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APPENDICES

Appendix A Experimental Data of Liquid Feed Calibration of GC 5890

1. Benzene

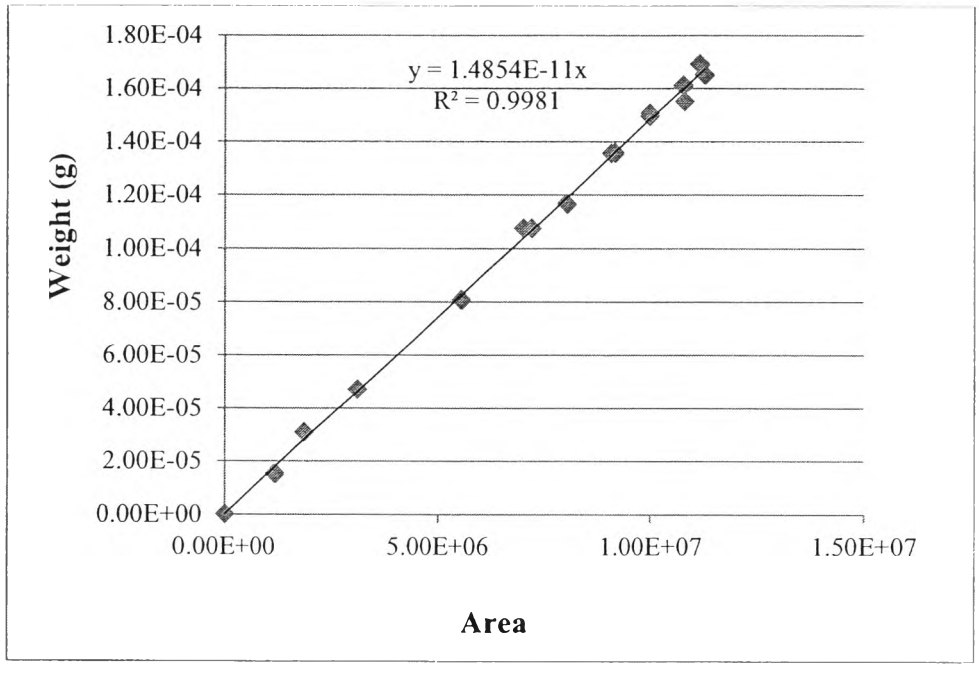

Figure A1 Calibration curve of benzene.

2. Ethanol

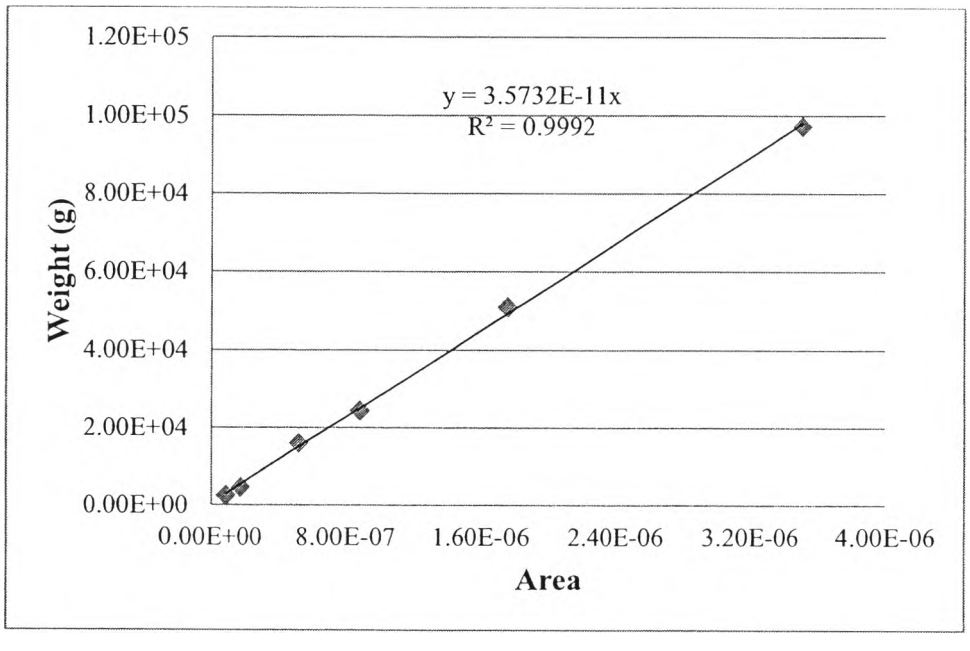

Figure A2 Calibration curve of ethanol.

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

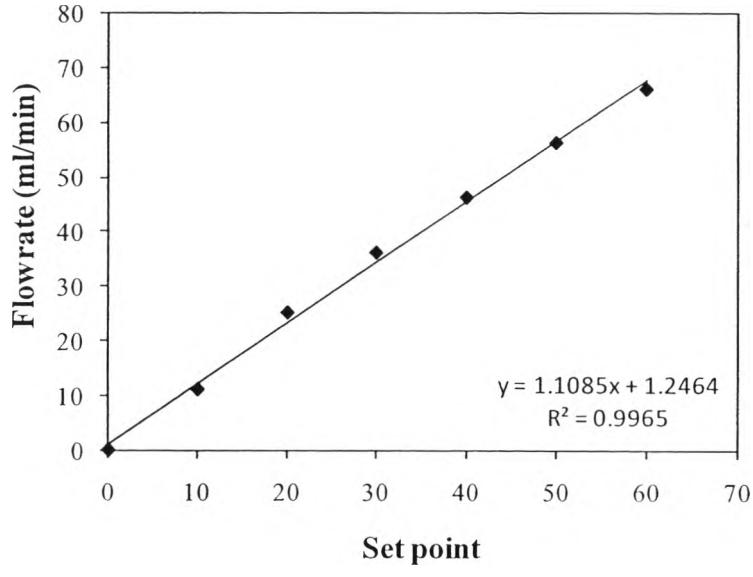

Figure B1 Calibration curve of nitrogen.

