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APPENDICES

Appendix A Product Distribution

Table A1 Effect of zeolites on product distribution (wt%)

-	Non-Catalyst	HBETA	HY	HMOR	KL
Gas	11.6	8.00	10.8	11.6	11.7
Liquid	46.0	43.3	42.6	43.8	43.5
Solid	42.4	41.6	42.2	41.6	41.5
Coke	-	7.03	4.49	3.02	3.27

Table A2 Effect of Cu-loaded catalysts on product distribution (wt%)

	Cu/HBETA	Cu/HY	Cu/HMOR	Cu/KL
Gas	12.3	13.0	12.1	15.8
Liquid	38.7	40.6	42.3	38.7
Solid	41.4	41.4	42.2	42.6
Coke	7.55	5.05	3.42	2.98

Table A3 Effect of Zn-loaded catalysts on product distribution (wt%)

	Zn/HBETA	Zn/HY	Zn/HMOR	Zn/KL
Gas	13.1	13.0	12.7	14.9
Liquid	39.8	39.8	42.7	40.7
Solid	42.0	42.3	42.1	42.4
Coke	5.10	4.83	2.44	2.00

Table A4 Effect of zeolites on product compositions (wt%)

	Non-Catalyst	**HBETA**	**HY**	**HMOR**	**KL**
Gas Products					
Methane	2.36	1.16	1.93	2.08	2.23
Ethylene	0.815	0.370	0.639	0.595	0.804
Ethane	1.88	0.878	1.48	1.74	1.86
Propylene	1.15	0.760	1.11	0.980	1.15
Propane	1.14	0.761	1.06	1.78	1.13
Mixed-C_4	2.66	2.68	2.73	2.65	2.66
Mixed-C_5	1.63	1.39	1.80	1.73	1.88
Total	11.6	8.00	10.8	11.6	11.7
Petroleum Products					
Full range naphtha	10.0	16.6	14.0	13.84	9.45
Kerosene	10.8	9.55	8.75	9.45	12.2
Light gas oil	9.25	7.40	7.13	7.32	8.36
Heavy gas oil	8.40	5.54	6.95	7.41	7.09
Long residue	7.41	4.14	5.68	5.67	6.30
Total	45.9	43.3	42.5	43.7	43.5
Others					
Asphaltene	0.0642	0.0511	0.0221	0.101	0.0622
Carbon Black	42.4	41.6	42.2	41.6	41.5
Coke	-	7.03	4.49	3.02	3.27

Table A5 Effect of Cu-loaded catalysts on product compositions (wt%)

	Cu/HBETA	**Cu/HY**	**Cu/HMOR**	**Cu/KL**
Gas Products				
Methane	1.83	2.12	2.43	3.12
Ethylene	0.59	0.86	0.58	1.13
Ethane	1.44	1.80	2.00	2.48
Propylene	1.12	1.46	1.02	1.59
Propane	1.18	1.27	1.64	1.46
Mixed-C_4	4.05	3.34	2.68	3.55
Mixed-C_5	2.11	2.10	1.73	2.44
Total	12.3	13.0	12.1	15.8
Petroleum Products				
Gasoline	2.70	7.29	12.1	5.90
Kerosene	14.0	10.92	12.4	13.4
Gas oil	15.3	14.68	11.6	12.1
LVGO	1.99	2.35	1.90	1.99
HVGO	4.67	5.34	4.31	5.29
Total	38.7	40.6	42.3	38.7
Others				
Asphaltene	0.0213	0.0227	0.0313	0.00936
Carbon Black	41.4	41.4	42.2	42.6
Coke	7.55	5.05	3.42	2.98

Table A6 Effect of Zn-loaded catalysts on product compositions (wt%)

