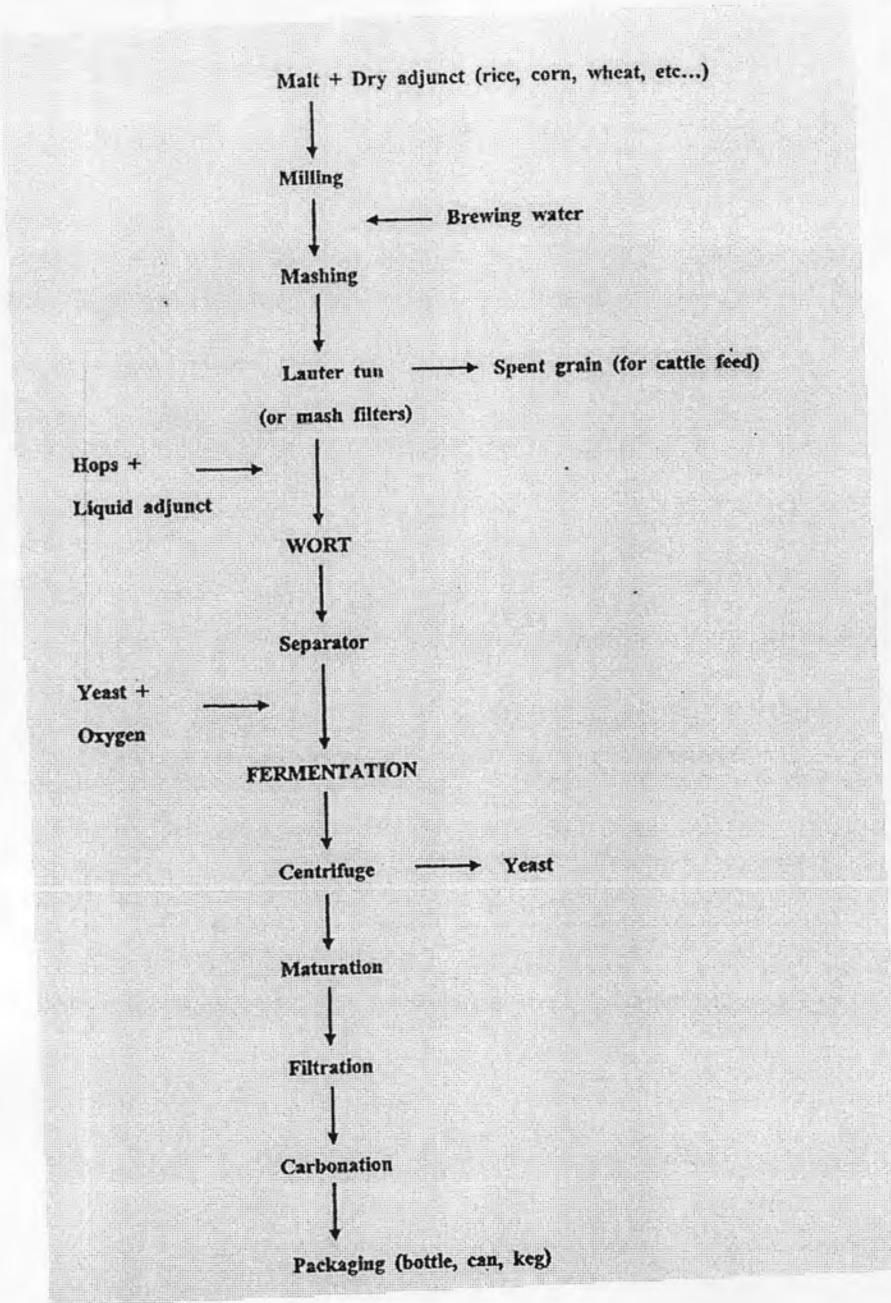


Figure C-1 Schematic outline of the brewing process (Lee, 1996)

Wort Production

The first step in wort production is mashing, which is simply the mixing of warm water with ground malt, with a suitable standing period (5-7 days). At this time dry malt adjuncts may be added. Malt, which is a sugar-containing material, is prepared from barley grains by soaking or steeping the grain in water at 10-15.6°C and allowing it to germinate at 15.6 – 21°C for 3-4 days or more (7 days). This malting step activates the enzyme systems (armylases and proteases). The α and β armylases breakdown the barley's endosperm to fermentable sugars, while proteases produce amino aids that will be used by the yeast. The germination is then arrested by kilning, which is basically the use of the heat to dry the green malt from a moisture content of about 45% to 4%; this stop can enzymatic and chemical reactions. The heating process produces some of the characteristic colors and flavors of beer. The dried malt can then be stored until needed. Drying is normally carried out on so-called kilning floors made from perforated sheets (arranged in layers to a height of 60-120 cm) by the direct mixing of gases with the dried air. Figure C-2 Schematic outline of the brewing process.

The aqueous extract called wort is separated from the grain and filtered. The spent grains can be sold as cattle feed. The clarified wort is then boiled with hops in a kettle for 1-1.5 hours to give flavor to the beer. The boiling of the wort with hops concentrates the liquid, sterilizes it, inactivates enzymes, extracts the hop solubles, precipitates protein, and caramelizes sugars. Liquid adjuncts, such as sugar solutions or corn syrup, may be added at this time to increase the amount of fermentable sugar.

