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APPENDICES

Appendix A Calculation of Catalysts Composition

The catalysts composition is calculated base on the Si/Al ratio of HZSM-5 equal to 20.

The formula of HZSM-5 with Si/Al ratio 20 is represented by $AlSi_{20}O_{42}H$.

The formula weight of HZSM-5 is 1260 g/mol.

The molecular weight of $InCl_3$ is 221 g/mol.

The catalysts was prepared base on 5 g of HZSM-5.

The weight of loaded $InCl_3$ is represented by

$$m = \frac{5 \times 221 \times n}{1260}$$

Where n = required In/Al ratio

m = weight of $InCl_3$ required

The prepared catalysts was using the composition as shown in Table A1.

Table A1 The ingredients of prepared catalysts

In/Al ratios	HZSM-5 (g)	$InCl_3$ (g)	Loading (wt. %)
0.1	5.00	0.0877	1.7
0.3	5.00	0.2631	5.0
0.5	5.00	0.4385	8.1
1.0	5.00	0.8770	14.9

Appendix B Calibration Data and Feed Flow Adjustment

The calibration curve and regression equation of raw materials and some products is shown below. The response factors used for calculate the products amount that derived from the slope of calibration curve is also shown.

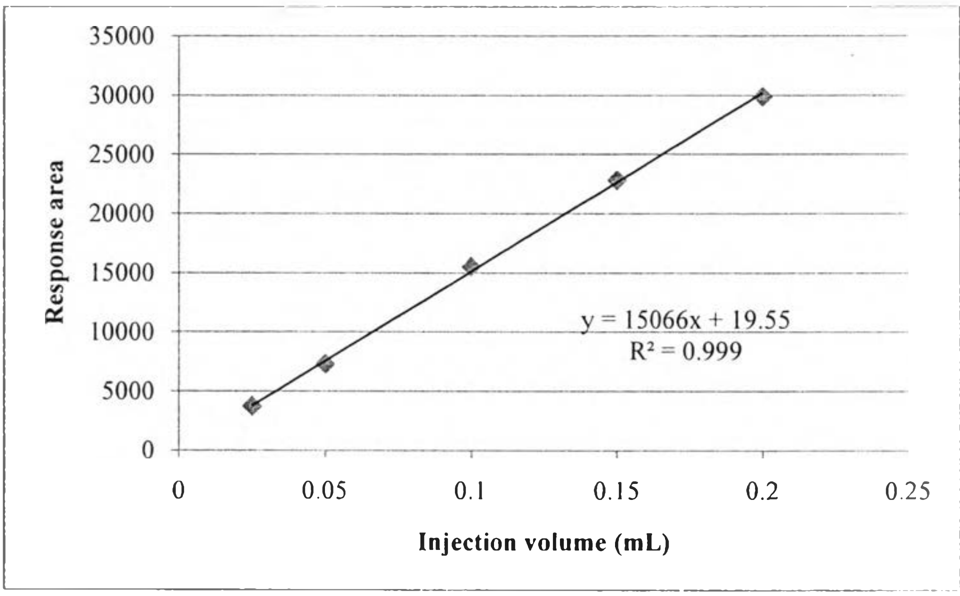

Figure B1 Response area from GC FID as a function of injection volume of methane.

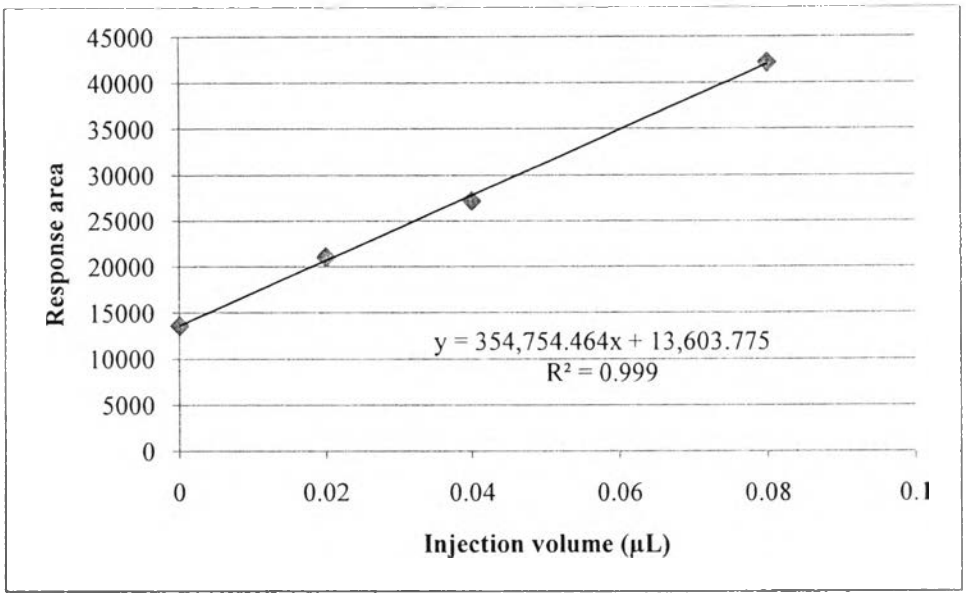

Figure B2 Response area from GC FID as a function of injection volume of benzene.

