以NaHCO3為碳源於雙槽式光生化反應器連續培養Tetraselmis Chui

Le Thi Huong Mai、余世宗

E-mail: 9606929@mail.dyu.edu.tw

摘 要

全球溫暖化已成為國際環保問題，化石燃料燃燒所排放之二氧化碳被認為是造成全球溫暖化的主要原因，整合鹼液吸收與微藻光合作用以處理工廠煙道排放之二氧化碳是相當有潛力的方法。以氫氣化鈉溶液吸收二氧化碳其水溶液含有高濃度之碳酸氫鈉，本研究於一雙槽式光生化反應器以連續培養方式探討培養基之碳酸氫鈉濃度、光強度及稀釋速率對Tetraselmis chui生長及固定二氧化碳效率之影響。培養基修改自Walne培養基。 改變進料槽之碳酸氫鈉濃度(0.02 ~ 0.06 M)對周氏扁藻生長的影響，實驗結果顯示光生化反應器中之生質濃度、葉綠素濃度及二氧化碳固定速率隨碳酸氫鈉濃度之提高而增加，光生化反應器亮槽及暗槽之最高生質濃度分別可達0.23和0.15 g l-1 ，最高葉綠素濃度分別達3.27 和2.19 μg l-1。進料槽之碳酸氫鈉濃度為0.06 M時，有最高之生質生產速率及比生長速率(0.063 h-1)，二氧化碳固定速率亦達最高值。但進料槽之碳酸氫鈉濃度為0.04 M時有最高之二氧化碳固定效率。 改變光強度 (10000 ~ 30000 Lux)對周氏扁藻生長的影響，實驗結果顯示，光強度為30000 Lux 光生化反應器中亮槽及暗槽之最高生質濃度分別可達0.21和0.13 g l-1，亮槽中最高生質濃度與最高生質濃度之比為1.9、而暗槽中最高生質濃度與最高生質濃度之比為1. 6。光強度為30000 Lux亮槽及暗槽有最高之比生長速率及比呼吸速率、分別達0.065和0.044 h-1、最高葉綠素濃度分別達2.79 和2.31 μg l-1，最高二氧化碳固定速率及二氧化碳固定效率分別為0.052 g h-1和32.63%。 改變稀釋速率 (0.03 ~ 0.16 h-1)對周氏扁藻生長的影響，實驗結果顯示，稀釋速率為0.03 h-1光生化反應器中亮槽及暗槽有最高生質濃度分別達0.24和0.20 g l-1，但稀釋速率為0.16 h-1有最高之生比生長速率(0. 10 h-1)。葉綠素濃度隨稀釋速率之提高而降低，光生化反應器亮槽及暗槽之最高葉綠素濃度分別達8.82 和6.83 μg l-1 ，最高葉綠素濃度分別達3.27 和2.19 μg l-1。稀釋速率為0.16 h-1有最高之二氧化碳固定速率及二氧化碳固定效率分別為0.09 g h-1和23.1%。