	Zn/HBETA	Zn/HY	Zn/HMOR	Zn/KL
Gas Products				
Methane	2.11	2.72	2.6	2.88
Ethylene	0.765	0.852	0.768	1.09
Ethane	1.69	2.04	2.06	2.37
Propylene	1.36	1.38	1.26	1.52
Propane	1.21	1.24	1.26	1.4
Mixed-C_4	3.91	2.98	2.91	3.39
Mixed-C_5	2.07	1.84	1.87	2.27
Total	13.1	13.0	12.7	14.9
Petroleum Products				
Gasoline	13.5	14.7	14.2	6.66
Kerosene	11.9	13.1	12.2	14.3
Gas oil	9.37	8.53	10.9	13.0
LVGO	1.41	1.07	1.59	1.92
HVGO	3.64	2.38	3.76	4.86
Total	39.8	39.8	42.7	40.7
Others				
Asphaltene	0.0174	0.0159	0.0649	0.0114
Carbon Black	42.0	42.3	42.1	42.4
Coke	5.10	4.83	2.44	2.00

Appendix B Maltene Compositions

Table B1 Maltene compositions in zeolite cases

Catalyst	P	Ole	Nap	Mono	Di	Poly	Polar
No Catalyst	3.64	9.22	13.9	40.0	10.2	15.4	7.67
HBETA	1.55	4.96	10.5	45.3	18.2	12.9	6.59
HY	2.47	5.01	7.86	48.4	15.9	11.9	8.38
HMOR	2.90	8.50	11.7	46.1	10.4	11.4	9.08
KL	3.81	10.3	11.6	43.3	10.6	13.7	6.62
Cu/HBETA	2.13	6.36	12.0	39.3	18.1	13.0	9.16
Cu/HY	2.73	4.30	6.11	41.1	19.8	16.7	9.32
Cu/HMOR	3.26	8.33	10.7	48.8	10.7	10.5	7.66
Cu/KL	2.79	7.44	12.6	50.7	9.09	9.09	8.24
Zn/HBETA	3.52	0.249	8.70	50.1	22.1	8.91	6.48
Zn/HY	7.73	1.37	2.13	55.8	16.9	8.58	7.46
Zn/HMOR	4.26	0.987	5.58	58.2	11.6	11.5	7.82
Zn/KL	5.19	2.50	5.78	51.5	10.5	12.8	11.7

P = Paraffins
Ole = Olefins
Nap = Naphthenes
Mono = Mono-aromatics
Di = Di-aromatics
Poly = Poly-aromatics
Polar = Polar-aromatics

Appendix C Yields of Sulfur-containing Compound Species in Oils

Table C1 Effect of zeolites on the composition of major groups of sulfur-containing compounds in oils (g per 100 g tire)

	Non-Catalyst	HBETA	HY	HMOR	KL
Thiophenes	0.0579	0.0383	0.0340	0.0649	0.0656
Benzothiophenes	0.423	0.648	0.424	0.373	0.528
Dibenzothiophenes	0.0567	0.0385	0.00858	0.0187	0.0228
Naphthothiophenes	-	0.00178	0.00809	-	0.00699
Isothiocyanates	0.781	0.505	0.541	0.548	0.575
Benzothiazoles	0.0614	0.0151	0.0669	0.0234	0.0290
Others	0.163	0.0665	0.152	0.121	0.108

Table C2 Effect of Cu-loaded catalysts on the composition of major groups of sulfur-containing compounds in oils (g per 100 g tire)

	Cu/HBETA	Cu/HY	Cu/HMOR	Cu/KL
Thiophenes	0.0394	0.00957	0.0442	0.0739
Benzothiophenes	0.559	0.393	0.401	0.248
Dibenzothiophenes	0.0167	0.0383	0.00677	0.00269
Naphthothiophenes	-	0.0118	-	-
Isothiocyanates	0.568	0.493	0.491	0.616
Benzothiazoles	0.0240	0.0260	0.0501	0.0723
Others	0.112	0.170	0.121	0.169

Table C3 Effect of Zn-loaded catalysts on the composition of major groups of sulfur-containing compounds in oils (g per 100 g tire)

	Zn/HBETA	Zn/HY	Zn/HMOR	Zn/KL
Thiophenes	-	-	-	-
Benzothiophenes	0.232	0.240	0.143	0.219
Dibenzothiophenes	-	-	-	-
Naphthothiophenes	-	-	-	-
Isothiocyanates	0.351	0.293	0.673	0.723
Benzothiazoles	0.173	0.253	0.168	0.200
Others	0.154	0.101	0.401	0.153

Appendix D Sulfur Analysis by Using S-Analyzer

Table D1 Effect of zeolites on overall sulfur distribution (wt%)