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

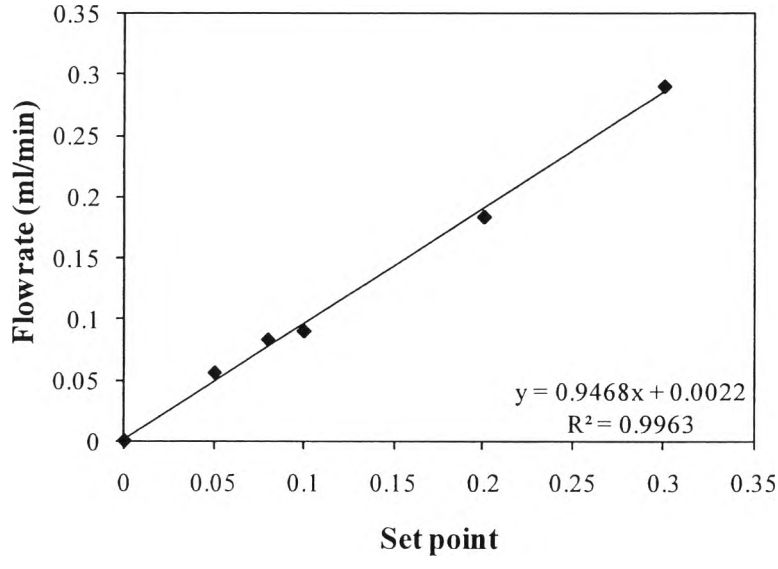

Figure C1 Calibration curve of liquid feed.

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 ZSM-5 is $Na_nAl_nSi_{96-n}O_{192}$

In the case of HZ5-A2(25),

Si = 98.682 wt% Al = 1.075 wt%

Si = 3.513065 mol Al = 0.039844 mol

Si/ Al= 88.1705

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

Si/ Al= 88.1705= (96-n)/n

89.1705n = 96

n = 1.07658

So, Si = 94.9234

Al = 1.07658

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

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

In the case of HZSM-5 (B1) with,

Si = 94.9234

Al = 1.07658

From the above, the general formula of HZSM-5 is $H_{1.07658}Al_{1.07658}Si_{94.9234}O_{192}$. The weight of unit cell of HZSM-5 (U) is

U = 1.07658 (1) + 1.07658 (26.98) + 94.9234 (28.09) + 192(16.00)

U = 5768.5210 g

The theoretical acidity ($[H^+]$) of HZSM-5 (B1) is

$[H^+]$ = 1.07658/5768.5210

$[H^+]$ = 0.187 mmol/g

However, from the chemical composition determined by XRF method was noticed some remained of Na.

In the case of HZ5-A2(25),

Na = 0.243 wt%

Na = 0.296 mol%

So, H = 1.07658-0.296 = 0.78058

From the above, the general formula of HZSM-5 is $H_{0.78058}Al_{1.07658}Si_{94.9234}O_{192}$. The weight of unit cell of HZSM-5 (U) is

U = 0.78058 (1) + 1.07658 (26.98) + 94.9234 (28.09) + 192(16.00) + 0.296 (23)

U = 5775.0330 g

The actual acidity ([H+]) of HZSM-5 (B1) is

[H+] = 0.78058 /5775.0330

[H+] = 0.135 mmol/g

Appendix E The Other Catalyst Preparation

In this work, the author had investigated the other low temperature ZSM-5 synthesis (less than 150 °C) conditions, which used NaOH as a mineralizing agent. The molar ratio of H_2O/SiO_2 in the initial gel, time, and temperature were varied to prove the minimum conditions required to completely formation of ZSM-5 synthesis. The synthesized ZSM-5 (SiO_2/Al_2O_3 of ca. 195) at various conditions are designated as Z5-(a, b, w), where a, b, w are the synthesis temperature (°C), synthesis time (h), and molar ratio of the H_2O/SiO_2 in the gel, respectively.

The synthesized HZSM-5 catalysts, which used NH_4F as a mineralizing agent, were chosen to be the tested sample also. As mentioned previously, the synthesized HZSM-5 catalysts obtained at 120 °C for 72 h is designated as HZ5-F1(w), obtained at 140 °C for 72 h is designated as HZ5-F2(w) , and obtained at 170 °C for 42 h is designated HZ5-F3(w). The characterizations are described below.

Result & Disscusion

E.1 X-ray Diffraction

The XRD patterns of ZSM-5 obtained at different conditions are shown in Figure E1, the crystallinity and purity of ZSM-5 zeolite synthesized under H_2O/SiO_2 in the gel condition over 20 are rather than that as H_2O/SiO_2 below 20. The figure E1(d) clearly showed the specific peaks of ZSM-5 zeolite at H_2O/SiO_2 of 30 provided higher peaks of ZSM-5 than ZSM-5 zeolite halving H_2O/SiO_2 of 20. According to Gu *et al.* (2009), when the H_2O/SiO_2 ratio is too low (<20), the viscosity of the aluminosilicate gel would be too dense for substrates to diffuse freely and/or interact to each other, leading to the failed formation of ZSM-5. Although, it can not absolutely conclude that H_2O/SiO_2 in the gel condition over 20 is the best, however, it still has the other factors could also affect the formation of ZSM-5, in the case of 130-24-30, having the H_2O/SiO_2 ratio over than 20 is still not sufficient to promote the formation of ZSM-5. Therefore, it reveals that the other factors encouraging the formation of ZSM-5 such as synthesis temperature and time would be concerned also. Kim and Ahn (1991) pointed that the reaction temperature strongly affects the nucleation process and crystal growth process. The higher the

temperature, bigger the energy can enhance concentration of each chemical group in sol, and it is also beneficial to crystalline. According to Figure E1(e) and E1(f) that the higher the temperature and time will provide the higher intensity peak.

By comparison of different mineralizing agents for HZSM-5 synthesis methods, Figure E1(g) shows the peak intensity of HZSM-5 using NH_4F as a mineralizing agent, it behaves the highest intensity peak. The increase in the XRD peak intensity of HZSM-5 is most probably due to the much larger crystals.

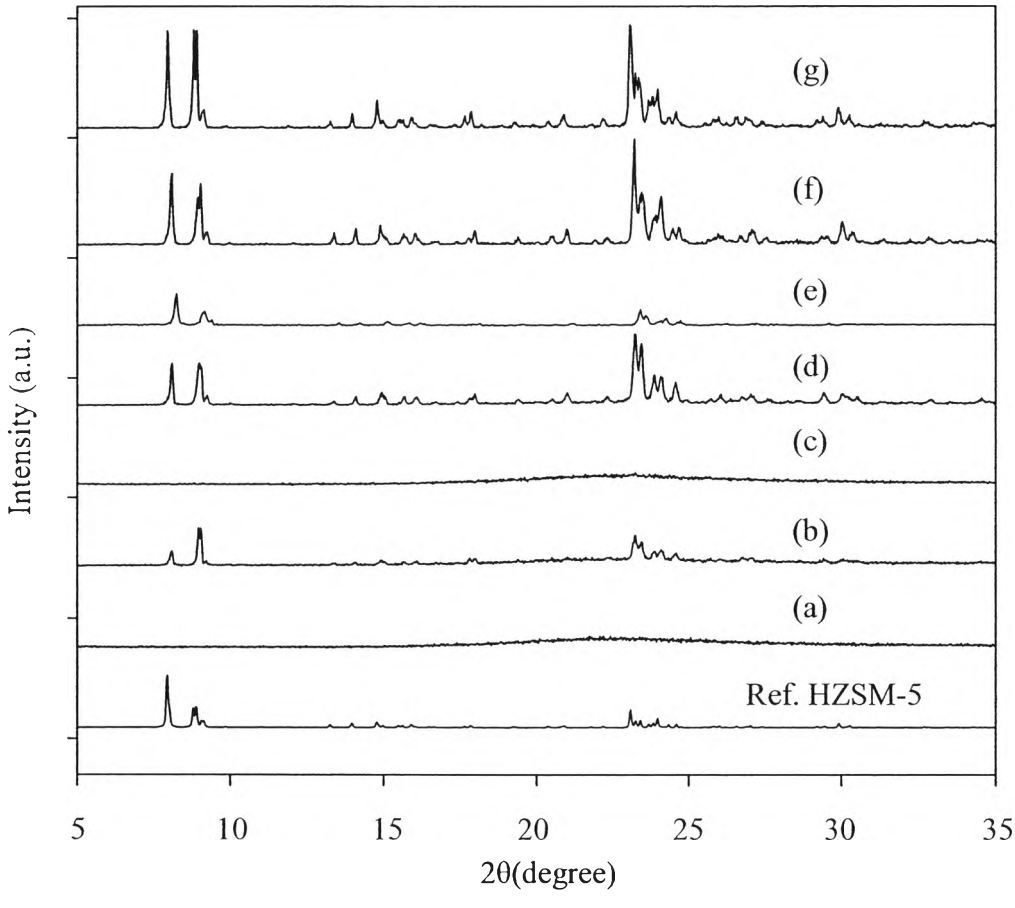

Figure E1 XRD patterns of the synthesized catalysts: (a) Z5-(120, 48, 20), (b) Z5-(140, 72, 20), (c) Z5-(130, 24, 30), (d) Z5-(140, 72, 30), (e) Z5-(110, 240, 82), (f) Z5-(130, 240, 82), and (g) HZ5-F3(33) .

E.2 Scanning Electron Microscopy (SEM)

Figure E2 shows the SEM images of ZSM-5 at various H_2O/SiO_2 ratio. It was observed that at H_2O/SiO_2 ratio of 20, the product was clearly incomplete ZSM-5 (Figure E2(a) and E2(b)), its skin surface have many clusters of smaller crystals like a nano-sized crystal, it may be affected by increasing the rate of nucleation by aging step (Stirred for 24 h at room temperature), moreover, the synthesis time providing to the system might be too low, which that affected to appear incomplete form of ZSM-5. According to Mochizuki *et al.* (2011), the pre-aging process with short time did not give nano-sized crystals. This is probably because such conditions do not enhance the nucleation before the crystallization process, resulting in the larger-sized crystals. In contrast, long time and/or high temperature pre-aging process enhance the nucleation during the crytallization, resulting in the smaller-sized crystals.

The SEM photographs of the ZSM-5 catalysts synthesized with synthesis temperatures of 110 °C and 130 °C h for synthesis time of 240 h are shown in Figure E2(c) and (d). As both of them, the unidentified amorphous solids of irregular shape and crystalline were found. It represents that the ZSM-5 zeolite could not be produced under too high water content, Kim et al. (Shin et al., 2004) pointed out that the lower water content is, the faster the crystallization. It indicates that short distance between nutrients in the solution should have enhanced the nucleation and thus crystallization. On the other hand, too high water content could provide long distance between nutrients in the solution affecting to reduction of the nucleation and thus crystallization.