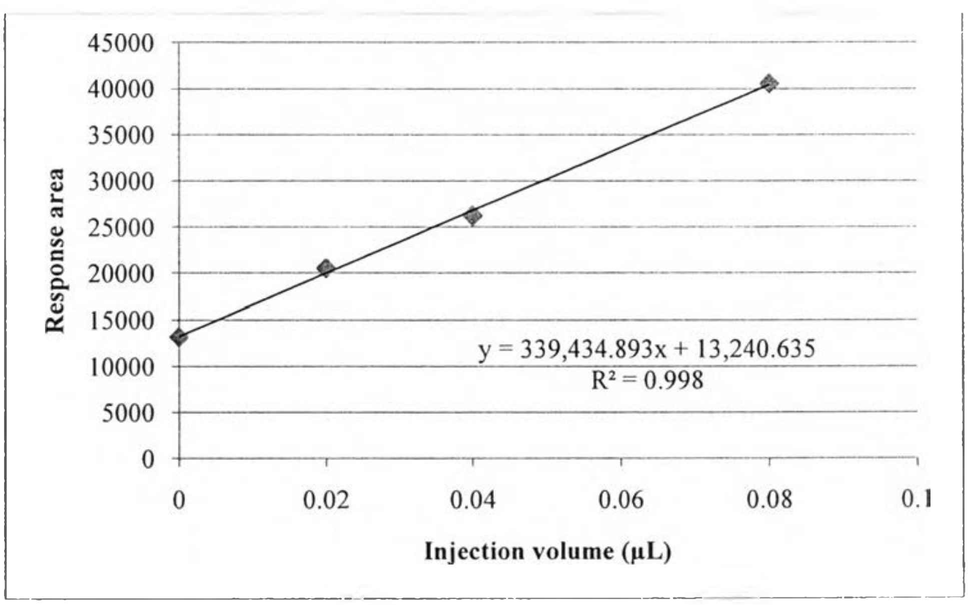

Figure B3 Response area from GC FID as a function of injection volume of toluene.

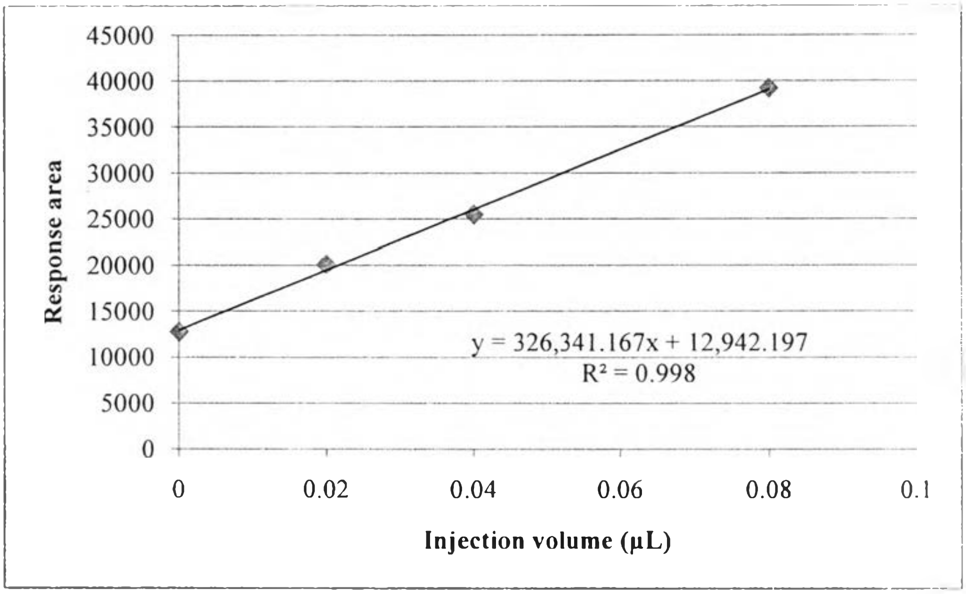

Figure B4 Response area from GC FID as a function of injection volume of *p*-xylene.

