REFERENCES

Adebajo, M.O., Howe, R.F., Long, M.A. (2000). Methylation of benzene with methanol over zeolite catalysts in a low pressure flow reactor. Catalysis Today, 63, 471-478.

Degnan Jr., T.F., Smith, C.M., Venkat, C.R. (2001). Alkylation of aromatics with ethylene and propylene: recent developments in commercial process. Applied Catalysis A: General, 221, 283–294.

Etrl, G., Knozinger, H., Weitkamp, J. (1997). Handbook of Heterogeneous Catalysis. Weinheim: Wiley-VCH.

Franck, H.G., Stadelhofer, J.W. (1988). Industrial Aromatic Chemistry. Berlin: Springer-Verlag.

Ganti, R., Bhatia S. (1995). Benzene alkylation with ethanol over shape selective zeolite catalysts. Studies in Surface Science and Catalysis, 98, 171-173.

Gao, J., Zhang, L., Hu, J., Li, W., Wang, J. (2009). Effect of zinc salt on the synthesis of ZSM-5 for alkylation of benzene with ethanol. Catalysis Communications, 90, 1220-1225.

Gates, B.C. (1992) Catalytic Chemistry. New York: John Wiley & sons, Inc.

Guan, X.X., Li, N., Wu, G.J., Chen, J.X., Zhang, F.X., Guan, N.J. (2006). Para-selectivity of modified HZSM-5 zeolites by nitridation for ethylation of ethylbenzene with ethanol. Journal of Molecular Catalysis A: Chemical, 248, 220–225.

Guisnet, M., Magnoux, P. (2001). Organic chemistry of coke formation. Applied Catalysis A: General, 212, 83–96.

Kumar, S., Sinha, A.K., Hegde, S.G., Sivasanker, S. (2000). Influence of mild dealumination on physicochemical, acidic and catalytic properties of H-ZSM-5. Journal of Molecular Catalysis A: Chemical, 154, 115–120.

Li, Y., Xue, B., He, X. (2009). Catalytic synthesis of ethylbenzene by alkylation of benzene with diethyl carbonate over HZSM-5. Catalysis Communications, 10, 702-707.

Li, Y., Xue, B., Yang, Y. (2009). Synthesis of ethylbenzene by alkylation of benzene with diethyl oxalate over HZSM-5. Fuel Processing Technology, 90, 1220-1225.

Lukyanov, D.B., Vazhnova, T. (2008). A kinetic study of benzene alkylation with ethane into ethylbenzene over bifunctional PtH-MFI catalyst. Journal of catalysis, 257, 382-389.

Matar, S., Mirbach, M.J., Tayim, H.A. (1989). Catalysis in Petrochemical Process. Netherlands: Kuwer Academic Publishers.

Mcketta, J.J. (1993). Chemical Processing Handbook. New York: Marcel Dekker.

Meyers, R.A. (2005). Handbook of Petrochemical Production Processes. New york: McGraw-Hill.

Moser, W.R., Thompson, R.W., Chiang. C.C., Tong, H. (1989). Silicon-rich H-ZSM-5 catalyszed conversion of aqueous ethanol to ethylene. Journal of catalysis, 117, 19-32.

Nandhini, K.U., Arabindoo, B., Palanichamy, M., Murugesan, V. (2006). Vapour phase reaction of ethylbenzene with diethyl carbonate over Al-MCM-41 supported phosphotungstic acid. Catalysis Communications, 7, 351–356.

Odedairo, T., Al-Khattaf, S. (2010). Kinetic analysis of benzene ethylation over ZSM-5 based catalyst in a fluidized-bed reactor. Chemical Engineering Journal, 157, 204-215.

Park, S.H., Rhee, H.K. (2001). Shape selective properties of MCM-22 catalysts for the disproportionation of ethylbenzene. Applied Catalysis A: General, 219, 99–105.

Perego, C., Ingallina, P. (2002). Recent advances in the industrial alkylation of aromatics: new catalysts and new processes. Catalysis Today, 73, 3-22.

Raimondo, M., Perez, G., Stefanis, A.D., Tomllnson, A.A.G., Ursini O. (1997). PLS vs. zeolites as sorbents and catalysts 4. Effects of acidity and porosity on alkylation of benzene by primary alcohols. Applied Catalysis A: General, 164, 119-126.

Raj, K.J.A., Padma Malar, E.J., Vijayaraghavan, V.R. (2006). Shape-selective reactions with AEL and AFI type molecular sieves alkylation of benzene, toluene and ethylbenzene with ethanol, 2-propanol, methanol and *t*-butanol. Journal of Molecular Catalysis A: Chemical, 243, 99-105.