The morphology of prismatic structure, Figures. E3(a) – E3(a), is seen in the SEM images of HZSM-5 synthesized by NH_4F. It indicates that the crystal size of those catalysts is much larger in length than the HZSM-5 synthesized by NaOH method corresponding to the results from XRD, as mentioned previously.

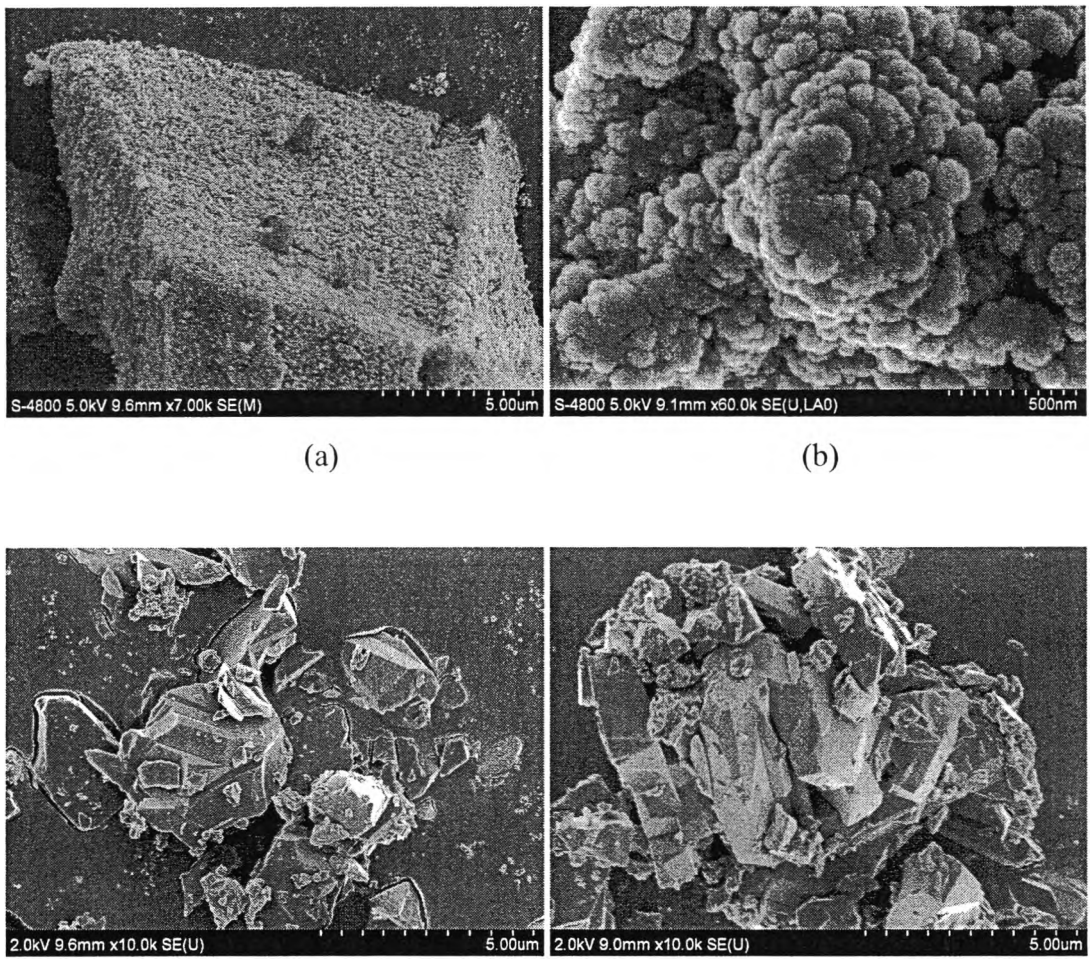

Figure E2 SEM images of the synthesized ZSM-5 catalysts using NaOH as a mineralizing agent : (a) Z5-(120, 48, 20), (b) Skin surface of Z5-(120, 48, 20), (c) Z5-(110, 240, 82), and (d) Z5-(130, 240, 82).