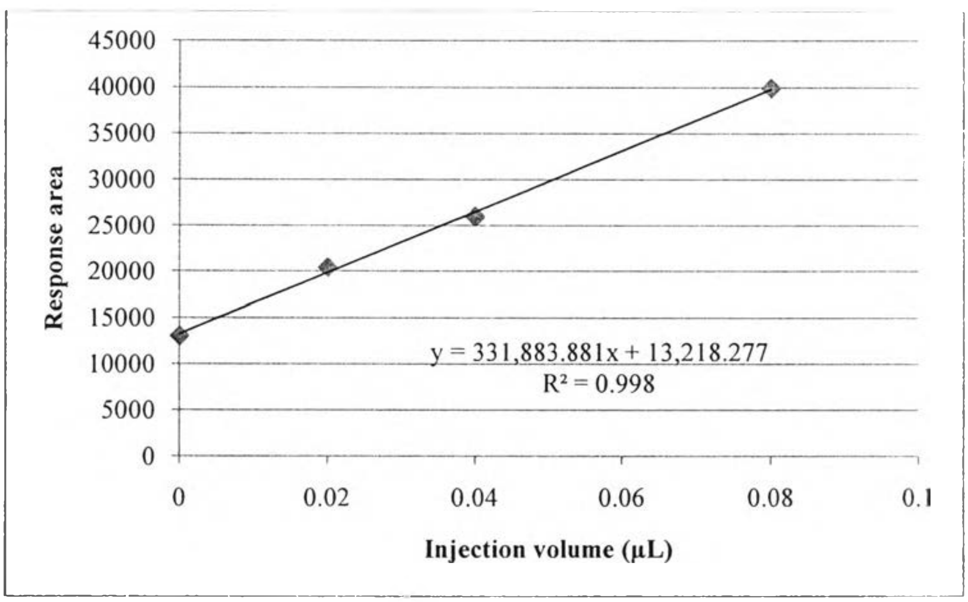

Figure B5 Response area from GC FID as a function of injection volume of *m*-xylene.

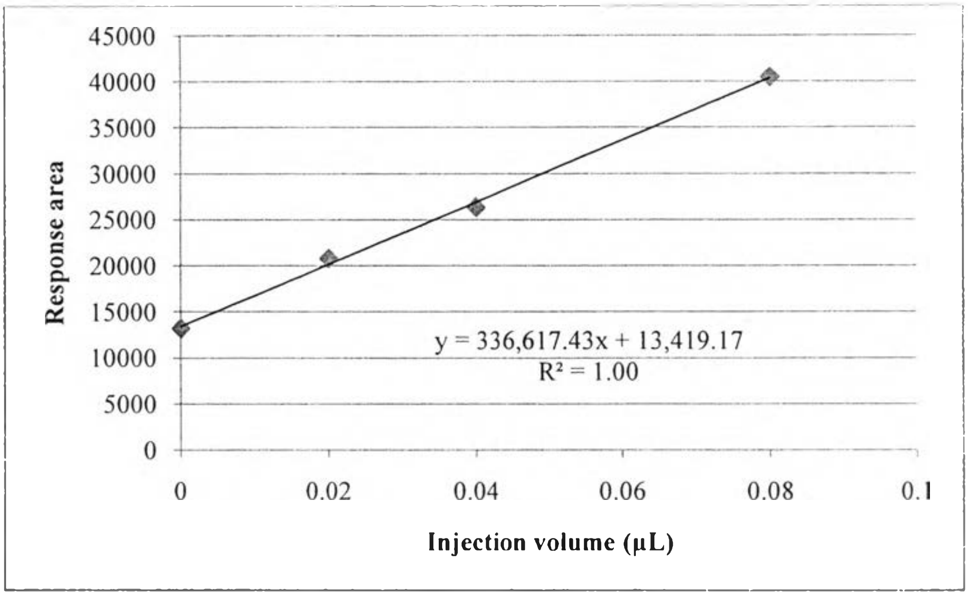

Figure B6 Response area from GC FID as a function of injection volume of *o*-xylene.

Table B1 The response factor calculated from calibration curve of each substances

Chemicals	Slope(Area/ml)	Density(g/ml)	(Area/g)	MW(g/mol)	Response factor (Area/mol)
Methane	150669	-	-	-	**3685027598**
Benzene	354754464	0.88	403130073	78	**31444145673**
Toluene	339434893	0.87	390155049	92	**35894264547**
p-Xylene	326341167	0.86	379466473	106	**40223446165**
m-Xylene	331883881	0.86	385911490	106	**40906617891**
o-Xylene	336617430	0.88	382519807	106	**40547099523**

The value of response factors calculated from the calibration curve that shown in Table B1 is further used in the products quantification for each chemical. For the non-calibrated chemicals found during the analysis would use the response factor of *p*-xylene to represent and calculate amount of that chemicals.