	Non-Catalyst	HBETA	HY	HMOR	KL**
Gas	31.4	28.1	35.1	34.8	30.3/23.6
Oil	23.2	21.2	17.8	21.0	19.8/23.4
Carbon Black	45.4	44.9	43.5	41.9	46.8/49.1
Coke	-	5.83	3.58	2.23	3.19/3.92

* Sulfur content in whole tire = 2.25 wt%
** Value for Chapter 4/ Value for Chapter 7

Table D2 Effect of Cu-loaded catalysts on overall sulfur distribution (wt%)

	Cu/HBETA	Cu/HY	Cu/HMOR	Cu/KL
Gas	26.4	27.7	27.2	29.4
Oil	13.4	14.8	17.1	15.8
Carbon Black	45.3	41.9	43.3	48.5
Coke	15.0	15.7	12.5	6.20

* Sulfur content in whole tire = 2.25 wt%

Table D3 Effect of Zn-loaded catalysts on overall sulfur distribution (wt%)

	Zn/HBETA	Zn/HY	Zn/HMOR	Zn/KL
Gas	14.8	12.2	14.9	28.8
Oil	11.3	13.1	9.27	16.8
Carbon Black	31.1	32.8	25.9	48.3
Coke	42.8	41.9	50.0	6.02

* Sulfur content in whole tire = 2.25 wt%

Appendix E BET Surface Area and Pore Volume

Table E1 BET surface area and pore volume of all catalysts

	BET Surface Area (m^2/g)	**Pore Volume (cm^3/g)**
Zeolites		
HBETA	539	0.257
HY	515	0.266
HMOR	395	0.199
KL	200	0.104
Copper-loaded Catalysts		
Cu/HBETA	413	0.200
Cu/HY	488	0.256
Cu/HMOR	345	0.180
Cu/KL	191	0.0911
Zinc-loaded Catalysts		
Zn/HBETA	493	0.233
Zn/HY	515	0.259
Zn/HMOR	380	0.185
Zn/KL	135	0.0691

Appendix F XRD Patterns of Cu- and Zn-loaded Catalysts

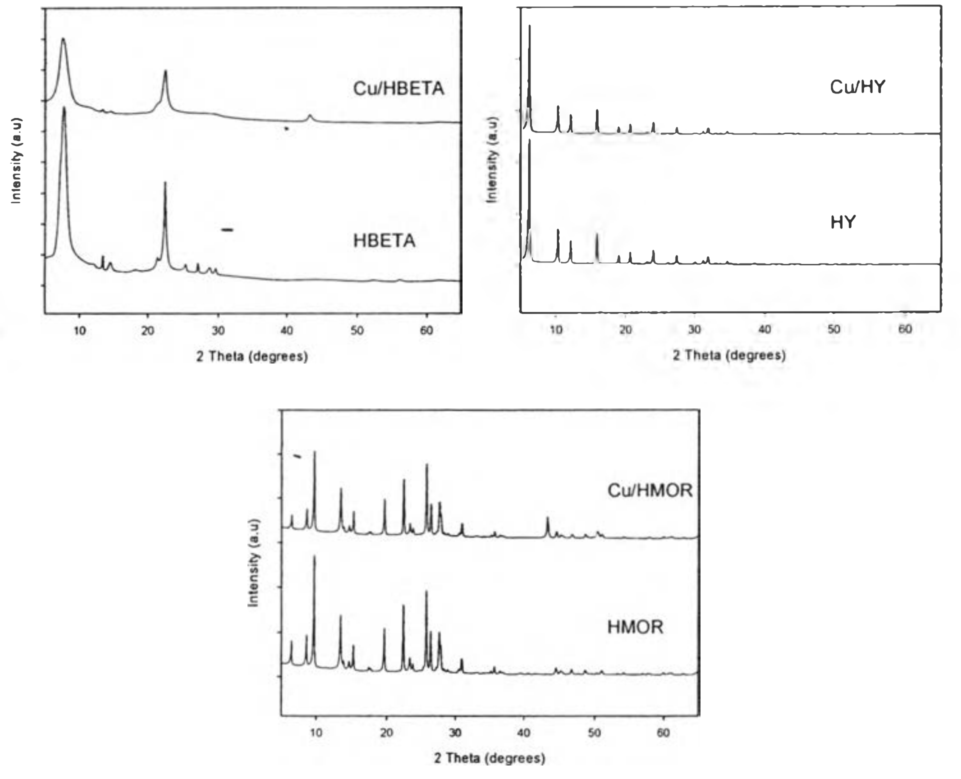

Figure F1 XRD patterns of Cu-loaded acid zeolites.