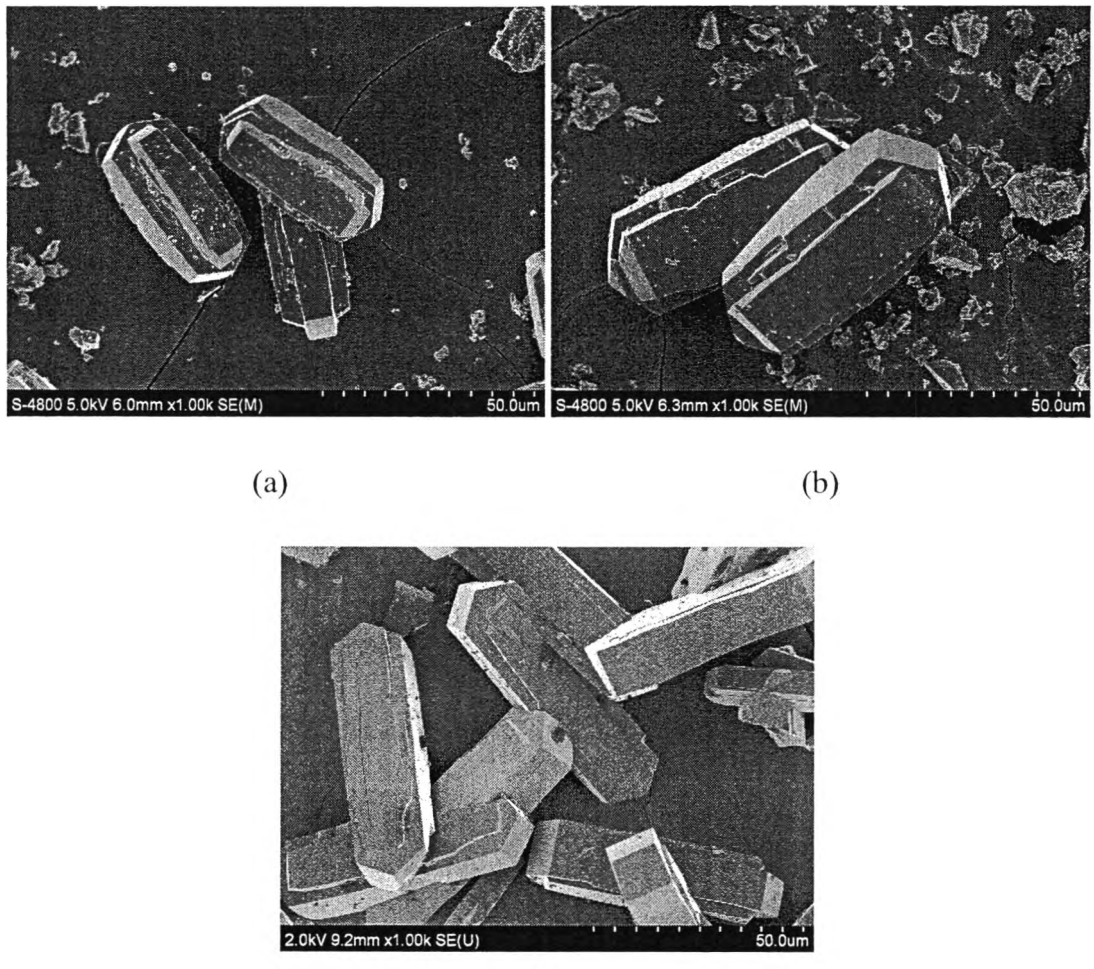

Figure E3 SEM images of the synthesized HZSM-5 catalysts using NH_4F as a mineralizing agent : (a) HZ5-F1(25), (b) HZ5-F2(25), and (c) HZ5-F3(33).

E.3 Catalyst composition

The chemical compositions of synthesized HZSM-5 catalysts are analyzed by X-ray fluorescence (XRF) technique. The results are summarized in Table E1. For the NaOH utilization, it is notice that the SiO_2/Al_2O_3 of ca.195 for both case of H_2O/SiO_2 of 20 and 30. So, it can be roughly concluded that for the NaOH utilization, the effect of H_2O/SiO_2 ratio to the catalyst composition were not significant.

However, for the NH_4F utilization, it was observed that SiO_2/Al_2O_3 molar ratios of the HZSM-5 synthesized by NH_4F utilization clearly fluctuate, rather much higher than the target value of 195, which this can interpret in term of element incorporated into the structure that the Al values in the crystals are lower than those having in the total available amount of aluminum in the initial gel corresponding to Aienllo *et al.* (1999), they found that high NH_4^+ concentrations in the gel not prefer the aluminum incorporation affecting to fail to archive a desirable SiO_2/Al_2O_3 ratio of 195.

Table E1 The chemical compositions of synthesized HZSM-5 catalysts

Catalyst	Compound (mol %)			Si/Al	SiO_2/Al_2O_3
	Si	Al	Na		
Z5-(140, 72, 20)	98.226	1.021	0.753	96	192
Z5-(140, 72, 30)	98.286	1.103	0.611	89	178
HZ5-F1(25)	100	nil.	nil.	n/a	n/a
HZ5-F2(25)	99.97	0.03	n/a	3201	6401
HZ5-F3(33)	99.918	0.082	n/a	1170	2341

E.4 Acidity Determination

The group of HZSM-5 synthesized by NH_4F was not found the amount of Brönsted acid site, it means that HZSM-5 synthesized by NH_4F method have insufficiently amount of Al in the structure to seize the proton [H^+] resulting in failure to detect the Brönsted acid site. The scarcity of the acid site in the group of HZSM-5 synthesized by NH_4F utilization is a weakness of this method, it well known that acid site is the origin of active species of reactant such as carbenium ion, the shortage of acid site affects to form much less carbenium ion, as resulting in low benzene conversion.

Appendix F Experimental Data of Catalytic Activity Test for Ethylation of Benzene with Ethanol over synthesized HZSM-5 Catalyst.

Table F1 Catalytic activity testing over HZSM-5 with different synthesis at temperature 500 °C, B/E = 4, WHSV = 20 h^{-1}.

Component	catalyst	Conversion (%)						
		15 min	60 min	130 min	200 min	270 min	340 min	410 min
Benzene	HZ5-A1(25)	4.26	7.33	8.49	10.18	9.98	6.25	5.79
	HZ5-A2(25)	6.68	7.74	9.39	8.41	7.95	9.22	7.50
	HZ5-A3(25)	1.21	1.36	4.22	3.28	2.23	2.81	3.00
	HZ5-B1(25)	3.88	4.94	6.00	8.14	9.06	8.35	8.33
	HZ5-B2(25)	3.45	4.31	5.43	4.29	3.86	4.09	3.28
	HZ5-B3(25)	7.32	7.01	6.69	7.07	8.07	7.66	8.78
	HZ5-B2(40)	5.98	6.34	5.89	6.00	7.74	8.41	9.21
	HZ5-F1(25)	1.80	1.75	0.68	0.77	3.02	2.39	1.88
	HZ5-F2(25)	3.50	2.61	4.85	2.33	1.19	2.28	0.50
	HZ5-F3(33)	0.61	3.25	1.84	1.94	2.23	1.85	4.53
Ethanol	HZ5-A1(25)	99.97	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-A2(25)	99.98	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-A3(25)	99.99	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-B1(25)	99.96	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-B2(25)	99.99	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-B3(25)	99.98	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-B2(40)	99.99	99.99	99.99	99.99	99.99	99.99	99.99
	HZ5-F1(25)	99.82	99.89	99.86	99.75	99.79	99.69	99.76
	HZ5-F2(25)	99.93	99.91	99.96	99.95	99.97	99.95	99.95
	HZ5-F3(33)	99.99	99.99	99.99	99.99	99.99	99.99	99.99

Table F2 Catalytic activity testing on different temperature for HZ5-A2(25), B/E = 4, WHSV = 20 h^{-1}.

