## REFERENCES


Chen, J.P. and Wu (2004) Acid/Base-Treated Activated Carbons: Characterization of Functional Groups and Metal Adsorptive Properties. Langmuir 20(6), 2233-2242.

Chen, Y., Zhou, T., Liu, D., Li, A., Xu, S., Liu, Q., Li, B., and Ying, H. (2013) Production of butanol from glucose and xylose with immobilized cells of *Clostridium acetobutylicum*. Biotechnology and Bioprocess Engineering 18(2), 234-241.

Ezeji, T.C., Qureshi, N., and Blaschek, H.P. (2007) Bioproduction of butanol from biomass: from genes to bioreactors. Current Opinion in Biotechnology 18(3), 220-227.

Jang, Y.-S., Malaviya, A., Cho, C., Lee, J. and Lee, S.Y. (2012) Butanol production from renewable biomass by *clostridia*. Bioresource Technology 123(0), 653-663.

Lee, S.Y., Park, J.H., Jang, S.H., Nielsen, L.K., Kim, J. and Jung, K.S. (2008) Fermentative butanol production by clostridia. Biotechnology and Bioengineering 101(2), 209-228.

Liu, S. and Qureshi, N. (2009) How microbes tolerate ethanol and butanol. New Biotechnology 26(3–4), 117-121.

Nielsen, L.E., Kadavy, D.R., Rajagopal, S., Drijber, R. and Nickerson, K.W. (2005) Survey of Extreme Solvent Tolerance in Gram-Positive Cocci: Membrane Fatty Acid Changes in *Staphylococcus haemolyticus* Grown in Toluene. Applied and Environmental Microbiology 71(9), 5171-5176.

Pfromm, P.H., Amanor-Boadu, V., Nelson, R., Vadlani, P. and Madl, R. (2010) Bio-butanol vs. bio-ethanol: A technical and economic assessment for corn and switchgrass fermented by yeast or *Clostridium acetobutylicum*. Biomass and Bioenergy 34(4), 515-524.

Qureshi, N. and Blaschek, H.P. (1999) Butanol recovery from model solution/ fermentation broth by pervaporation: evaluation of membrane performance. Biomass and Bioenergy 17(2), 175-184.

Qureshi, N., Saha, B.C., Hector, R.E., Hughes, S.R. and Cotta, M.A. (2008) Butanol production from wheat straw by simultaneous saccharification and fermentation using *Clostridium beijerincki*: Part I—Batch fermentation. Biomass and Bioenergy 32(2), 168-175.

Qureshi, N., Schripsema, J., Lienhardt, J. and Blaschek, H.P. (2000) Continuous solvent production by *Clostridium beijerinckii* BA101 immobilized by adsorption onto brick. World Journal of Microbiology and Biotechnology 16(4), 377-382.

Sekaran, G., Karthikeyan, S., Gupta, V.K., Boopathy, R. and Maharaja, P. (2013) Immobilization of *Bacillus sp.* in mesoporous activated carbon for degradation of sulphonated phenolic compound in wastewater. Materials Science and Engineering: C 33(2), 735-745.

Metwalli, E., Haines, D., Becker, O., Conzone, S. and Pantano, C.G. (2006) Surface characterizations of mono-, di-, and tri-aminosilane treated glass substrates. Journal of Colloid and Interface Science 298(2), 825-831.

Shanmugharaj, A.M., Bae, J.H., Lee, K.Y., Noh, W.H., Lee, S.H. and Ryu, S.H. (2007) Physical and chemical characteristics of multiwalled carbon nanotubes functionalized with aminosilane and its influence on the properties of natural rubber composites. Composites Science and Technology 67(9), 1813-1822.

Wang, L., Ma, L., Wang, A., Liu, Q. and Zhang, T. (2007) CO2 Adsorption on SBA-15 Modified by Aminosilane. Chinese Journal of Catalysis 28(9), 805-810.

Sukumaran, R.K., Gottumukkala, L.D., Rajasree, K., Alex, D. and Pandey, A. (2011) Butanol Fuel from Biomass: Revisiting ABE Fermentation. In Pandey, A., Larroche, C., Ricke, S.C., Dussap, C.-G. and Gnansounou, E., Biofuels. (pp 571-586). Amsterdam: Academic Press.