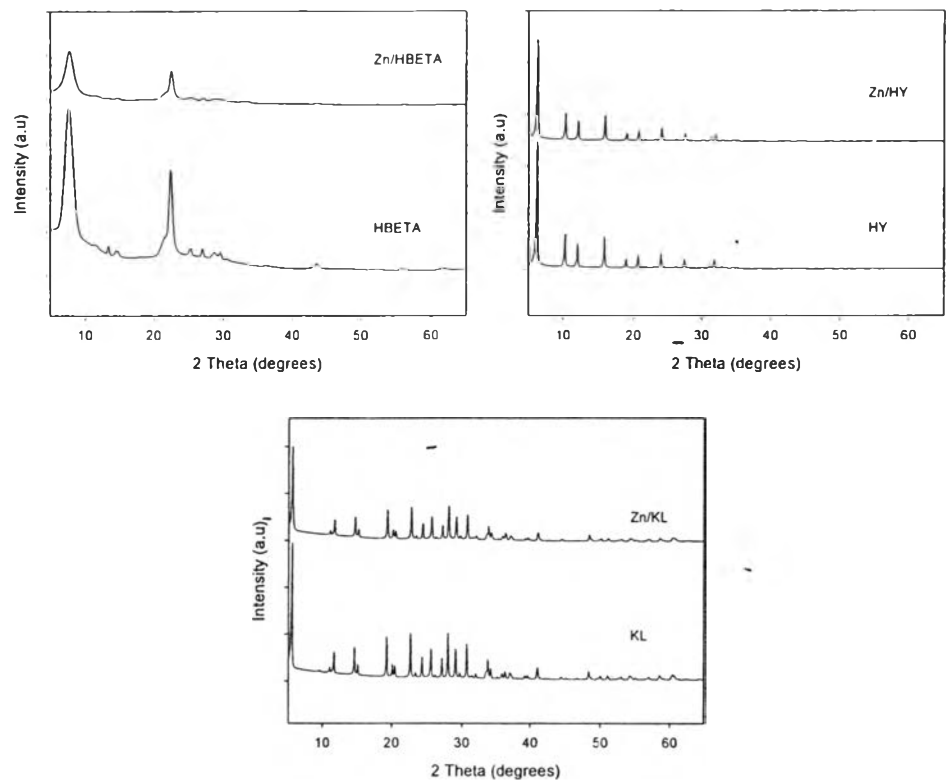

Figure F2 XRD patterns of Zn-loaded acid zeolites.

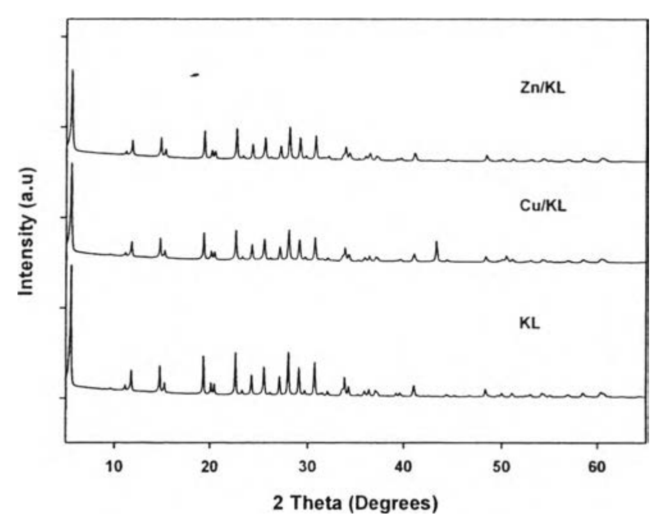

Figure F3 XRD patterns of Cu/KL and Zn/KL catalysts.