In the case of feed adjustment, the feed flow controller and catalyst weight in various reaction conditions is shown in Table B2.

Table B2 Flow controller adjustment and catalyst weight in various reaction conditions

Reaction condition		Flow controller adjustment (ml/min)		catalyst weight (g)
WHSV (h^{-1})	M/B feed ratio	Methane	Oxygen	
1.8	45	21.0	9.0	0.940
6.6	19	15.0	15.0	0.250
	45	21.0	9.0	
	105	25.5	4.5	
13.2	45	21.0	9.0	0.125

Appendix C Raw Data of Reaction Results

The reaction results as a raw data of GC FID peak area and calculated data are shown below.

Table C1 The results of the reaction with N_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 300 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	31792	6233.2	4.6	0	0	0.19836	0.00013	**0.065**	**100**	0
40	31932	6239.6	6.9	0	0	0.19863	0.00019	**0.097**	**100**	0
70	31825	6262.3	6.8	0	0	0.19935	0.00019	**0.095**	**100**	0
100	31763	6225.6	6.5	0	0	0.19817	0.00018	**0.091**	**100**	0
130	31774	6178.1	6.6	0	0	0.19666	0.00018	**0.093**	**100**	0
160	31561	6120.1	6.6	0	0	0.19482	0.00018	**0.094**	**100**	0

Table C2 The results of the reaction with N_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	32995	6515.8	76.1	0	0	0.20934	0.00212	**1.013**	**100**	0
40	33037	6486.9	51.9	0	0	0.20775	0.00145	**0.696**	**100**	0
70	33018	6656.5	39.8	0	0	0.21280	0.00111	**0.521**	**100**	0
100	32904	6566.4	31.7	0	0	0.20971	0.00088	**0.421**	**100**	0
130	32919	6566.6	28.4	0	0	0.20962	0.00079	**0.377**	**100**	0
160	33017	6643.6	26.1	0	0	0.21201	0.00073	**0.343**	**100**	0

Table C3 The results of the reaction with N_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 400 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	31875	5641.4	186.9	4.23	3.17	0.18480	0.00539	**2.917**	**96.604**	3.396
40	31893	5855.6	74	0	0.89	0.18831	0.00208	**1.107**	**98.938**	1.062
70	31960	5881.7	46	0	0	0.18833	0.00128	**0.680**	**100**	0
100	31606	5894.5	32.7	0	0	0.18837	0.00091	**0.484**	**100**	0
130	31729	5958.5	22.9	0	0	0.19013	0.00064	**0.336**	**100**	0
160	31837	5974.4	12.3	0	0	0.19034	0.00034	**0.180**	**100**	0

Table C4 The results of the reaction with O_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	32711	6672.9	51.1	0	0	0.21364	0.00142	**0.666**	**100**	0
40	32825	6668.7	42.1	0	0	0.21325	0.00117	**0.550**	**100**	0
70	32660	6741.6	37.9	0	0	0.21546	0.00106	**0.490**	**100**	0
100	32600	6627.3	34.1	0	0	0.21171	0.00095	**0.449**	**100**	0
130	32571	6719.1	31.6	0	0	0.21456	0.00088	**0.410**	**100**	0
160	32780	6735.2	29.6	0	0	0.21502	0.00082	**0.384**	**100**	0

Table C5 The results of the reaction with H_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33058	6282.5	13.5	0	0	0.20017	0.00038	**0.188**	**100**	0
40	32940	6249.7	12.4	0	0	0.19910	0.00035	**0.174**	**100**	0
70	32888	6420.4	8.9	0	0	0.20443	0.00025	**0.121**	**100**	0
100	32662	6417.7	6.7	0	0	0.20429	0.00019	**0.091**	**100**	0
130	32898	6457	5.8	0	0	0.20551	0.00016	**0.079**	**100**	0
160	32884	6420.1	4.6	0	0	0.20430	0.00013	**0.063**	**100**	0

Table C6 The results of the reaction with H_2 treatment at 350 °C followed by O_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33111	6543.7	95.6	0	9.7	0.21101	0.00290	**1.376**	**91.697**	8.303
40	33133	6801.1	20.6	0	0	0.21687	0.00057	**0.265**	**100**	0
70	33120	6750.6	11.2	0	0	0.21500	0.00031	**0.145**	**100**	0
100	33241	6800.7	7.7	0	0	0.21649	0.00021	**0.099**	**100**	0
130	33006	6688.8	5.9	0	0	0.21288	0.00016	**0.077**	**100**	0
160	33023	6702.5	5	0	0	0.21330	0.00014	**0.065**	**100**	0