Romannikov, V.N., Ione, K.G. (1994). The peculiarities of the ethylation of toluene and benzene on modified beta zeolites. Journal of catalysis, 146, 211-217.

Sridevi, U., Bhaskar Rao, B.K., Pradhan, N.C. (2001). Kinetics of alkylation of benzene with ethanol on $AlCl_3$-impregnated 13X zeolites. Chemical Engineering Journal, 83, 185-189.

Sudha, S., Palanichamy, M., Arabindoo, B., Murugesan, V. (2007). Unsymmetrical alkylation of benzene over large pore zeolites. Catalysis Communications, 8, 1137-1144.

Sun, L., Guo, X., Liu, M., Wang, X. (2009). Ethylation of coking benzene over nanoscale HZSM-5 zeolites: Effects of hydrothermal treatment, calcination and La_2O_3 modification. Applied Catalysis A: General, 355, 184-191.

Stocker, M. (2005). Gas phase catalysis by zeolites. Microporous and Mesoporous Materials, 82, 257–292.

Tanabe, K., Holderich, W.F. (1999). Industrial application of solid acid-base catalysts. Applied Catalysis A: General, 181, 399-434.

Vijayaraghavan, V.R., Raj, K.J.A. (2004). Ethylation of benzene with ethanol over substituted large pore aluminophosphate-based molecular sieves. Journal of Molecular Catalysis A: Chemical, 207, 41-50.

Wade, L. G. "Chapter 17 Reactions of Aromatic Compounds." *Organic Chemistry, 6th Edition*. 13 Apr. 2009 <http://www.csmet.scsu.edu/Hamidi/Chem%20307/307Lecture/BookSixEd/c chapte_17au.ppt >

"Electrophilic Aromatic Substitution Reactions." *Chemistry 2600 Lecture Notes*. 6 Apr. 2009 <http://classes.uleth.ca/200201/chem2600a/notesch12.pdf>.

"Nucleophilic aromatic substitution." *Wikipedia*. 13 Apr. 2009 <http://en.wikipedia.org/wiki/Nucleophilic_aromatic_substitution>

APPENDICES

Appendix A Experimental Data of Liquid Feed Calibration of GC 5890

1. Benzene

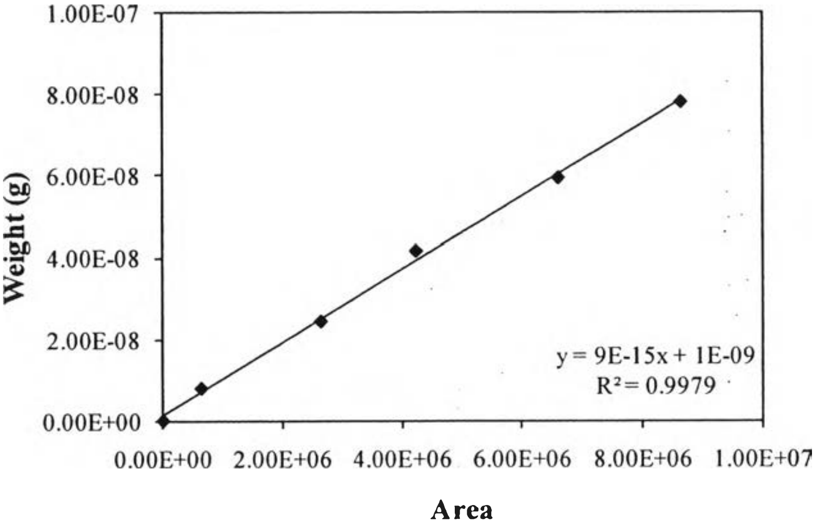

Figure A1 Calibration curve of benzene.

2. Ethanol

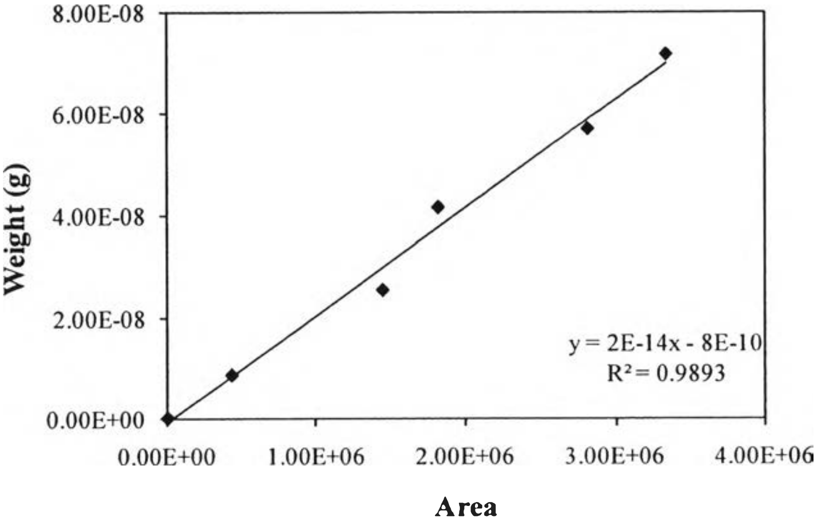

Figure A2 Calibration curve of ethanol.