Appendix G Zinc Contents and Species

Table G1 Zinc loading

Catalyst	wt% Theoretical Metal Loading (Impregnation)	wt% Real Metal Loading (from AAS)
Zn/HBETA	5.00	3.61
Zn/HY	5.00	3.04
Zn/HMOR	5.00	2.92
Zn/KL	5.00	3.07

Table G2 Amount and binding energy of zinc in catalysts (from XPS)

Catalyst	Metallic Zinc (wt% / eV)	Zinc Oxide (wt% / eV)
Zn/HBETA	82.2 / 1021.5	17.8 / 1023.3
Zn/HY	90.4 / 1021.3	9.60 / 1022.4
Zn/HMOR	93.1 / 1021.3	6.88 / 1023.0
Zn/KL	90.4 / 1020.4	9.58 / 1022.0

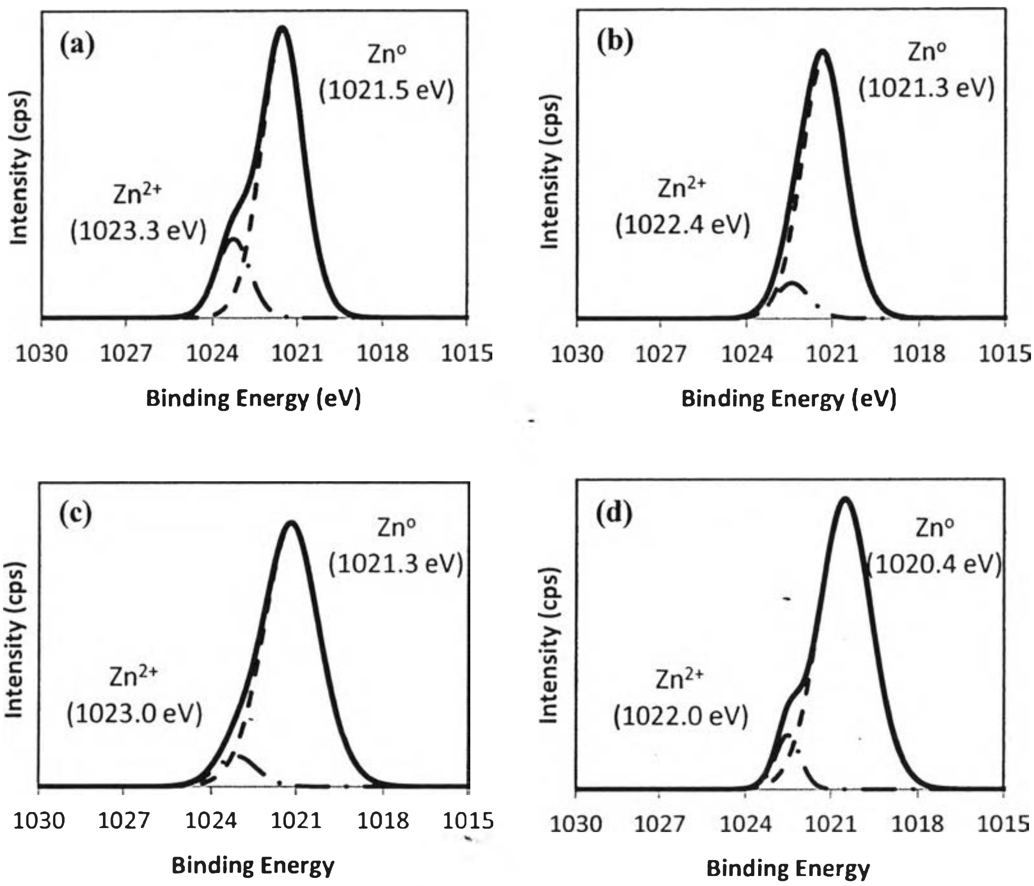

Figure G1 XPS spectra of zinc-loaded catalysts; (a) Zn/HBETA, (b) Zn/HY, (c) ZnHMOR, and (d) Zn/KL.

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Proceedings:

1. Yuwapornpanit, R.; and Jitkarnka, S. (2014, April 22) Sulfur removal from pyrolysis oils by using 5 wt%Cu/HBETA and 5 wt%Cu/HY. Proceeding of the 5th Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and the 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Queen Sirikit National Convention Centre, Bangkok, Thailand.
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