Welsh, F.W., Williams, R.E. and Veliky, I.A. (1987) Solid carriers for a *Clostridium acetobutylicum* that produces acetone and butanol. Enzyme and Microbial Technology 9(8), 500-502.

Yen, H.-W., Li, R.-J. and Ma, T.-W. (2011) The development process for a continuous acetone–butanol–ethanol (ABE) fermentation by immobilized *Clostridium acetobutylicum*. Journal of the Taiwan Institute of Chemical Engineers 42(6), 902-907.

Zhu, Y. (2007) Immobilized Cell Fermentation for Production of Chemicals and Fuels. In Yang, S.-T. Bioprocessing for Value-Added Products from Renewable Resources. (pp 373-396). Amsterdam: Elsevier.

# APPENDICES

## Appendix A The Analysis Calculation

- Fourier Transform Infrared (FTIR) intensity

These intensity were integrated by OMNIC 9.2.106, Thermo Fisher Scientific Inc. Then, a small peak at 780 $cm^{-1}$ was considered as a reference.

$$Intensity^{x-AC}_{z\ cm^{-1}} = \frac{Intensity^{DI-AC}_{y\ cm^{-1}}}{Intensity^{DI-AC}_{y\ cm^{-1}}} \times Intensity^{x-AC}_{z\ cm^{-1}} \qquad \text{eq (A1)}$$

Which, x is the treated activated carbon sample.
y is 780 $cm^{-1}$, which is a reference peak.
z is the wavenumber of interesting peak.

- Coefficient Butanol Production Factor

It is used to compare the butanol concentration between immobilization and free cell system in each batch.

$$Coeff\ BuOH = \frac{Butanol\ concentration_{Immobilization}}{Butanol\ concentration_{Free\ cell}} \qquad \text{eq (A2)}$$