Table C7 The results of the reaction with N_2 treatment at 450 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33007	6630.9	46.4	0	0	0.21217	0.00129	**0.609**	**100**	0
40	33239	6716.9	37	0	0	0.21464	0.00103	**0.480**	**100**	0
70	33090	6790.9	33.2	0	0	0.21689	0.00092	**0.426**	**100**	0
100	32970	6812.8	30.1	0	0	0.21750	0.00084	**0.386**	**100**	0
130	32987	6701	28	0	0	0.21389	0.00078	**0.365**	**100**	0
160	32906	6574.5	25.7	0	0	0.20980	0.00072	**0.341**	**100**	0

Table C8 The results of the reaction with O_2 treatment at 450 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33044	6710.5	68	0	0	0.21530	0.00189	**0.880**	**100**	0
40	33118	6633.4	50.7	0	0	0.21237	0.00141	**0.665**	**100**	0
70	33052	6634.8	41.1	0	0	0.21215	0.00115	**0.540**	**100**	0
100	33083	6688.9	35.5	0	0	0.21371	0.00099	**0.463**	**100**	0
130	32975	6644.9	31.3	0	0	0.21220	0.00087	**0.411**	**100**	0
160	32961	6695.4	28.6	0	0	0.21373	0.00080	**0.373**	**100**	0

Table C9 The results of the reaction with H_2 treatment at 450 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33248	6542.5	14.9	0	0	0.20848	0.00042	**0.199**	**100**	0
40	33319	6649.8	6	0	0	0.21165	0.00017	**0.079**	**100**	0
70	33139	6550.6	4.4	0	0	0.20845	0.00012	**0.059**	**100**	0
100	33079	6558.4	3.7	0	0	0.20868	0.00010	**0.049**	**100**	0
130	33001	6513.3	3.2	0	0	0.20723	0.00009	**0.043**	**100**	0
160	30002	6499.8	3	0	0	0.20679	0.00008	**0.040**	**100**	0

Table C10 The results of the reaction with H_2 treatment at 450 °C followed by O_2 treatment at 350 °C and N_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33164	6567.8	85.3	0	12.7	0.21156	0.00269	**1.273**	**88.272**	11.73
40	33191	6592.2	23.7	0	3.6	0.21040	0.00075	**0.356**	**88.063**	11.94
70	33016	6638.2	12.8	0	0	0.21147	0.00036	**0.169**	**100**	0
100	32934	6685.6	8.6	0	0	0.21286	0.00024	**0.113**	**100**	0
130	33182	6727.2	6.7	0	0	0.21413	0.00019	**0.087**	**100**	0
160	33004	6785.7	5.4	0	0	0.21595	0.00015	**0.070**	**100**	0

Table C11 The results of the reaction with N_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33118	6095	17.1	0	34.1	0.19516	0.00132	**0.679**	**35.977**	64.02
40	32879	5824	59.7	0	21.7	0.18742	0.00220	**1.175**	**75.525**	24.48
70	33019	6072.2	67	0	12.1	0.19528	0.00217	**1.110**	**86.111**	13.89
100	32973	6146.5	65.4	0	10.5	0.19756	0.00208	**1.054**	**87.468**	12.53
130	32740	6227.4	60.3	0	8.63	0.19994	0.00189	**0.948**	**88.675**	11.33
160	32581	6306.8	55.1	0	6.7	0.20227	0.00170	**0.841**	**90.211**	9.789

Table C12 The results of the reaction with O_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	32827	6316.4	34.7	0	32	0.20264	0.00176	**0.870**	**54.857**	45.14
40	33026	6287.1	56.5	0	27.4	0.20220	0.00226	**1.115**	**69.795**	30.21
70	32798	6242.5	50.7	0	18.7	0.20040	0.00188	**0.937**	**75.227**	24.77
100	32780	6354.2	44.6	0	11.9	0.20362	0.00154	**0.755**	**80.795**	19.21
130	32773	6351	42.3	0	8.4	0.20336	0.00139	**0.682**	**84.947**	15.05
160	32731	6553.8	40.9	0	8.3	0.20977	0.00135	**0.642**	**84.667**	15.33

Table C13 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	32974.8	4847.5	200.1	1.7	62.8	0.16134	0.00718	**4.449**	**77.661**	22.339
40	33044.2	5527.6	138.3	0	19	0.18012	0.00433	**2.401**	**89.079**	10.921
70	32967.8	5798.2	97.7	0	8.4	0.18733	0.00293	**1.564**	**92.874**	7.126
100	32851.7	5967.5	70.7	0	5.9	0.19190	0.00212	**1.103**	**93.069**	6.931
130	32972.3	6009.9	52.7	0	3.4	0.19268	0.00155	**0.806**	**94.556**	5.444
160	33125.1	6057.3	40.5	0	2.7	0.19383	0.00120	**0.617**	**94.385**	5.615