Appendix B Experimental Data of Gas Flow Calibration of Sierra C100L Mass Flow Controller

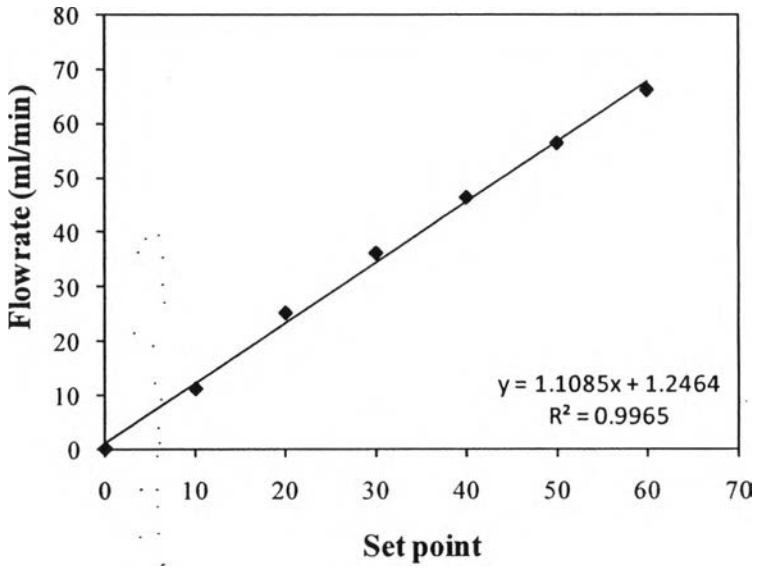

Figure B1 Calibration curve of nitrogen.

Appendix C Experimental Data of Liquid Feed Flow Calibration of Gilson 307 Pump

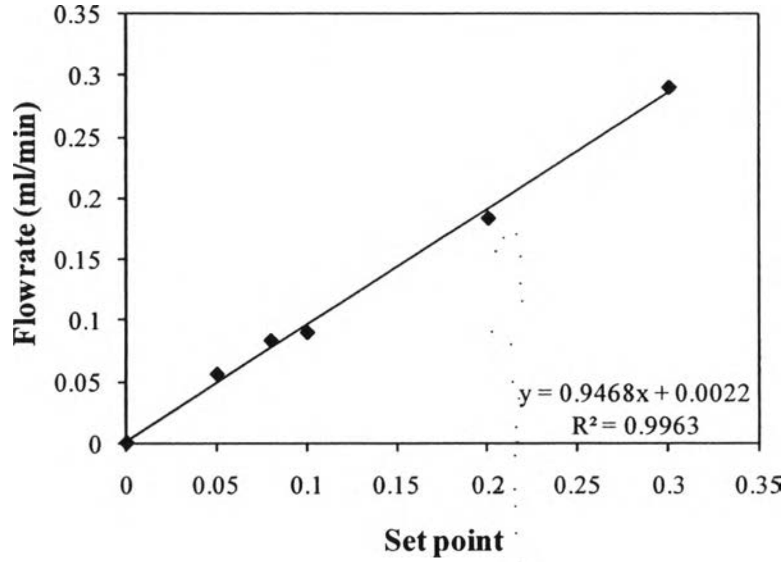

Figure C1 Calibration curve of liquid feed.

Appendix D Calculation of Si/Al Ratio and Theoretical Acidity

From the chemical composition determined by XRF method, the Si/Al ratio is calculated as follows:

The general formula of HZSM-5 is $Al_nSi_{96-n}O_{192}$

In the case of HZSM-5 (45),

SiO_2	=	98.937 wt%	Al_2O_3	=	0.93 wt%
SiO_2	=	1.65 mol	Al_2O_3	=	0.009 mol

SiO_2/ Al_2O_3 = 180

SiO_2 has O atom 3.29 mol in total O atom 3.32 mol

From the general formula, SiO_2 has O atom 190.3 mol in total O atom 192 mol. So, SiO_2 has Si atom 95.15 mol.