## Appendix B The Physical Properties of Various Activated Carbon

Adsorption-Desorption isotherm of various treated activated carbon

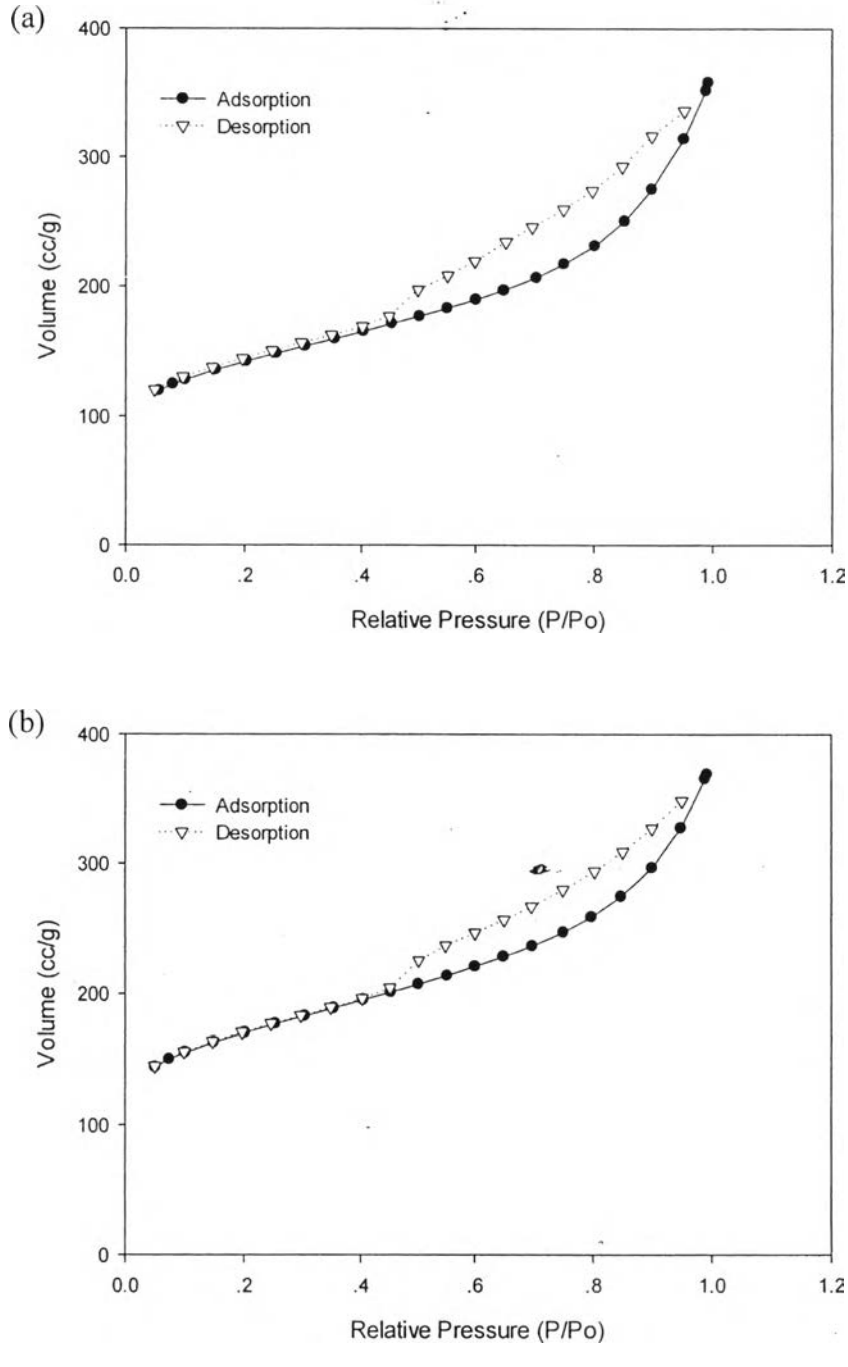



**Figure B1** Adsorption-desorption isotherms of untreated and treated activated carbons (a) SH-AC; and (b) SH-AC(R).

Pore size distribution of various activated carbons.