Component	Temperature (°C)	Conversion (%)						
		15 min	60 min	130 min	200 min	270 min	340 min	410 min
Benzene	300	6.13	10.85	6.00	7.36	7.49	8.39	5.70
	400	8.22	11.13	11.51	13.25	10.73	11.66	12.27
	500	6.68	7.74	9.39	8.41	7.95	9.22	7.50
	600	3.23	3.56	3.52	3.69	3.79	3.57	3.70
Ethanol	300	99.96	99.99	99.99	99.99	99.99	99.99	99.99
	400	99.99	99.99	99.99	99.99	99.99	99.99	99.99
	500	99.98	99.99	99.99	99.99	99.99	99.99	99.99
	600	99.95	99.99	99.99	99.99	99.99	99.99	99.99

Table F3 Catalytic activity testing on different feed molar ratio for HZ5-A2(25), WHSV = 20 h^{-1}, T = 500 °C.

Component	B/E (mol/mol)	Conversion (%)						
		15 min	60 min	130 min	200 min	270 min	340 min	410 min
Benzene	1	10.19	10.98	12.65	12.95	12.67	13.13	12.11
	2	7.32	14.32	12.24	12.09	11.23	10.07	10.28
	4	6.68	7.74	9.39	8.41	7.95	9.22	7.50
Ethanol	1	99.99	99.99	99.99	99.99	99.99	99.99	99.99
	2	99.97	99.99	99.99	99.99	99.92	99.99	99.99
	4	99.98	99.99	99.99	99.99	99.99	99.99	99.99

Table F4 Catalytic activity testing on different feed ratio for HZ5-A2(25), B/E = 4, T = 500 °C.

Component	WHSV (h^{-1})	Conversion (%)						
		15 min	60 min	130 min	200 min	270 min	340 min	410 min
Benzene	10	14.45	13.43	17.39	13.89	18.64	20.65	17.62
	20	6.68	7.74	9.39	8.41	7.95	9.22	7.50
Ethanol	10	99.98	99.99	99.99	99.99	99.99	99.99	99.99
	20	99.98	99.99	99.99	99.99	99.99	99.99	99.99

Table F5 Product selectivity of liquid sample over HZSM-5 with different synthesis at temperature 500 °C, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min.

Component	Product selectivity (wt%)				
	HZ5-A1(25)	HZ5-A2(25)	HZ5-A3(25)	HZ5-B1(25)	HZ5-B2(25)
ethylene	0.07	0.12	0.10	0.07	0.06
methanol	0.01	0.03	0.03	0.01	0.01
toluene	0.27	0.24	0.28	0.24	0.23
EB	94.56	94.91	94.55	94.63	94.62
m-xylene	0.15	0.18	0.24	0.23	0.21
xylene	1.34	1.21	1.30	1.27	1.28
o-xylene	-	-	-	-	-
cumene	0.04	0.04	0.06	0.05	0.04
propyl-benzene	0.06	0.06	0.06	0.09	0.06
p-ethyl toluene	0.05	0.03	0.06	0.04	0.03
o-ethyl toluene	0.04	0.04	0.10	0.07	0.06
1,2,3-trimethylbenzene	0.07	0.04	0.07	0.05	0.04
(2-methylpropyl)-benzene	0.01	0.02	0.03	0.04	0.02
(1-methylpropyl)-benzene	0.12	0.10	0.16	0.14	0.12
indane	0.12	0.12	0.18	0.16	0.18
1-propenyl benzene	0.04	0.04	0.08	0.07	0.05
1,3-diethylbenzene	0.67	0.77	0.68	0.70	0.81
1,4-diethylbenzene	1.83	1.64	1.53	1.61	1.70
1,2-diethylbenzene	0.06	0.04	0.04	0.04	0.04
2-butenylbenzene	0.07	0.07	0.09	0.08	0.08
1-butenylbenzene	0.11	0.10	0.11	0.10	0.11
1-ethyl-3-(1-methylethyl)-benzene	-	-	-	-	-

Table F5 Product selectivity of liquid sample over HZSM-5 with different synthesis at temperature 500 °C, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min. (Continued)

Component	Product selectivity (wt%)				
	HZ5-A1(25)	HZ5-A2(25)	HZ5-A3(25)	HZ5-B1(25)	HZ5-B2(25)
1-ethyl-4-(1-methylethyl)-benzene	-	-	-	-	-
1-methyl-4-(1-methylpropyl)-Benzene	-	-	-	-	-
1-butynyl-benzene	-	-	-	0.06	-
1-methyl-1H-Indene	0.06	0.04	0.06	0.04	0.04
1,2-dihydro-Naphthalene	0.07	0.06	0.07	0.07	0.07
1,2,3,4-tetrahydronaphthalene	0.05	0.03	0.03	0.03	0.05
naphthalene	0.05	0.03	0.05	0.04	0.03
(1-ethyl-1-propenyl)-Benzene	0.01	-	0.01	0.03	0.02
2-methyl-Naphthalene	0.04	0.03	0.03	0.04	0.03
Total	100.00	100.00	100.00	100.00	100.00

Table F6 Product selectivity of liquid sample over HZSM-5 with different synthesis at temperature 500 °C, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min.