Table C14 The results of the reaction with H_2 treatment at 350 °C and 2% O_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33247	6351.6	85.5	1.05	5.39	0.20454	0.00254	**1.243**	**93.71**	6.29
40	33153	6492.5	70.9	0	5.03	0.20858	0.00210	**1.007**	**94.046**	5.954
70	33089	6466.6	62.8	0	5.46	0.20754	0.00189	**0.908**	**92.8**	7.200
100	33024	6489.3	47.6	0	5.2	0.20783	0.00146	**0.700**	**91.117**	8.883
130	33228	6512.3	42.8	0	5.3	0.20843	0.00132	**0.635**	**90.049**	9.951
160	33211	6555.8	40.5	0	5.3	0.20975	0.00126	**0.601**	**89.543**	10.46

Table C15 The results of the reaction with H_2 treatment at 350 °C and 21% O_2 carrier using In/Al ratio 0.5, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (µmol)	Total aromatic product (µmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33511	5919.5	126.7	0.9	46.7	0.19297	0.00471	**2.442**	**74.892**	25.11
40	33372	6062.3	118.3	0	36.7	0.19700	0.00421	**2.136**	**78.318**	21.68
70	33504	6115	106.6	0	22.5	0.19800	0.00353	**1.782**	**84.15**	15.85
100	33375	6189.1	91	0	15.6	0.19975	0.00292	**1.463**	**86.732**	13.27
130	33533	6261.7	76.6	0	12.2	0.20157	0.00244	**1.209**	**87.556**	12.44
160	33292	6208.1	64.4	0	9.6	0.19947	0.00203	**1.019**	**88.259**	11.74

Table C16 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 0.1, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (µmol)	Total aromatic product (µmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33373	5312.6	48.3	0	53.1	0.17162	0.00267	**1.553**	**50.478**	49.52
40	33357	5719.5	33.4	0	26.7	0.18349	0.00159	**0.869**	**58.365**	41.64
70	33183	5964.6	23.1	0	13.6	0.19067	0.00098	**0.515**	**65.557**	34.44
100	33252	6165.1	20.1	0	8.6	0.19684	0.00077	**0.393**	**72.369**	27.63
130	33388	6228.1	17.5	0	6.2	0.19871	0.00064	**0.323**	**75.979**	24.02
160	33237	6266.6	13.6	0	4.6	0.19979	0.00049	**0.247**	**76.815**	23.19

Table C17 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 0.3, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	25476	4052.7	69.1	0	66.4	0.13246	0.00358	**2.700**	**53.836**	46.16
40	25608	4411.8	52.2	0	33.6	0.14260	0.00229	**1.606**	**63.516**	36.48
70	25523	4623.6	38	0	10.8	0.14837	0.00133	**0.895**	**79.769**	20.23
100	25402	4525.1	27.1	0	6.6	0.14483	0.00092	**0.635**	**82.147**	17.85
130	25099	4557.9	19	0	4.2	0.14559	0.00063	**0.435**	**83.524**	16.48
160	25373	4632.9	13.8	0	2.6	0.14779	0.00045	**0.304**	**85.607**	14.39

Table C18 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 1.0, WHSV 6.6 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33345	5353.6	399.3	11.6	27.1	0.18234	0.01208	**6.628**	**92.053**	7.947
40	33386	5860.8	225.9	3.3	17.4	0.19320	0.00681	**3.524**	**92.441**	7.559
70	33343	5980.1	163.4	1.8	12	0.19508	0.00490	**2.509**	**92.992**	7.008
100	33177	6114	123.5	1.1	8.1	0.19811	0.00367	**1.852**	**93.767**	6.233
130	33468	6108.5	100.1	0.78	6.8	0.19724	0.00298	**1.509**	**93.67**	6.330
160	33129	6194.1	84	0	6.3	0.19948	0.00250	**1.252**	**93.727**	6.273

Table C19 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 1.0, WHSV 1.8 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	32526	3455.5	262.3	8.3	117	0.12031	0.01041	**8.655**	**70.177**	29.82
40	32828	4253	137.4	0	135	0.14245	0.00719	**5.050**	**53.209**	46.79
70	32935	4793.8	135.2	0	96.9	0.15863	0.00618	**3.893**	**60.991**	39.01
100	32812	5313.5	131.5	0	54.8	0.17401	0.00503	**2.888**	**72.893**	27.11
130	32868	5710.4	112.5	0	9.4	0.18497	0.00337	**1.821**	**93.061**	6.939
160	32582	5867.4	89.8	0	6.1	0.18925	0.00265	**1.402**	**94.285**	5.715