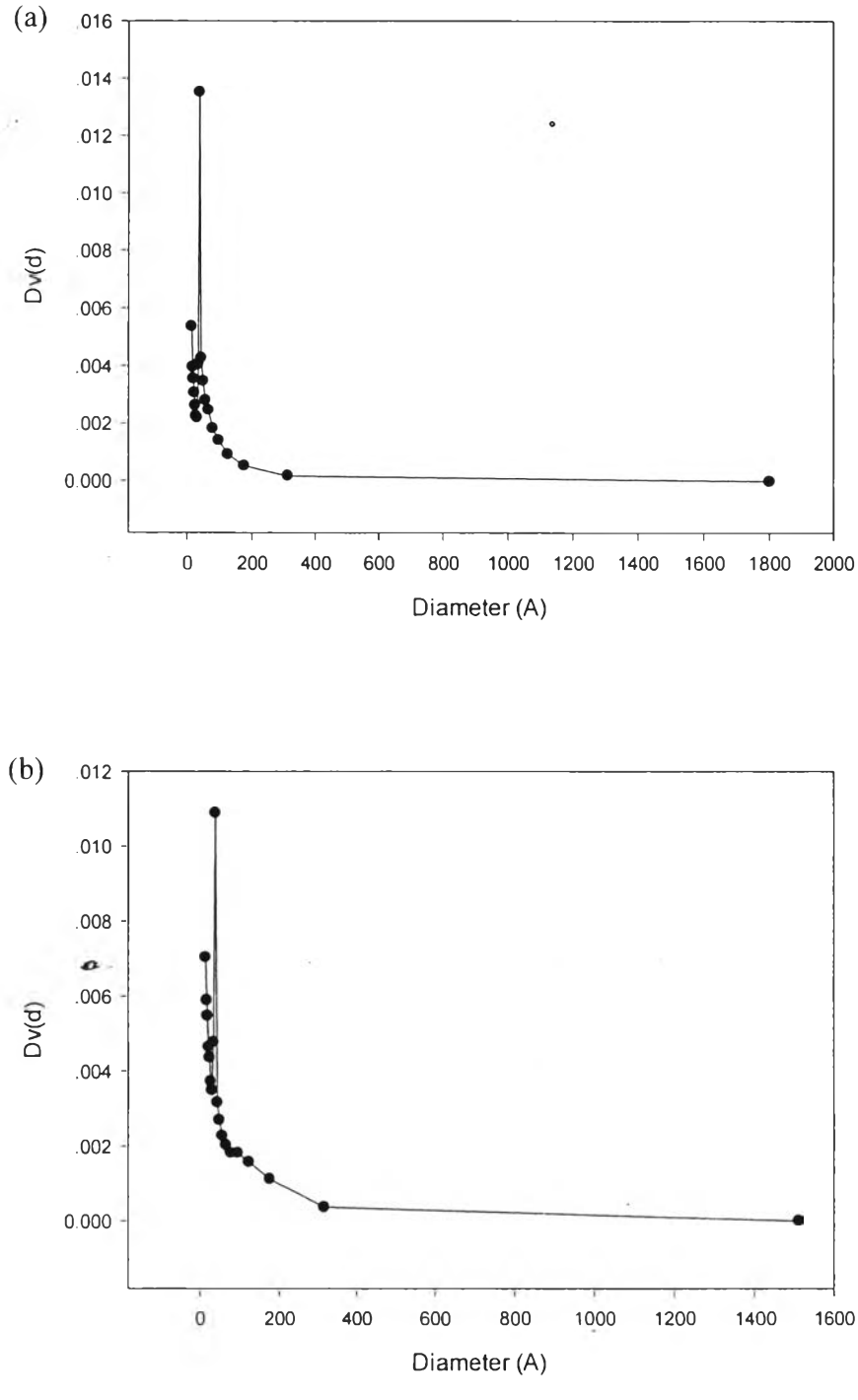
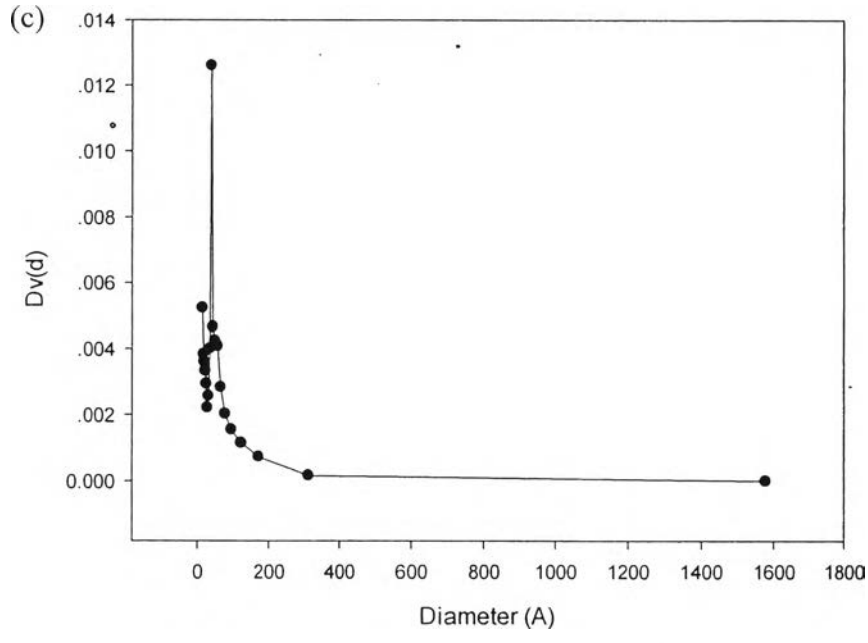



**Figure B2** Pore size distribution of various activated carbons (a) DI-AC; (b) NASH-AC; (c) SH-AC; (d) AS-AC(R); and (e) SH-AC(R).