關鍵詞 : 光生化反應器 ; Tetraselmis chui ; 碳酸氫鈉 ; 光強度 ; 稀釋速率

目錄

TABLE OF CONTENTS FRONT COVER SIGNATURE CERTIFICATE OF AUTHORIZATION iii ABSTRACT iv 中文摘要 vi ACKNOWLEDGMENTS viii TABLE OF CONTENTS ix LIST OF FIGURES xii LIST OF TABLES xvi Chapter I. INTRODUCTION 1 Chapter II. LITERATURE REVIEW 3 2.1 Mitigation of carbon dioxide using biological methods 3 2.2 Mitigation of carbon dioxide using chemical methods 10 2.3 Mitigation of carbon dioxide using physical methods 16 2.3.1 CO2 absorption by solids 17 2.3.2 CO2 absorption by liquid solvents 18 2.3.3 CO2 absorption by ionic liquids 20 2.4. Photobioreactors 21 2.4.1 Tubular photobioreactors 23 2.4.2 Flat photobioreactors 27 2.4.3 Air lift photobioreactors 28 2.4.4 Bubble-column photobioreactors 30 2.4.5 Stirred tank photobioreactors 32 Chapter III. METHODS AND MATERIALS 33 3.1 Experiment design 33 3.2 Cultivation system and operation procedure 34 3.3 Methods 38 3.3.1 Measurements 38 3.3.2 CO2 fixation rate and CO2 fixation efficiency 42 3.3.3 Specific growth rate (m) and specific respiration rate (g) of T.chui 45 3.4 Materials 47 3.4.1 Microalgae strain 47 3.4.2 Culture medium 47 3.5 Apparatuses 48 Chapter IV. RESULTS AND DISCUSSION 49 4.1 Effects of NaHCO3 concentration on T.chui growth 49 4.1.1 Growth characteristic of T.chui 49 4.1.2 Variation of pH values in culture medium of T.chui 53 4.1.3 Variation of dissolved oxygen (DO) concentrations in culture medium of T.chui 55 4.1.4 Chlorophyll concentrations 55 4.1.5 CO2 fixation by T.chui at steady-state 58 4.2 Effects of light intensity on T.chui growth 61 4.2.1 Growth characteristic of T.chui 61 4.2.2 Variation of pH values in culture medium of T.chui 64 4.2.3 Variation of dissolved oxygen (DO) concentrations in culture medium of T.chui 66 4.2.4 Chlorophyll concentrations 68 4.2.5 CO2 fixation by T.chui at steady-state 69 4.3 Effects of dilution rate on T.chui growth 73 4.3.1 Growth characteristic of T.chui 73 4.3.2 Variation of pH values in culture medium of T.chui 76 4.3.3 Variation of dissolved oxygen (DO) concentrations in culture medium of T.chui 78 4.3.4 Chlorophyll concentrations 79 4.3.5 CO2 fixation by T.chui at steady-state 80 Chapter V. CONCLUSIONS AND SUGGESTIONS 84 5.1. Conclusions 84 5.2. Suggestions 84 REFERENCES 86

參考文獻

1. Akimoto, M., Ohara, T., Ohtaguchi, K., Kozokoide, (1994), “ Carbon Dioxide Fixation and ?-Linolenic Acid Production by the Hot-Spring Alga Cyanidium caldarium ”, Journal of Chemical Engineering of Japan, 27(3), 329 - 333. 2. Arakawa, H., Dubois, J.L., Sayama, K., (1992),

“ Selective conversion of CO2 to methanol by catalytic hydrogenation over promoted copper catalyst ” , Energy Convers. Mgmt, 33(5-8), 521 - 528. 3. Aroonwilas, A., Tontiwachwuthikul, P., (1997), “ High-efficiency structured packing for CO2 separation using 2-amino-2-methyl-1-propanol (AMP) ” , Separation and Purification Technology, 12, 67 - 79. 4. Aroonwilas, A., Tontiwachwuthikul, P., (2000), “ Mechanistic model for prediction structured packing mass transfer performance in CO2? absorption with chemical reactions ” , Chemical Engineering Science, 55, 3651 - 3663. 5. Audus, H., Oonk, H., (1997), “ An assessment procedure for chemical ultilisation schemes intended to reduce CO2 emissions to atmosphere ” , Energy Convers. Mgmt, 38, 409 - 414. 6. Baquerisse, D., Nouals, S., Isambert, A., Santos, P. F. D., Durand, G., (1999), “ Modelling of a continuous pilot photobioreactor for microalgae production ” , Journal of Biotechnology, 70, 335 - 342. 7. Barbosa, M.J., Janssen, M., Ham, N., Tramper, J., Wijffels, R.H., (2003), “ Microalgae cultivation in air-lift reactors: modeling biomass yield and growth rate as a function of mixing frequency ” , Biotechology and Bioengineering, 82, 170 - 179. 8. Benemann, J.L., (1993), “ Utilization of carbon dioxide from fossil fuel-burning power plants with biological systems ” , Energy Convers. Mgmt, 34(9-11), 999-1004. 9. Benemann, J.L., (1997), “ CO2 mitigation with microalgae systems ” , Energy Convers. Mgmt, 38, 475 - 479. 10. Brown, L.M., (1996), “ Uptake of carbon dioxide from flue gas by microalgae ” , Energy Convers. Mgmt, 37(6-8), 1363 - 1367. 11. Carlozzi, P., Sacchi, A., (2001), “ Biomass production and studies on Rhodopseudomonas palustris grown in an outdoor, temperature controlled, underwater tubular photobioreactor ” , Journal of Biotechnology, 88, 239- 249. 12. Chae, S.R., Hwang, E.J., Shin, H.S., (2006), “ Single cell protein production of Euglena gracilis and carbon dioxide fixation in an innovative photo-bioreactor ” , Bioresource Technology, 97, 322 - 329. 13. Cheng, L., Zhang, L., Chen, H., Gao, C., (2006), “ Carbon dioxide removal from air by microalgae cultured in a membrane-photobioreactor ” , Separation and Purification Technology, 50, pp. 324 - 329. 14. Cheng, S.S., (2006), “ Continuous cultivation of Tetraselmis chui in photobireactor using sodium carbonate and sodium bicarbonate as carbon sources ” , Master Thesis. 094DYU00515013. 15. Chu, G.H., Park, J.B., Cheong, M., (2000), “ Synthesis of dimethyl carbonate from carbon dioxide over polymer supported iodide catalysts ” , Inorganica Chimica Acta, 307, 131 - 133. 16. David, O.H., Fernandez, F.G.A., Guerrero, E.C., Rao, K.K., Grima, E.M., (2003), “ Outdoor helical tubular photobioreactors for microalgal production: modeling of fluid-dynamics and mass transfer and assessment of biomass productivity ” , Biotechnol Bioengineering, 82, 62 - 73. 17. Degen, Y., Uebele, A., Retze, A., Ulrike, S.S., Trosch, W., (2001), “ A novel airlift photobioreactor with baffles for improved light utilization through the flashing light effect ” , Journal of Biotechnology, 92, 89 - 94. 18. Fernandez, F.G.A., Camacho, F.G., Perez, J.A.S., Sevilla, J.M.F., Grima, E. M., (1998), “ Modeling of biomass productivity in tubular photobioreactors for microalgal cultures: effects of dilution rate, tube diameter, and solar irradiance ” , Biotechnology Bioengineering, 58, 605 - 616. 19. Feron, P.H.M., Jansen A.E., (1995), “ Capture of carbon dioxide using membrane gas absorption and reuse in the horticultural industry ” , Energy Convers. Mgmt, 36(6-9), 411 - 414. 20. Fleischer, C., Becker, S., Eigenberger, G., (1996), “ Detailed modeling of chemisorption of CO2 into NaOH in a bubble column ” , Chemical Engineering science, 51(10), 1715 - 1724. 21. Grima, E.M., Fernandez, F.G.A., Camacho, F.G., Chisti, Y., (1999), “ Photobioreactors: light regime, mass transfer and scaleup ” , Journal of Biotechnology, 70, 231 - 247. 22. Hirata, S., Hayashitani, M., Taya, M., Tone, S., (1996), “ Carbon dioxide fixation in batch culture of Chlorella sp. using a photobioreactor with a sunlight-collection device ” , Jounal of Fermentation and Bioengineering, 81(5), 470 - 472. 23. Hori, Y., Ito, H., Okano, K., Nagasu, K., Sato, S., (2003), “ Silver-coated ion exchange membrane electrode applied to electrochemical reduction of carbon dioxide ” , Electrochimica Acta, 48, 2651 - 2657. 24. Hu, Q., Guterman, H., Richmond, A., (1996), “ A flat inclined module photobioreactor for outdoor mass cultivation of photoautotrophs ” , Biotechnology and Bioengineering, 51, 51 - 60. 25. Huang, Y.M, Gregory, L.R., (2002), “ Optimal temperature and photoperiod for the cultivation of Agardhiella subulata microplantlets in a bubble-column photobioreactor ” , Biotechology and Bioengineering, 79, 135 - 144. 26. Ichikawa, S., (1995), “ Chemical conversion of carbon dioxide by catalytic hydrogenation and room temperature photoelectrocatalysis ” , Energy Convers. Mgmt, 36(6-9), 613 - 616. 27. Ishibashi, M., Ota, H., Akutsu, N., Umeda, S., Tajika, M., Izumi, J., Yasutake, A., Kabata, T., Kageyama, Y., (1996), “ Technology for removing carbon dioxide from power plant flue gas by the physical adsorption method ” , Energy Convers. Mgmt, 37??(6-8), 929 - 933. 28. Janssen, M., Tramper, J., Mur, L.R., Wijffels, R.H., (2003), “ Enclosed outdoor photobioreactors: light regime, photosynthetic efficiency, scale-up, and future prospects ” , Biotechology and Bioengineering, 81, 193 - 210. 29. Kajiwara, S., Yamada, H., Ohkuni, N., Ohtaguchi, K., (1997), “ Design of the bioreactor for carbon dioxide fixation by Synechococcus PCC 7942 ” , Energy Convers. Mgmt, 38, 529 - 532. 30. Kasuga, K., Kabata, N., (1997), “ The fixation of carbon dioxide with 1, 2-epoxypropane catalyzed by alkali-metal halide in the present of crown ether ” , Inorganica Chimica Acta, 257, 177 - 178. 31. Kishimoto, M., Okakura, T., Nagashima, H., Minowa, T., Yayokoyama, S., Yamaberi, K., (1994), “ CO2 fixation and oil production using micro-algae ” , Journal of Fermentation and Bioengineering, 78(6), 479 - 482. 32. Kojima, T., Nagamine, A., Ueno, N., Uemiya, S., (1997), “ Absorption and fixation of carbon dioxide by rock weathering ” , Energy Convers. Mgmt, 38, 461 - 466. 33. Koleli, F., Balun, D., (2004), “ Reduction of CO2 under high pressure and high temperature on Pb-granule electrodes in a fixed-bed reactor in aqueous medium ” , Applied Catalysis A, General, 274(1-2), 237 - 242. 34. Krichnavaruk, S., Loataweesup, W., Powtongsook, S., Pavasant, P., (2005), “ Optimal growth conditions and the cultivation of Chaetoceros calcitrans in airlift photobioreactor ” , Chemical Engineering Journal, 105, 91 - 98. 35. Kurano, N., Ikemoto, H., Miyashita, H., Hasegawa, T., Hata, H., Miyachi, S. (1995), “ Fixation and ultilization of carbon dioxide by microalgal photosynthesis ” , Energy Convers. Mgmt, 36(6-9), 689 - 692. 36. Lopez, M.C.G.M., Sanchez, E.D.R., Lopez, J.L.C., Fernandez, F.G.A., Sevilla, J.M.F., Rivas, J., Guerrero, M.G., Grima, E.M., (2006), “ Comparative analysis of the out door culture of Haematococcus pluvialis in tubular and bubble column photobioreactors ” , Journal of Biotechnology, 123, 329 - 342. 37. Lu, X.B., Xiu, J.H., He, R., Jin, K., Luo, L.M., Feng, X.J., (2004), “ Chemical fixation of CO2 to ethylene carbonate under supercritical conditions: continuous and selective ” , Applied Catalysis A: General, 275, 73 - 78. 38. Luo, H.P., Kemoun, A.,

Al-Dahhan, M.H., Sevilla, J.M.F., Sanchez, J.L.G., Camacho, F.G. and Grima, E.M., (2003), " Analysis of photobioreactors for culturing high value microalgae and cyanobacteria via an advanced diagnostic technique: CARPT " , Chemical Engineering Science, 58, 2519 - 2527. 39. Maeda, K., Owada, M., Kimura, N., Omata, K., Karube, I., (1995), " CO2 fixation from the flue gas on coal-fired thermal power plant by microalgae " , Energy Convers. Mgmt, 36(6-9), 717 - 720. 40. Merchuk, J.C., Ladwa, N., Cameron, A., Bulmer, M., Berzinb, I., Pickett, A.M., (1996), " Liquid flow and mixing in concentric tube air- lift reactors " , Journal of Chemical Technology & Biotechnology, 66, 174-182. 41. Merchuk, J.C., Ronen, M., Giris, S., Arad, S., (1998), " Light/Dark cycles in the growth of the red microalga Porphyridium Sp. " , Biotechnology Bioengineering, 59, 705 - 713. 42. Miron, A.S., Garc?a, M.C.C., Camacho, F.G., Grima, E.M., Chisti, Y., (2002), " Growth and biochemical characterization of microalgal biomass produced in bubble column and airlift photobioreactors: studies in fed-batch culture " , Enzyme and Microbial Technology, 31, 1015 - 1023. 43. Molina, E., Fernandez, J., Acien, F.G., Chisti, Y., (2001), " Tubular photobioreactor design for algal cultures " , Journal of Biotechnology, 92, 113 - 131. 44. Morita, M., Watanabe, Y., Saiki, H., (2000), " Investigation of photobioreactor design for enhancing the photosynthetic productivity of microalgae " , Biotechology and Bioengineering, 69(6), 693 - 698. 45. Morita, M., Watanabe, Y., Saiki, H., (2002), " Photosysthetic productivity of conical helical tubular photobioreactor incorporating Chlorella sorokiniana under field conditions " , Biotechnology and Bioengineering, 77(2), 155 - 162. 46. Nishikawa, N., Ishibashi, M., Ohta, H., Akutsu, N., Matsumoto, H., Kamata, T., Kitamura, H., (1995), " CO2 removal by hollow-fiber gas-liquid contactor " , Energy Convers. Mgmt, 36(6-9), 415 - 418. 47. Nishikawa, N., Koyu, H.N., Hirano, A., Ikuta, Y., Hukuda, Y., Negoro, M., Kaneko, M., Hada, M., (1992), " Reduction of carbon dioxide emission from flue gas with microalgae cultivation " , Energy Convers. Mgmt, 33(5-8), 553-560. 48. Ogbonna, J.C., Yada, H., Masui, H., Tanaka, H., (1996), " A novel internally illuminated stirred tank photobioreactor for large-scale cultivation of photosynthesis cells " , Journal of Fermentation and Bioengineering, 82(1), 61 - 67. 49. Ohta, K., Hasimoto, A., Mizuno, T., (1995), " Electrochemical reduction of carbon dioxide by the use of copper tube electrode " , Energy Convers. Mgmt, 36(6-9), 625 - 628. 50. Ohtaguchi, K., Kajiwara, S., Mustaqim, D., Takahashi, N., (1997), " Cyanobacterial bioconversion of carbon dioxide for fuel production " , Energy Convers. Mgmt, 38, 523 - 528. 51. Ono, E., Cuello, J.L., (2004), " Design parameters of solar concentrating systems for CO2-mitigating algal photobioreactors " . Energy, 29, 1651-1657. 52. Ono, E., Cuello, J.L., (2007), " Carbon dioxide mitigation using thermophilic Cyanobacteria " , Biosystems Engineering, 96(1), 129 - 134. 53. Otsuki, T., (2001), " A study for the biological CO2 fixation and utilization system " , The Science of the Total Environment, 277, 21 - 25. 54. Pulz, O., (2001), " Photobioreactors: production systems for phototrophic microorganisms " , Appl Microbiol Biotechnol, 57, 287 - 293. 55. Richmond, A., Zhang, C.W., (2001), " Optimization of a flat plate glass reactor for mass production of Nannochloropsis sp. outdoors " , Journal of Biotechnology, 85, 259 - 269. 56. Rorrer, G.L., Mullikin, R.K., (1999), " Modeling and simulation of a tubular recycle photobioreactor for macroalgal cell suspension cultures " , Chemical Engineering Science, 54, 3153 - 3162. 57. Ruth, A.R., Kathering, J.H., (1997), " A comparison of greenhouse gas mitigation options " , Energy, 22(2-3), 115 - 120. 58. Shannon L.M., Jennifer H.A., Gary H.W., (2005), " Photoperiod and light intensity effects on growth and utilizationof nutrients by the aquaculture feed microalga, Tetraselmis chui (PLY429) " , Aquaculture, 246, 393 - 404. 59. Shen, Y.M., Duan, W.L., Shi, M., (2004), " Chemical fixation of carbon dioxide co-catalyzed by a combination of Schiff bases or Phenols and organic bases " , European Journal of Organic Chemistry, 2004(14), 3080 - 3089. 60. Sobczuk, T.M., Camacho, F.G., Rubio, F.C., Fernandez, F.G.A., Grima, E.M., (2000), " Carbon dioxide uptake efficiency by outdoor microalgal cultures in tubular airlift photobioreactors " , Biotechology and Bioengineering, 67, 465 - 475. 61. Steinberg, M., (1992), " History of CO2 greenhouse gas mitigation technologies " , Energy Convers. Mgmt, 33(5-8), 311 - 315. 62. Takeuchi, T., Utsunomiya, K., Kobayashi, K., Owada, M., Karube, I., (1992), " Carbon dioxide fixation by a unicellular green alga Oocystis sp " , Journal of Biotechnology, 25, 261 - 267. 63. Watanabe, Y., David, O.H., (1995), " Photosynthesis CO2 fixation technologies using a helical tubular bioreactor incorporating the filamentous cyanobacterium Spirulina Platensis " , Energy Convers. Mgmt, 36(6-9), 721 - 724. 64. Watanabe, Y., David, O.H., (1996), " Photosynthetic CO2 conversion technologies using a photobiorector incorporating microalgae - Energy and material balances " , Energy Conversion and Management, 37(6-8), 1321 - 1326. 65. Watanabe, Y., Saiki, H., (1997), " Development of photobioreactor incorporating Clorella sp. for removal CO2 in stack gas " . Energy Convers. Mgmt, 38, 499 - 503. 66. Yamamoto, S., Kawabata, K., Moriya, O., Endo, T., (2005), " Effective fixation of carbon dioxide into poly(glycidyl methacrylate) in the presence of pyrrolidone polymers " , Journal of Polymer Science Part A: Polymer Chemistry, 43(19), 4578 - 4585. 67. Yun, Y.S., Lee, S.B., Park, J.M., Lee, C.I., Jang, J.W., (1997), " Carbon dioxide fixation by algal cultivation using wastewater nutrients " , J. Chem. Tech. Biotechnol, 69, 451 - 455. 68. Zeiler, K.G., Heacox, D.A., Toon, S.T., Kadam, K.L., Brown, L.M., (1995), " The use of microalgae for assimilation and utilization of carbon dioxide from fossil fuel-fired power plant flue gas " , Energy Convers. Mgmt, 36(6-9), 707 - 712. 69. Zhang, J., Zhang, S., Dong, K., Zhang, Y., Shen, Y., Xingmei L. (2006), " Supported absorption of CO2 by Tetrabutylphosphonium Amino acid ionic liquids " , Chemistry - A European Journal, 12(15), 4021 - 4026. 70. Zhang, S., Chen, Y., Li, F., Lu, X., Dai, W., Mori, R., (2006), " Fixation and conversion of CO2 using ionic liquids " , Catalysis Today, 115(1-4), 61 - 69. 71. Zhang, X., Zhao, N., Wei, W., Sun, Y., (2006), " Chemical fixation of carbon dioxide to propylene carbonate over amine-functionalized silica catalysts " , Catalysis Today, 115, 102 - 106.