Component	Product selectivity (wt%)				
	HZ5-B3(25)	HZ5-B2(40)	HZ5-F1(25)	HZ5-F2(25)	HZ5-F3(33)
ethylene	0.02	0.06	1.11	0.72	0.32
methanol	-	0.01	0.23	0.17	0.10
toluene	0.25	0.24	1.78	1.57	0.87
EB	94.78	94.30	93.06	91.68	93.88
m-xylene	0.23	0.26	0.15	0.10	0.14
xylene	1.44	1.44	0.25	0.17	0.34
o-xylene	-	-	-	-	-
cumene	0.04	0.03	0.12	-	0.08
propyl-benzene	0.07	0.06	0.14	-	0.04
p-ethyl toluene	0.05	0.04	0.11	0.06	0.16
o-ethyl toluene	0.05	0.06	0.28	0.34	0.20
1,2,3-trimethylbenzene	0.06	0.04	0.10	0.05	0.17
(2-methylpropyl)-benzene	0.01	0.03	-	-	-
(1-methylpropyl)-benzene	0.13	0.10	0.11	0.11	0.37
indane	0.18	0.19	0.08	-	0.13
1-propenyl benzene	0.07	0.05	0.09	-	0.07
1,3-diethylbenzene	0.73	1.29	0.13	0.10	0.24
1,4-diethylbenzene	1.46	1.40	1.52	0.10	2.70
1,2-diethylbenzene	0.03	0.04	0.07	4.63	0.03
2-butenylbenzene	0.08	0.09	0.11	-	-
1-butenylbenzene	0.08	0.07	0.07	0.07	0.05
1-ethyl-3-(1-methylethyl)-benzene	-	-	-	-	-

Table F6 Product selectivity of liquid sample over HZSM-5 with different synthesis at temperature 500 °C, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min. (Continued)

Component	Product selectivity (wt%)				
	HZ5-B3(25)	HZ5-B2(40)	HZ5-F1(25)	HZ5-F2(25)	HZ5-F3(33)
1-ethyl-4-(1-methylethyl)-benzene	-	-	-	-	0.10
1-methyl-4-(1-methylpropyl)-Benzene	-	-	-	-	-
1-butynyl-benzene	-	-	-	-	-
1-methyl-1H-Indene	0.03	0.05	0.05	-	-
1,2-dihydro-Naphthalene	0.07	0.05	0.04	0.03	-
1,2,3,4-tetrahydronaphthalene	0.02	0.04	0.10	0.05	-
naphthalene	0.03	0.03	0.05	-	-
(1-ethyl-1-propenyl)-Benzene	0.03	0.02	0.05	-	-
2-methyl-Naphthalene	0.03	0.02	0.18	0.05	-
Total	100.00	100.00	100.00	100.00	100.00

Table F7 Product selectivity of liquid sample over HZ5-A2(25) at different temperature, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min.

Component	Product selectivity (wt%)			
	300 (°C)	400 (°C)	500 (°C)	600 (°C)
ethylene	0.14	0.06	0.12	0.17
methanol	0.03	0.01	0.03	0.07
toluene	0.37	0.15	0.24	2.28
EB	84.60	88.77	94.91	79.58
m-xylene	0.20	0.12	0.18	0.98
xylene	0.12	0.25	1.21	11.40
o-xylene	-	-	-	-
cumene	1.59	0.06	0.04	0.08
propyl-benzene	0.18	0.07	0.06	0.15
p-ethyl toluene	0.71	0.07	0.03	0.05
o-ethyl toluene	0.02	0.03	0.04	0.28
1,2,3-trimethylbenzene	0.05	0.02	0.04	0.21
(2-methylpropyl)-benzene	1.07	0.01	0.02	0.03
(1-methylpropyl)-benzene	0.06	0.04	0.10	0.47
indane	0.02	0.03	0.12	1.30
1-propenyl benzene	0.01	0.01	0.04	0.97
1,3-diethylbenzene	1.17	3.02	0.77	0.18
1,4-diethylbenzene	9.25	7.06	1.64	0.35
1,2-diethylbenzene	-	0.04	0.04	0.06
2-butenylbenzene	0.07	0.03	0.07	0.09
1-butenylbenzene	-	0.05	0.10	0.14
1-ethyl-3-(1-methylethyl)-benzene	0.05	-	-	0.04

Table F7 Product selectivity of liquid sample over HZ5-A2(25) at different temperature, B/E = 4, WHSV = 20 h^{-1}, and TOS 410 min. (Continued)

Component	Product selectivity (wt%)			
	300 (°C)	400 (°C)	500 (°C)	600 (°C)
1-ethyl-4-(1-methylethyl)-benzene	0.06	-	-	0.07
1-methyl-4-(1-methylpropyl)-Benzene	0.02	0.01	-	0.04
1-butynyl-benzene	0.05	0.01	-	0.01
1-methyl-1H-Indene	-	0.01	0.04	0.24
1,2-dihydro-Naphthalene	0.08	0.02	0.06	0.31
1,2,3,4-tetrahydronaphthalene	-	0.02	0.03	0.09
naphthalene	-	0.01	0.03	0.19
(1-ethyl-1-propenyl)-Benzene	0.05	0.02	-	0.04
2-methyl-Naphthalene	0.02	0.01	0.03	0.12
Total	100.00	100.00	100.00	100.00

Table F8 Product selectivity of liquid sample over HZ5-A2(25) at different feed molar ratio of B/E, Temperature 500 °C, WHSV = 20 h^{-1}, and TOS 410 min.