Hops are dried blossoms of the female hop plant (*Humulus lupulus*) and contain a group of compounds, called *humulones* or α acids; which are very insoluble in water but undergo and isomerization during the brewing processing to form isohumulones or iso-α-acids, which account for most of bitterness of beer. The hop industry has sought to maximize the α-acid content of its hops, and brewers use α–acid content as a criterion for purchase. Hunulones can be isomerizes in aqueous sodium or potassium carbonate, and under these conditions for formation of degradation products (e.g., humulinic acid) is minimized. Hop extracts also contain a small amount of odorous volatile oil compounds such as terpenes, humaladienone, capryophyllene, epoxiide, linalool, geraniol, and ketones, some of which survive into the finished beer, resulting in the hoppy aroma of some beers. After boiling, the aqueous wort is separated from the trub (precipitates and spent hops) by oe of many method such as filtration or whirlpool separation. The wort is cooled in a heat exchanger to the temperature desired for fermentation. Immedietly after cooling, he wort is aerated to provide oxygen for the yeast. Yeast (about a pound of liquid) from a preceding brew is pitched in per barrel of wort, which will give me a count of about 12×10^6 cells per milliliter.

Fermentation

Yeasts are added to the wort, which contains oxygen, fermentable sugars, and various nutrients. The yeast quickly consumes the oxygen and minor nutrients, and then metabolizes sugars and amino acids. Although wort fermentations in the production of beer are largely anaerobic, some oxygen must be made available to the yeast because the new inoculum contains no reserved of necessary lipids such as sterols and unsaturated fatty acids, which are essential membrane components. Two types of yeast are used in the brewing industry. The first is a bottom-fermenting (settle-out) yeast, *Sacchromyces uvarvm* (*S. carlsbergensis*). Fermentation takes 8-10 days at 7-15C and yield a product called lager. *S. uvarvm* has a marked ability to flocculate when fermentable sugars are exhausted. Some brewers hasten this setting by using centrifuges to collect their yeast. On the other hand, ale beer is produced using the top-fermenting yeast *S. cerevisiae*. Top-fermenting yeasts tend to be somewhat less flocculent, and cells adsorb to CO_2 bubbles, which cause the yeasts to rise to the top of its fermenting tank, where it may be collected by skimming. Fermentation takes place at slightly higher temperatures (15-22°C) for 3-5 days. The yeasts ferment the sugars (primary fermentation) maintain via Embden-Meyerhof (EM) pathway to yield equimolar amount of ethanol and carbon hydroxide that is given off is usually collected and cleaned for re injection at a later stage. Part of the leftover yeast can be easily recycled from 5 to 100 times before viability and contamination become a problem.

Finishing/ Packaging

The fermented beer is separated from the yeast sediment into wooden or stainless steel casks for maturation. During the next 2-6 weeks, at temperature close to 0 °C, the beer undergoes a secondary fermentation, using up the remaining added sugars; the precipitation of yeasts, resins, proteins, and other undesirable substances occurs, as well. Caramel may be added at this stage to control the color of the finished products. Similarly isomerized hop extracts may be added to control bitterness. Larger, which is also held at low temperatures, is stored in larging tanks for up to 9 months. During this time the remaining yeast, tannins, and proteins settle out to yield a haze free beer with a long shelf life. The cooled, aged beer can then be clarified by filtration and pasteurized at 60 °C for 6-8 minutes or at 71-74 °C for 15 seconds. The beer is rapidly cooled, filtered, and packaged in cans or bottles or kegs (for use in restaurants and taverns). If such packaged beer has not been sterile-filtered, the pasteurization may be done just before filling (bulk pasteurization) for a minute, or after filing in long tunnels with hot-water sprays (tunnel pasteurization) for about an hour. Because the delicate flavor of beer is adversely affected by oxygen, great care must be taken to minimize oxygen pickup. Modern fillers evacuate the bottle before it is facturing that has largely been eliminated is the tendency of the product to become cloudy during chilling. The source of the cloudiness, a reversibly insoluble protein-polyphenol complex, can be removed by the enzyme papain; or, the polyphenols may be romoved by absorption on silica gel.

Generally, there are two major sources of brewery residue arising from the beer production. These are spent grains and spent yeast (or waste yeast). The handling of these residues is shown in Fig. A. After the wash filtering in the lauter tun has been completed, a considerable amount of sludge in left on the underside of the filter. It is flushed by water and run through the decanter centrifuge. The clarified water, which containing a certain amount of extract, is re-used as mash liquor while the sludge from separated by a rotating vacuum filter, is pumped to the yeast grain dryer, where the yeast is mixed with the spent grains in the dried form (Meyer, 1973).

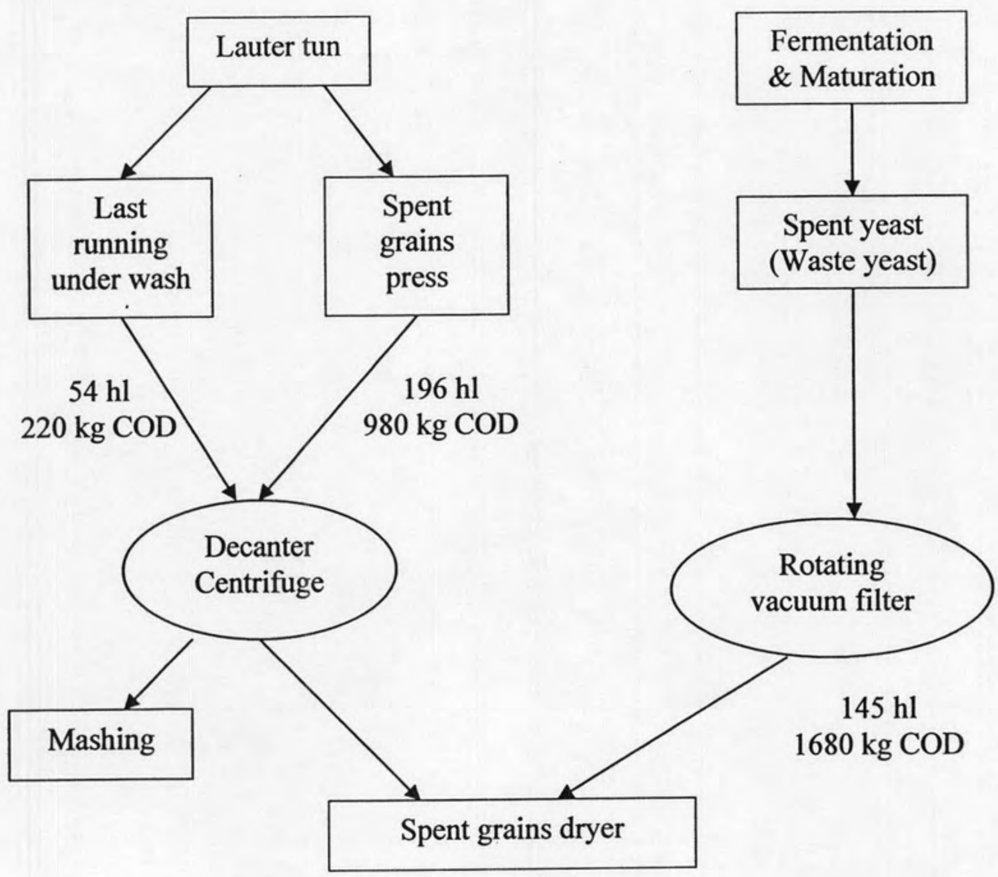


Figure C-2 The typical form of spent grains and waste yeast handling (a case study at PRIPPS BROMMA, Sweden when producing 5260hl beer)

Table C-2 Amino acid content in yeast when growing on a giving carbon substrate

Amino acids	Yeasts/ Paraffin	Yeasts/ Carbohydrates
Selected amino acids, g/16 g nitrogen		
Isoleucine	3	4.5
Alanine	6	6
Leucine	5.5	6.5
Glycine	3	5
Lysine	6.5	6.5
Phenylalanine	2.5	3.5
Methionine	2	1.5
Proline	2.5	3.5
Threonine	3.5	5.5
Aspartic acid	8	8
Tryptophan	0.5	1
Glutamic acid	9	10
Valine	3.5	5
Tyrosine	3	3.5
Arginine	3.5	4.5
Histidine	2	3
Serine	3	3.5

Source: Lee, 1996. p. 272

APPENDIX D

Table D-1 Spreadsheet for fitting the integrated Monod equation to glucose utilization rate data (Batch test of glucose with no waste yeast adding)

	B	C	D	E	G	H	I	J	K
1	X_0	=	12000	mg/l					
2	S_0	=	7000	mg/l					
3	Yg	=	0.1						
4	Ks	–	2313.035442	mg/l					
5	k	–	0.520455939	d^{-1}					
6									
7	Time	Time	S	Tpredicted	Xa	SLOPE	ERROR	Weighted	W.ERRORsq
8	hr	day	mg/l	day	mg/l		tobs-tpre	slope*error	
9	5	0.21	6,424.00	0.12	12,057.60	-4,614.09228	0.084602319	-390.3629069051	152,383.199087
10	7	0.29	6,208.00	0.17	12,079.20	-4,580.16873	0.120951533	-553.9784305526	306,892.101518
11	8	0.33	6,098.00	0.19	12,090.20	-4,562.00136	0.138554132	-632.0841406570	399,530.360870
12	9	0.38	5,753.00	0.27	12,124.70	-4,500.79485	0.104093482	-468.5034092690	219,495.444497
13	10	0.42	5,693.00	0.28	12,130.70	-4,489.45380	0.132412400	-594.4593512420	353,381.920279
14	12	0.50	5,581.00	0.31	12,141.90	-4,467.69555	0.190738089	-852.1597133038	726,176.176978
15	15	0.63	4,985.50	0.44	12,201.45	-4,337.78889	0.180536252	-783.1281481111	613,289.696364
16	18	0.75	4,083.00	0.66	12,291.70	-4,083.79975	0.091477751	-373.5768174582	139,559.638542
17	19	0.79	4,004.50	0.68	12,299.55	-4,057.64270	0.113860594	-462.0056084935	213,449.182279
18	20	0.83	3,753.00	0.74	12,324.70	-3,968.56910	0.092865824	-368.5444402208	135,825.004418
19	21	0.88	3,192.00	0.89	12,380.80	-3,736.24580	-0.010975086	41.0056175331	1,681.460669
20	22	0.92	2,443.67	1.10	12,455.63	-3,330.31868	-0.180688443	601.7500994438	362,103.182181
21	23	0.96	2,264.00	1.15	12,473.60	-3,211.20424	-0.193945147	622.7974798703	387,876.700933
22	24	1.00	1,725.00	1.33	12,527.50	-2,785.27033	-0.331785323	924.1118168022	853,982.649954
23	25	1.04	925.50	1.67	12,607.45	-1,875.16286	-0.632467735	1,185.9800037534	1,406,548.569303
24	26	1.08	813.00	1.74	12,618.70	-1,708.02897	-0.653604084	1,116.3747086958	1,246,292.490216
25	27	1.13	377.50	2.07	12,662.25	-924.64088	-0.947801292	876.3758221028	768,034.581566
26	28	1.17	82.00	2.65	12,691.80	-226.15651	-1.486045382	336.0788391915	112,948.986152
27	29	1.21	22.00	3.12	12,697.80	-62.26466	-1.914034280	119.1767029472	14,203.0865254
28								SSWE	8,413,654.43

Table D-2 Spreadsheet for fitting the integrated Monod equation to glucose utilization rate data (Batch test of glucose+waste yeast)

	A	B	C	D	E	G	H	I	J
1	X_0	=	12000	mg/l					
2	S_0	=	7000	mg/l					
3	Yg	=	0.1						
4	Ks	=	2357.6468	mg/l					
5	k	=	1.84252425	d^{-1}					
6									
7									
8	Time	Time	S	Tpredicted	S	SLOPE	ERROR	Weighted	W.ERRORsq
9	hr	day	mg/l	day	mg/L		tobs-tpre	slope*error	
10	0	0.0000	7000.00	0	7000.00	-16539.63223	0	0	0
11	1	0.041667	6469.33	0.03233569	6469.33	-16276.39233	0.009330972	-151.8745687	23065.88461
12	2	0.083333	5943.33	0.06495221	5943.33	-15969.91618	0.018381123	-293.5449998	86168.66688
13	3	0.125000	5119.33	0.11749005	5119.33	-15375.71124	0.007509948	-115.4707875	13333.50277
14	4	0.166667	4511.33	0.15773676	4511.33	-14822.51081	0.008929903	-132.3635886	17520.1196
15	5	0.208333	3502.50	0.2285828	3502.50	-13600.06631	-0.020249462	275.3940248	75841.8689
16	6	0.250000	3404.00	0.23586426	3404.00	-13454.28264	0.014135745	-190.186304	36170.83023
17	7	0.291667	2420.00	0.31407703	2420.00	-11626.87125	-0.022410365	260.5624338	67892.7819
18	8	0.333333	2150.00	0.33796415	2150.00	-10972.11469	-0.004630821	50.80990101	2581.646041
19	9	0.375000	1725.00	0.3789404	1725.00	-9752.701059	-0.003940404	38.42958673	1476.833137
20	10	0.416667	1390.00	0.41545855	1390.00	-8584.076381	0.001208119	-10.37058378	107.549008
21	11	0.458333	997.33	0.46616051	997.33	-6901.497408	-0.007827172	54.01920548	2918.074561
22	12	0.500000	768.00	0.50253938	768.00	-5714.838915	-0.002539376	14.51212652	210.6018162
23	13	0.541667	667.00	0.52116698	667.00	-5133.117276	0.020499689	-105.2273076	11072.78626
24	14	0.583333	464.33	0.56651996	464.33	-3836.207396	0.01681337	-64.499576	4160.195304
25	15	0.625000	242.50	0.64165276	242.50	-2178.215032	-0.016652757	36.27328561	1315.751249
26	17	0.708333	197.00	0.66457318	197.00	-1801.681842	0.043760152	-78.84187214	6216.040802
27	19	0.791667	32.00	0.85487878	32.00	-313.2735675	-0.06321211	19.80268335	392.1462678
28								SSWE	350445.2793

Table D-3 The experimental data of the reactor operated at HRT 24, 12, 8 and 4 hours.

Day	HRT (hr)	VSS (g/l)	So (mg/l)	mlBiogas (STP)	%CO2	%H2	ml H2 (STP)	SS e (mg/l)	S e (mg/l)	VFA HAc	VFA HBu	VFA HPr	%glucose consumption rate	SHPR sp.H2 Production Rate (ml / gVSS.h)	VHPR Vol. H2 Prod. Rate (l / L.d)	OLR (g / l.d)	OL (g glu.used/d)	H2 yield mol/mol glucose used	SRT (day)
0	40	9.54	7000	0.00									100				16.10	0.00	
1	24	9.54	7000	1171.74				360	76				98.9				15.93	0.00	
2	24	9.54	7000	1307.80				107	72	304.5	394.66	181.7	99.0	4.41	0.00	7	15.93	0.00	89.16
3	24	9.54	7000	1305.22	35.7	36.6	477.87	113	76	380.17	629.96	233.58	98.9	4.40	0.37	7	15.93	0.27	84.42
4	24	9.54	7000	1579.42	30.2	42.6	673.25	154	42	315.66	367.69	171.46	99.4	5.32	0.52	7	16.00	0.37	61.95
5	24	9.54	7000	1261.45	35.8	35.5	447.32	89	0	359.6	404.15	164.47	100	4.25	0.35	7	16.10	0.25	107.19
6	24	9.54	7000	1172.51	35.7	39.5	463.04	75	0	314.5	356.66	131.7	100	3.95	0.36	7	16.10	0.25	127.20
7	24	9.54	7000	1312.57	33.7	38.0	498.71	69	0	356.17	546.65	245.32	100	4.42	0.38	7	16.10	0.27	138.26
8	24	9.54	7000	1576.30	29.1	48.9	770.25	87	0	315.32	334.12	171.46	100	5.31	0.59	7	16.10	0.42	109.66
9	24	9.54	7000	1259.79	37.9	36.1	454.71	73	0	376.6	302.45	174.32	100	4.25	0.35	7	16.10	0.25	130.68
10	24	9.54	7000	1262.29	34.5	37.1	468.32	64	0				100	4.25	0.36	7	16.10	0.26	149.06
11	24	9.54	7000	1263.12	31.4	42.1	531.37	62	0				100	4.26	0.41	7	16.10	0.29	153.87
12	12	8.505	7000	2213.39	35.7	36.6	810.37	110	28		192.9	111.5	99.6	8.37	0.63	14	32.07	0.22	38.66
13	12	8.505	7000	2256.32	31.9	46.5	1049.35	142	35				99.5	8.53	0.81	14	32.04	0.29	29.95
14	12	8.505	7000	4061.37	23.0	56.8	2305.85	144	69	219.3	351.2		99.0	15.35	1.78	14	31.88	0.64	29.53
15	12	8.505	7000	3789.36	30.9	46.6	1767.06	168	88	219.3	351.2		98.7	14.32	1.36	14	31.80	0.49	25.31
16	12	8.505	7000	3654.03	31.0	47.4	1730.20	142	102	293.3	351.2		98.5	13.81	1.34	14	31.73	0.48	29.95
17	12	8.505	7000	3152.60	29.6	46.0	1449.73	208	117	425.1	442.3	209.1	98.3	11.92	1.12	14	31.66	0.40	20.44
18	12	8.505	7000	6802.85	31.0	47.4	3224.22	198	154	347.2	471.3	171.5	97.8	25.72	2.49	14	31.49	0.90	21.48
19	12	8.505	7000	7208.31	34.8	44.7	3219.74	138	138	235.5	572.5	204.4	98.0	27.25	2.48	14	31.57	0.90	30.82
20	12	8.505	7000	7208.31	30.9	47.6	3429.73	210	120	326.9	183.0	131.6	98.3	27.25	2.65	14	31.65	0.96	20.25
21	12	8.505	7000	7210.69	27.0	55.6	4008.58	154	154	428.4	472.6	276.9	97.8	27.26	3.09	14	31.49	1.12	27.61
22	8	5.904	7000	6217.17	24.2	53.9	3351.62	98	588	836.7	435.2	399.0	91.6	33.86	2.59	21	44.24	0.67	20.06
23	8	5.904	7000	6258.09	24.3	53.1	3324.61	164	765				89.1	34.08	2.57	21	43.02	0.68	11.99
24	8	5.904	7000	7558.75	22.7	57.8	4367.03	104	810	3563.6	2285.4	929.3	88.4	41.16	3.37	21	42.71	0.90	18.90
25	8	5.904	7000	7553.78	35.8	47.5	3588.60	102	880	1288.7			87.4	41.13	2.77	21	42.23	0.75	19.27
26	8	5.904	7000	7553.78	21.9	62.9	4750.72	106	942	1108.8	1179.4		86.5	41.13	3.67	21	41.80	1.00	18.55
27	8	5.904	7000	8436.37	49.2	36.3	3064.90	138	1072	1253.8	1589.0		84.7	45.94	2.36	21	40.90	0.66	14.25
28	8	5.904	7000	8436.37	23.0	58.0	4889.09	154	1078	1522.7	1368.0	429.1	84.6	45.94	3.77	21	40.86	1.06	12.77
29	8	5.904	7000	8455.82	22.6	59.2	5006.33	108	1029	1783.8	1258.4		85.3	46.05	3.86	21	41.20	1.07	18.20
30	8	5.904	7000	8450.26	23.3	57.4	4850.79	102	1081	1534.5	1356.6		84.6	46.02	3.74	21	40.84	1.05	19.27
31	8	5.904	7000	8458.61	25.8	53.9	4561.61	101	1012	1322.4	1238.1		85.5	46.06	3.52	21	41.32	0.98	19.47
32	4	5.76	7000	9028.26	26.6	57.8	5222.37	94	4425	2828.9	2325.2	1164.6	36.8	50.39	4.03	42	35.54	1.30	10.23
33	4	5.76	7000	9766.66	22.5	69.6	6801.08	106	5073				27.5	54.51	5.25	42	26.59	2.26	9.07
34	4	5.76	7000	10309.25	18.6	67.9	6997.47	114	4178	5291.3	2871.0	1327.1	40.3	57.54	5.40	42	38.94	1.59	8.44
35	4	5.76	7000	12393.46	26.2	58.5	7255.66	48	4782	2191.9	1145.2	523.7	31.7	69.18	5.60	42	30.61	2.09	20.04
36	4	5.76	7000	10026.74	25.8	58.4	5856.21	60	5266	7422.7	4503.0	1841.7	24.8	55.97	4.52	42	23.93	2.16	16.03
37	4	5.76	7000	10514.41	26.2	57.7	6068.29	60	5570	1480.4	1454.0		20.4	58.69	4.68	42	19.73	2.72	16.03
38	4	5.76	7000	10271.85	27.2	59.0	6060.45	56	5985	1997.2	1942.1	836.8	14.5	57.33	4.68	42	14.01	3.82	17.18
39	4	5.76	7000	10441.72	23.2	58.9	6150.91	59	5521	2421.4	1872.3	676.6	21.1	58.28	4.75	42	20.41	2.66	16.30
40	4	5.76	7000	10238.07	21.8	62.0	6346.28	62	5288	2121.5	1913.5	598.3	24.5	57.15	4.90	42	23.63	2.37	15.51
41	4	5.76	7000	10278.63	19.7	65.3	6709.76	57	5450	1597.2	1492.8	785.2	22.1	57.37	5.18	42	21.39	2.77	16.88

VHPR = Volumetric hydrogen production rate
SHPR = Specific hydrogen production rate

Table D-4 The experimental data of the reactor operated at HRT 4, 8, 4, 12 and 24 hours

Day	HRT (hr)	VSS (g/l)	So (mg/l)	mlBiogas (STP)	%CO2	%H2	ml H2 (STP)	SS e (mg/l)	S e (mg/l)	%glucose used	SHPR (ml / gVSS.h)	VHPR (l / L.d)	OLR (g / l.d)	OL glu.used/nol	H2 yield glucose used)	VFA (mg/l) HAc	Hbu	HPr	SRT (day)
1	12	11.08	7000					87	855.1	87.8				14.13	0.00				
2	12	11.08	7000					64	343.7	95.1									
3	4	11.08	7000	9055.44				143	4083	41.7				6.71	0.00				12.94
4	4	11.08	7000	9100.49				108	4827	31.0	0.000	0.00	42	29.99	0.00				17.13
5	4	11.08	7000	9145.55	33.4	66.6	6090.93	110	4864	30.5	17.674	4.70	42	29.48	1.83				16.82
6	4	11.08	7000	9551.01	35.1.	64.9	6198.61	154	5273	24.7	17.986	4.78	42	23.83	2.30				12.02
7	4	11.08	7000	10812.47	37.3	62.7	6779.42	117	5357	23.5	19.671	5.23	42	22.67	2.64				15.82
8	4	11.08	7000	11713.51	39.6	60.4	7074.96	134	5250	25.0	20.529	5.46	42	24.15	2.59				13.81
9	4	11.08	7000	11713.51	38.8	61.2	7168.67	96	5313	24.1	20.801	5.53	42	23.28	2.72	2481.42	2659.02	1723.12	19.27
10	4	11.08	7000	11893.72	41.3	58.7	6981.61	89	5327	23.9	20.258	5.39	42	23.09	2.67	2253.99	2484.96	1224.50	20.79
11	4	11.08	7000	11803.61	41.7	58.3	6881.51	62	5292	24.4	19.968	5.31	42	23.57	2.58	2140.69	2267.46	1718.56	29.84
12	4	11.08	7000	11893.72	46.8	53.2	6327.46	58	5541	20.8	18.360	4.88	42	20.13	2.78	2268.08	2687.09	1632.10	31.90
13	4	11.08	7000	11848.66	45.0	55.0	6516.77	61	5497	21.5	18.909	5.03	42	20.74	2.78	2317.81	2235.13	1210.34	30.33
14	4	11.08	7000	11758.56	46.0	54.0	6349.62	76	5483	21.7	18.424	4.90	42	20.93	2.68	2290.67	2396.19	1480.55	24.35
15	8	8.864	7000	10812.47	42.0	58.0	6271.23	68	4013	50.9	22.746	4.84	21.02	20.61	2.69				43.41
16	8	8.864	7000	10812.47	42.6	57.4	6206.36	56	3987	51.1	22.511	4.79	21.02	20.79	2.64				52.71
17	8	8.864	7000	10677.31	40.6	59.4	6342.32	78	3434	50.9	23.004	4.89	21.02	24.61	2.28				37.84
18	8	8.864	7000	9731.22	47.5	52.5	5108.89	68	3421	51.1	18.530	3.94	21.02	24.70	1.83				43.41
19	8	8.864	7000	9866.38	42.4	57.6	5683.03	63	3252	53.5	20.613	4.39	21.02	25.86	1.94				46.85
20	8	8.864	7000	9731.22	44.0	56.0	5449.48	76	4033	42.4	19.766	4.20	21.02	20.47	2.35				38.84
21	8	8.864	7000	9731.22	53.1	46.9	4563.94	65	3677	47.5	16.554	3.52	21.02	22.93	1.76				45.41
22	8	8.864	7000	9731.22	44.6	55.4	5391.10	57	3340	52.3	19.554	4.16	21.02	25.25	1.89	1288.69		320.08	51.78
23	8	8.864	7000	9641.12	38.5	61.5	5929.29	52	3285	53.1	21.506	4.58	21.02	25.63	2.04	1108.76	1179.35		56.76
24	8	8.864	7000	9776.27	50.2	49.8	4868.58	48	3120	55.4	17.659	3.76	21	26.77	1.61	1253.80	1588.99		61.49
25	8	8.864	7000	9596.07	36.9	63.1	6055.12	43	3204	54.2	21.962	4.67	21	26.19	2.04	1522.68	1368.02	249.09	68.64
26	8	8.864	7000	9731.22	41.4	58.6	5702.50	46	3191	54.4	20.683	4.40	21	26.28	1.92	1783.80	1258.42		64.17
27	4	6.645	7000	10677.31	43.1	56.9	6075.39	67	5206	25.6	29.394	4.69	42	24.76	2.17				16.56
28	4	6.645	7000	10812.47	48.8	51.2	5535.98	56	5328	23.9	26.785	4.27	42	23.07	2.12				19.82
29	4	6.645	7000	11713.51	53.5	46.5	5446.78	78	5396	22.9	26.353	4.20	42	22.14	2.17				14.23
30	4	6.645	7000	11848.66	47.2	52.8	6256.09	68	5279	24.6	30.269	4.83	42	23.75	2.33				16.32
31	4	6.645	7000	11893.72	48.6	51.4	6113.37	63	5004	28.5	29.578	4.72	42	27.54	1.96				17.61
32	4	6.645	7000	11893.72	50.0	50.0	5946.86	76	5221	25.4	28.772	4.59	42	24.55	2.14				14.60
33	4	6.645	7000	11938.77	52.6	47.4	5658.98	65	5113	27.0	27.380	4.37	42	26.04	1.92				17.07
34	4	6.645	7000	11803.61	41.7	58.3	6881.51	57	5332	23.8	33.294	5.31	42	23.02	2.64				19.47
35	4	6.645	7000	11488.25	41.4	58.6	6732.11	52	5451	22.1	32.572	5.19	42	21.38	2.78	2086.27	2515.58	1232.08	21.34
36	4	6.645	7000	11893.72	43.0	57.0	6779.42	48	5487	21.6	32.801	5.23	42	20.88	2.87	1960.48	2541.84	1243.66	23.12
37	4	6.645	7000	11713.51	39.5	60.5	7086.67	43	5378	23.2	34.287	5.47	42	22.38	2.80	1968.81	2487.07	1223.65	25.81
38	4	6.645	7000	11848.66	34.1	65.9	7808.27	46	5310	24.1	37.778	6.02	42	23.32	2.96	2212.36	2243.57		24.12
39	4	6.645	7000	11893.72	38.8	61.2	7278.95	42	5252	25.0	35.217	5.62	42	24.12	2.67	2197.50	2327.56	1136.82	26.42
40	4	6.645	7000	11938.77	41.4	58.6	6996.12	56	5332	23.8	33.849	5.40	42	23.02	2.68	2059.73	2532.39	1570.58	19.82
41	4	6.645	7000	11893.72	35.9	64.1	7623.87	38	5312	24.1	36.886	5.88	42	23.29	2.89	2158.59	2265.67	1022.45	29.20
42	4	6.645	7000	11893.72	39.7	60.3	7171.91	32	5376	23.2	34.700	5.53	42	22.41	2.83	2106.28	2353.00	1223.10	34.68

Table D-4 (cont.) The experimental data of the reactor operated at HRT 4, 8, 4, 12 and 24 hours.

Day	HRT (hr)	VSS (g/l)	So (mg/l)	mlBiogas (STP)	%CO2	%H2	ml H2 (STP)	SS e (mg/l)	S e (mg/l)	%glucose used	SHPR (ml / gVSS.h	VHPR (l / L.d)	OLR (g / l.d)	OL g glu.used/d)		H2 yield (mol/mol glucose used)	VFA (mg/l) HAc	Hbu	HPr	SRT (day)
43	12	6.049	7000	8649.98	51.0	49.0	4238.49	34	3565.096	49.1	22.527	3.27	14	15.80	0.08	2.37				88.96
44	12	6.049	7000	8649.975	53.3	46.7	4039.54	31	3339.49	52.3	21.470	3.12	14	16.84	0.09	2.12				97.56
45	12	6.049	7000	8649.975	44.6	55.4	4792.09	49	3074.65	56.1	25.470	3.70	14	18.06	0.09	2.34				61.72
46	12	6.049	7000	7568.728	52.1	47.9	3625.42	35	2628.79	62.4	19.269	2.80	14	20.11	0.10	1.59				86.41
47	12	6.049	7000	6487.481	56.8	43.2	2802.59	47	2447.771	65.0	14.896	2.16	14	20.94	0.11	1.18				64.35
48	12	6.049	7000	5766.65	58.8	41.2	2375.86	42	1815.541	74.1	12.628	1.83	14	23.85	0.12	0.88				72.01
49	12	6.049	7000	5721.598	60.1	39.9	2282.92	48	1729.936	75.3	12.134	1.76	14	24.24	0.12	0.83				63.01
50	12	6.049	7000	5586.442	62.0	38.0	2122.85	37	1075.414	84.6	11.283	1.64	14	27.25	0.14	0.69				81.74
51	12	6.049	7000	5811.702	71.0	29.0	1685.39	46	981	86.0	8.958	1.30	14	27.69	0.14	0.54				65.75
52	12	6.049	7000	5676.546	66.6	33.4	1895.97	35	718.7261	89.7	10.077	1.46	14	28.89	0.15	0.58	235.47	572.48	204.41	86.41
53	12	6.049	7000	5586.442	56.8	43.2	2413.34	28	695.5414	90.1	12.827	1.86	14	29.00	0.15	0.74	347.18	471.30	178.50	108.02
54	12	6.049	7000	5721.598	64.1	35.9	2054.05	31	672.3567	90.4	10.917	1.58	14	29.11	0.15	0.62				97.56
55	12	6.049	7000	5676.546	64.1	35.9	2037.88	23	595.6688	91.5	10.831	1.57	14	29.46	0.15	0.61	326.87	183.02	148.56	131.50
56	12	6.049	7000	5496.338	55.4	44.6	2451.37	30	671.465	90.4	13.029	1.89	14	29.11	0.15	0.74	453.37	472.60	132.40	100.82
57	12	6.049	7000	5586.442	51.0	49.0	2737.36	24	693.758	90.1	14.549	2.11	14	29.01	0.15	0.83	750.06	435.19		126.02
58	24	5.842	7000	5406.235	45.5	54.5	2946.40	19	565.3503	91.9	16.2149	2.27	7	14.80	0.07	1.76				307.47
59	24	5.842	7000	5406.235	48.0	52.0	2811.24	23	520.7643	92.6	15.4711	2.17	7	14.90	0.08	1.67				254.00
60	24	5.842	7000	5406.235	47.6	52.4	2832.87	17	436.051	93.8	15.5901	2.19	7	15.10	0.08	1.66				343.65
61	24	5.842	7000	5271.079	56.3	43.7	2303.46	18	337.0701	95.2	12.6766	1.78	7	15.32	0.08	1.33				324.56
62	24	5.842	7000	5180.975	64.2	35.8	1854.79	12	129.2994	98.2	10.2074	1.43	7	15.80	0.08	1.04				486.83
63	24	5.842	7000	3423.949	71.6	28.4	972.40	15	0	100.0	5.3514	0.75	7	16.10	0.08	0.53				389.47
64	24	5.842	7000	3243.741	74.7	25.3	820.67	13	0	100.0	4.5164	0.63	7	16.10	0.08	0.45				449.38
65	24	5.842	7000	3198.689	73.2	26.8	857.25	16	0	100.0	4.7177	0.66	7	16.10	0.08	0.47				365.13
66	24	5.842	7000	3288.793	75.7	24.3	799.18	18	0	100.0	4.3981	0.62	7	16.10	0.08	0.44				324.56
67	24	5.842	7000	3243.741	76.9	23.1	749.30	14	0	100.0	4.1236	0.58	7	16.10	0.08	0.41	312.23	372.54		417.29
68	24	5.842	7000	3243.741	74.5	25.5	827.15	12	0	100.0	4.5521	0.64	7	16.10	0.08	0.45	328.64	367.69	123.32	486.83
69	24	5.842	7000	3243.741	76.4	23.6	765.52	8	0	100.0	4.2129	0.59	7	16.10	0.08	0.42	359.60	404.15		730.25
70	24	5.842	7000	3243.741	78.4	21.6	700.65	11	0	100.0	3.8559	0.54	7	16.10	0.08	0.38	323.35	356.23	167.76	531.09
71	24	5.842	7000	3243.741	77.6	22.4	725.30	15	0	100.0	3.9915	0.56	7	16.10	0.08	0.40	246.14	246.33		389.47
72	24	5.842	7000	3243.741	78.2	21.8	707.14	9	0	100.0	3.8916	0.55	7	16.10	0.08	0.39	322.08	302.34		649.11

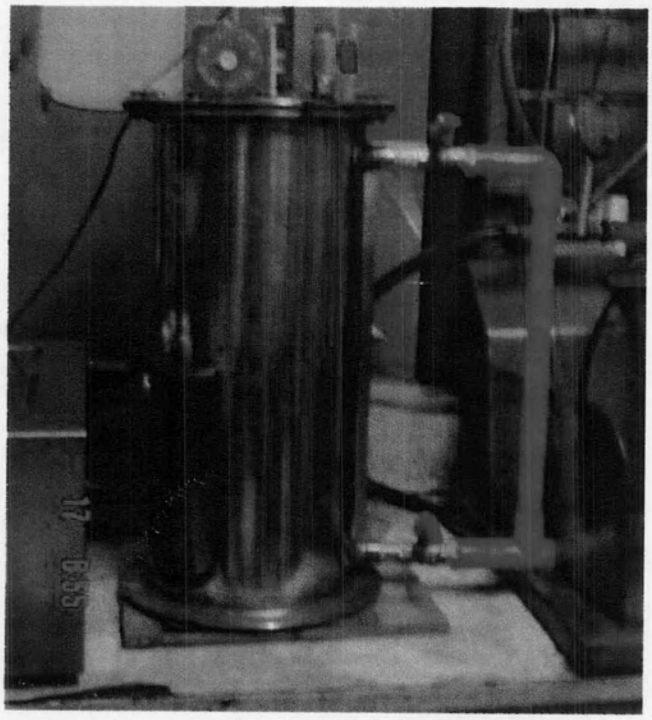


Figure D-1 Photo of 30 L CSTR of the stock culture of hydrogen producing bacteria

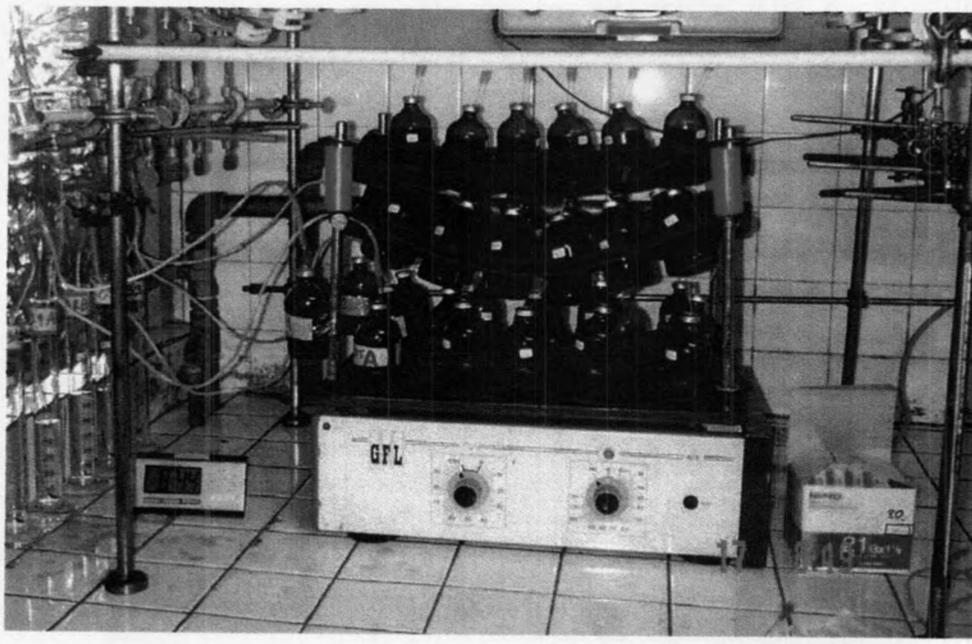


Figure D-2 Photo of the preliminary test by using serum vial technique.

BIOGRAPHY

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Education

- M. Sc. (Environmental Science) Chulalongkorn University, Thailand, 1991. Thesis Title: Treatment of Brewery Wastewater using Upflow Anaerobic Sludge Blanket (UASB) Process
- B. Sc. (General Science) Chulalongkorn University, Thailand, 1982.
- Certificate of the ISO 14001 Training Course, Thailand Environment Institute, 1999.
- Certificate of the Workshop on Advanced EMS Auditor Training Course, ERM Certification and Verification Services, 1999.
- Certificate of the Workshop on Clean Technology Auditor (CTA) Training Course, Ministry of Industry, 2000.
- Certificate of the Workshop on ISO/IEC 17025 Training Course, Ministry of Science, Technology and Environment, 2001.
- Certificate of the Management Development Program, Chulalongkorn University, 2004.

Field of specialization

- Supervisor of Environmental Pollution Control System, License No. 100-48-00099, Department of Industrial Works, Ministry of Industry.
- Consultant of The Project "Promotion of Biogas Utilization from Industrial wastes" in charge of Anaerobic Digestion, Department of Alternative Energy Development and Efficiency, Ministry of Energy, 2005-2006.