REFERENCES

[1] Could reducing fossil-fuel emissions cause global warming? [online]. Available from: http://www.nature.com/nature/journal/v349/n6309/abs/349503a0.html [accessed 2008, January 3]

[2] National Biodiesel Board [online]. Available from: http://biodiesel.org/pdf_files/fuel factsheets/emissions.pdf [accessed 2009, March 9]

[3] International Energy Outlook 2008 [online]. Available from: http://www.eia.doe. gov/oiaf/ieo/world.html [accessed 2008, March 3]

[4] Review on biodiesel standardization world-wide [online]. Available from: www.task39.org/LinkClick.aspx?fileticket=GUVQalgvfo4%3D&tabid=18 06&mid=3280&language=en-US [accessed 2009, January 12]

[5] Transesterification [online]. Available from: http://share.psu.ac.th/file/waraporn. ra/transesterification.jpg [accessed 2008, August 24]

[6] Biodiesel in the Asia Pacific Region: Advancement Amidst Uncertainty [online]. Available from: http://www.frost.com/prod/servlet/market-insighttop.pag? docid=85998218 [accessed 2008, June12]

[7] Glycerol: Properties and Production [online]. Available from: http://www.rsc.org/ ebooks/archive/free/BK9780854041244/BK9780854041244-00001.pdf [accessed 2009, March 9]

[8] Biodiesel & SVO discussion [online]. Available from: http://biodiesel.infopop.cc/ eve/forums/a/tpc/f/719605551/m/2051077632 [accessed 2009, March 9]

[9] Stein, Y.S.; and Antal, M.J. A study on the gas-phase pyrolysis of glycerol. *J. Anal. Appl. Pyrolysis.* 4(1983): 283.

[10] Bühler, W.; Dinjus, E.; Ederer, H.J.; Kruse, A.; and Mas, C. Ionic reactions and pyrolysis of glycerol as competing reaction pathways in near- and supercritical water. *J. of Supercritical Fluids.* 22(2002): 37.

[11] Ito, T.; Nakashimada, Y.; Senba, K.; Matsui, T.; and Nishio, N. Hydrogen and ethanol production from glycerol-containing waste discharged after biodiesel manufacturing process. *J. Biosci. Bioeng.* 100(2005): 260.

[12] Klepáčová, K.; Mravec, D.; Kaszonyi, A.; and Bajus, M. Etherification of glycerol and ethylene glycol by isobutylene. *Appl. Catal A.* 328(2007): 1.

[13] Corma, A.; Huber, G.W.; Sauvanaud, L.; and Connor, P.O. Processing biomass-derived oxygenates in the oil refinery: Catalytic cracking (FCC) reaction pathways and role of catalyst. *J. Catal.* 247(2007): 307.

[14] Adhikari, S.; Fernando, S.D.; and Haryanto, A. Hydrogen production from glycerin by steam reforming over nickel catalysts. *Renewable energy.* 33 (2008): 1097.

[15] Valliyappan, T.; Bakhshi, N.N.; and Dalai, A.K. Pyrolysis of glycerol for the production of hydrogen or syn gas. *Bioreource Tech. 99*(2008): 4476.

[16] Fernández, Y.; Arenillas, A.; Díez, M.A.; Pis, J.J.; and Menéndez, J.A. Pyrolysis of glycerol over activated carbons for syngas production. *J. Anal. Appl. Pyrolysis*. 2009, article in press. (DOI: 10.1016/j.jaap.2009.01.004)

[17] Wang, X.; Li, M.; Wang, M.; Wang, H.; Li, S.; Wang, S.; and Ma, X. Thermodynamic analysis of glycerol dry reforming for hydrogen and synthesis gas production. *Fuel.* 2009, article in press. (DOI: 10.1016/j.fuel. 2009.01.015)

[18] Yong, K.C.; Ooi, T.L.; Dzulkefly, K.; Wanyunus, W.M.Z.; and Hazimah, A.H. Characterization of glycerol residue from a palm kernel oil methyl ester plant. *Journal of Oil Palm Research.* 13(2001): 1.

[19] Ooi, T.L.; Yong, K.C.; Dzulkefly, K.; Wanyunus, W.M.Z.; and Hazimah, A.H. Crude glycerine recovery from glycerol residue waste from a palm kernel oil methyl ester plant. *Journal of Oil Palm Research.* 13(2001): 16.

[20] Dou, B.; Dupont, V.; Williams, P.T.; Chen, H.; and Ding, Y. Thermogravimetric kinetics of crude glycerol. *Bioresource Technology.* 100(2009): 2613.

[21] Beck, J.S.; Vartuli, J.C.; Roth, W.J.; Leonowicz, M.E.; Kresge, C.T.; Schmitt, K.D.; Chu, C.T.W.; Olson, D.H.; Sheppard, E.W.; MeCullen, S.B.; Higgins, J.B.; and Schlenker, J.L. A new family of mesoporous molecular sieves prepared with liquid crystal templates. *J. Am. Chem. Soc.* 114(1992): 10834.

[22] Lin, Y.H.; and Yang, M.H. Catalytic reactions of post-consumer polymer waste over fluidized cracking catalysts for producing hydrocarbons. *J. Mol. Catal. A,* 231(2005): 113.

[23] Zhao, D.; Feng, J.; Huo, Q.; Melosh, N.; Fredrickson, G,H.; Chmelka, F.B.; and Stucky, G.D. Triblock copolymer syntheses of mesoporous silica with periodic 50 to 300 angstorm pores. *Science.* 279(1998): 548.

[24] Zhaohua, L.; Hartmann, M.; Zhao, D.; Zhou, D.; and Kevan, L. Alumination and ion exchange of mesoporous SBA-15 molecular sieve. *Chem. Mater.* 11(1999): 1621.

[25] Aguado, J.; Serrano, D. P.; Miguel, G.S.; Escola, J. M.; and Rodríguez J. M. Catalytic activity of zeolitic and mesostructured catalysts in the cracking of pure and waste polyolefins. *J. Anal. Appl. Pyrol.* 78(2007): 153.

[26] Serrano, D .P.; Aguado, J.; Escola, J. M.; Rodríguez, J. M.; Morselli, L.; and Orsi, R. Thermal and catalytic cracking of a LDPE–EVA copolymer mixture. *J. Anal. Appl. Pyrol.,* 68(2003): 481.

[27] Activation energy [online]. Available from: http://en.wikipedia.org/wiki/Activation_ energy [accessed 2009, March 9]

[28] Hagen, J. *Industrial Calysis.* New York, Weinheim Wiley, 1999.

[29] Szostak, R. *Zeolite Molecular Sieves. Principles of Synthesis and Identification.* New York, Van: Nostrand Reinhold, 1989.

[30] Continuation report [online].Available from: http://mch3w.ch.man.ac.uk/theory/ staff/student/mbdtscw/transfer_html/node1.html [accessed 2009, March 9]

[31] Soler-Illia, G.J.A.A.; Sanchez, C.; Lebeau, B.; and Patarin, J. Chemical strategies to design textured materials: from microporous and mesoporous oxides to nanonetworks and hierarchical structures. *Chem. Rev.* 102(2002): 4093.

[32] Tanev, P.T.; and Pinnavania, T.J. Mesoporous silica molecular sieves prepared by ionic and neutral surfactant templating: a comparison of physical properties. *Chem. Mater.* 8(1996): 2068.

[33] Ying, J.Y.; Mehnert, C.P.; and Wong, M.S. Synthesis and applications of supramolecular-templated mesoporous materials. *Angew. Chem. Int. Ed.* 38(1999): 56.

[34] Melosh, N.A.; Lipic, P.; Bates, F.A.; and Stucky, G.D. Molecular and mesoscopic structure of transparent block copolymer silica monoliths. *Macromolecules*. 32(1999): 4332.

[35] Yue, Y.; Bonaedet, A.; Melosh, J.L.; and Espinose, J.B. Direct synthesis of AlSBA mesoporous molecular sieves: characterization and catalytic activities. *Chem. Commun.* 19(1999): 1967.

[36] Hu, W.; Luo, Q.; Su, Y.; Chen, L.; Yue, Y.; Ye, C.; and Deng, F. Acid sites in mesoporous Al-SBA-15 material as revealed by solid-state NMR spectroscopy. *Micropor. Mesopor. Mater.* 92(2006): 22.

[37] Han, Y.; Wu, S.; Sun, Y.Y.; Li, D.S.; Xiao, F.S.; Liu, J.; and Zhang, X. Hydrothermally stable ordered hexagonal mesoporous aluminosilicates assembled from a triblock copolymer and preformed aluminosilicate precursors in strongly acidic media. *Chem. Mater.* 14(2002): 1144.

[38] Kao, H.M.; Ting, C.C.; and Chao, S.W. Post-synthesis alumination of mesoporous silica SBA-15 with high framework aluminum content using ammonium hexafluoroaluminate. *J. Mol. Catal. A: Chem.* 235(2005): 200.

[39] Trombetta, M.; Busca, G.; Lenarda, M.; Storaro, L.; Pavan, M. An investigation of the surface acidity of mesoporous Al-containing MCM-41 and of the external surface of ferrierite through pivalonitrile adsorption. *Appl. Catal. A*. 182(1999): 225.

[40] Moore, D.M.; and Reynolds, J.R.C. *X-Ray Diffraction and the Identifiation and Analysis of Clay Minerals*. New York, Oxford University Press, 1989.

[41] Gabriel, B.L. *SEM: A User's Manual for Material Science*. Ohio: American Society for Metal, 1985.

[42] Basic operating principles of the sorptomatic [online]. Available from: http://saf.chem.ox.ac.uk/Instruments/BET/sorpoptprin.html [accessed 2009, March 9]

[43] *Analysis software user's manual*, BELSORP, BEL JAPAN, INC.

[44] Le Page, J.F.; Cosyns, J.; Courty, P.; and Freund, E.F. *Applied Heterogeneous Catalysis: Design-Manufacture-Use of Solid Catalysts*. Paris, Editions Technip, 1987.

[45] Clague, A.D.H.; Alma, N.C.M.; Sternhell S.; and Field, L.D. *Analytical NMR*. New York, John Wiley and son, 1989.

[46] George Odian. *Principle of Polymerization*. 4th ed., Singapore: Megraw-hill, 1987.

[47] Lewis, F.; Sami, M. *Chemistry of Petrochemical Process*. 2nd ed., New York, Gulf Professional, 2001.

[48] 1,3-Butadiene [online]. Available from: http://en.wikipedia.org/wiki/Butadiene [accessed 2009, March 15]

[49] Carbondioxide [online]. Available from: http://en.wikipedia.org/wiki/Carbon_ dioxide [accessed 2009, April 13]

[50] Shiota, K.; Tanaka, K.; and Minai, M. *Method for producing 2-cyclopentenones*. United States Patent. 1985.

[51] Pauson-khand reaction [online]. Available from: http://www.organic-chemistry.org/ namedreactions/pauson-khand-reaction.shtm [accessed 2009, January 12]

[52] Nazarov cyclization [online]. Available from: http://www.organic-chemistry.org/ namedreactions/nazarov-cyclization.shtm [accessed 2009, January 12]

[53] Jasmone [online]. Available from: http://en.wikipedia.org/wiki/Jasmone [accessed 2009, March 9]

[54] Jasmonate [online]. Available from: http://en.wikipedia.org/wiki/Jasmone [accessed 2009, March 9]

[55] Prostaglandin [online]. Available from: http://en.wikipedia.org/wiki/ Prostaglandin [accessed 2009, March 9]

[56] Chaipurimat, A. *Catalytic cracking of polypropylene waste using Al-SBA-15*, Master's Thesis, Program of Petrochemistry and Polymer Science, Fauclty of Science, Chulalongkorn University, 2006.

[57] Determination of glycerol content, BS 5711: Part 3: 1979.

[58] Determination of ash: gravimetric method, BS 5711: Part 6: 1979.

[59] Standard test method for water in liquid naval stores: Moisture by azeotropic distillation, D890-98: 2003.

[60] Calculation of Matter (Organic) Non-Glycerol (MONG), BS 5711: Part9: 1979.

[61] Determination of density and relative density, BS 5711: Part4: 1979.

[62] Determination of alkalinity or acidity: volumetric method, BS 5711: Part5: 1979.

[63] Pangma, W. *Preparation of tungstic oxide supported on SBA-15 for metathesis of 1-hexene*, Master's Thesis, Program of Petrochemistry and Polymer Science, Fauclty of Science, Chulalongkorn University, 2003.

[64] Zhao, D.; Huo, Q.; Feng, J.; Chmelka, B.F.; and Stucky, G.D. Nonionic triblock and star diblock copolymer and oligomeric surfactant syntheses of highly ordered, hydrothermally stable, mesoporous silica structures. *J. Am. Chem. Soc. 120*(1998): 6024.

[65] Eswaramoorthi, I.; and Dalai, A.K. Synthesis, characterization and catalytic performance of boron substituted SBA-15 molecular sieves, *Micropor. Mesopor. Mater. 93*(2006): 1.

[66] Ooi, Y.; Zakaria, R.; Mohamed, A. R.; and Bhatia, S. Hydrothermal stability and catalytic activity of mesoporous aluminum-containing SBA-15. *Catal. Com.*, 5(2004): 441.

[67] Zeng, S.; Blanchard, J.; Breysse, M.; Shi, Y.; Shu, X.; Nie, H.; and Li, D. Post synthesis alumination of SBA-15 in aqueous solution: a versatile tool for preparation of acidic Al-SBA-15 supports. *Micropor. Mesopor. Mater.* 85(2005): 297.

[68] Busio, M.; Janchen, J.; and Hooff, J.H.C.V. Aluminum incorporation in MCM-41 mesoporous molecular sieves. *Microporous Mater.* 5(1995): 211.

[69] Cazalillaa, M. G.; Robles, J. M. M.; Gurbani, A.; Rodrıguez-Castello, E.; Lopez, A.J. Characterization and acidic properties of Al-SBA-15 materials prepared by post-synthesis alumination of a low-cost ordered mesoporous silica. *J. Solid State Chemistry.* 180(2007): 1130.

[70] Bournay, L.; Casanave, D.; Delfort, B.; Hillion, G.; and Chodorge, J.A. New heterogeneous process for biodiesel production: A way to improve the quality and the value of the crude glycerin produced by biodiesel plants. *Catalysis Today.* 106(2005): 190.

[71] Ahluwalia, V.K.; and Goyal, M. *A textbook of organic chemistry.* New Delhi, Narosa, 2000.

APPENDICES

1. % Selectivity of gas products

$$\% \text{ Selectivity of X} = \frac{\text{Concentration of X} \times 100}{\text{Total concentration of products}}$$

$$\text{Concentration of X} = \frac{b \times c}{a}$$

a = Peak area of X in standard gas,

b = % molar of X in standard gas,

c = Peak area of X in sample products.

2. % Selectivity of liquid products

$$\% \text{ Selectivity of Y} = \frac{\text{Concentration of X} \times 100}{\text{Total concentration of products}}$$

$$\text{Concentration of X} = \frac{b \times c}{a}$$

a = Peak area of X in standard liquid,

b = % molar of X in standard liquid,

c = Peak area of X in sample products.

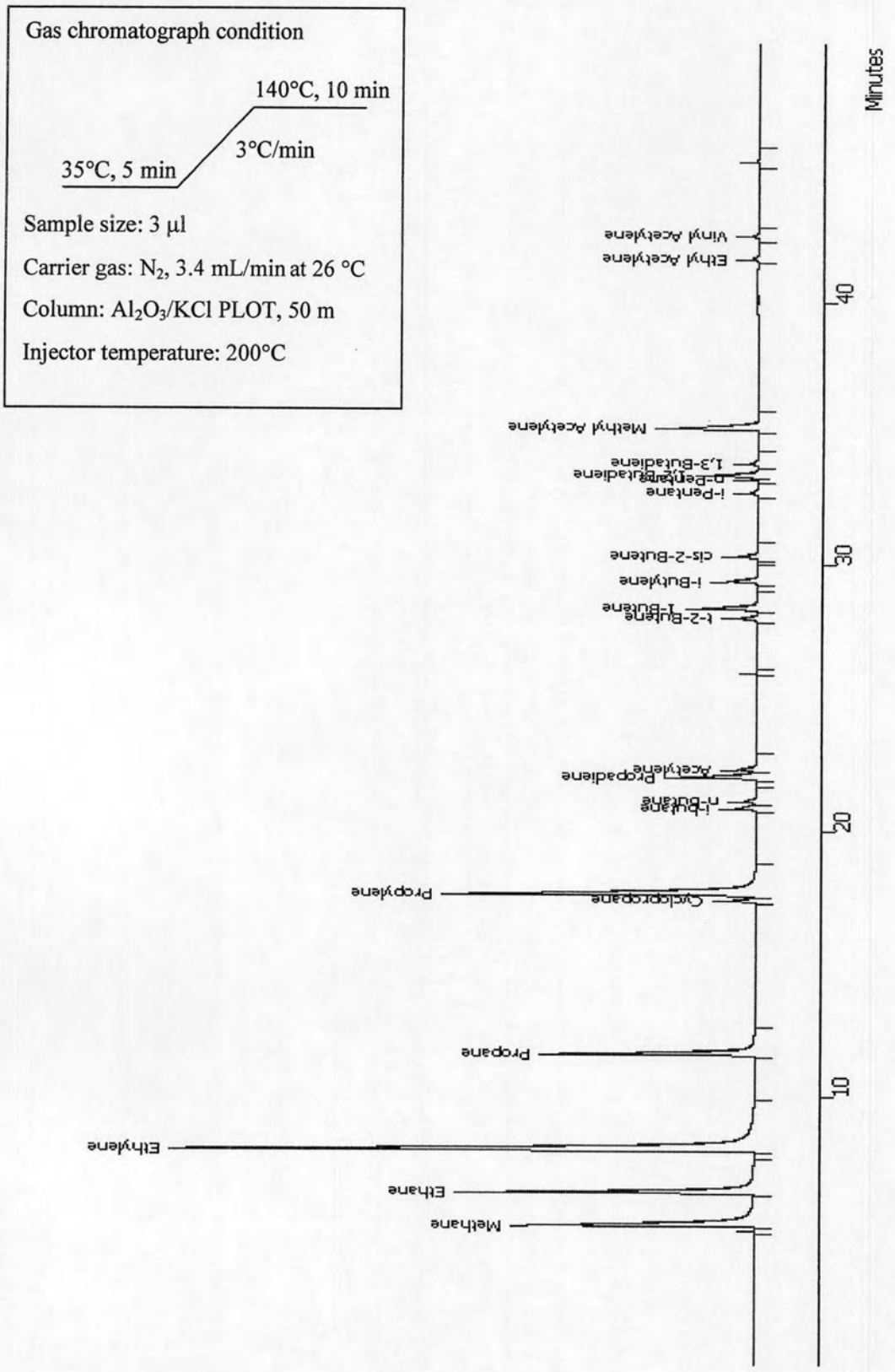

Figure A-1 Gas chromatogram of standard HC gas mixture.

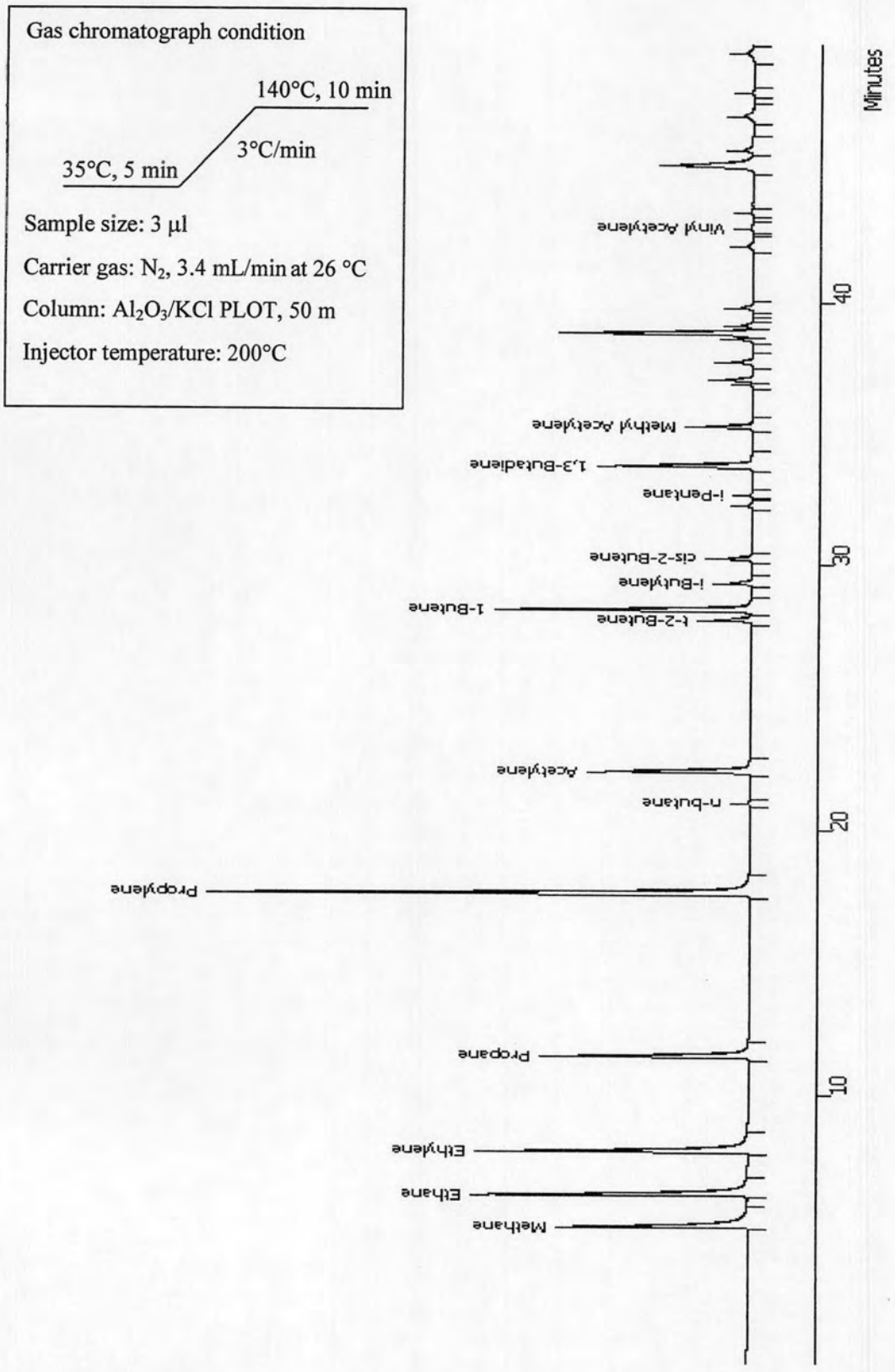

Figure A-2 Gas chromatogram of gas product obtained from catalytic cracking of WBP over Al-SBA-15(100) at 400°C.

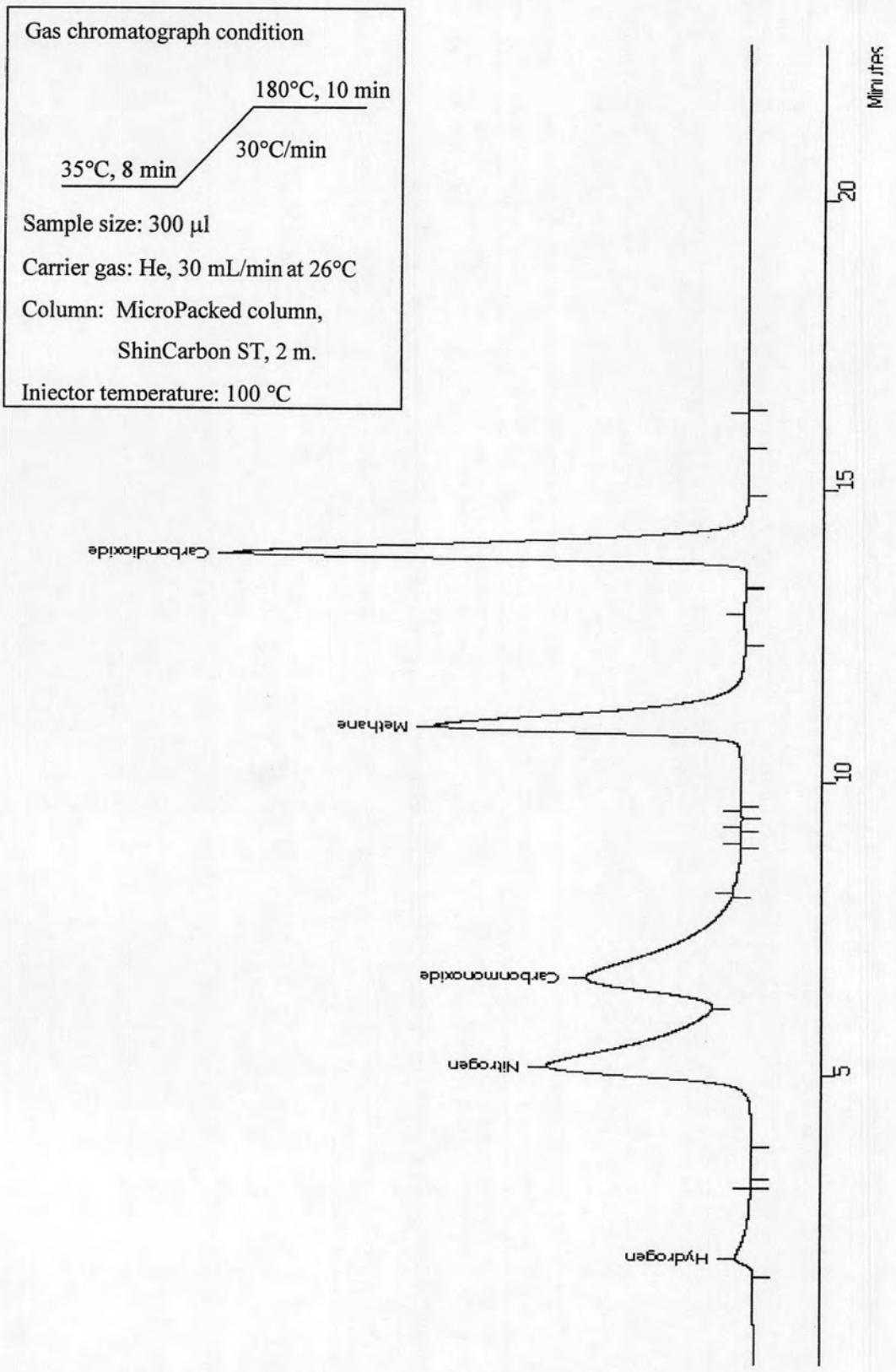

Figure A-3 Gas chromatogram of standard permanent gas mixture.

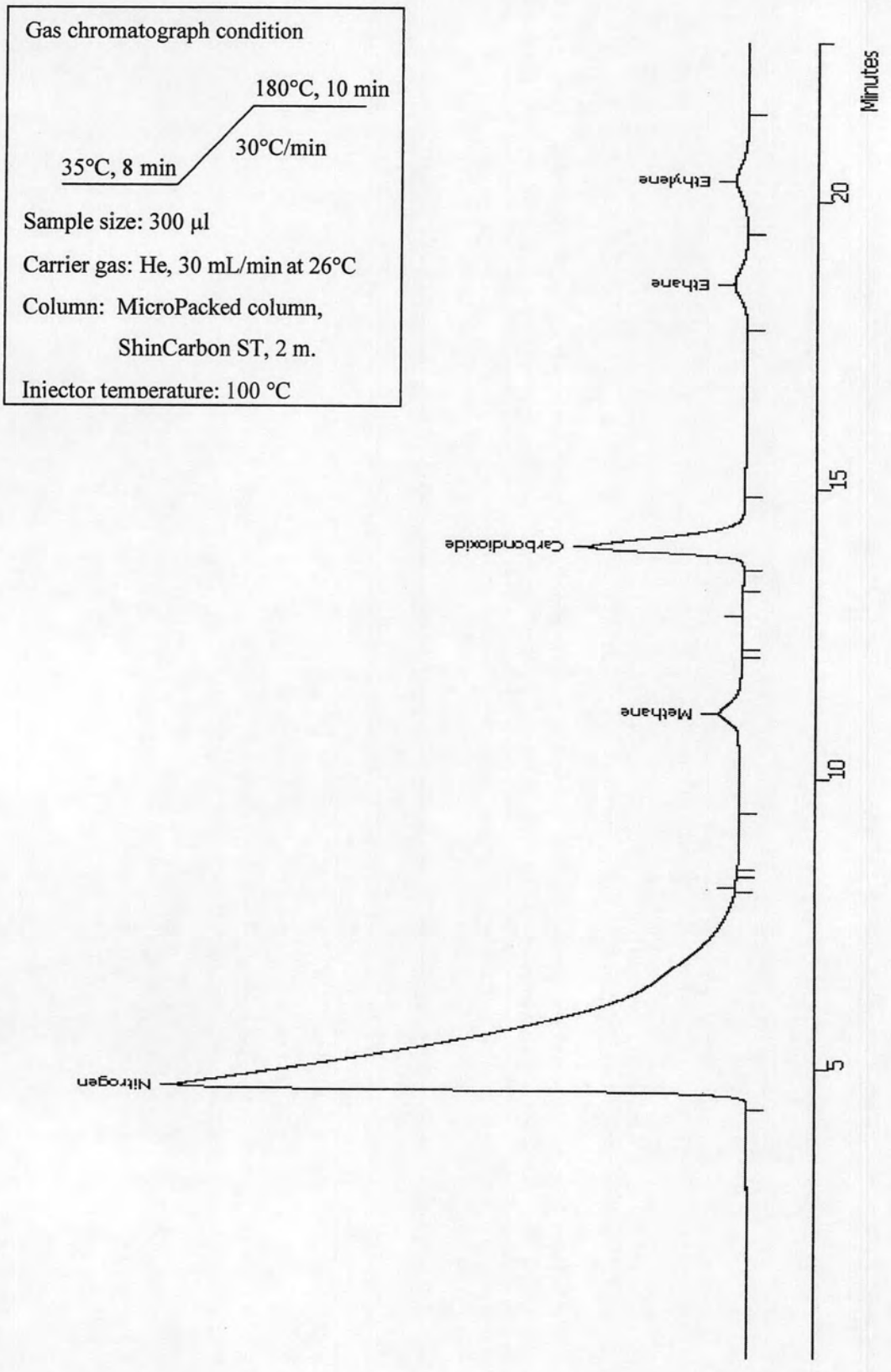

Figure A-4 Gas chromatogram of gas product obtained from catalytic cracking of WBP over Al-SBA-15(100) at 400°C.

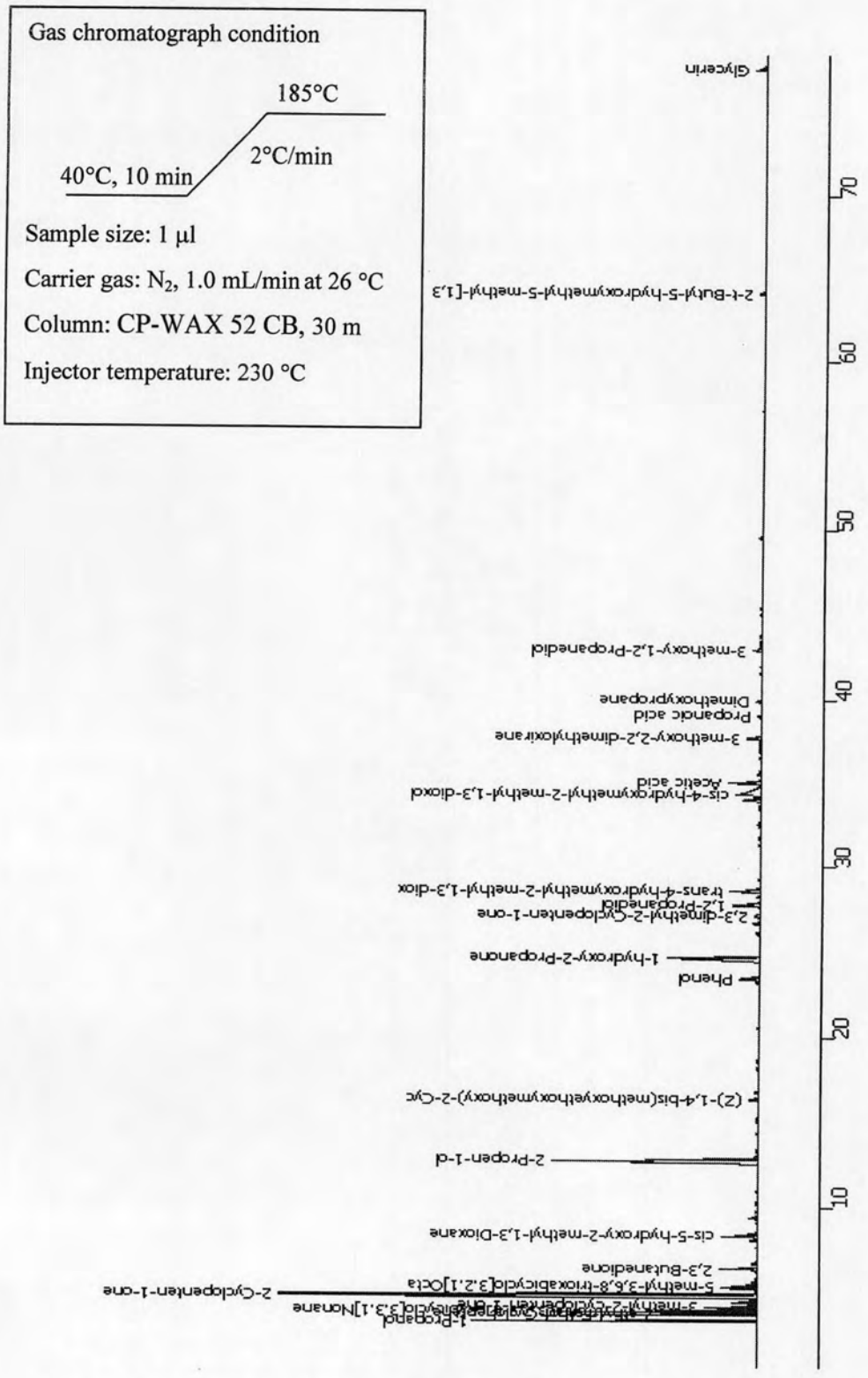

Figure A-5 Liquid chromatogram of liquid product obtained from catalytic cracking of WBP over Al-SBA-15(100) at 400°C.

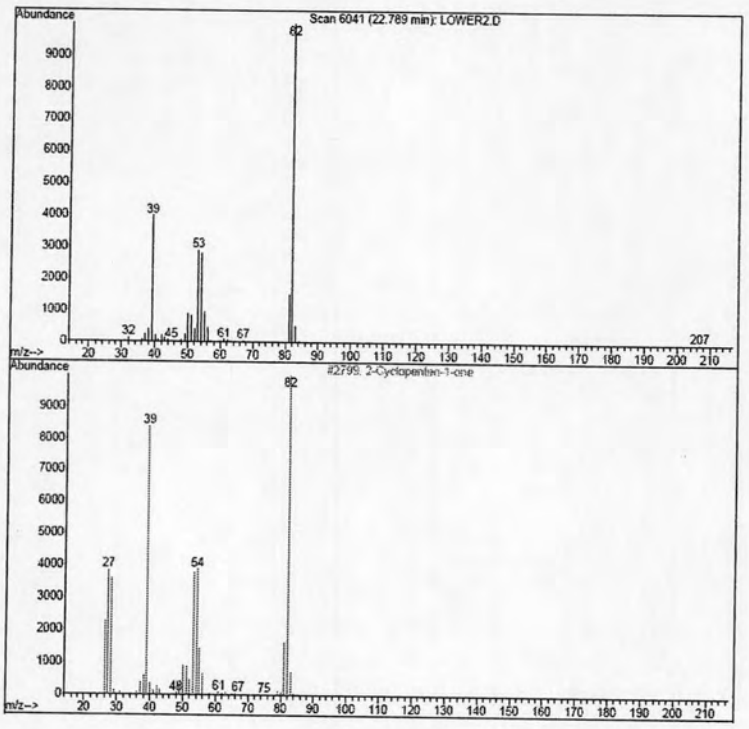

Figure A-6 Mass spectrum of 2-cyclopenten-1-one (Quality 91%).

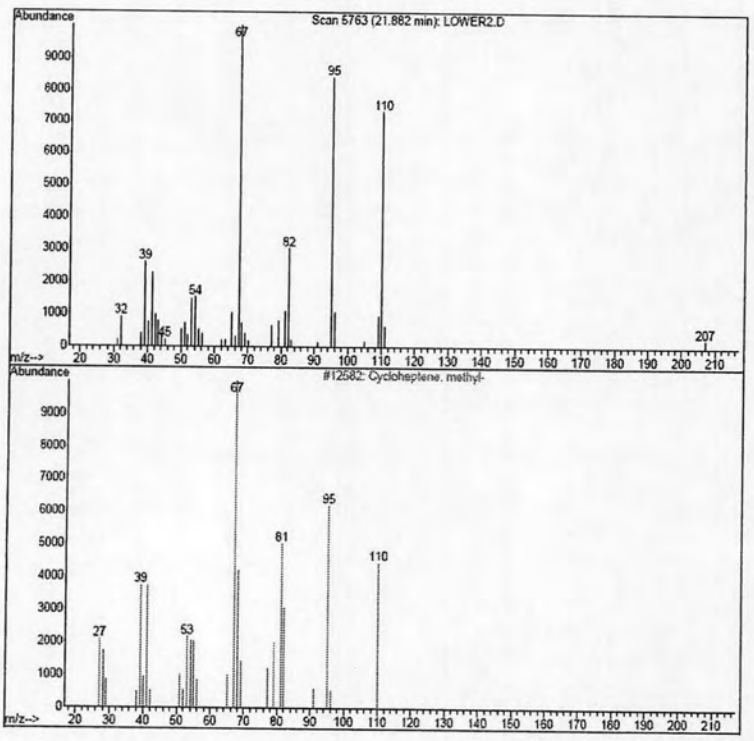

Figure A-7 Mass spectrum of methyl-cycloheptene (Quality 87%).

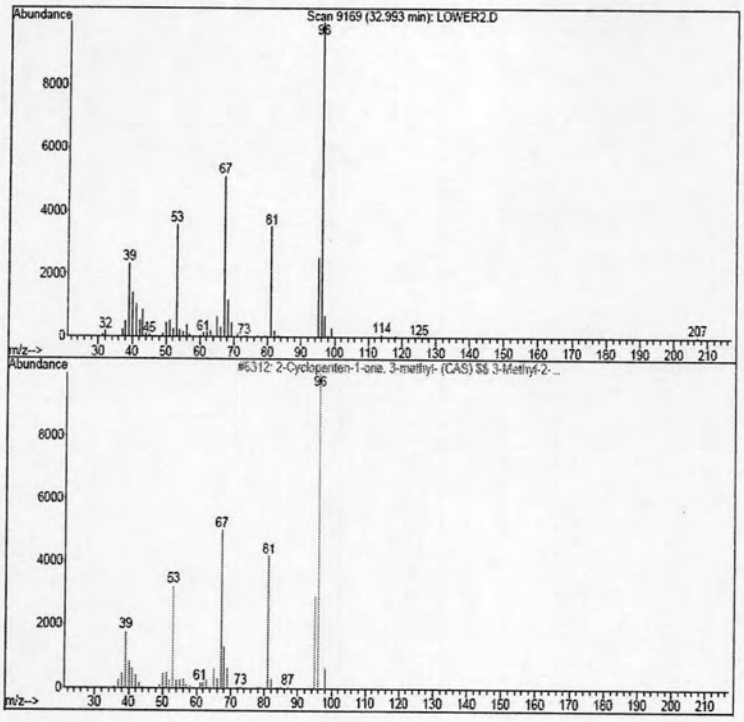

Figure A-8 Mass spectrum of 3-methyl-2-cyclopenten-1-one (Quality 94%).

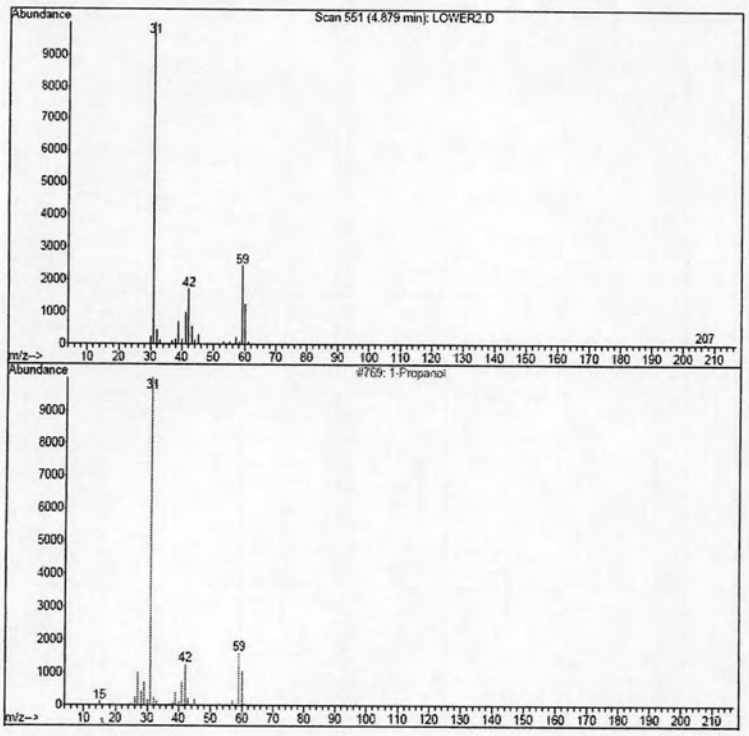

Figure A-9 Mass spectrum of 1-propanol (Quality 91%).

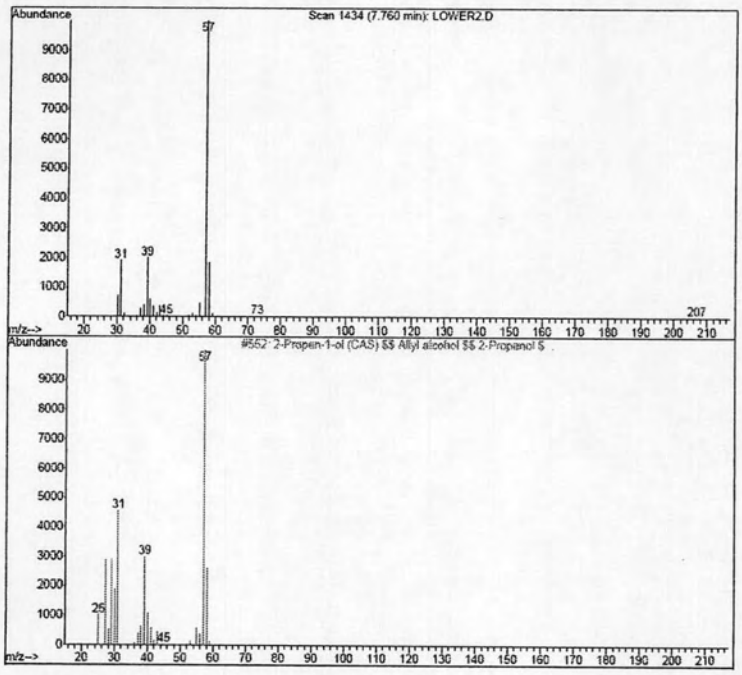

Figure A-10 Mass spectrum of 2-propen-1-ol (Quality 80%).

VITAE

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