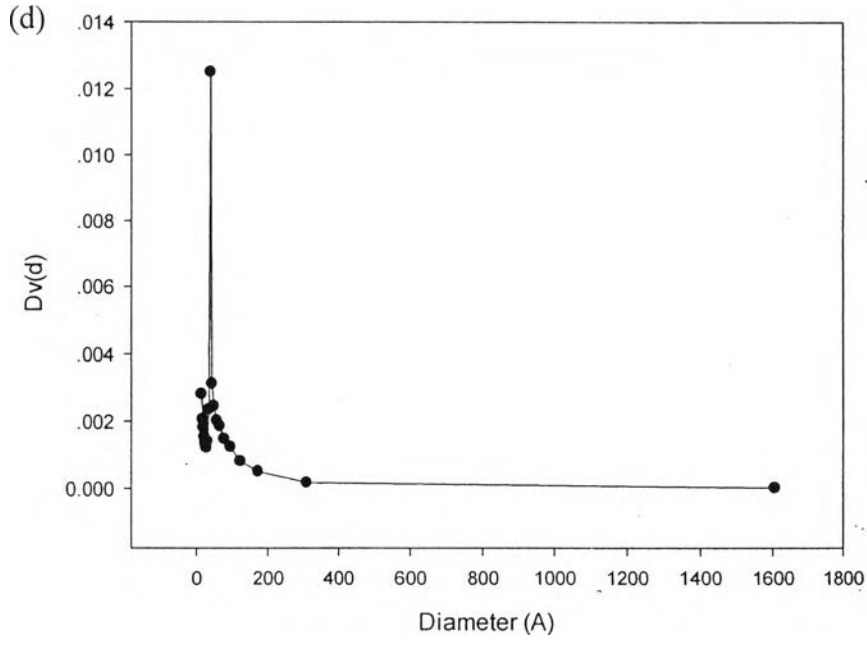




**Figure B2** Pore size distribution of various activated carbons (a) DI-AC; (b) NASH-AC; (c) SH-AC; (d) AS-AC(R); and (e) SH-AC(R). (con't.)

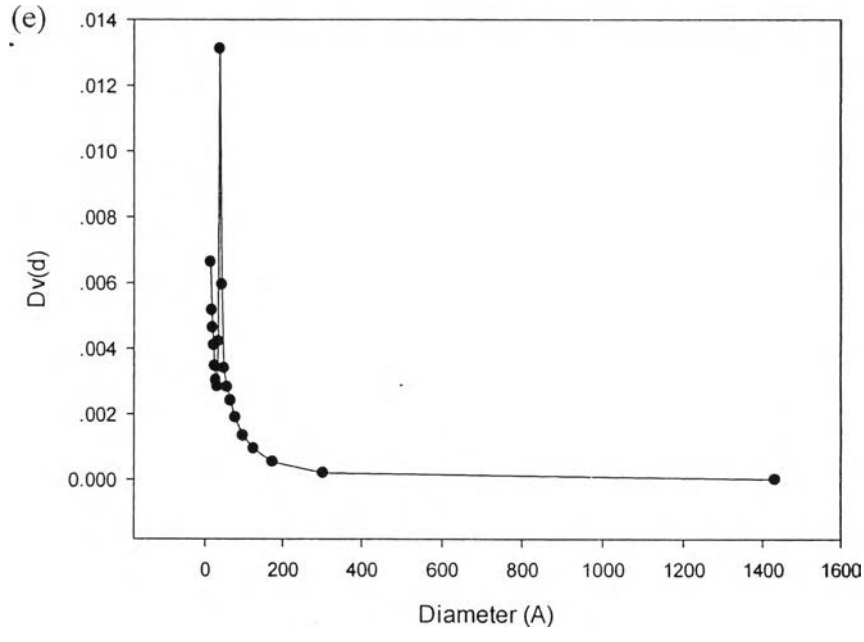



**Figure B2** Pore size distribution of various activated carbons (a) DI-AC; (b) NASH-AC; (c) SH-AC; (d) AS-AC(R); and (e) SH-AC(R). (con't.)

The effect of butanol adsorption on immobilized materials.

**Table B1** The effect of butanol adsorption on immobilized materials.

| Time (h) | Butanol concentration (g/l) | | | |
|---|---|---|---|---|
| | AS-AC(R) | SH-AC(R) | NASH-AC | SH-AC |
| 0 | 10 | 10 | 10 | 10 |
| 24 | 8.83 | 9.24 | 8.77 | 9.03 |
| 48 | 8.23 | 7.69 | 7.69 | 7.84 |
| 72 | 8.05 | 7.98 | 7.97 | 7.74 |

## Appendix C The Fermentation Results

- ABE Fermentation with Acid-Base Treatment

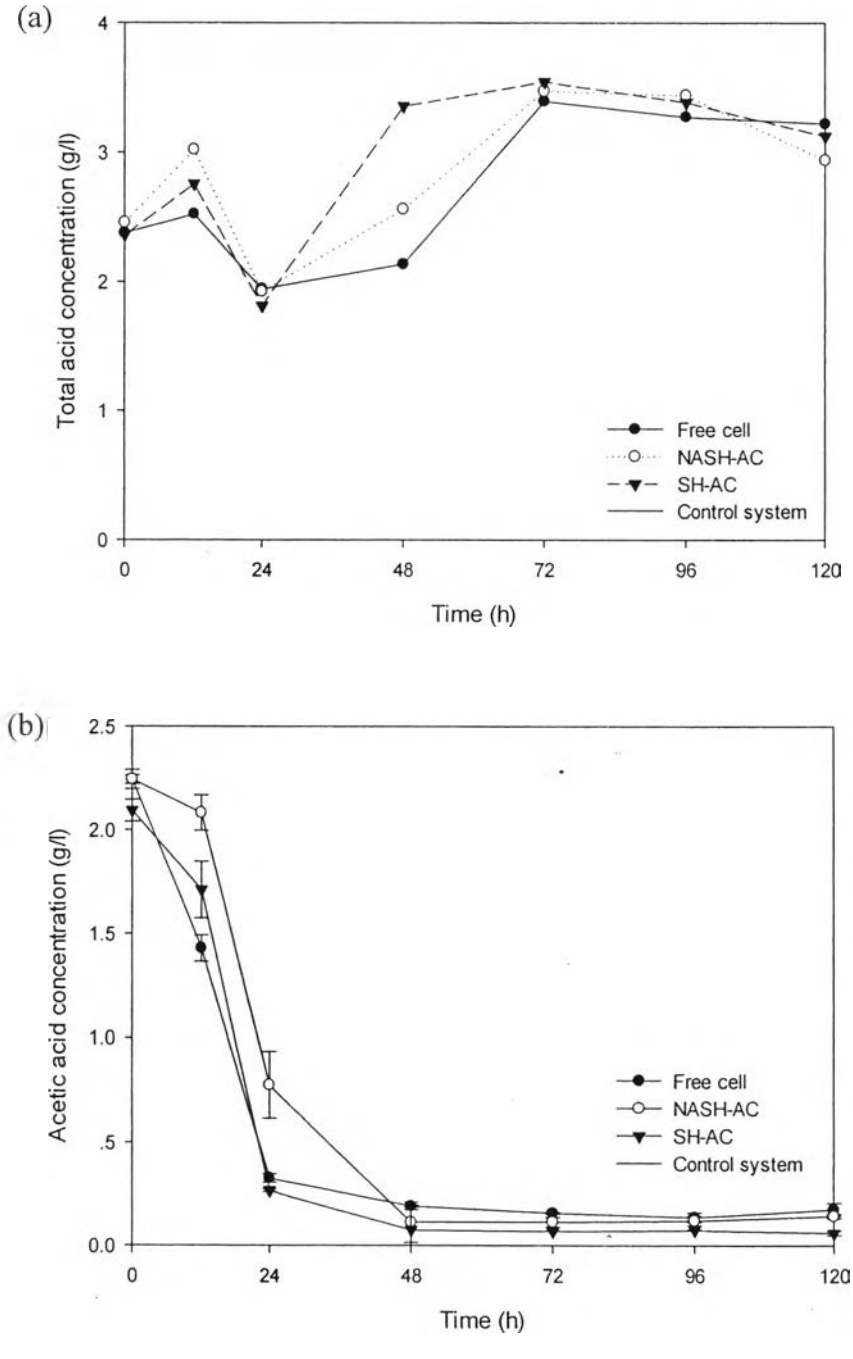



**Figure C1** Acid profiles of acid-base immobilized activated carbon fermentation (a) Total acid profile; (b) Acetic acid profile; and (c) Butyric acid profile.

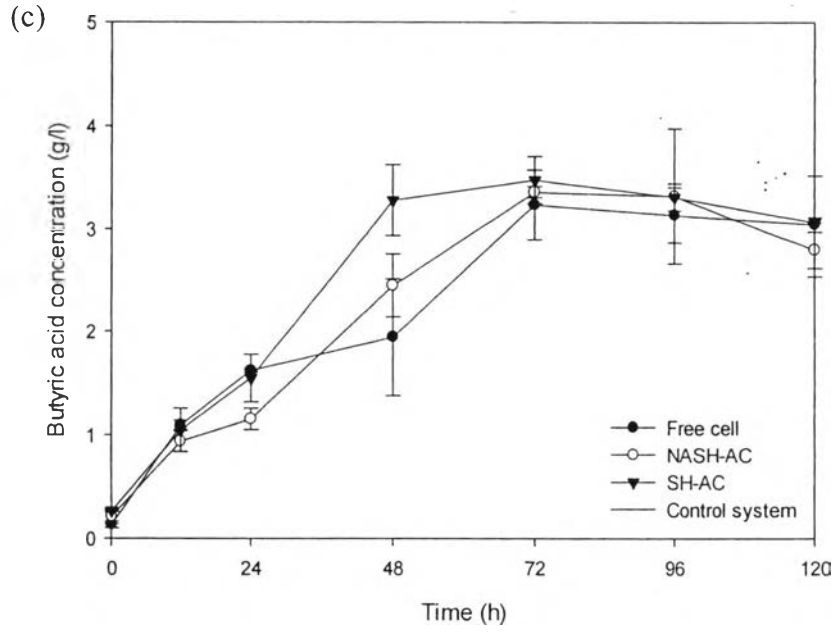



**Figure C1** Acid profiles of acid-base immobilized activated carbon fermentation (a) Total acid profile; (b) Acetic acid profile; and (c) Butyric acid profile. (con't.)

ABE Fermentation with Amine-Base Treatment

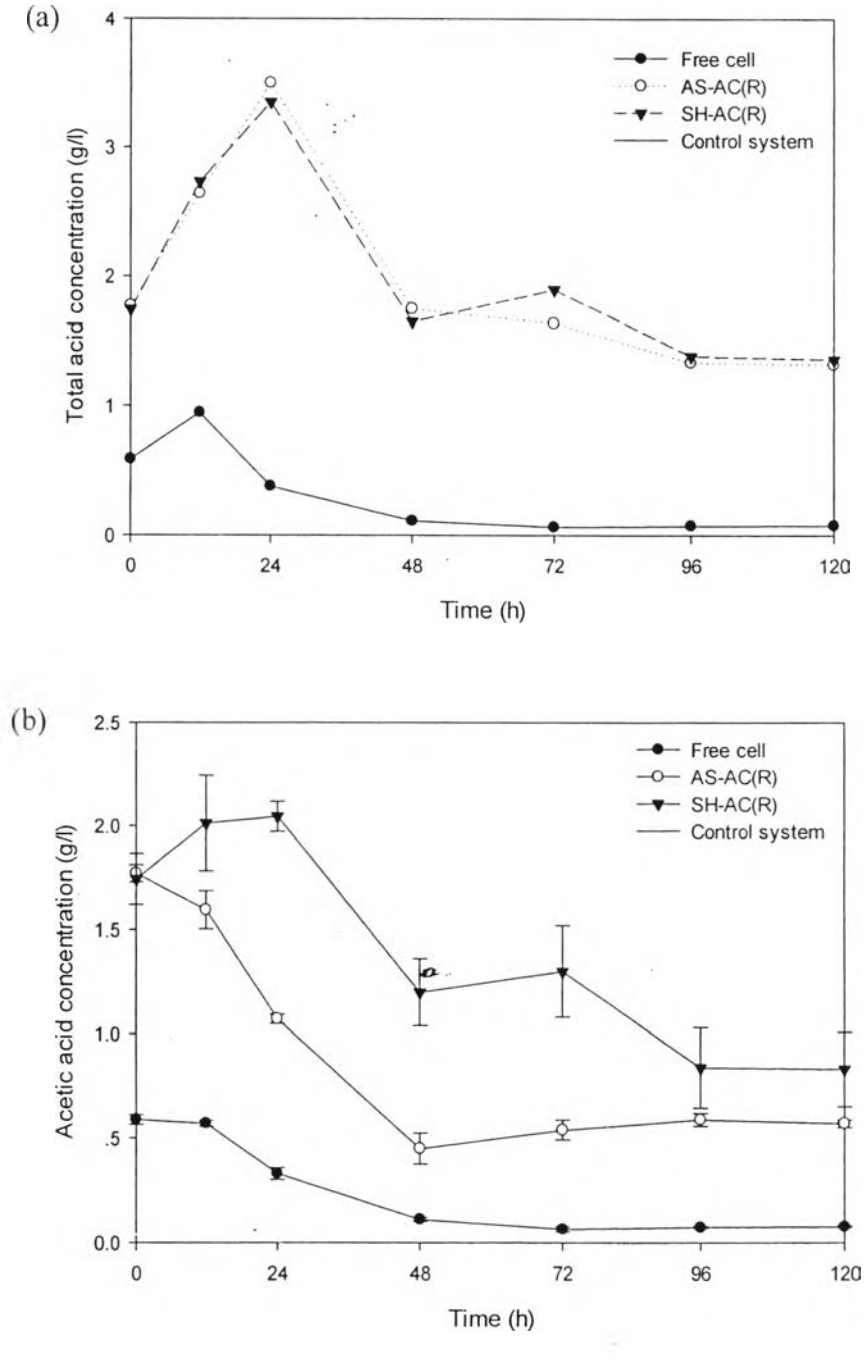



**Figure C2** Acid profiles of amine-base immobilized activated carbon fermentation (a) Total acid profile; (b) Acetic acid profile; and (c) Butyric acid profile.

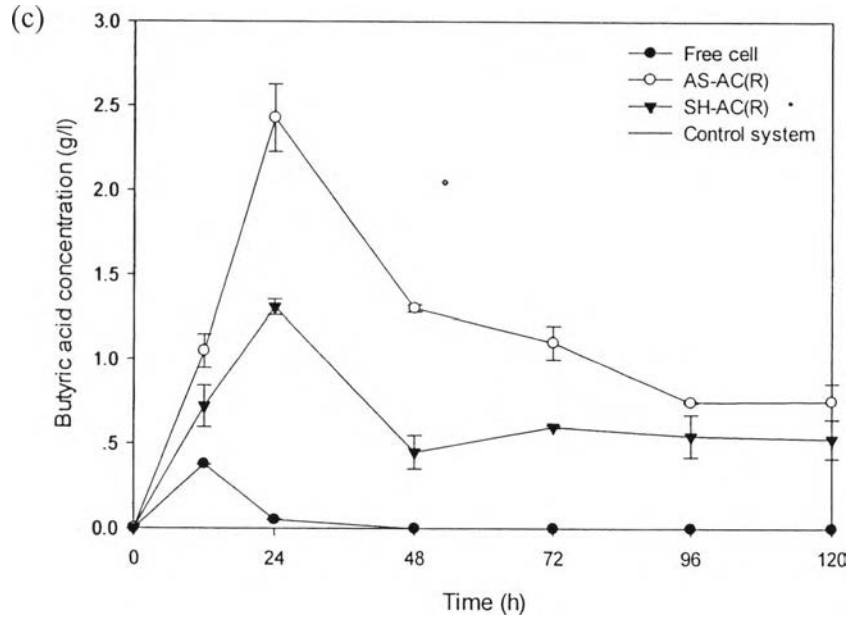



**Figure C2** Acid profiles of amine-base immobilized activated carbon fermentation (a) Total acid profile; (b) Acetic acid profile; and (c) Butyric acid profile. (con't.)

Butanol concentration of ABE Fermentation

**Table C1** Butanol concentrations as function of time all ABE fermentations.

| Time (h) | Butanol concentration (g/l) | | | | | |
|---|---|---|---|---|---|---|
| | Acid-Base treatment | | | Amine-Base treatment | | |
| | Free cell | NASH-AC | SH-AC | Free cell | AS-AC (R) | SH-AC (R) |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1.384 | 0.969 | 1.040 | 0.131 | 0.221 | 0 |
| 24 | 4.629 | 2.869 | 3.989 | 3.186 | 4.369 | 0.692 |
| 48 | 6.527 | 6.729 | 6.941 | 5.413 | 7.867 | 3.695 |
| 72 | 7.476 | 7.877 | 7.478 | 4.156 | 11.163 | 5.441 |
| 96 | 7.605 | 7.426 | 7.180 | 4.500 | 10.471 | 5.612 |
| 120 | 7.417 | 7.315 | 7.000 | 4.784 | 10.334 | 5.877 |

- Butanol concentration of ABE Fermentation from previous work

**Table C2** Butanol concentrations from previous work (Vichuviwat *et al.*, 2014)

| System | Butanol concentration (g/l) | Total solvent concentration (g/l) |
|---|---|---|
| Free cell | 5.29 | 9.85 |
| Brick | 5.80 | 10.71 |
| Activated carbon | 2.93 | 6.61 |
| Zeolite 13X | 8.58 | 14.63 |

# CURRICULUM VITAE

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**Proceedings:**

1. Chinwatpaiboon, P., Luengnaruemitchai, A. (2015, April 21) Biobutanol Production by Immobilized *Clostridium beijerinckii* TISTR1461 onto Carbon materials. Proceedings of The 6th Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and The 21th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.