Component	Product selectivity (wt%)		
	B/E=1	B/E=2	B/E=4
ethylene	0.08	0.10	0.12
methanol	0.03	0.03	0.03
toluene	0.15	0.19	0.24
EB	90.46	93.40	94.91
m-xylene	0.22	0.22	0.18
xylene	0.51	0.79	1.21
o-xylene	-	-	-
cumene	0.05	0.04	0.04
propyl-benzene	0.10	0.08	0.06
p-ethyl toluene	0.06	0.04	0.03
o-ethyl toluene	0.04	0.04	0.04
1,2,3-trimethylbenzene	0.04	0.04	0.04
(2-methylpropyl)-benzene	0.02	0.02	0.02
(1-methylpropyl)-benzene	0.11	0.10	0.10
indane	0.14	0.14	0.12
1-propenyl benzene	0.02	0.03	0.04
1,3-diethylbenzene	2.30	1.48	0.77
1,4-diethylbenzene	5.31	2.94	1.64
1,2-diethylbenzene	0.06	0.06	0.04
2-butenylbenzene	0.06	0.06	0.07
1-butenylbenzene	0.09	0.07	0.10
1-ethyl-3-(1-methylethyl)-benzene	0.01	0.01	-

Table F8 Product selectivity of liquid sample over HZ5-A2(25) at different feed molar ratio of B/E, Temperature 500 °C, WHSV = 20 h^{-1}, and TOS 410 min. (Continued)

Component	Product selectivity (wt%)		
	B/E=1	B/E=2	B/E=4
1-ethyl-4-(1-methylethyl)-benzene	0.01	0.01	-
1-methyl-4-(1-methylpropyl)-Benzene	0.01	0.01	-
1-butynyl-benzene	0.02	0.02	-
1-methyl-1H-Indene	0.02	0.01	0.04
1,2-dihydro-Naphthalene	0.03	0.02	0.06
1,2,3,4-tetrahydronaphthalene	0.01	0.03	0.03
naphthalene	0.01	0.02	0.03
(1-ethyl-1-propenyl)-Benzene	0.02	0.01	-
2-methyl-Naphthalene	0.02	0.01	0.03
Total	100.00	100.00	100.00

Table F9 Product selectivity of liquid sample over HZ5-A2(25) at different WHSV, Temperature 500 °C, B/E = 4, and TOS 410 min.

Component	Product selectivity (wt%)	
	WHSV = 10 h^{-1}	WHSV = 20 h^{-1}
ethylene	0.03	0.12
methanol	0.01	0.03
toluene	0.20	0.24
EB	91.59	94.91
m-xylene	0.17	0.18
xylene	3.19	1.21
o-xylene	-	-
cumene	0.03	0.04
propyl-benzene	0.06	0.06
p-ethyl toluene	0.05	0.03
o-ethyl toluene	0.08	0.04
1,2,3-trimethylbenzene	0.07	0.04
(2-methylpropyl)-benzene	0.01	0.02
(1-methylpropyl)-benzene	0.19	0.10
indane	0.24	0.12
1-propenyl benzene	0.16	0.04
1,3-diethylbenzene	0.96	0.77
1,4-diethylbenzene	2.06	1.64
1,2-diethylbenzene	0.04	0.04
2-butenylbenzene	0.15	0.07
1-butenylbenzene	0.19	0.10
1-ethyl-3-(1-methylethyl)-benzene	0.01	-

Table F9 Product selectivity of liquid sample over HZ5-A2(25) at different WHSV, Temperature 500 °C, B/E = 4, and TOS 410 min. (Continued)

Component	Product selectivity (wt%)	
	WHSV = 10 h^{-1}	WHSV = 20 h^{-1}
1-ethyl-4-(1-methylethyl)-benzene	0.02	-
1-methyl-4-(1-methylpropyl)-Benzene	0.01	-
1-butynyl-benzene	-	-
1-methyl-1H-Indene	0.08	0.04
1,2-dihydro-Naphthalene	0.14	0.06
1,2,3,4-tetrahydronaphthalene	0.05	0.03
naphthalene	0.09	0.03
(1-ethyl-1-propenyl)-Benzene	0.03	-
2-methyl-Naphthalene	0.05	0.03
Total	100.00	100.00

Appendix G Calculation of the minimum ratio the bed length to the particle size

$$\frac{L_b}{d_p} > \frac{8n}{Pe_p} \ln\left(\frac{1}{1-x}\right)$$

L_b= length of bed

d_p = diameter of particle

Pe = Peclet number

n = order of reaction

x = conversion of reaction

Taking Pe_p = 0.5 for the low Reynolds region of interest for laboratory–scale operation .

Taking d_p = 0.05 cm for the particle sieve at mesh 20-40

Assume n = 1

If x = 0.4

$$\frac{L_b}{0.05} > \frac{8}{0.5} \ln\left(\frac{1}{1-0.4}\right)$$

$$L_b = 0.04 \text{ cm}$$

If x = 0.5

$$\frac{L_b}{0.05} > \frac{8}{0.5} \ln\left(\frac{1}{1-0.5}\right)$$

$$L_b = 0.55 \text{ cm}$$

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1. Rugwong, T., Rirksomboon, T., and Jongpatiwut, S. (2012, April 24) Ethylation of Benzene with Ethanol to Ethylbenzene Using Synthesized HZSM-5 Catalysts: Effects of Textural Properties and Acidity. Proceedings of 3rd Research Symposium on Petrochemical and Materials Technology and 18th PPC Symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand.