REFFERENCES

Abramova, A.V. (2010). Synthesis of ethylene and propylene on a SAPO-34 silica-alumina-phosphate catalyst. Catalysis in Industry, 2, 29-37.

Arenamnart, S., and Trakarnpruk, W. (2006). Ethanol conversion to ethylene using metal-mordenite catalysts. Applied Science and Engineering, 2006, 21-32.

Baba, T., Inazu, K., Koyama, T., and Miyaji, A. (2008). Propene production from ethene and methane using silver- and proton-exchanged zeolite catalysts. Journal of the Japan Petroleum Institute, 51, 205-216.

Chen, Y., Wu, Y., Tao, L., Dai, B., Yang, M., Chen, Z., and Zhu, X. (2010). Dehydration reaction of bio-ethanol to ethylene over modified SAPO catalysts. Journal of Industrial and Engineering Chemistry, 16, 717-722.

Costa, E., Ugulna, A., Aguado, J., and Herndndez, P.J. (1985). Ethanol to gasoline process: Effect of variables, mechanism, and kinetics. Industrial and Engineering Chemistry Process Design and Development, 24, 239-244.

Froment, G.F., Dehertog, W.J.H., and Marchi, A.J. (1992). Zeolite catalysis in the conversion of Methanol into Olefins. Catalysis (London), 9, 1-64.

Furumoto, Y., Harada, Y., Tsunoji, N., Takahashi, A., Fujitani, T., Ide, Y., Sadakane, M., and Sano, T. (2011). Effect of acidity of ZSM-5 zeolite on conversion of ethanol to propylene. Applied Catalysis A: General, 399, 262-267.

Gayubo, A.G., Alonso, A., Valle, B., Aguayo, A.G., and Bibao, J. (2010). Selective production of olefins from bioethanol on HZSM-5 zeolite catalysts treated with NaOH. Applied Catalysis B: Environmental, 97, 299-306.

Gayubo, A.G., Alonso, A., Valle, B., Aguayo, V.T., Olazer, M., and Bibao, J. (2010). Hydrothermal stability of HZSM-5 catalysts modified with Ni for the transformation of bioethanol into hydrocarbon. Fuel, 89, 3365-3372.

Goto, D., Harada, Y., Furumoto, Y., Takahashi, A., Fujitani, T., Oumi, Y., Sadakane, M., and Sano, T. (2010). Conversion of ethanol to propylene over HZSM-5 types zeolites containing alkaline earth metals. Applied Catalysis A: General, 283, 89-95.

Hereijgers, B.P.C., Bleken, F., Nilsen, M.H., Svelle, S., Lillerud, K.P., Bjørgen, M., Weckhuysen, B.M., and Olsbye, U. (2009). Product shape selectivity dominates the methanol-to-olefins (MTO) reaction over H-SAPO-34 catalysts. Journal of Catalysis, 264, 77-87.

Inaba, M., Murata, K., and Takahara, I. (2009). Effect of Fe-loading and reaction temperature on the production of olefins from ethanol by Fe/H-ZSM-5 zeolite catalysts. Reaction Kinetics and Catalysis Letters, 97, 19-26.

Inaba, M., Murata, K., Takahara, I., and Inoue, K. (2011). Production of olefins from ethanol by Fe and/or P;modified H-ZSM-5 zeolite catalysts. Journal of Chemical Technology & Biotechnology, 86, 95-104.

Inoue, K., Inab, M., Takhara, I., nd Murat, K. (2010). Conversion of ethanol to propylene by H-ZSM-5 with Si/Al_2 ratio of 280. Cattalysis Letters, 136, 14-19.

Lok, B.M., Messina, C.A., Patton, R.L., Gajek, R.T., Cannan, T.R., and Flanigen, E.M. (1982). Crystalline silicoaluminophosphates. U.S. Patent 4 440 871.

Lok, B.M., Messina, C.A., Patton, R.L., Gajek, R.T., Cannan, T.R., and Flanigen, E.M. (1984). Silicoaluminophosphate molecular sieves: Another new class of microporous crystalline inorganic solids. Journal of the American Chemical Society, 106, 6092-6093.

Morschbacker, A. (2009). Bio-ethanol based ethylene. Journal of Macromolecular Science, 49, 79-84.

Murata, K., Inaba, M., and Takahara, I. (2008). Effects of surface modification of H-ZSM-5 catalysts on direct transformation of ethanol into lower olefins. Journal of the Petroleum Institute, 51, 234-239.

Oikawa, H., Shibata, Y., Inazu, K., Iwase, Y., Murai, K., Hyodo, S., Kobayashi, G., and Baba, T. (2006). Highly selective conversion of ethene to propene over SAPO-34 as a solid acid catalyst. Applied Catalysis A: General, 312, 181-185.

Ouyang, J., Kong, F., Su, G., Hu, Y., and Song, Q. (2009). Catalytic conversion of bio-ethanol to ethylene over La-modified HZSM-5 catalysts in a bioreactor. Catalysis Letters, 132, 64-74.

Phillips, C.B., and Datta, R. (1997). Production of ethylene from hydrous ethanol on H-ZSM-5 under mild conditions. Industrial and Engineering Chemistry Research, 36, 4466-4475.

Ramesh, K., Hui, L.M., Han, Y.F., and Borgan, A. (2009). Structure and reactivity of phosphorous modified H-ZSM-5 catalysts for ethanol dehydration. Catalysis Communications, 10, 567–571.

Saeed, M.H., and Al, W. (2003). Conversion of methanol to light olefins on SAPO-34: kinetic modeling and reactor design. Texas A&M University.

Seungdo, K., and Dale, B.E. (2003). Global potential bioethanol production from wasted crops and crop residues. Biomass and Bioenergy, 26, 361-375.

Song, Z., Takahashi, A., Mimura, N., and Fujitani, T. (2009). Production of propylene from ethanol over ZSM-5 zeolites. Catalysis Letters, 131, 364-369.

Song, Z., Takhashi, A., Nakamura, I., and Fujitani, T. (2010). Phosphorus-modified ZSM-5 for conversion of ethanol to propylene. Applied Catalysis A: General, 384, 201-205.

Stöcker, M. (1999). Methanol-to-hydrocarbons: catalytic materials and their behavior. Microporous and Mesoporous Materials, 29, 3-48.

Takahara, I., Saito, M., Inaba, M., and Murata, K. (2005). Dehydration of ethanol into ethylene over solid acid catalysts. Catalysis Letters, 105, 249-252.

Talukdar, A.K., Bhattacharyya, K.G., and Sivasanker, S. (1997). HZSM-5 catalysed conversion of aqueous ethanol to hydrocarbons. Applied Catalysis A: General, 148, 357-371.

Tsao, U., and Zasloff, H.B. (1979). Production of ethylene from ethanol. U.S. Patent 4 134 926.

Wilson, S., and Barger, P. (1999). The characteristics of SAPO-34 which influence the conversion of methanol to light olefins. Microporous and Mesoporous Matterials, 29, 117-126.

Wu, X., and Anthony, R.G. (2001). Effect of feed composition on methanol conversion to light olefins over SAPO-34. Applied Catalysis A: General, 218, 241-250.

Wu, X., Abraha, M.G., and Anthony, R.G. (2004). Methanol conversion on SAPO-34: reaction condition for fixed-bed reactor. Applied Catalysis A: General, 260, 63-69.

Zhang, D., Wang, R., and Yang, X. (2008). Effect of P content on the catalytic performance of P-modified HZSM-5 catalysts in dehydration of ethanol to ethylene. Catalysis Letters, 124, 384-391.

Zhang, X., Wang, R., Yang, X., and Zhang, F. (2008). Comparison of four catalysts in the catalytic dehydration of ethanol to ethylene. Microporous and Mesoporous Materials, 116, 210-215.

APPENDICES

Appendix A Scanning Electron Microscopy Micrograph

The scanning electron images of SAPO-34 catalyst with various resolutions are shown in Figures A1 to A3. A typical cubic morphology with the crystal of about 5 – 10 μm.

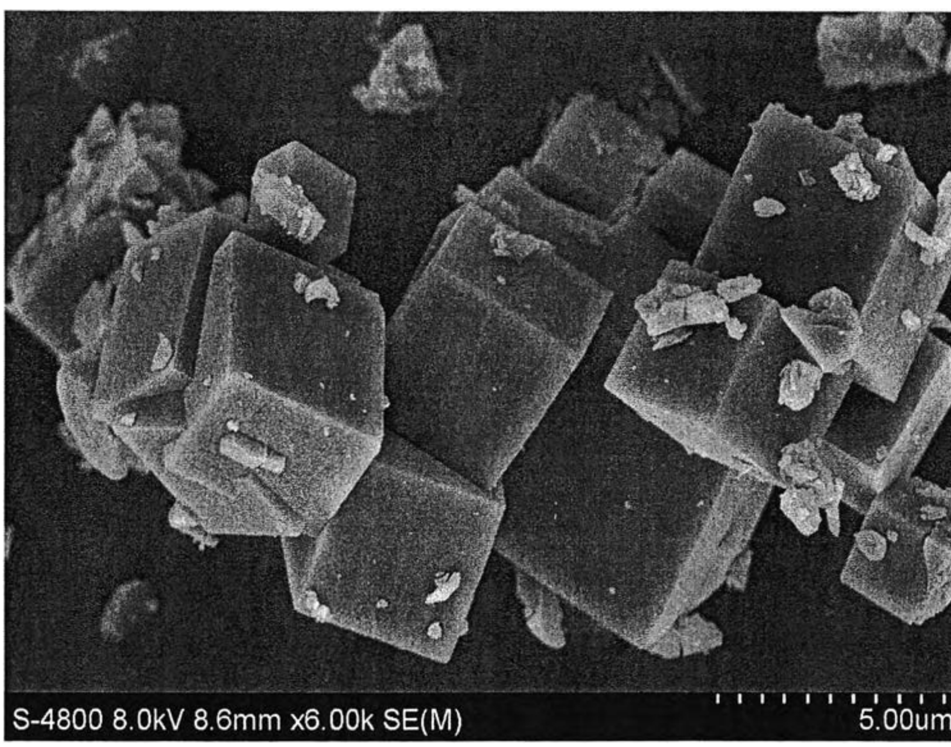

Figure A1 SEM image of SAPO-34 (8.0kV 8.6mm x6.00k).

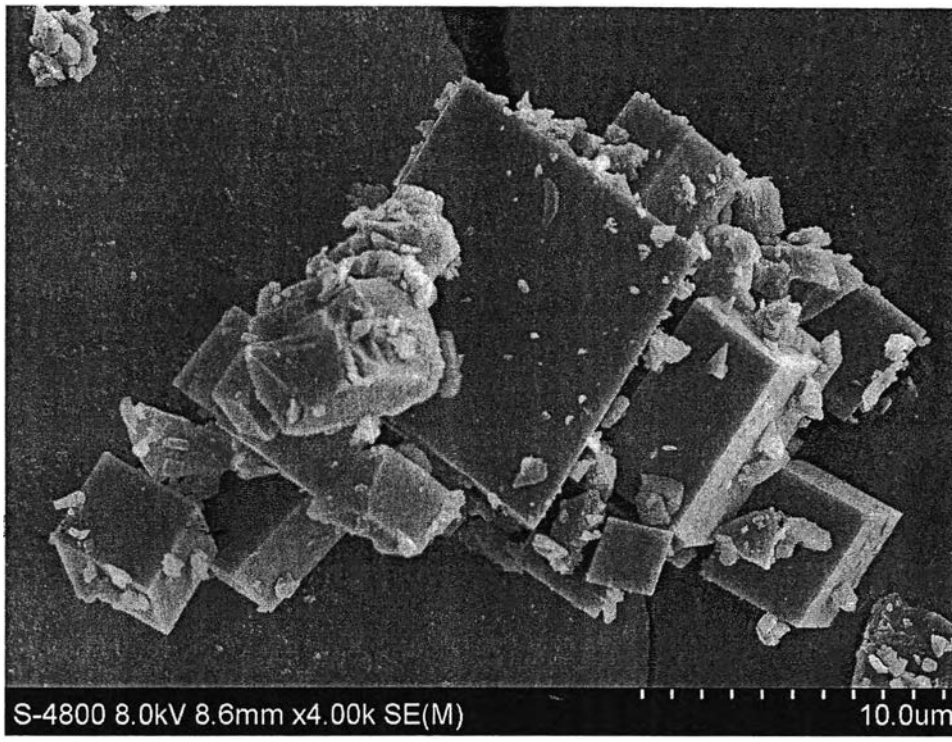

Figure A2 SEM image of SAPO-34 (8.0kV 8.6mm x4.00k).

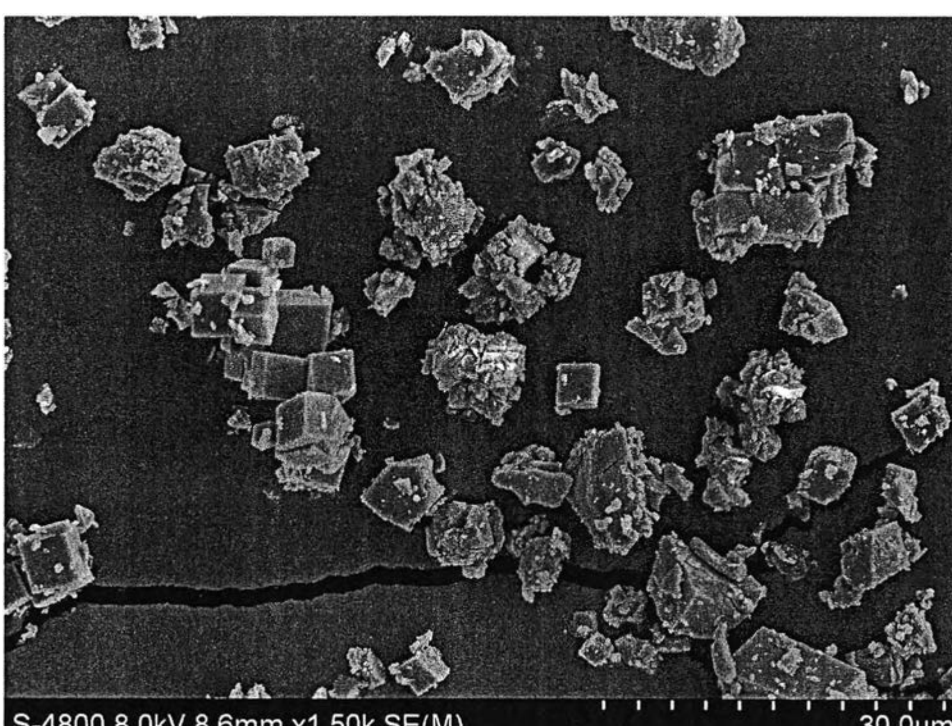

Figure A3 SEM image of SAPO-34 (8.0kV 8.6mm x1.50k).

Appendix B X-Ray Diffraction Pattern of SAPO-34

A x-ray diffraction pattern of SAPO-34 catalyst is shown in Figure B1. The position and intensity of the diffraction peak of SAPO-34 catalyst are matched with JCPDS files (PDF#47-0429).

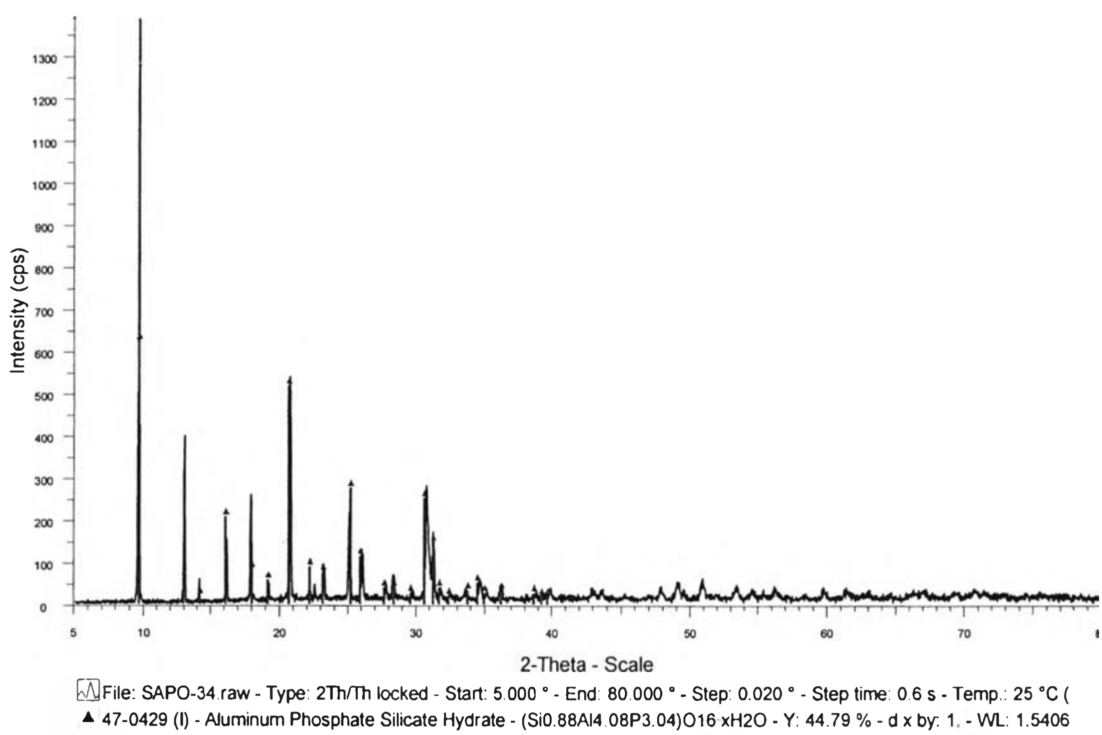

Figure B1 XRD pattern of SAPO-34 catalyst.

Appendix C X-Ray Fluorescence Results of SAPO-34

A x-ray fluorescence data of SAPO-34 catalyst is shown in Figure C1. From the result, Si to Al ratio of SAPO-34 catalyst is 0.4381.

Table C1 Elemental composition of SAPO-34 sample using XRF

Analyst	Al	Si	P
Calibration status	Calibrated	Calibrated	Calibrated
Compound formula	Al	Si	P
Measured (kcps)	1330	244.0	1712
Used (kcps)	1330	244.0	1712
Concentration (%)	36.31	16.55	47.14
Calculation method	Calculate	Calculate	Calculate

Appendix D Catalytic Activity of SAPO-34 Catalyst at Various Reaction Temperatures and LHSVs

Table D1 Product distribution data at various LHSVs of SAPO-34 catalyst (at a fixed temperature of 350 °C)

Selectivity (%)	LHSV (h^{-1})		
	0.2	0.5	1.0
Methane	0	0.134	0.181
Carbondioxide	0.160	0.044	0.053
Ethylene	96.7	92.6	95.1
Ethane	0.645	0.962	0.942
Propylene	1.19	2.85	2.10
Propane	0.342	2.42	0.959
C_4 Products	0.844	0.784	0.674
C_{5+} Products	0.168	0.183	0.034
Ethanol Conversion (%)	89.6	88.5	88.2

Table D2 Product distribution data at various LHSVs of SAPO-34 catalyst (at a fixed temperature of 400 °C)

Selectivity (%)	LHSV (h^{-1})		
	0.2	0.5	1.0
Methane	0.301	3.40	0.281
Carbondioxide	0.667	2.81	0.258
Ethylene	87.1	39.7	83.3
Ethane	1.32	9.40	1.53
Propylene	0.397	12.6	7.54
Propane	0	25.9	5.41
C_4 Products	8.24	5.66	1.54
C_{5+} Products	2.00	0.608	0.111
Ethanol Conversion (%)	97.7	92.5	91.8

Table D3 Product distribution data at various LHSVs of SAPO-34 catalyst (at a fixed temperature of 450 °C)

Selectivity (%)	LHSV (h^{-1})		
	0.2	0.5	1.0
Methane	4.07	2.91	0.334
Carbondioxide	5.10	0.895	0.241
Ethylene	72.5	60.5	91.3
Ethane	6.15	7.16	0.91
Propylene	3.21	8.72	0.343
Propane	0.290	13.5	0.019
C_4 Products	8.03	6.10	5.95
C_{5+} Products	0.608	0.209	0.858
Ethanol Conversion (%)	99.2	98.1	91.8

Table D4 Product distribution data at various LHSVs of SAPO-34 catalyst (at a fixed temperature of 500 °C)

Selectivity (%)	LHSV (h^{-1})		
	0.2	0.5	1.0
Methane	21.5	2.83	2.67
Carbondioxide	9.91	0.630	0.826
Ethylene	46.9	84.4	85.0
Ethane	6.19	3.80	1.85
Propylene	7.56	1.38	1.59
Propane	0.461	0.167	0.094
C_4 Products	7.22	6.51	7.72
C_{5+} Products	0.263	0.252	0.267
Ethanol Conversion (%)	99.2	98.3	98.1

Table D5 Product distribution data at various reaction temperatures of SAPO-34 catalyst (at a fixed LHSV of 0.2 h^{-1})

Selectivity (%)	Temperature (^{o}C)			
	350	400	450	500
Methane	0	0.301	4.07	21.5
Carbondioxide	0.160	0.667	5.10	9.91
Ethylene	96.7	87. 1	72.5	46.9
Ethane	0.645	1.32	6.15	6.19
Propylene	1.19	0.397	3.21	7.56
Propane	0.343	0	0.290	0.461
C_4 Products	0.845	8.24	8.03	7.22
C_{5+} Products	0.168	2.00	0.608	0.263
Ethanol Conversion (%)	89.6	97.7	99.2	99.2

Table D6 Product distribution data at various reaction temperatures of SAPO-34 catalyst (at a fixed LHSV of 0.5 h^{-1})

Selectivity (%)	Temperature (^{o}C)			
	350	400	450	500
Methane	0.135	3.40	2.91	2.83
Carbondioxide	0.044	2.81	0.895	0.630
Ethylene	92.6	39.7	60.5	84.4
Ethane	0.962	9.40	7.16	3.80
Propylene	2.85	12.6	8.72	1.38
Propane	2.42	25.9	13.5	0.167
C_4 Products	0.784	5.66	6.10	6.51
C_{5+} Products	0.183	0.608	0.209	0.252
Ethanol Conversion (%)	88.5	92.5	98.1	98.3

Table D7 Product distribution data at various reaction temperatures of SAPO-34 catalyst (at a fixed LHSV of 1.0 h^{-1})

Selectivity (%)	Temperature (°C)			
	350	400	450	500
Methane	0.181	0.281	0.334	2.67
Carbondioxide	0.053	0.258	0.241	0.826
Ethylene	95.1	83.3	91.3	85.0
Ethane	0.942	1.53	0.906	1.85
Propylene	2.09	7.54	0.34	1.59
Propane	0.959	5.41	0.019	0.093
C_4 Products	0.674	1.54	5.95	7.72
C_{5+} Products	0.034	0.111	0.858	0.267
Ethanol Conversion (%)	88.2	91.8	91.8	98.1

Appendix E Catalytic Activity of SAPO-34 Catalyst as a Function of Time on Stream at Various Reaction Temperatures and LHSVs

Table E1 Product distribution data of SAPO-34 catalyst as a function of time (at 350 °C temperature and 0.2 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0	0	0.101	0.127
Carbondioxide	0.160	0.093	0.102	0.115
Ethylene	96.7	98.0	95.2	90.8
Ethane	0.645	0.578	0.740	0.932
Propylene	1.19	0.221	0.216	0.231
Propane	0.343	0.060	0.048	0.051
C_4 Products	0.844	0.814	1.32	1.80
C_{5+} Products	0.168	0.211	2.18	5.92
Ethanol Conversion (%)	89.6	78.6	73.2	67.1

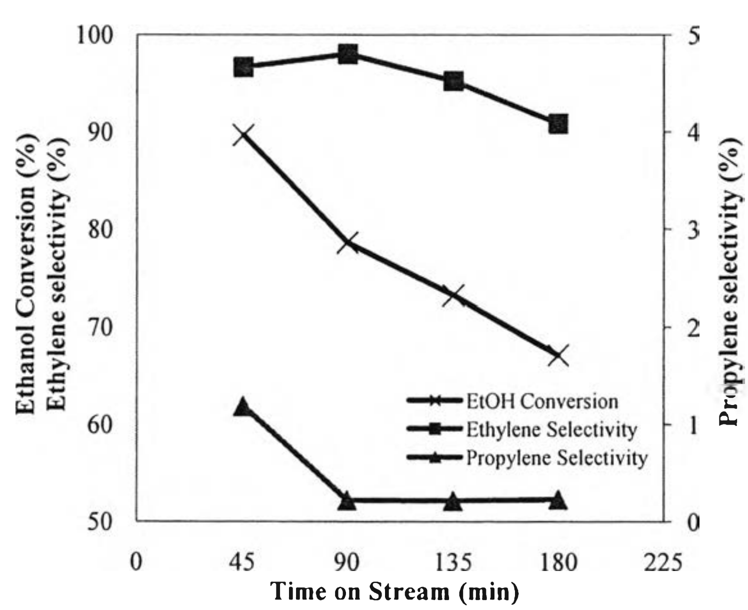

Figure E1 Catalytic activity of SAPO-34 catalyst as a function of time (at 350 °C temperature and 0.2 h^{-1} LHSV).

Table E2 Product distribution data of SAPO-34 catalyst as a function of time (at 400 °C temperature and 0.2 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0.215	0.301	0.239	0.257
Carbondioxide	0.212	0.667	0.186	0.178
Ethylene	95.3	87.1	85.7	83.9
Ethane	1.29	1.32	1.24	1.14
Propylene	0.248	0.397	0.239	0.229
Propane	0	0	0	0
C_4 Products	1.95	8.24	3.72	3.80
C_{5+} Products	0.770	2.00	8.73	10.5
Ethanol Conversion (%)	97.7	70.9	68.7	65.6

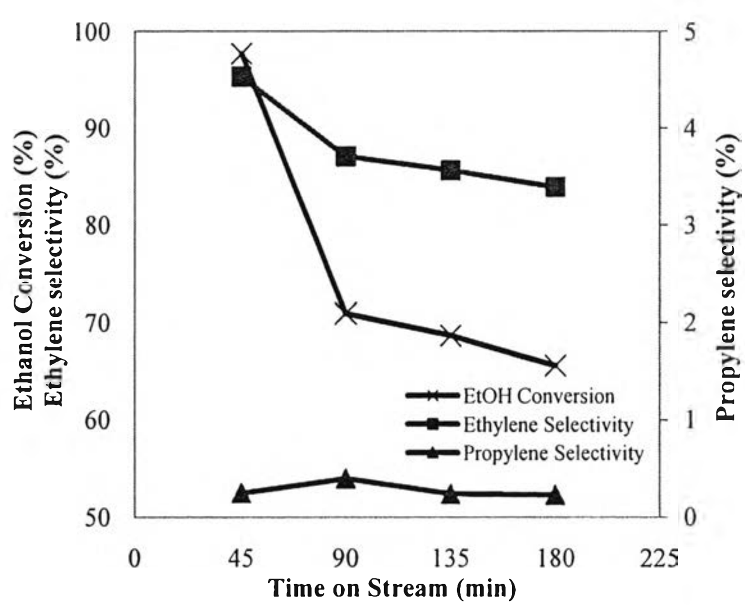

Figure E2 Catalytic activity of SAPO-34 catalyst as a function of time (at 400 °C temperature and 0.2 h^{-1} LHSV).

Table E3 Product distribution data of SAPO-34 catalyst as a function of time (at 450 °C temperature and 0.2 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	4.07	4.01	1.69	1.35
Carbondioxide	5.10	3.37	1.39	1.02
Ethylene	72.5	83.5	87.9	88.2
Ethane	6.15	3.85	2.27	1.93
Propylene	3.21	2.27	1.56	1.33
Propane	0.289	0.177	0.121	0.105
C_4 Products	8.03	2.81	4.97	5.90
C_{5+} Products	0.608	0.022	0.097	0.114
Ethanol Conversion (%)	99.2	97.0	98.1	97.5

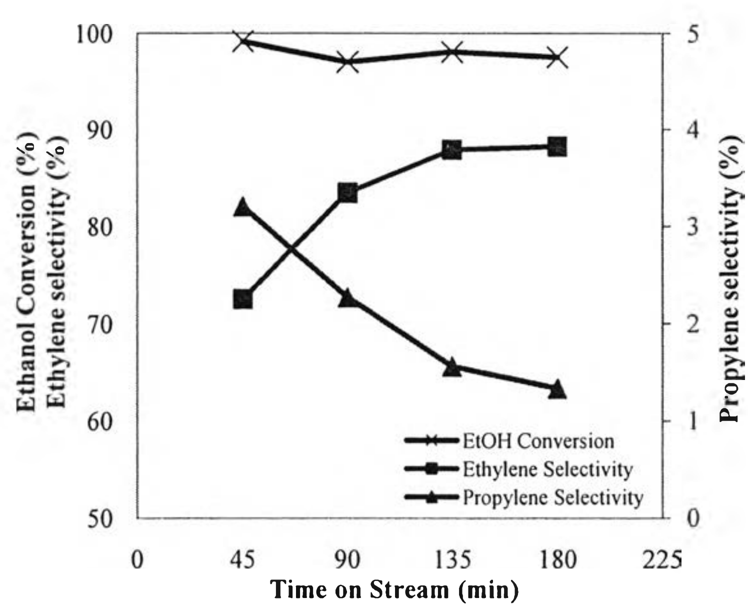

Figure E3 Catalytic activity of SAPO-34 catalyst as a function of time (at 450 °C temperature and 0.2 h^{-1} LHSV).

Table E4 Product distribution data of SAPO-34 catalyst as a function of time (at 500 °C temperature and 0.2 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	21.5	13.0	17.5	8.37
Carbondioxide	9.91	4.83	6.19	2.21
Ethylene	46.9	59.7	52.9	70.4
Ethane	6.19	6.34	6.53	6.87
Propylene	7.56	6.46	7.27	3.65
Propane	0.461	0.473	0.505	0.383
C_4 Products	7.22	8.82	8.94	7.86
C_{5+} Products	0.263	0.354	0.173	0.222
Ethanol Conversion (%)	99.2	98.7	98.4	98.7

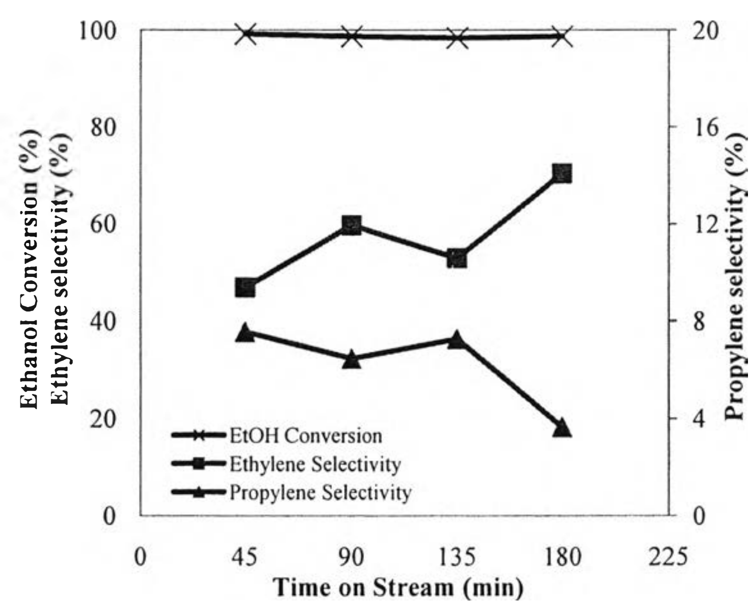

Figure E4 Catalytic activity of SAPO-34 catalyst as a function of time (at 500 °C temperature and 0.2 h^{-1} LHSV).

Table E5 Product distribution data of SAPO-34 catalyst as a function of time (at 350 °C temperature and 0.5 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0.135	0.138	0.139	0.127
Carbondioxide	0.044	0	0	0
Ethylene	92.6	86.2	77.3	73.2
Ethane	0.962	0.789	0.752	0.733
Propylene	2.85	0.867	0.551	0.421
Propane	2.42	0.904	0.604	0.441
C_4 Products	0.784	1.52	1.70	1.58
C_{5+} Products	0.18	9.58	18.9	23.5
Ethanol Conversion (%)	88.5	78.1	82.1	79.5

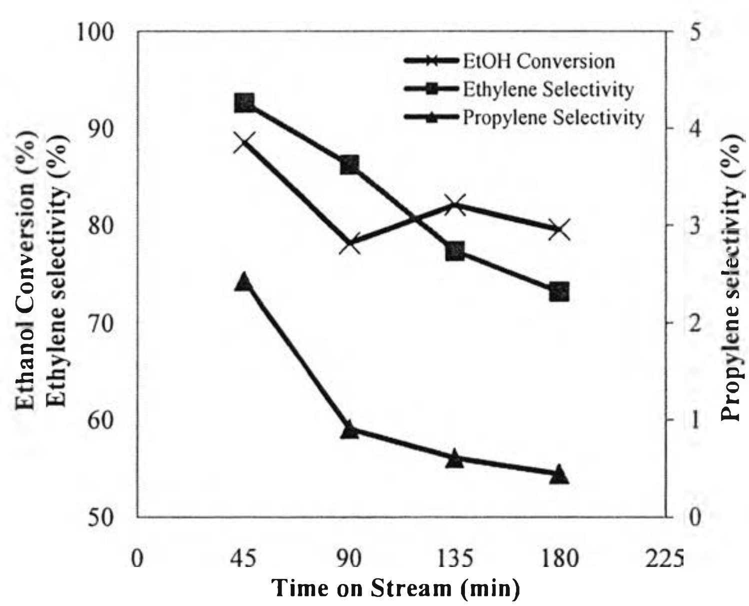

Figure E5 Catalytic activity of SAPO-34 catalyst as a function of time (at 350 °C temperature and 0.5 h^{-1} LHSV).

Table E6 Product distribution data of SAPO-34 catalyst as a function of time (at 400 °C temperature and 0.5 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	3.40	1.20	0.80	0.483
Carbondioxide	2.81	0.574	0.306	0.179
Ethylene	39.7	84.8	84.8	87.1
Ethane	9.40	1.98	1.32	1.068
Propylene	12.6	1.08	0.655	0.428
Propane	25.9	0.536	0.171	0.105
C_4 Products	5.66	8.66	9.63	8.01
C_{5+} Products	0.608	1.22	2.28	2.63
Ethanol Conversion (%)	92.5	89.2	86.6	84.7

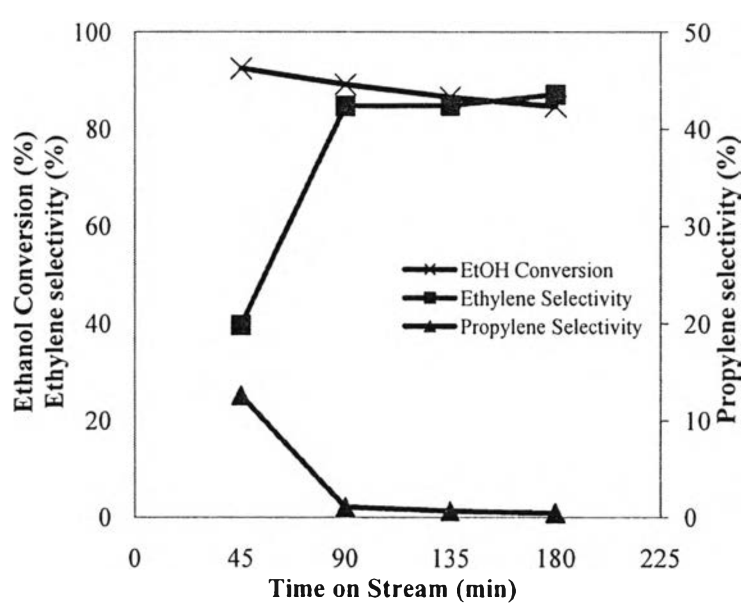

Figure E6 Catalytic activity of SAPO-34 catalyst as a function of time (at 400 °C temperature and 0.5 h^{-1} LHSV).

Table E7 Product distribution data of SAPO-34 catalyst as a function of time (at 450 °C temperature and 0.5 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	2.91	5.91	5.71	9.73
Carbondioxide	0.895	1.61	1.27	1.60
Ethylene	60.5	71.8	66.9	54.5
Ethane	7.16	2.83	2.13	2.36
Propylene	8.72	2.88	2.56	3.14
Propane	13.5	0.269	0.147	0.175
C_4 Products	6.10	14.2	20.3	27.2
C_{5+} Products	0.209	0.522	0.940	1.29
Ethanol Conversion (%)	98.1	97.8	97.7	90.6

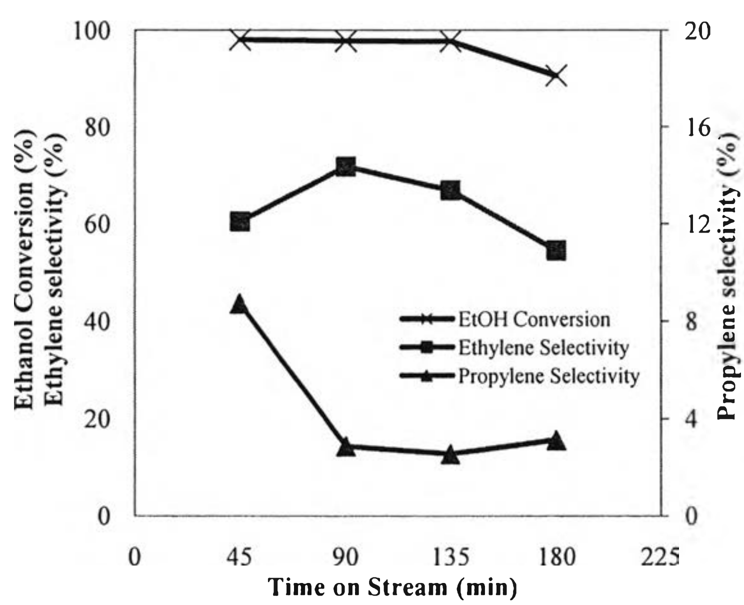

Figure E7 Catalytic activity of SAPO-34 catalyst as a function of time (at 450 °C temperature and 0.5 h^{-1} LHSV).

Table E8 Product distribution data of SAPO-34 catalyst as a function of time (at 500 °C temperature and 0.5 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	2.83	4.05	3.23	2.27
Carbondioxide	0.630	1.35	0.581	0.753
Ethylene	84.4	74.7	81.5	91.4
Ethane	3.80	6.86	4.49	2.67
Propylene	1.38	8.07	1.36	1.02
Propane	0.167	3.32	0.193	0.107
C_4 Products	6.51	1.48	8.26	1.81
C_{5+} Products	0.252	0.174	0.410	0.019
Ethanol Conversion (%)	97.8	98.3	96.6	96.4

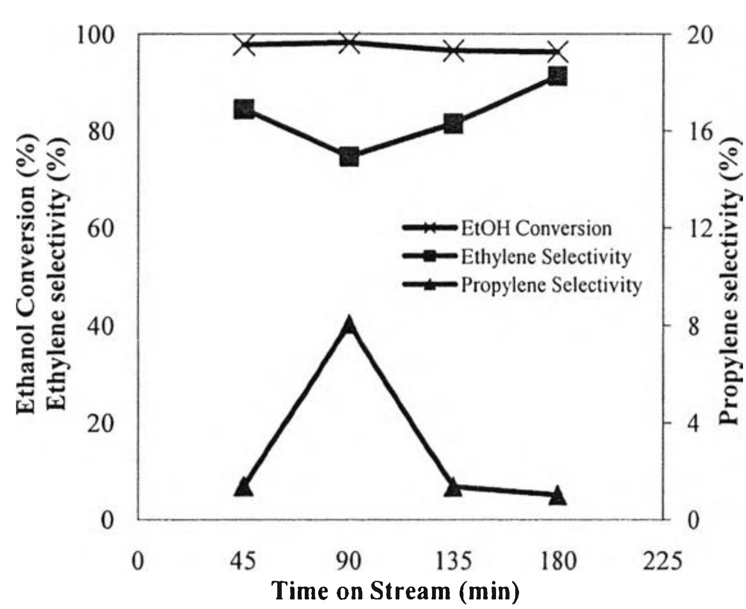

Figure E8 Catalytic activity of SAPO-34 catalyst as a function of time (at 500 °C temperature and 0.5 h^{-1} LHSV).

Table E9 Product distribution data of SAPO-34 catalyst as a function of time (at 350 °C temperature and 1.0 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0.181	0.212	0.098	0.098
Carbondioxide	0.053	0.076	0	0
Ethylene	95.1	93.8	84.3	81.4
Ethane	0.942	0.977	0.599	0.564
Propylene	2.09	0.488	0.181	0.162
Propane	0.959	0.210	0.039	0.035
C_4 Products	0.674	2.133	2.00	2.52
C_{5+} Products	0.034	2.11	12.7	15.19
Ethanol Conversion (%)	88.2	88.0	87.4	86.2

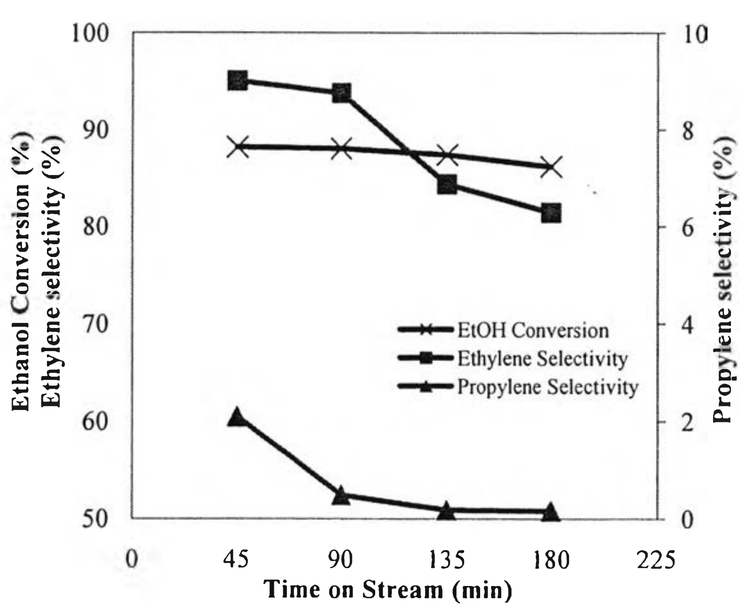

Figure E9 Catalytic activity of SAPO-34 catalyst as a function of time (at 350 °C temperature and 1.0 h^{-1} LHSV).

Table E10 Product distribution data of SAPO-34 catalyst as a function of time (at 400 °C temperature and 1.0 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0.281	0.179	0.079	0.085
Carbondioxide	0.258	0.140	0.052	0.057
Ethylene	83.3	94.6	75.6	63.7
Ethane	1.53	0.700	0.478	0.440
Propylene	7.54	1.43	0.614	0.376
Propane	5.41	0.936	0.259	0.178
C_4 Products	1.54	1.45	1.36	1.27
C_{5+} Products	0.111	0.532	21.5	33.9
Ethanol Conversion (%)	91.8	88.30	88.7	88.1

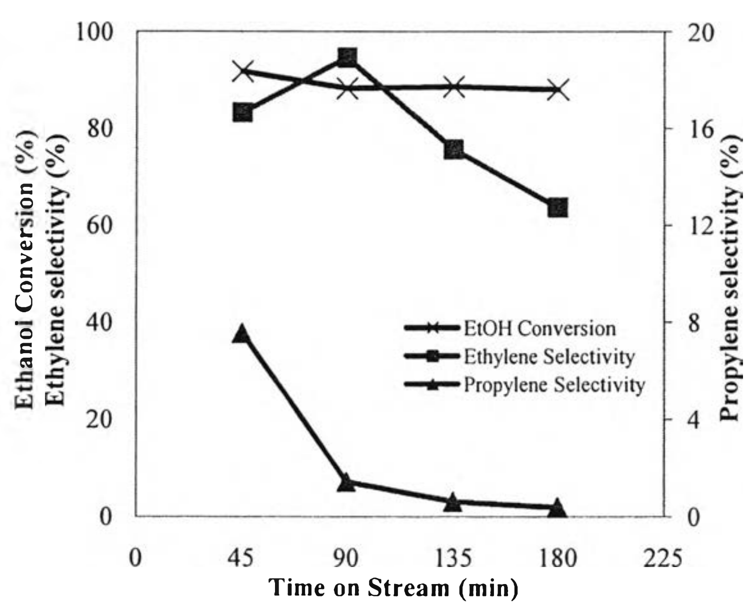

Figure E10 Catalytic activity of SAPO-34 catalyst as a function of time (at 400 °C temperature and 1.0 h^{-1} LHSV).

Table E11 Product distribution data of SAPO-34 catalyst as a function of time (at 450 °C temperature and 1.0 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	0.334	0.362	1.84	0.112
Carbondioxide	0.241	0.303	0.089	0.061
Ethylene	91.3	89.8	90.8	92.4
Ethane	0.906	0.793	0.596	0.512
Propylene	0.343	0.410	0.178	0.151
Propane	0.019	0.027	0.011	0.010
C_4 Products	5.95	7.42	4.56	4.30
C_{5+} Products	0.858	0.886	1.946	2.47
Ethanol Conversion (%)	91.8	93.6	94.5	91.7

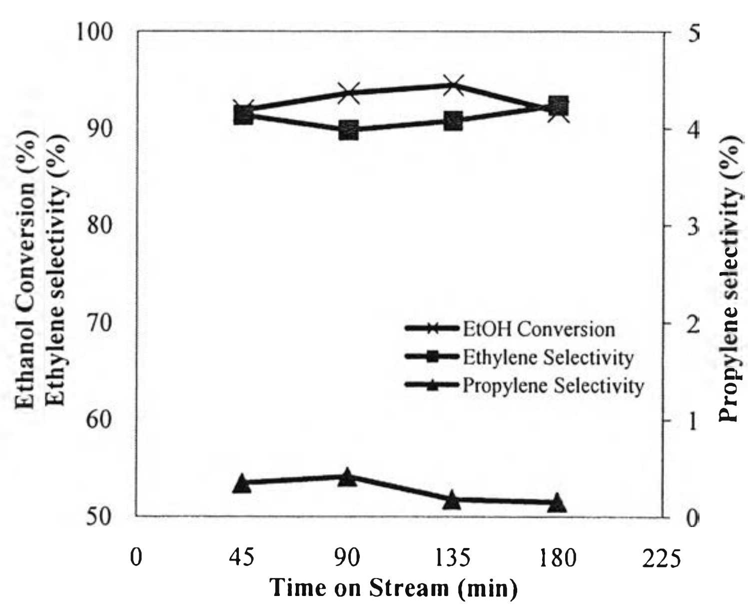

Figure E11 Catalytic activity of SAPO-34 catalyst as a function of time (at 450 °C temperature and 1.0 h^{-1} LHSV).

Table E12 Product distribution data of SAPO-34 catalyst as a function of time (at 500 °C temperature and 1.0 h^{-1} LHSV)

Selectivity (%)	Time on stream (minutes)			
	45	90	135	180
Methane	2.67	2.10	2.35	3.46
Carbondioxide	0.826	0.549	0.501	0.713
Ethylene	85.0	80.2	76.8	70.3
Ethane	1.85	2.69	4.05	4.56
Propylene	1.59	1.13	0.94	1.24
Propane	0.094	0.109	0.160	0.164
C_4 Products	7.72	12.9	14.1	17.3
C_{5+} Products	0.267	0.263	1.10	2.27
Ethanol Conversion (%)	98.1	82.5	78.8	80.5

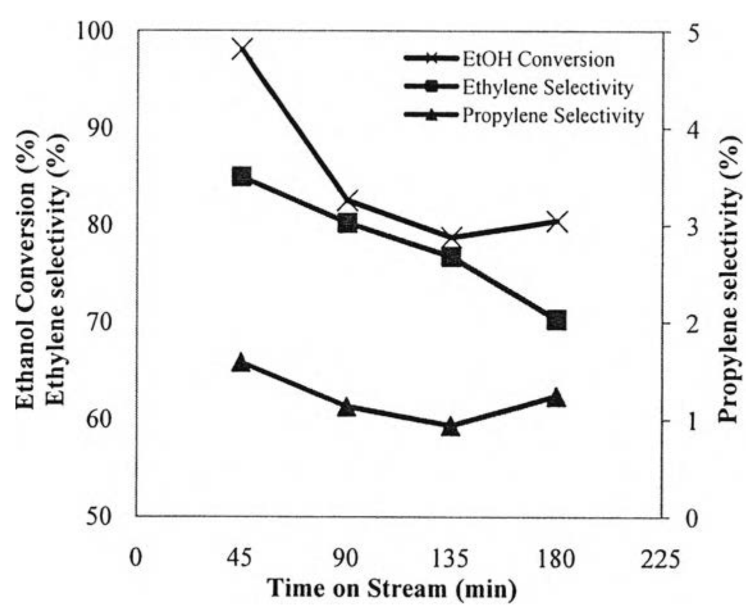

Figure E12 Catalytic activity of SAPO-34 catalyst as a function of time (at 500 °C temperature and 1.0 h^{-1} LHSV).

Appendix F Economic Evaluation Data

Table F1 Products distribution at 400 °C reaction temperature and 0.5 h^{-1} LHSV (172.2 ton per day of ethanol feed)

Composition	% Weight (%)	Weight (ton/day)	Weight (ton/year)
Methane	1.02	1.76	587.8
Carbondioxide	2.33	4.02	1,340
Ethylene	20.9	36.1	12,024
Ethane	5.32	9.15	3,051
Propylene	9.96	17.1	5,716
Propane	21.5	36.95	12,313
C_4 Products	5.55	9.55	3,183
C_{5+} Products	0.894	1.54	513.0
Water	25.0	43.1	14,368
Unconverted Ethanol	7.50	12.9	4,305

Table F2 Heating value and revenues of gaseous products

Composition	Weight (ton/year)	Heating Value (BTU/lb)	Heating Value (Mil.BTU/Year)	Revenue (Mil.Baht/year)
Methane	587.8	23,811	30,791	13.62
Carbondioxide	1,340	14,150	41,702	18.49
Ethane	3,051	22,198	148,994	65.89
Propane	12,313	21,564	584,118	258.3
C_4 Products	3,183	21,640	151,548	67.03
C_6 Products	513.0	20,526	23,165	10.24

Table F3 Inputs and basic assumptions of economic evaluation

Plant capacity		
Ethylene product, polymer grade	12,024	ton/year
Propylene product, polymer grade	5,716	ton/year
Working time	8,000	hours/year
Ethylene product	1.503	ton/hrs
	36.07	ton/day
Propylene product	0.7145	ton/hrs
	17.15	ton/day
Raw material capacity	172.2	ton/day
	57,400	ton/year
	218,251	liters/day
Prices		
Ethanol	17.2	Baht/liter
Ethylene, polymer grade	46.8	Baht/kg
Propylene, polymer grade	50.4	Baht/kg
Natural gas	442.3	Baht/Mil.BTU
Economic		
All CAPEX is paid at zero year		
Economic life	20	years
Corporate tax	30	%
Depreciation	20	years

Table F4 Plant information

Total capital cost		
Total investment	4,515	Mil.Baht
Operating cost		
Raw material cost	1,251	Mil.Baht/year
Labor cost and maintenance cost	140.0	Mil.Baht/year
Utilities cost	208.2	Mil.Baht/year
Revenue		
Ethylene price	562.7	Mil.Baht/year
Propylene price	288.1	Mil.Baht/year
Natural gas price	433.6	Mil.Baht/year

Table F5 Summary of project economic evaluation

Profitability indicators:	Value	
IRR after tax	-	% per year
NPV after tax	-5,772.73	Mil.Bahts
Profitability index (NPV/Fixed cost)	-1.28	-
Simple payback period before tax	-172.0	Months

Table F6 Economic evaluation: ethanol price sensitivity

EtOH price (Baht/l)	Margin (Baht/year)	IRR (%)	NPV (Mil.Bahts)	PI (-)	PB (Months)
17.2	-315.0445699	-	-5772.734	-1.278568	-171.9757
16	-227.7441897	-	-5269.741	-1.167163	-237.8985
15	-154.9938728	-	-4850.58	-1.074326	-349.5622
14	-82.24355597	-	-4431.419	-0.981488	-658.775
13	-9.493239116	-	-4012.258	-0.888651	-5707.22
12	63.25707774	-5.91221	-3593.097	-0.795813	856.50495
11	136.0073946	-2.92324	-3173.937	-0.702976	398.36069
10	208.7577115	-0.510061	-2754.776	-0.610139	259.53532
9	281.5080283	1.569342	-2335.615	-0.517301	192.46343
8	354.2583452	3.4312005	-1916.454	-0.424464	152.93923
7	427.008662	5.1407347	-1497.293	-0.331626	126.88267
6	499.7589789	6.7383545	-1078.132	-0.238789	108.41226
5	572.5092957	8.2508847	-658.9714	-0.145952	94.636018
4	645.2596126	9.6970581	-239.8105	-0.053114	83.966204
3	718.0099295	11.090472	179.35034	0.0397232	75.458566
2	790.7602463	12.441299	598.5112	0.1325606	68.516343
1	863.5105632	13.757338	1017.6721	0.225398	62.743876
0.9	870.7855949	13.887275	1059.5881	0.2346818	62.219679
0.8	878.0606265	14.016932	1101.5042	0.2439655	61.704168
0.7	885.3356582	14.146313	1143.4203	0.2532492	61.197128
0.6	892.6106899	14.275424	1185.3364	0.262533	60.698354
0.5	899.8857216	14.40427	1227.2525	0.2718167	60.207645
0.4	907.1607533	14.532855	1269.1686	0.2811005	59.724806
0.3	914.435785	14.661184	1311.0847	0.2903842	59.24965
0.2	921.7108167	14.789263	1353.0007	0.2996679	58.781994
0.1	928.9858483	14.917094	1394.9168	0.3089517	58.321663
0	936.26088	15.044684	1436.8329	0.3182354	57.868486

Table F7 Economic evaluation: product prices sensitivity

Product price increasing (%)	Ethylene price (Baht/ton)	Propylene price (Baht/ton)	NG price (Baht/Mil.BTU)
0	46800	50400	442.2615946
10	51480	55440	486.487754
20	56160	60480	530.7139135
30	60840	65520	574.940073
40	65520	70560	619.1662324
50	70200	75600	663.3923919
60	74880	80640	707.6185513
70	79560	85680	751.8447108
80	84240	90720	796.0708702
90	88920	95760	840.2970297
100	93600	100800	884.5231892
110	98280	105840	928.7493486
120	102960	110880	972.9755081

Table F8 Economic evaluation: product prices sensitivity (Cont.)

Product price increasing (%)	Margin (Baht/year)	IRR (%)	NPV (Mil.Bahts)	PI (-)	PB (Months)
0	-315.0445699	-	-5772.734	-1.278568	-171.9757
10	-186.6065727	-	-5032.721	-1.114667	-290.3435
20	-58.1685754	-	-4292.708	-0.950766	-931.4308
30	70.26942185	-5.58683	-3552.695	-0.786865	771.03239
40	198.7074191	-0.819969	-2812.682	-0.622964	272.66219
50	327.1454164	2.7578992	-2072.669	-0.459063	165.61442
60	455.5834136	5.7798787	-1332.656	-0.295162	118.92443
70	584.0214109	8.4837492	-592.6428	-0.131261	92.770571
80	712.4594081	10.985773	147.37025	0.0326401	76.046438
90	840.8974054	13.3516	887.38327	0.1965411	64.431166
100	969.3354026	15.621812	1627.3963	0.3604421	55.893966
110	1097.7734	17.823071	2367.4093	0.5243431	49.354448
120	1226.211397	19.973665	3107.4223	0.6882441	44.184877

Appendix G Ethanol to Olefins Plant Cost Estimation

According to the process overview below for Ethanol to light olefins plants, the upstream processes (i.e. adiabatic reactor system, quench tower and compressor) were duplicated with Chematur plant, but the downstream process was added for the separation of gas products

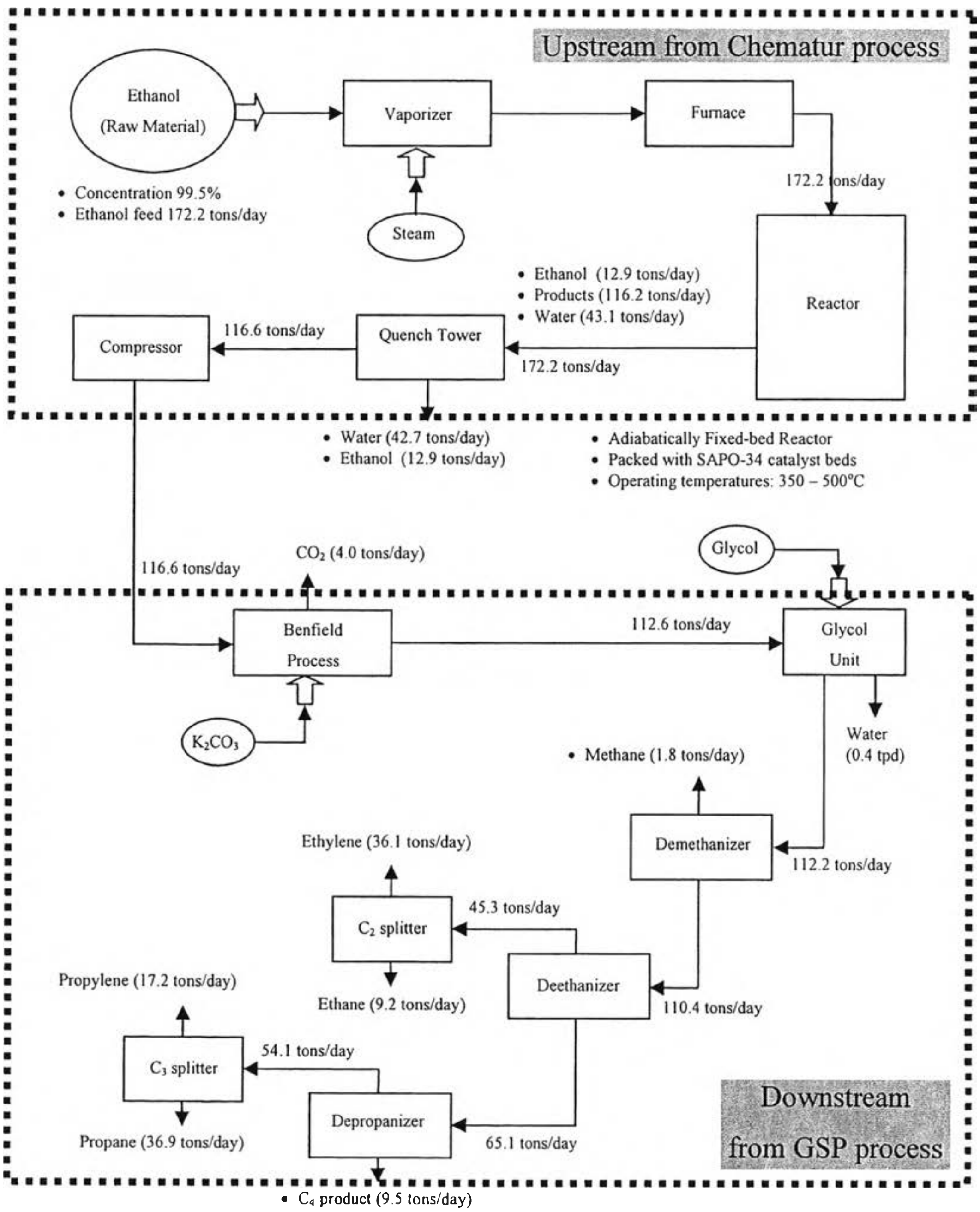

Figure G1 Block diagram of ethanol to olefin plant for cost estimation.

Thus, estimated cost was broken-down follows:

(1) Overall Chematur plant

(2) Deduction cost of drying and purification systems of Chematur plant

(3) Additional estimated cost of scale-down from gas separation plant (GSP)

Note:

- Estimation accuracy = +/- 50%
- ISBL+OSBL are included.
- Instrumentation and electrical are included.

With reference to Chematur plant (ethanol to ethylene) on table below:

Table G1 Estimated CAPEX of Chematur plant

Plant	Capacity	Estimated CAPEX
Chematur	33,000 tons/year	\$ 94 m.

25% cost deduction for drying and purification systems was estimated (see details in Figures G2 and Table G2). So, the remaining portion of adiabatic reactor, quench tower, and compressor systems that were applied for cost estimation of ethanol to light-olefins plant is \$70.7 m, plus the additional \$80 m portion of gas separation plant. (see details Table G3)

Overall CAPEX estimation = \$70.5 m. + \$80 m. = \$150.5 m.

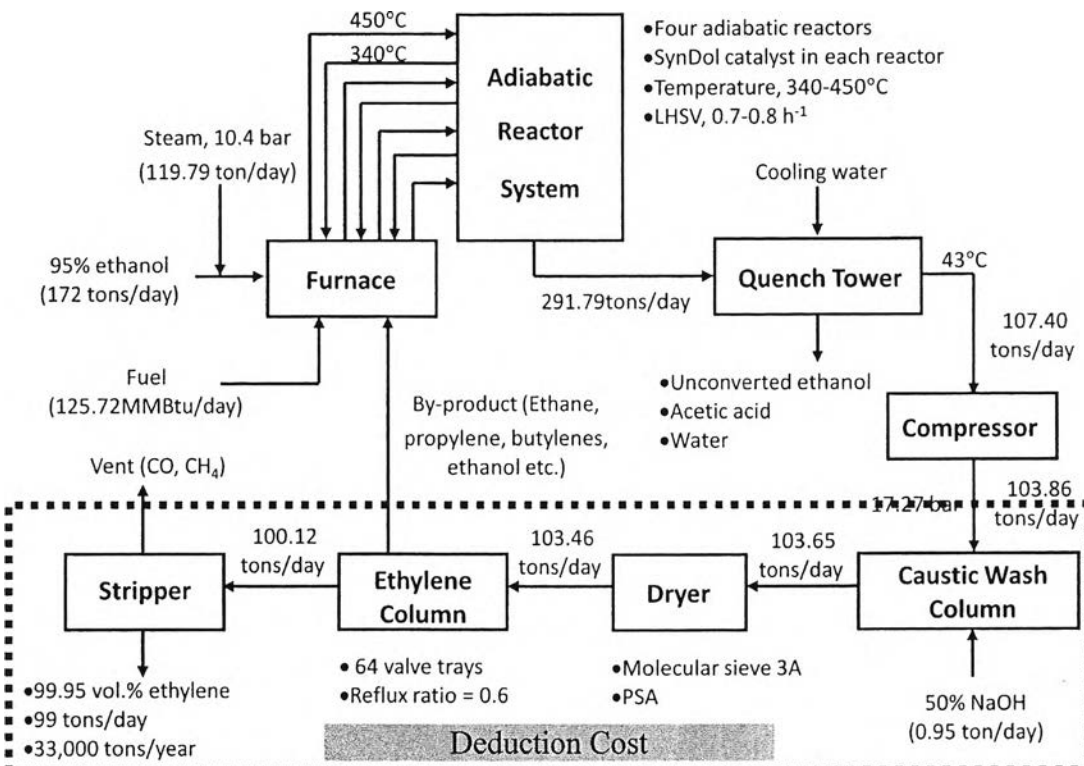

Figure G2 Block diagram of Chematur plant (Deduction cost of drying and purification systems).

Table G2 Deduction cost breakdown

Equipment group	**Deduction cost m.THB ($ m.)**
PSA	200 m.THB ($6.67 m.)
Column incl. internal	80 m.THB ($2.67 m.)
Exchangers	50 m.THB ($1.67 m.)
Drum	15 m.THB ($0.5 m.)
Pump + Piping system	150 m.THB ($5 m.)
Other facilities (incl. OSBL) + 42%	210 m.THB ($7 m.)
Total	705 m.THB ($23.5 m.)

Note:

- Exchange rate = 30 THB/$
- Equipments cost are from in-house data information.
- Piping, civil, instrumentation and electrical are inclusion of deduction.

Regarding with mass flow capacity of C3/C4, comparing with LPG production of GSP-5 from PTT's gas separation plants.

Table G3 Estimated cost of scale-down from gas separation plant (PTT GSP-5)

Plant capacity (MMscfd)	530 (Unit 5)
Methane (MMscfd)	337
Ethane (tons/Year)	520,000
Propane (tons/Year)	151,000
LPG (tons/Year)	495,000
Natural gasoline (tons/Year)	177,000
Reference year	2005
Overall project investment	14,000 m.THB ($467 m.)

Basis of scaled-down estimated cost as same as conversion of Petrobas to Chematur plant

$$\text{Cost } \alpha \text{ Size}^{0.6}$$

Inflation cost shall be added by 3%/year as compound basis from 2005 till 2012

$$\text{Cost(Present)} = \text{Cost}(1 + \text{Inflation rate})^{\text{year}}$$

Scale-down estimation cost including with inflation cost = $80 m. (2,400 m.THB)

Appendix H Coke Formation on Spent Catalysts

The coke formation on catalysts was determined by Thermogravimetric /Differential Thermal Analysis (TG/DTA). The amount of coke formation on spent catalysts data was shown in Table H1.

Table H1 Coke formation on spent catalysts

Temperature / LHSV	TG (%)		
	$0.2\ h^{-1}$	$0.5\ h^{-1}$	$1\ h^{-1}$
350 °C	1.3	1.2	1
400 °C	5.1	3.8	1.5
450 °C	5.5	5.2	2.6
500 °C	12	11.6	2.9

Appendix I Basic Properties of SAPO-34 Catalyst

Description: Crystal structure of SAPO-34, which is a micro pore zeolite similar to chabazite, has special water absorbing capacity and Brønsted acidity. So, this type could be used as an adsorbent, a catalyst and a catalyst support in low carbon olefin transfer, auto gas purification, MTO reaction, etc.

Table I1 Basic properties of SAPO-34 catalyst

Technical parameter	Value
Appearance	White powder
Specific surface area (m^2/g)	662.6
Total pore volume (cm^3/g)	0.4494
Median pore width (Å)	7.957
SiO_2 (%)	~10
Al_2O_3 (%)	~42
Na_2O (%)	≤0.1

Appendix J Material Safety Data Sheet of SAPO-34

** Section 1 – CHEMICAL PRODUCT AND COMPANY IDENTIFICATION **

MSDS Name: Zeolite

Catalog Numbers: CTF-01-50, CTF-02, CTF-03, CTF-03F, CTF-04, CTF-04s, CTF-05

Synonyms: MOLECULAR SIEVE, ALUMINOSILICATE, SILICO-ALUMINO-PHOSPHATE, SILICA, ALUMINA

Company: Tianjin Chemist Scientific Ltd.

Address: 1-C-8, No.13 Ziyuan Road, Huayuan Industry Park, Tianjin 300384, China

Telephone: 0086-22-58627636

Fax: 0086-22-58627636

** Section 2 – COMPOSITION, INFORMATION ON INGREDIENTS **

Cas#	Chemical Name	%	EINECS#
1318-02-1	ZEOLITE		215-283-8

Hazard Symbols: None listed.

Risk Phrases: None listed.

** Section 3 – HAZARDOUS IDENTIFICATION **

EMERGENCY OVERVIEW

Hygroscopic (absorbs moisture from the air).

Potential Health Effects

Eye: May cause eye irritation.

Skin: May cause skin irritation.

Ingestion: The toxicological properties of this substance have not been fully investigated. May be harmful if swallowed.

Inhalation: May cause respiratory tract irritation. The toxicological properties of this substance have not been fully investigated.

Chronic: Not available.

** Section 4 – FIRST AID MEASURES **

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin: Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes.

Ingestion: Get medical aid. Wash mouth out with water.

Inhalation: Remove from exposure and move to fresh air immediately. If not breathing give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

** Section 5 – FIRE FIGHTING MEASURES **

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, SHA/NIOSH (approved or equivalent), and full protective gear.

Extinguishing Media: Use extinguishing media most appropriate for the surrounding fire.

** Section 6 – ACCIDENTAL RELEASE MEASURES **

General Information: Use proper personal protective equipment as indicated in Section 8

Spills/Leaks: Vacuum or sweep up material and place into a suitable disposal container.

** Section 7 – HANDLING AND STORAGE **

Handling: A void breathing dust, vapour mist, or gas. Avoid contact with skin and eyes. Take precautionary measures against static discharges.

Storage: Store in a cool, dry place. Store in a tightly closed container.

** Section 8 – EXPOSURE CONTROLS, PERSONAL PROTECTION **

Engineering Controls: Use adequate ventilation to keep airborne concentrations low.

Personal Protective Equipment

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 European Standard EN166.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 European Standard EN149. Always use a NIOSH or European Standard EN149 approved respirator when necessary.

** Section 9 – PHYSICAL AND CHEMICAL PROPERTIES **

Physical State:	Powder
Color:	White
Odor:	Odorless or slight odor
pH:	Not available.
Vapor Pressure:	Not available.
Viscosity:	Not available.
Boiling Point:	Not available.
Freezing/Melting Point:	Not available.
Autoignition Temperature:	Not available.
Flash Point:	Not available.
Explosion Limits, lower:	Not available.
Explosion Limits, upper:	Not available.

Decomposition Temperature:	
Solubility in water:	insoluble
Specific Gravity/Density:	
Molecular Formula:	
Molecular Weight:	

** Section 10 – STABILITY AND REACTIVITY **

Chemical Stability:	Not available.
Conditions to Avoid:	Incompatible materials, dust generation, exposure to moist air or water.
Incompatibilities with Other Materials:	Strong acids, strong bases, hydrogen fluoride.
Hazardous Decomposition Products:	Not available.
Hazardous Polymerization:	Has not been reported.

** Section 11 – TOXICOLOGICAL INFORMATION **

RTECS#:	Unlisted.
LD50/LC50:	Not available.
Carcinogenicity:	MOLECULAR SIEVES – Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA.

** Section 12 – ECOLOGICAL INFORMATION **

See actual entry in RTECS for complete information.

** Section 13 – DISPOSAL CONSIDERATIONS **

Dispose of in a manner consistent with federal, state, and local regulations.

** Section 14 – TRANSPORT INFORMATION **

IATA: Not regulated as a hazardous material.

IMO: Not regulated as a hazardous material.

RID/ADR: Not regulated as a hazardous material.

DOT: Non-Hazardous for Transport: This substance is considered to be non-hazardous for transport.

Section 15 – REGULATORY INFORMATION **

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols: Not available.

Risk Phrases:

Safety Phrases: S24/25 Avoid contact with skin and eyes.

WGK (Water Dander/Protection)

No information available.

United Kingdom Occupational Exposure Limits

United Kingdom Maximum Exposure Limits

Canada

None of the chemicals in this product are listed on the DSL/NDSL list.

Not listed on Canada's Ingredient Disclosure List.

Exposure Limits

US FEDERAL

TSCA

Not listed on the TSCA inventory.

It is for research and development use only.

Section 16 – ADDITIONAL INFORMATION **

The information above is believed to be accurate and represent the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no way shall the company be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if the company has been advised of the possibility of such damages.

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	Company name:	Fortune Parts Industry Public Company Limited, Pathumthani, Thailand

Proceedings:

1. Chaitanarit, A., Wungtanagorn, C., and Jitkarnka, S. (2012, April 24) Effect of temperature on bio-ethanol conversion to light olefins using SAPO-34 catalyst. Proceedings of The 3rd Research Symposium on Petrochemical and Materials Technology and The 18th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.