Table C20 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 1.0, WHSV 13.2 h^{-1} and methane to benzene feed ratio 45 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (μmol)	Total aromatic product (μmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	33364	5954.4	235.2	5.3	17	0.19647	0.00711	**3.617**	**92.199**	7.801
40	33239	6213.1	125.3	1.8	17.4	0.20156	0.00397	**1.969**	**87.971**	12.03
70	33355	6343.5	92.7	1	5.9	0.20449	0.00275	**1.347**	**93.771**	6.229
100	32952	6330.9	73.7	0	4.7	0.20351	0.00217	**1.066**	**94.616**	5.384
130	33233	6344	61.1	0	4	0.20356	0.00180	**0.885**	**94.48**	5.520
160	33202	6383.4	51.7	0	3	0.20452	0.00151	**0.741**	**95.077**	4.923

Table C21 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 1.0, WHSV 6.6 h^{-1} and methane to benzene feed ratio 19 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (µmol)	Total aromatic product (µmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	27071	10922	402.7	4.4	55.1	0.36003	0.01270	**3.527**	**88.351**	11.65
40	27174	11762	178.1	1.1	37.2	0.37996	0.00591	**1.557**	**83.892**	16.11
70	27218	12021	121.1	0	20.1	0.38617	0.00387	**1.003**	**87.077**	12.92
100	27110	12121	92.5	0	15.6	0.38846	0.00297	**0.763**	**86.897**	13.10
130	27107	12214	74.7	0	13.9	0.39086	0.00243	**0.621**	**85.76**	14.24
160	27173	12303	62.1	0	11.5	0.39327	0.00202	**0.513**	**85.818**	14.18

Table C22 The results of the reaction with H_2 treatment at 350 °C and 100% O_2 carrier using In/Al ratio 1.0, WHSV 6.6 h^{-1} and methane to benzene feed ratio 105 at reaction temperature 350 °C

Time on stream (min)	FID area					Total aromatic (µmol)	Total aromatic product (µmol)	Benzene conversion(%)	selectivity (%)	
	Reactants		Products							
	Methane	Benzene	Toluene	C8	C9+				Toluene	Other
10	36833	2326.1	287.5	15.4	7.6	0.08255	0.00858	**10.392**	**93.361**	6.639
40	36931	2523.4	217.6	6.4	10.2	0.08673	0.00647	**7.466**	**93.626**	6.374
70	36674	2611.8	174.6	4	7	0.08820	0.00514	**5.825**	**94.677**	5.323
100	36835	2680.2	145.8	2.9	5.1	0.08950	0.00426	**4.761**	**95.332**	4.668
130	36828	2709	124.1	2.1	4.5	0.08977	0.00362	**4.034**	**95.469**	4.531
160	36583	2698.1	105.5	1.6	3.1	0.08886	0.00306	**3.439**	**96.177**	3.824

Appendix D Raw Data of Catalysts Characterization

The temperature program desorption (TPD) characterization results is shown in Figure D1. The peak in the range of 150 to 200 °C represented to the weak Bronsted acid while the peak in the range of 220 to 300 °C represented to the strong Bronsted acid.