From $Al_nSi_{96-n}O_{192}$, n = 96 - 95.15

n = 0.85

So, Si = 95.15

Al = 0.85

Si/Al = 112

From the chemical composition determined by XRF method, the theoretical acidity of zeolite is calculated as follows:

The general formula of HZSM-5 is $Al_nSi_{96-n}O_{192}$

In the case of HZSM-5 (45) with,

Si = 95.15

Al = 0.85

From the above, the general formula of HZSM-5 is $Al_{0.85}Si_{95.15}O_{192}$. The weight of unit cell of HZSM-5 (U) is

U = 0.85(1) + 0.85(26.98) + 93.91(28.09) + 192(15.99)

U = 5766.627 g

The theoretical acidity ($[H^+]$) of HZSM-5 (45) is

$[H^+]$ = 0.85/5766.627

$[H^+]$ = 0.147 mmol/g

Appendix E Experimental Data of Catalytic Activity Test for Alkylation of Benzene with Ethanol over HZSM-5 Catalyst.

Table E1 Catalytic activity testing over HZSM-5 with different Si/Al ratio at temperature 300°C, B/E = 1, WHSV = 8 h^{-1}

Component	Si/Al	Conversion (%)					
		1 h	2 h	3 h	4 h	5 h	6 h
Benzene	77	59.39	61.67	64.05	64.73	64.73	62.40
	112	51.80	55.46	55.34	54.98	56.34	54.22
	109	36.18	32.39	36.59	34.08	33.01	38.21
Ethanol	77	96.93	98.75	99.34	98.75	98.75	95.95
	112	93.23	92.24	92.62	91.25	92.95	93.15
	109	91.72	91.69	91.88	92.69	92.41	92.26

Table E2 Catalytic activity testing on different temperature for HZSM-5 (A), B/E = 1, WHSV = 8 h^{-1}

Component	Temperature (°C)	Conversion (%)					
		1 h	2 h	3 h	4 h	5 h	6 h
Benzene	300	59.39	61.67	64.05	64.73	64.73	62.40
	350	49.09	45.28	46.81	47.03	46.21	48.32
	400	42.03	42.97	44.31	43.97	44.87	45.79
	500	26.60	30.95	28.12	24.13	25.80	26.81
Ethanol	300	96.93	98.75	99.34	98.75	98.75	95.95
	350	92.44	91.83	94.67	93.59	96.02	96.62
	400	88.51	88.31	91.21	92.20	89.45	90.39
	500	87.65	87.91	87.07	86.54	84.91	85.77

Table E3 Product distribution over HZSM-5 with different Si/Al ratio at temperature 300°C, B/E = 1, WHSV = 8 h^{-1} and Time on stream = 6 h

Component	Product distribution (wt%)					
	liquid phase			gas phase		
	77	112	109	77	112	109
ethylene	0.00	0.00	0.00	2.66	7.40	2.80
methanol	0.06	0.01	0.00	0.28	0.05	0.00
toluene	1.10	0.15	0.03	3.27	1.02	0.12
EB	47.75	53.69	65.25	69.33	74.53	86.93
xylenes	1.47	0.37	0.21	3.68	4.64	2.61
cumene	3.02	1.81	0.68	2.31	2.09	0.84
propyl-benzene	3.28	0.67	0.10	1.88	0.47	0.12
p-ethyl toluene	2.21	1.07	0.73	1.37	0.69	0.46
o-ethyl toluene	0.12	0.01	0.00	0.13	0.04	0.04
1,2,3-trimethylbenzene	0.30	0.11	0.06	0.18	0.05	0.04
(2-methylpropyl)-benzene	0.28	0.05	0.01	0.11	0.01	0.01
(1-methylpropyl)-benzene	0.49	0.33	0.55	0.26	0.06	0.20
indane	0.72	0.06	0.01	0.20	0.13	0.02
1-propenyl benzene	0.19	0.03	0.02	0.06	0.06	0.01
1,4-diethylbenzene	21.02	25.15	22.85	6.86	3.69	1.62
1,3-diethylbenzene	12.50	14.39	8.86	4.30	2.43	3.94
1,2-diethylbenzene	1.05	0.67	0.11	0.95	0.68	0.00
2-butenylbenzene	0.14	0.01	0.02	0.07	0.06	0.00
1-butenylbenzene	0.40	0.28	0.18	0.30	0.13	0.06
m-ethylcumene	0.51	0.15	0.02	0.23	0.04	0.03
p-ethylcumene	0.32	0.14	0.05	0.13	0.01	0.02
1-Methyl-4-sec-butylbenzene	0.81	0.23	0.03	0.40	0.06	0.03
1-butynyl-benzene	0.48	0.13	0.05	0.20	0.03	0.01
1-methyl-1H-Indene	0.22	0.01	0.00	0.10	0.13	0.01
1,2-dihydro-Naphthalene	0.27	0.05	0.04	0.13	0.15	0.01
1,2,3,4-tetrahydronaphthalene	0.27	0.04	0.02	0.10	0.19	0.01
naphthalene	0.18	0.07	0.02	0.13	0.45	0.01
(1-ethyl-1-propenyl)-Benzene	0.44	0.15	0.08	0.16	0.07	0.02
2-methyl-Naphthalene	0.40	0.19	0.01	0.20	0.64	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table E4 Product distribution at different temperature over HZSM-5 (A), B/E = 1, WHSV = 8 h^{-1}, and Time on stream = 6 h.

Component	Product distribution (wt%)			
	liquid phase		gas phase	
	300°C	350°C	300°C	350°C
ethylene	0.00	0.00	2.66	0.44
methanol	0.06	0.09	0.28	0.54
toluene	1.10	10.20	3.27	31.25
EB	47.75	46.47	69.33	52.04
xylenes	1.47	4.84	3.68	5.98
cumene	3.02	2.18	2.31	0.98
propyl-benzene	3.28	3.93	1.88	1.10
p-ethyl toluene	2.21	3.01	1.37	1.15
o-ethyl toluene	0.12	0.09	0.13	0.18
1,2,3-trimethylbenzene	0.30	0.84	0.18	0.22
(2-methylpropyl)-benzene	0.28	0.20	0.11	0.05
(1-methylpropyl)-benzene	0.49	0.22	0.26	0.11
indane	0.72	2.78	0.20	0.74
1-propenyl benzene	0.19	0.77	0.06	0.20
1,4-diethylbenzene	21.02	8.07	6.86	1.31
1,3-diethylbenzene	12.50	4.37	4.30	0.78
1,2-diethylbenzene	1.05	1.07	0.95	0.38
2-butenylbenzene	0.14	0.97	0.07	0.21
1-butenylbenzene	0.40	0.83	0.30	0.33
m-ethylcumene	0.51	0.50	0.23	0.13
p-ethylcumene	0.32	0.22	0.13	0.05
1-Methyl-4-sec-butylbenzene	0.81	0.55	0.40	0.13
1-butynyl-benzene	0.48	0.36	0.20	0.05
1-methyl-1H-Indene	0.22	0.69	0.10	0.18
1,2-dihydro-Naphthalene	0.27	0.61	0.13	0.16
1,2,3,4-tetrahydronaphthalene	0.27	1.47	0.10	0.24
naphthalene	0.18	1.72	0.13	0.42
(1-ethyl-1-propenyl)-Benzene	0.44	0.62	0.16	0.08
2-methyl-Naphthalene	0.40	2.31	0.20	0.57
Total	100.00	100.00	100.00	100.00

Table E5 Product distribution at different temperature over HZSM-5 (A), B/E = 1, WHSV = 8 h^{-1}, and Time on stream = 6 h (Continued)

Component	Product distribution (wt%)			
	liquid phase		gas phase	
	400°C	500°C	400°C	500°C
ethylene	0.00	0.00	2.41	2.54
methanol	0.10	0.03	1.99	0.86
toluene	14.54	29.32	23.02	55.12
EB	45.52	19.42	46.24	23.73
xylenes	6.06	14.49	10.20	12.38
cumene	1.56	0.50	1.26	0.28
propyl-benzene	2.57	1.11	1.22	0.51
p-ethyl toluene	2.49	2.09	1.57	0.94
o-ethyl toluene	0.36	0.38	0.39	0.17
1,2,3-trimethylbenzene	0.62	0.65	0.46	0.19
indane	3.86	4.96	1.60	0.84
1-propynyl benzene	1.23	13.23	0.53	0.57
1,4-diethylbenzene	3.87	0.69	0.99	0.25
1,3-diethylbenzene	1.92	0.40	0.65	0.15
1,2-diethylbenzene	0.64	0.10	0.52	0.02
2-butenylbenzene	0.93	0.47	0.41	0.05
1-butenylbenzene	1.41	0.54	0.74	0.09
1-methyl-indane	0.53	0.32	0.27	0.04
1-methyl-1H-indene	0.90	1.01	0.30	0.12
1,2-dihydro-naphthalene	0.74	0.73	0.30	0.10
1,2,3,4-tetrahydronaphthalene	1.11	0.30	0.42	0.06
naphthalene	2.41	0.12	1.28	0.65
2-methylnaphthalene	3.87	7.42	1.45	0.13
1-methylnaphthalene	1.11	0.03	1.04	0.05
1-ethyl-naphthalene	0.66	0.46	0.21	0.05
2,6-dimethyl-naphthalene	0.48	0.75	0.30	0.06
1,6-dimethyl-naphthalene	0.49	0.49	0.23	0.03
Total	100	100	100	101.00

Table E6 Catalytic activity testing on different WHSV for HZSM-5 (A), B/E = 1, T = 300 °C.

Component	WHSV (h^{-1})	Conversion (%)					
		1 h	2 h	3 h	4 h	5 h	6 h
Benzene	5	64.46	65.61	68.72	67.97	70.53	68.25
	8	59.39	61.67	64.05	64.73	64.73	62.40
	10	58.15	58.52	55.86	52.84	53.23	50.82
	12	45.82	52.41	49.18	49.04	47.07	40.45
	14	46.19	45.01	47.64	40.68	38.96	36.59
	20	16.01	13.47	11.48	10.58	12.65	14.08
Ethanol	5	97.74	98.51	99.49	98.62	98.07	99.23
	8	96.93	98.75	99.34	98.75	98.75	95.95
	10	99.62	98.62	99.63	99.41	99.52	97.76
	12	99.00	98.91	99.38	99.64	98.82	99.32
	14	99.45	99.76	98.35	97.73	99.52	99.40
	20	95.38	94.75	95.87	94.74	96.27	95.85

Table E7 Product distribution of liquid sample at different WHSV over HZSM-5 (A), T = 300 °C, B/E = 1, and Time on stream = 6 h

Component	product distribution (wt%)					
	5 h^{-1}	8 h^{-1}	10 h^{-1}	12 h^{-1}	14 h^{-1}	20 h^{-1}
ethylene	0.00	0.00	0.00	0.00	0.00	0.00
methanol	0.03	0.06	0.08	0.08	0.08	0.15
toluene	1.31	1.10	1.29	0.84	0.77	0.50
EB	43.83	47.75	53.13	54.61	58.29	69.20
xylenes	1.86	1.47	1.43	1.05	0.96	0.89
cumene	1.71	3.02	2.36	4.49	4.13	1.12
propyl-benzene	2.75	3.28	2.85	2.56	2.35	1.18
p-ethyl toluene	2.52	2.21	1.86	1.68	1.54	0.88
o-ethyl toluene	0.20	0.12	0.11	0.08	0.08	0.04
1,2,3-trimethylbenzene	0.33	0.30	0.25	0.22	0.20	0.12
(2-methylpropyl)-benzene	0.22	0.28	0.23	0.22	0.20	0.06
(1-methylpropyl)-benzene	0.26	0.49	0.38	0.47	0.43	0.31
indane	0.90	0.72	0.58	0.33	0.30	0.35
1-propenyl benzene	0.22	0.19	0.18	0.11	0.10	0.09
1,4-diethylbenzene	23.34	21.02	18.92	18.61	17.10	13.78
1,3-diethylbenzene	14.12	12.50	11.74	10.85	9.97	8.94
1,2-diethylbenzene	1.06	1.05	0.85	0.78	0.72	0.92
2-butenylbenzene	0.19	0.14	0.12	0.03	0.07	0.04
1-butenylbenzene	0.65	0.40	0.33	0.24	0.22	0.10
m-ethylcumene	0.51	0.51	0.41	0.37	0.34	0.15
p-ethylcumene	0.24	0.32	0.27	0.27	0.25	0.10
1-Methyl-4-sec-butylbenzene	0.77	0.81	0.69	0.62	0.57	0.26
1-butynyl-benzene	0.42	0.48	0.41	0.38	0.35	0.17
1-methyl-1H-Indene	0.26	0.22	0.18	0.11	0.10	0.07
1,2-dihydro-Naphthalene	0.27	0.27	0.24	0.18	0.16	0.09
1,2,3,4-tetrahydronaphthalene	0.31	0.27	0.20	0.16	0.15	0.07
naphthalene	0.46	0.18	0.20	0.12	0.06	0.12
(1-ethyl-1-propenyl)-Benzene	0.53	0.44	0.37	0.32	0.29	0.15
2-methyl-Naphthalene	0.71	0.40	0.33	0.22	0.21	0.17
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table E8 Product distribution of gas sample at different WHSV over HZSM-5 (A), T = 300 °C, B/E = 1, and Time on stream = 6 h

Component	product distribution (wt%)					
	5	8	10	12	14	20
ethylene	0.45	2.66	2.46	2.90	4.17	9.40
methanol	0.34	0.28	1.55	0.38	1.00	3.43
toluene	7.86	3.27	5.70	2.68	2.21	2.58
EB	65.16	69.33	59.83	70.54	59.41	75.41
xylenes	4.14	3.68	4.91	3.69	5.13	4.39
cumene	1.59	2.31	2.46	2.85	2.12	0.66
propyl-benzene	1.77	1.88	2.06	1.93	1.91	0.28
p-ethyl toluene	1.71	1.37	1.70	1.37	1.72	0.40
o-ethyl toluene	0.19	0.13	0.24	0.17	0.23	0.03
1,2,3-trimethylbenzene	0.24	0.18	0.29	0.22	0.27	0.06
(2-methylpropyl)-benzene	0.11	0.11	0.14	0.12	0.12	0.03
(1-methylpropyl)-benzene	0.21	0.26	0.32	0.26	0.33	0.14
indane	0.32	0.20	0.27	0.21	0.35	0.08
1-propenyl benzene	0.08	0.06	0.08	0.07	0.09	0.02
1,4-diethylbenzene	7.52	6.86	7.39	6.09	8.53	1.38
1,3-diethylbenzene	4.36	4.30	4.83	3.72	6.10	1.16
1,2-diethylbenzene	1.30	0.95	1.77	1.01	2.30	0.33
2-butenylbenzene	0.11	0.07	0.13	0.08	0.17	0.02
1-butenylbenzene	0.41	0.30	0.51	0.31	0.62	0.07
m-ethylcumene	0.27	0.23	0.38	0.22	0.42	0.04
p-ethylcumene	0.13	0.13	0.20	0.11	0.23	0.02
1-Methyl-4-sec-butylbenzene	0.35	0.40	0.59	0.24	0.62	0.02
1-butynyl-benzene	0.17	0.20	0.30	0.10	0.33	0.01
1-methyl-1H-Indene	0.11	0.10	0.19	0.08	0.20	0.01
1,2-dihydro-Naphthalene	0.14	0.13	0.26	0.10	0.24	0.01
1,2,3,4-tetrahydronaphthalene	0.12	0.10	0.41	0.11	0.28	0.01
naphthalene	0.23	0.13	0.21	0.12	0.18	0.01
(1-ethyl-1-propenyl)-Benzene	0.26	0.16	0.41	0.06	0.33	0.01
2-methyl-Naphthalene	0.34	0.20	0.40	0.27	0.38	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table E9 Catalytic activity testing on different feed ratio for HZSM-5 (A), WHSV = 8 h^{-1}, T = 300 °C.

Component	B/E (mol/mol)	Conversion (%)					
		1 h	2 h	3 h	4 h	5 h	6 h
Benzene	1	59.39	61.67	64.05	64.73	64.73	62.40
	2	51.05	50.76	52.03	54.09	52.71	53.51
	3	47.67	47.03	49.52	51.22	50.12	49.87
	4	45.29	45.99	45.13	45.03	45.30	46.07
Ethanol	1	96.93	98.75	99.34	98.75	98.75	95.95
	2	98.40	96.81	98.31	99.04	97.84	99.51
	3	93.37	94.88	94.73	93.18	93.93	93.25
	4	91.22	89.44	92.38	91.56	89.26	90.46

Table E10 Product distribution of liquid sample at different feed ratio for HZSM-5 (A), WHSV = 8 h^{-1}, T = 300 °C, and Time on stream = 6 h

Component	product distribution (wt%)			
	1	2	3	4
ethylene	0.00	0.00	0.00	0.00
methanol	0.06	0.01	0.01	0.01
toluene	1.10	2.31	1.67	1.51
EB	47.75	60.46	65.93	72.69
xylenes	1.47	1.13	0.85	0.97
cumene	3.02	1.62	1.75	1.16
propyl-benzene	3.28	2.28	2.67	2.04
p-ethyl toluene	2.21	1.66	1.17	0.86
o-ethyl toluene	0.12	0.11	0.06	0.07
1,2,3-trimethylbenzene	0.30	0.14	0.09	0.07
(2-methylpropyl)-benzene	0.28	0.18	0.21	0.13
(1-methylpropyl)-benzene	0.49	0.22	0.23	0.13
indane	0.72	0.77	0.53	0.84
1-propenyl benzene	0.19	0.17	0.13	0.16
1,4-diethylbenzene	21.02	15.80	14.75	11.41
1,3-diethylbenzene	12.50	9.16	7.21	5.28
1,2-diethylbenzene	1.05	0.62	0.50	0.76
2-butenylbenzene	0.14	0.14	0.08	0.09
1-butenylbenzene	0.40	0.39	0.25	0.21
m-ethylcumene	0.51	0.28	0.22	0.18
p-ethylcumene	0.32	0.13	0.12	0.07
1-Methyl-4-sec-butylbenzene	0.81	0.42	0.35	0.22
1-butynyl-benzene	0.48	0.24	0.19	0.12
1-methyl-1H-Indene	0.22	0.18	0.13	0.13
1,2-dihydro-Naphthalene	0.27	0.18	0.15	0.13
1,2,3,4-tetrahydronaphthalene	0.27	0.21	0.13	0.14
naphthalene	0.18	0.34	0.16	0.17
(1-ethyl-1-propenyl)-Benzene	0.44	0.33	0.23	0.20
2-methyl-Naphthalene	0.40	0.51	0.25	0.24
Total	100.00	100.00	100.00	100.00

Table E11 Product distribution of gas sample at different feed ratio for HZSM-5 (A), WHSV = 8 h^{-1}, T = 300 °C, and Time on stream = 6 h

Component	product distribution (wt%)			
	1	2	3	4
ethylene	2.66	0.98	0.17	0.08
methanol	0.28	0.22	0.14	0.08
toluene	3.27	8.15	6.93	4.65
EB	69.33	76.77	79.88	85.09
xylenes	3.68	4.60	4.88	5.32
cumene	2.31	1.40	1.51	0.86
propyl-benzene	1.88	1.16	1.29	0.70
p-ethyl toluene	1.37	0.90	0.70	0.39
o-ethyl toluene	0.13	0.12	0.11	0.07
1,2,3-trimethylbenzene	0.18	0.10	0.10	0.05
(2-methylpropyl)-benzene	0.11	0.06	0.06	0.03
(1-methylpropyl)-benzene	0.26	0.11	0.11	0.04
indane	0.20	0.13	0.13	0.12
1-propenyl benzene	0.06	0.03	0.03	0.02
1,4-diethylbenzene	6.86	2.64	2.06	1.32
1,3-diethylbenzene	4.30	1.73	1.19	0.76
1,2-diethylbenzene	0.95	0.46	0.36	0.26
2-butenylbenzene	0.07	0.03	0.03	0.02
1-butenylbenzene	0.30	0.11	0.08	0.04
m-ethylcumene	0.23	0.06	0.05	0.02
p-ethylcumene	0.13	0.03	0.02	0.01
1-Methyl-4-sec-butylbenzene	0.40	0.03	0.04	0.02
1-butynyl-benzene	0.20	0.02	0.01	0.01
1-methyl-1H-Indene	0.10	0.02	0.02	0.01
1,2-dihydro-Naphthalene	0.13	0.02	0.02	0.01
1,2,3,4-tetrahydronaphthalene	0.10	0.03	0.02	0.01
naphthalene	0.13	0.04	0.02	0.01
(1-ethyl-1-propenyl)-Benzene	0.16	0.03	0.02	0.01
2-methyl-Naphthalene	0.20	0.02	0.02	0.01
Total	100.00	100.00	100.00	100.00

Table E12 Stability test over HZSM-5 (A), T = 300 °C, WHSV = 8 h^{-1}, and B/E = 2.

Time (h)	Benzene conversion (%)	Ethanol conversion (%)	EB selectivity (%)
1	47.89	91.91	57.56
2	48.96	98.21	61.01
3	49.04	98.33	58.76
4	48.02	95.18	60.43
5	46.28	98.82	60.32
6	47.25	96.11	61.51
7	45.84	95.57	59.33
8	44.76	97.93	62.24
9	41.69	95.81	59.48
10	43.91	94.77	62.52
11	45.44	97.60	62.75
12	41.60	98.29	60.36
13	41.42	95.91	62.93
14	43.02	94.07	62.49
15	40.60	95.91	63.07
16	39.62	94.90	62.49
17	39.75	97.24	61.56
18	42.22	94.85	59.52
19	40.75	92.94	63.42
20	40.14	91.82	64.56
21	41.72	94.81	64.50
22	41.56	95.08	63.19
25	41.79	95.42	64.66
28	38.37	89.72	62.57
30	38.92	91.93	58.96
34	22.67	84.55	46.09

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Proceedings:

1. Udomsin, N., Rirksomboon, T., and Jonpatiwut, S. (2010, April 22) Alkylation of Benzene with Ethanol to Ethylbenzene using Commercial HZSM-5 Catalysts. Proceedings of 1st National Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and 16th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

Presentations:

1. Udomsin, N., Rirksomboon, T., and Jonpatiwut, S. (2010, April 22) Alkylation of Benzene with Ethanol to Ethylbenzene using Commercial HZSM-5 Catalysts. Poster presentation of 1st National Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and 16th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.