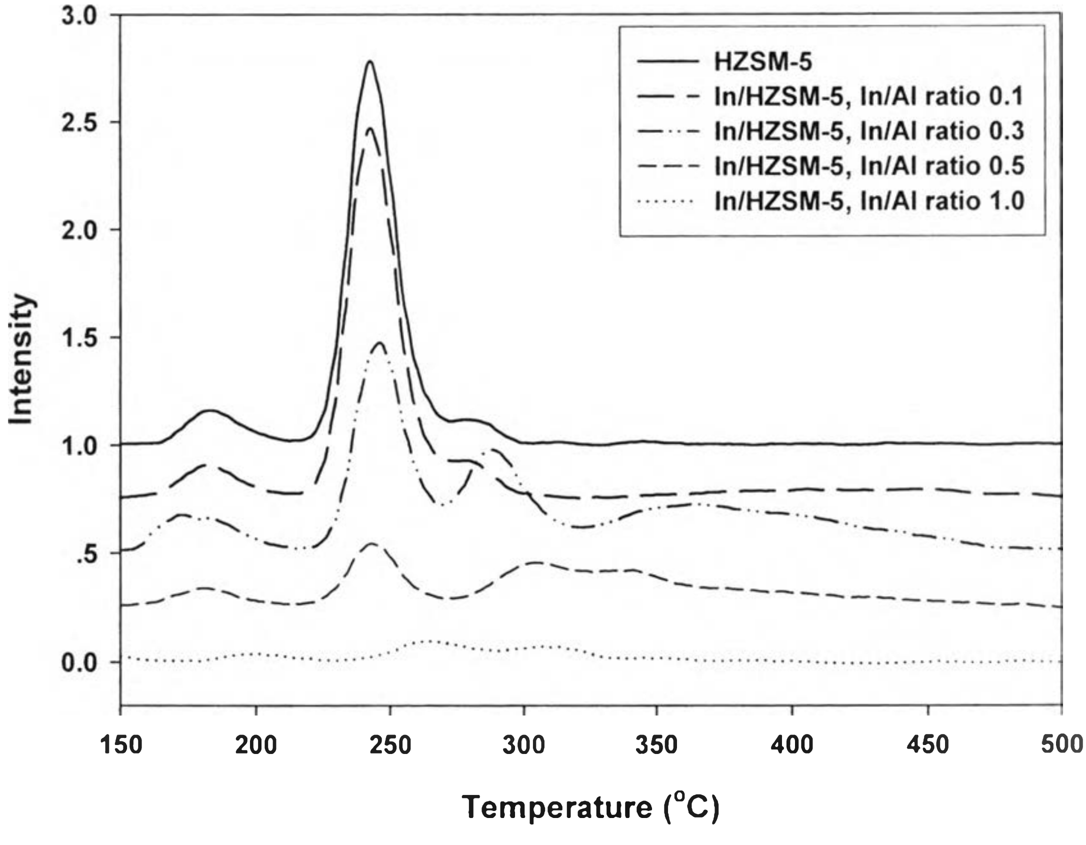

Figure D1 Temperature program desorption (TPD) profiles of catalyst with various In/Al ratios.

The desorption temperature and peak area, calculated from integration program (fityk) using Gaussian curve from obtained TPD profile, are shown in Table D1.

Table D1 Desorption temperature and peak area

	HZSM-5		In/Al ratio 0.1		In/Al ratio 0.3		In/Al ratio 0.5		In/Al ratio 1.0	
Acid sites	**Temp (°C)**	**Area**	**Temp (°C)**	**Area**	**Temp (°C)**	**Area**	**Temp (°C)**	**Area**	**Temp (°C)**	**Area**
	206.6	5.56	204.9	5.73	198.8	8.70	202.9	3.67	227.9	1.57
	284.4	42.65	284.6	42.56	288.9	29.27	285.6	8.66	314.9	3.69
	305.0	12.78	310.6	15.35	344.0	16.69	378.0	11.87	371.3	2.16
Weak acid		**5.56**		**5.73**		**8.70**		**3.67**		**1.57**
Strong acid		**55.43**		**57.91**		**45.96**		**20.53**		**5.85**
Total acid		**60.99**		**63.64**		**54.65**		**24.19**		**7.42**

The calculation of acidity from TPD peak area used the calibration factor from propylene to calculate.

The area of propylene per mole from the calibration is equal to 7.672×10^6

The weight of used catalysts is 0.0400 g.

The acidity of catalysts in μmol/g was calculated by

$$\text{Acidity } (\mu\text{mol/g}) = \frac{\text{Area}}{(7.672 \text{ area}/\mu\text{mol}) \times (0.0400 \text{ g})}$$

The acidity of the catalyst is already shown in Table 4.4.

The temperature program oxidation (TPO) characterization results are shown in Table D2.

The calibration factor was calculated by using CO_2 calibration.

The injection loop valve is 100 μL.

Mole of injected CO_2 calculated from ideal gas law.

$$n = \frac{(1\ \text{atm})\times(100\ \mu\text{L})}{(0.0821\ \text{atm.L/mol.K})\times(298\ \text{K})} = 4.087\ \mu\text{mol}$$

The calibration factor is represented by

$$\text{Calibration factor} = \frac{CO_2\ \text{area}}{4.087\ \mu\text{mol}}$$

The amount of carbon deposition determined by the area from TPO result divided by the calibration factor. Carbon deposition is calculated as the weight of carbon observed per weight of catalyst used.

Table D2 Calculation of carbon deposition from TPO

Spent catalyst carrier gas	TPO result (area)	CO_2 calibration (area)	Calibration factor (area/μmol)	Carbon (μmol)	Carbon (mg)	Spent catalyst used (mg)	Carbon deposition (%)
N_2	33059	16595	4060	8.142	0.0977	20.4	**0.48**
2% O_2	215948	16671	4079	52.95	0.6353	21.6	**2.94**
21% O_2	606698	14805	3622	167.5	2.010	20.2	**9.95**
100% O_2	745863	13201	3230	230.9	2.771	21.5	**12.89**

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1. Srisayan, T.; Jermwongratanachai, T.; Kitiyanan, B. and Apphakvan, T. (2012, April 24) Indium-Containing ZSM-5 Catalyst for Methylation of Benzene: Effect of Treatment and Co-feed. Proceedings of 3rd Research Symposium on Petrochemical and Materials Technology and 18th PPC Symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand.