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APPENDICES

Appendix A Product Distribution

The effect of all catalysts on product distribution and gas composition are displayed in below tables.

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

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Gas	11.89	8.84	10.61	9.82	10.83	10.94
Liquid	42.76	41.40	40.89	42.21	42.52	39.42
Soild	45.35	43.43	43.74	44.96	44.18	46.05
Coke	0.00	6.33	4.76	3.01	2.47	3.59

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

Catalyst	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Gas	8.68	7.79	9.69	12.02	13.00
Liquid	38.12	41.58	40.96	39.44	39.04
Soild	43.72	42.39	44.55	44.67	44.76
Coke	9.48	8.24	4.80	3.87	3.20

Table A3 Effect of core-shell composite of HBETA and MCM-41 on product distribution (wt %)

Catalyst	Non-cat	HBETA	MCM-41	HB/MCM-41
Gas	11.89	8.84	8.43	8.65
Liquid	42.76	41.40	41.48	42.79
Soild	45.35	43.43	43.61	43.26
Coke	0.00	6.33	6.48	5.30

Table A4 Effect of core-shell composite of HY and MCM-41 on product distribution (wt %)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Gas	11.89	10.61	8.43	9.28
Liquid	42.76	40.89	41.48	42.40
Soild	45.35	43.74	43.61	43.07
Coke	0.00	4.76	6.48	5.25

Table A5 Effect of zeolites on gas composition (wt %)

Catalysts	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Methane	22.92	14.19	17.71	20.40	15.48	21.08
Ethylene	9.06	5.81	8.46	6.79	5.57	9.15
Ethane	16.44	12.15	15.21	17.20	13.60	17.34
Propylene	9.68	8.87	10.46	8.27	7.28	9.67
Propane	8.87	11.69	10.58	15.67	27.46	9.77
Mixed-C4	21.45	33.71	24.47	21.94	22.94	21.53
Mixed-C5	11.59	13.57	13.12	9.72	7.68	11.46

Table A6 Effect of Ni-loaded catalysts on gas composition (wt %)

Catalysts	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Methane	16.51	18.24	19.92	16.97	19.96
Ethylene	8.35	8.85	6.53	6.59	10.87
Ethane	14.07	15.92	16.64	14.83	17.04
Propylene	10.70	10.66	8.43	7.74	10.65
Propane	9.21	9.85	11.62	23.51	9.23
Mixed-C4	27.79	23.80	19.57	21.66	21.02
Mixed-C5	13.36	12.67	10.50	8.69	11.23

Table A7 Effect of core-shell composites (HY/MCM-41 and HB/MCM-41) on gas composition (wt %)

Catalysts	**HBETA**	**HY**	**MCM-41**	**HY/MCM-41**	**HB/MCM-41**
Methane	14.19	17.71	20.13	20.42	18.08
Ethylene	5.81	8.46	8.64	9.51	8.19
Ethane	12.15	15.21	17.81	18.49	15.58
Propylene	8.87	10.46	9.82	7.72	11.01
Propane	11.69	10.58	10.39	7.61	7.19
Mixed-C4	33.71	24.47	21.05	23.45	27.51
Mixed-C5	13.57	13.12	12.16	12.80	12.44

Appendix B Oil Compositions

The effect of all catalysts on oil compositions are displayed in below tables

Table B1 Effect of zeolites on petroleum fractions (wt %)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Gasoline	7.1	17.0	14.9	14.2	12.8	16.1
Kerosene	38.2	39.5	45.8	36.4	38.0	39.3
Gas Oil	36.8	31.6	31.6	33.7	37.4	32.3
LVGO	5.0	3.6	2.3	6.6	4.1	4.1
HVGO	12.9	8.3	5.4	9.1	7.6	8.3

Table B2 Effect of Ni-loaded catalysts on petroleum fractions (wt %)

Catalyst	Ni/HBETA	NiHY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Gasoline	28.6	24.0	41.0	41.0	18.9
Kerosene	30.0	25.6	29.6	29.6	39.7
Gas Oil	20.3	21.0	16.7	16.7	30.6
LVGO	13.2	17.4	9.3	9.3	2.8
HVGO	8.1	11.9	3.4	3.4	8.0

Table B3 Effect of core-shell composite of HBETA and MCM-41 on petroleum fractions (wt %)

Catalyst	Non-cat	HBETA	MCM-41	HB/MCM-41
Gasoline	7.1	17.0	20.1	24.0
Kerosene	38.2	39.5	36.6	38.2
Gas Oil	36.8	31.6	33.9	28.4
LVGO	5.0	3.6	3.0	2.9
HVGO	12.9	8.3	6.3	6.4

Table B4 Effect of core-shell composite of HY and MCM-41 on petroleum fractions (wt %)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Gasoline	7.1	14.9	20.1	22.65
Kerosene	38.2	45.8	36.6	43.31
Gas Oil	36.8	31.6	33.9	29.18
LVGO	5.0	2.3	3.0	1.85
HVGO	12.9	5.4	6.3	3.00

Table B5 Effect of zeolites on maltene composition (wt %)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Para	2.94	3.00	4.56	4.04	2.64	3.60
ole	8.76	7.62	7.93	9.10	9.14	9.72
nap	16.13	11.92	8.67	10.99	15.07	14.26
mono	48.61	50.27	55.13	53.09	45.60	49.96
di	6.99	10.19	8.20	4.87	6.24	3.21
poly	9.32	10.67	8.25	10.00	13.48	10.94
polar	7.26	6.33	7.26	7.92	7.83	8.31

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

Table B6 Effect of Ni-loaded catalysts on maltene composition (wt %)

Catalyst	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Para	3.29	4.21	3.70	2.59	3.39
Ole	7.66	7.25	10.06	8.36	13.57
Nap	8.65	8.19	9.82	13.92	14.02
Mono	49.30	47.54	54.71	54.50	52.99
Di	11.01	9.70	4.95	5.87	3.33
Poly	12.22	15.27	9.34	8.75	5.84
Polar	7.87	7.84	7.43	6.02	6.87

Table B7 Effect of core-shell composite of HBETA and MCM-41 on maltene composition (wt %)

Catalyst	Non-cat	HBETA	MCM-41	HBETA/MCM-41
Para	2.94	3.00	4.25	2.96
Ole	8.76	7.71	10.01	7.61
Nap	16.13	11.91	10.92	11.26
Mono	48.61	50.22	52.63	56.08
Di	6.99	10.18	5.10	6.64
Poly	9.32	10.66	9.01	9.00
Polar	7.26	6.33	8.07	6.45

Table B8 Effect of core-shell composite of HY and MCM-41 on maltene composition (wt %)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Para	2.94	4.56	4.25	3.14
Ole	8.76	7.93	10.01	12.57
Nap	16.13	8.67	10.92	12.11
Mono	48.61	55.13	52.63	52.83
Di	6.99	8.20	5.10	5.45
Poly	9.32	8.25	9.01	7.30
Polar	7.26	7.26	8.07	6.61

Appendix C Petrochemicals in Oils

Petrochemicals in Oils obtained from all catalysts are displayed in below tables.

Table C1 Effect of zeolites on petrochemicals in maltene (wt %)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Ethylbenzene	1.29	2.02	2.20	1.09	1.54	1.20
Toluene	0.10	0.72	0.41	0.38	0.57	0.55
Mixed-xylenes	0.01	1.10	1.06	0.63	0.38	0.65
Cumene	0.77	0.00	1.22	0.37	0.10	0.96
Styrene	0.40	1.10	0.98	1.49	0.06	1.52

Table C2 Concentration of petrochemical in maltene obtained from zeolite (wt %)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Ethylbenzene	1.193	2.238	2.136	1.129	2.058	1.160
Toluene	0.232	1.354	0.962	0.925	3.400	1.301
P-xylene	0.617	1.142	0.936	0.539	0.017	0.546
Cumene	0.659	0.005	1.109	0.354	0.233	0.856

Table C3 Effect of Ni-loaded catalyst on petrochemicals in maltene (wt %)

Catalyst	Ni/HBETA	Ni/HY	NiHMOR	Ni/HZSM-5	Ni/KL
Ethylbenzene	1.14	0.90	1.70	2.03	3.37
Toluene	0.06	0.06	1.39	0.85	0.49
Mixed-xylenes	0.50	0.17	0.68	1.66	0.93
Cumene	0.75	0.02	1.11	0.97	2.03
Styrene	0.68	0.15	1.98	0.04	2.52

Table C4 Concentration of petrochemical in maltene obtained from Ni-loaded catalysts (wt %)

Catalyst	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Ethylbenzene	1.608	0.838	1.307	2.305	2.782
Toluene	0.206	0.120	2.596	2.431	1.070
P-xylene	0.671	0.106	0.410	2.234	0.870
Cumene	0.983	0.020	0.788	0.979	1.448

Table C5 Effect of core-shell composite of HBETA and MCM-41 on the petrochemicals in maltene (wt %)

Catalyst	Non-cat	HBETA	MCM-41	HB/MCM-41
Benzene	0	0	0	1.78
Ethylbenzene	1.29	2.02	1.97	2.64
Toluene	0.10	0.72	0.48	1.00
Mixed-xylenes	0.01	1.10	0.34	1.38
Cumene	0.77	0.00	1.07	0.90
Styrene	0.40	1.10	1.36	0.15

Table C6 Concentration of petrochemical obtained from core-shell composite of HBETA and MCM-41(wt %)

Catalyst	Non-cat	HBETA	MCM-41	HB/MCM-41
Benzene	0	0	0	2.722
Ethylbenzene	1.193	2.238	2.199	2.327
Toluene	0.232	1.354	1.320	2.176
P-xylene	0.617	1.142	0.816	1.057
Cumene	0.659	0.005	1.118	0.735

Table C7 Effect of core-shell composite of HY and MCM-41 on the petrochemicals in maltene (wt %)

Catalyst	Non-cat	MCM-41	HY	HY/MCM-41
Benzene	0	0.00	0.00	0.06
Ethylbenzene	1.29	1.97	2.20	4.14
Toluene	0.10	0.48	0.41	1.15
Mixed-xylenes	0.01	0.34	1.06	1.13
Cumene	0.77	1.07	1.22	1.03
Styrene	0.40	1.36	0.98	0.03

Table C8 Concentration of petrochemical obtained from core-shell composite of HY and MCM-41(wt %)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Benzene	0	0	0	0.103
Ethylbenzene	1.193	2.136	2.199	3.803
Toluene	0.232	0.962	1.320	2.494
P-xylene	0.617	0.936	0.816	0.917
Cumene	0.659	1.109	1.118	0.885

Appendix D Distribution of Sulfur-containing Compound Species in Oils

Distribution of sulfur-containing compounds in oils obtained from all catalysts are displayed in below tables.

Table D1 Effect of zeolites on the distribution of of sulfur-containing compounds in oils (wt % in maltene)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5
Th	0.71	0.65	0.56	0.78	0.49
BT	0.95	0.89	0.87	0.82	0.96
DBT	0.05	0.05	0.01	0.04	0.08
NTH	0.01	0.04	0.01	0.01	0.06
BTz	1.30	0.86	0.93	1.07	0.65
ITC	0.60	0.31	0.27	0.33	0.23
Others	0.26	0.07	0.10	0.19	0.27

Table D2 Effect of Ni-loaded catalysts on the distribution of sulfur-containing compounds in oils (wt % in maltene)

Catalyst	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5
Th	0.65	0.37	0.81	0.66
BT	1.30	1.02	0.71	0.76
DBT	0.03	0.04	0.02	0.02
NTH	0.03	0.01	0.01	0.01
BTz	1.03	1.39	1.08	0.79
ITC	0.38	0.40	0.46	0.37
Others	0.10	0.23	0.32	0.15

Table D3 Effect of core-shell composite of HBETA and MCM-41 on the distribution of sulfur-containing compounds in oils (wt % in maltene)

Catalyst	Non-cat	HBETA	MCM-41	HB/MCM-41
Th	0.71	0.65	0.84	0.72
BT	0.95	0.89	0.81	0.94
DBT	0.05	0.05	0.03	0.01
NTH	0.01	0.04	0.01	0.01
BTz	1.30	0.86	1.27	0.76
ITC	0.60	0.31	0.75	0.01
Others	0.26	0.07	0.25	0.09

Table D4 Effect of core-shell composite of HY and MCM-41 on the distribution of sulfur-containing compounds in oils (wt % in maltene)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Th	0.71	0.56	0.84	0.67
BT	0.95	0.87	0.81	0.70
DBT	0.05	0.01	0.03	0.01
NTH	0.01	0.01	0.01	0.01
BTz	1.30	0.93	1.27	0.72
ITC	0.60	0.27	0.75	0.05
Others	0.26	0.10	0.25	0.16

Appendix E Sulfur Analysis by Using S-Analyzer

Sulfur distribution on pyrolysis products are displayed in below tables.

Table E1 Effect of zeolites on overall sulfur distribution (wt %)

Catalyst	Non-cat	HBETA	HY	HMOR	HZSM-5	KL
Gas	28.8	25.6	23.9	27.5	26.5	31.7
Oil	20.4	16.9	17.8	18.9	16.5	15.7
Char	50.8	52.3	54.5	50.9	52.4	50.2
Spent catalyst	0.0	5.1	3.7	2.6	4.7	2.4

* Sulfur content in whole tire = 2.02 wt%

Table E2 Effect of Ni-loaded catalysts on overall sulfur distribution (wt %)

Catalyst	Ni/HBETA	Ni/HY	Ni/HMOR	Ni/HZSM-5	Ni/KL
Gas	20.12	12.9	18.8	18.7	19.7
Oil	14.24	16.5	15.8	13.3	14.4
Char	53.33	53.5	51.0	52.3	51.5
Spent catalyst	12.31	17.1	14.4	15.7	14.4

* Sulfur content in whole tire = 2.02 wt%

Table E3 Effect of core-shell composite of HBETA and MCM-41 on overall sulfur distribution (wt %)

Catalyst	Non-cat	HBeta	MCM-41	HB/MCM-41
Gas	28.8	25.6	20.5	27.2
Oil	20.4	16.9	18.2	16.8
Char	50.8	52.3	54.8	51.7
Spent catalyst	0.0	5.1	6.5	4.4

* Sulfur content in whole tire = 2.02 wt%

Table E4 Effect of core-shell composite of HY and MCM-41 on overall sulfur distribution (wt %)

Catalyst	Non-cat	HY	MCM-41	HY/MCM-41
Gas	28.8	23.9	20.5	26.0
Oil	20.4	17.8	18.2	17.5
Char	50.8	54.5	54.8	51.7
Spent catalyst	0.0	3.7	6.5	4.9

* Sulfur content in whole tire = 2.02 wt%

Appendix F GCxGC-TOF/MS Chromatograms

GCxGC-TOF/MS Chromatograms obtained from all catalysts are displayed in below figures.

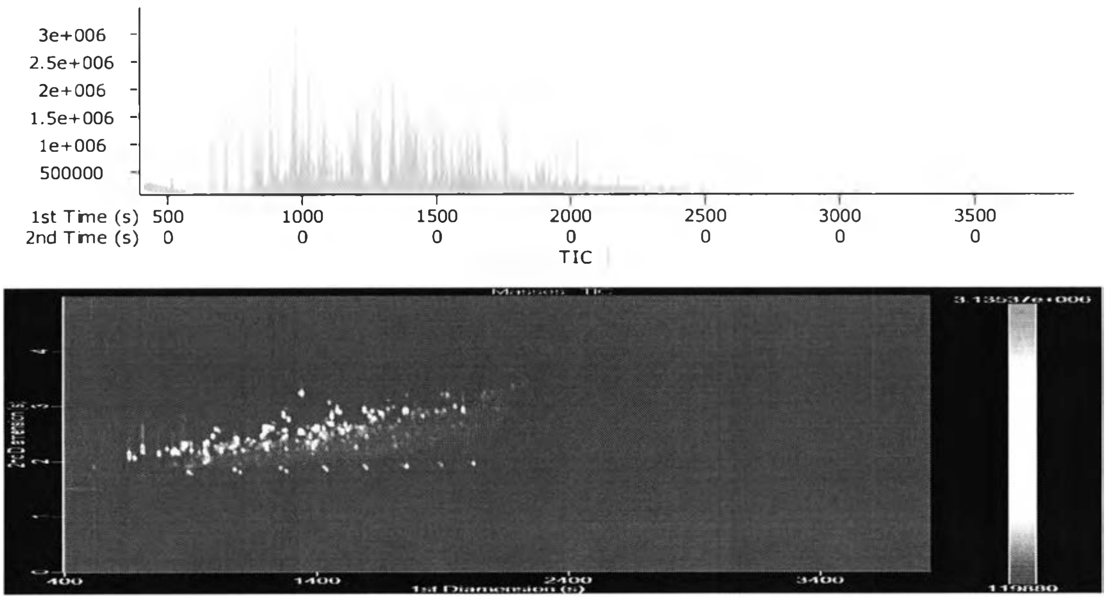

Figure F1 GCxGC-TOF/MS Chromatogram of non-cat.

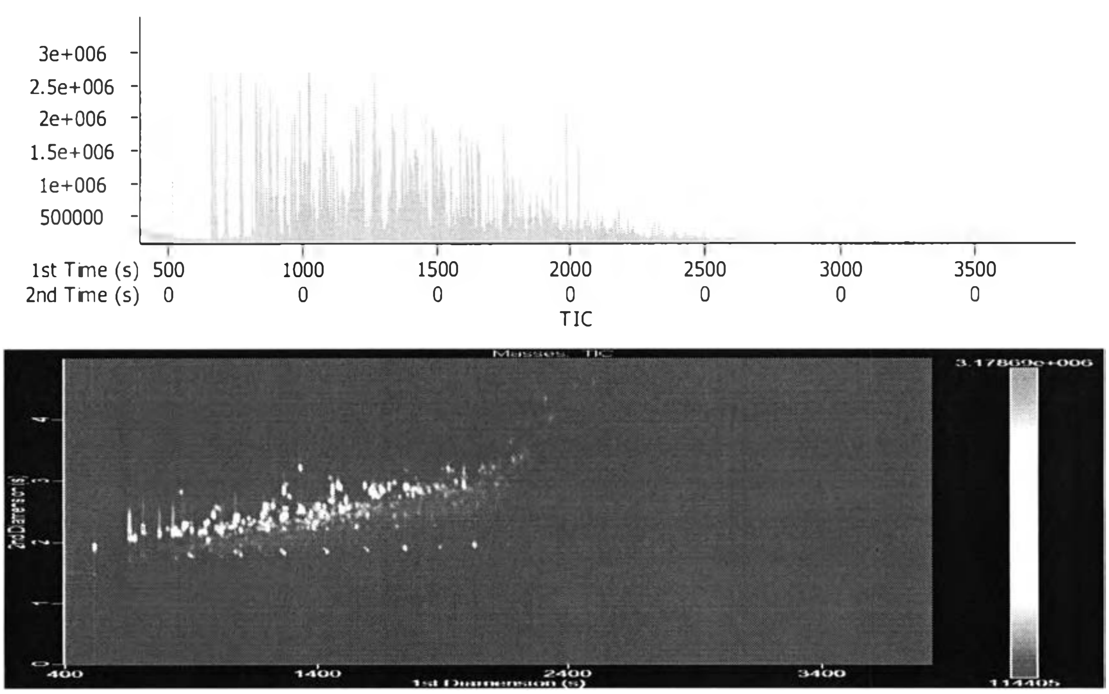

Figure F2 GCxGC-TOF/MS Chromatogram of HBETA.

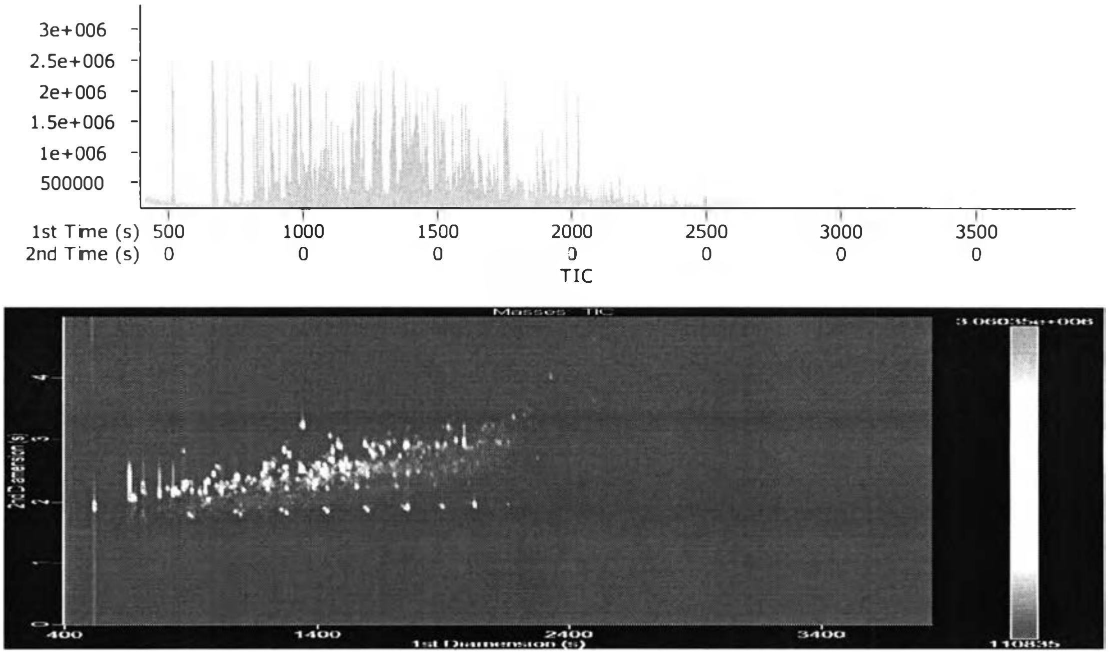

Figure F3 GCxGC-TOF/MS Chromatogram of MCM-41.

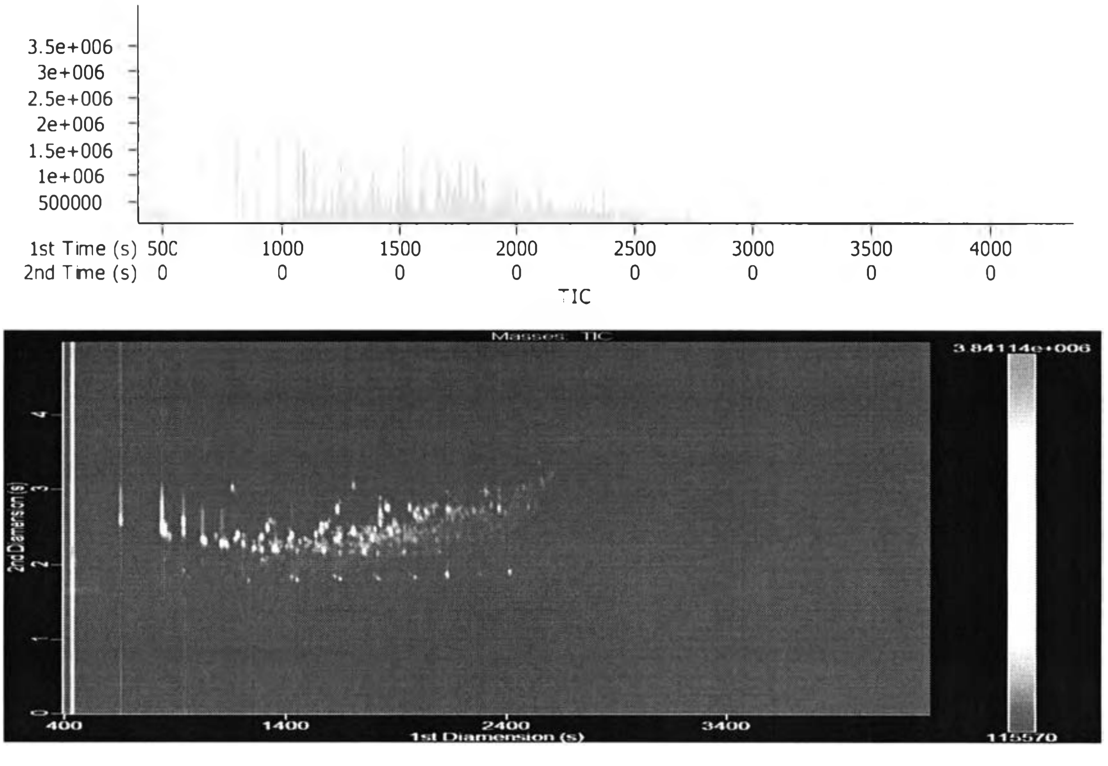

Figure F4 GCxGC-TOF/MS Chromatogram of core-shell composite of HBETA and MCM-41.

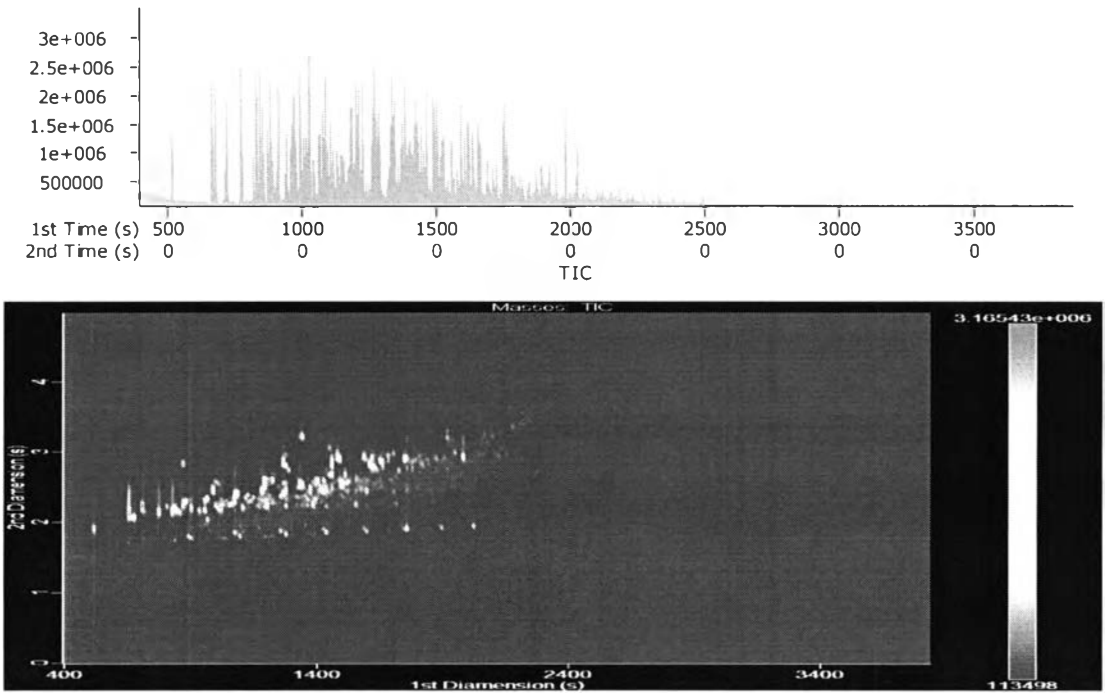

Figure F5 GCxGC-TOF/MS Chromatogram of HY.

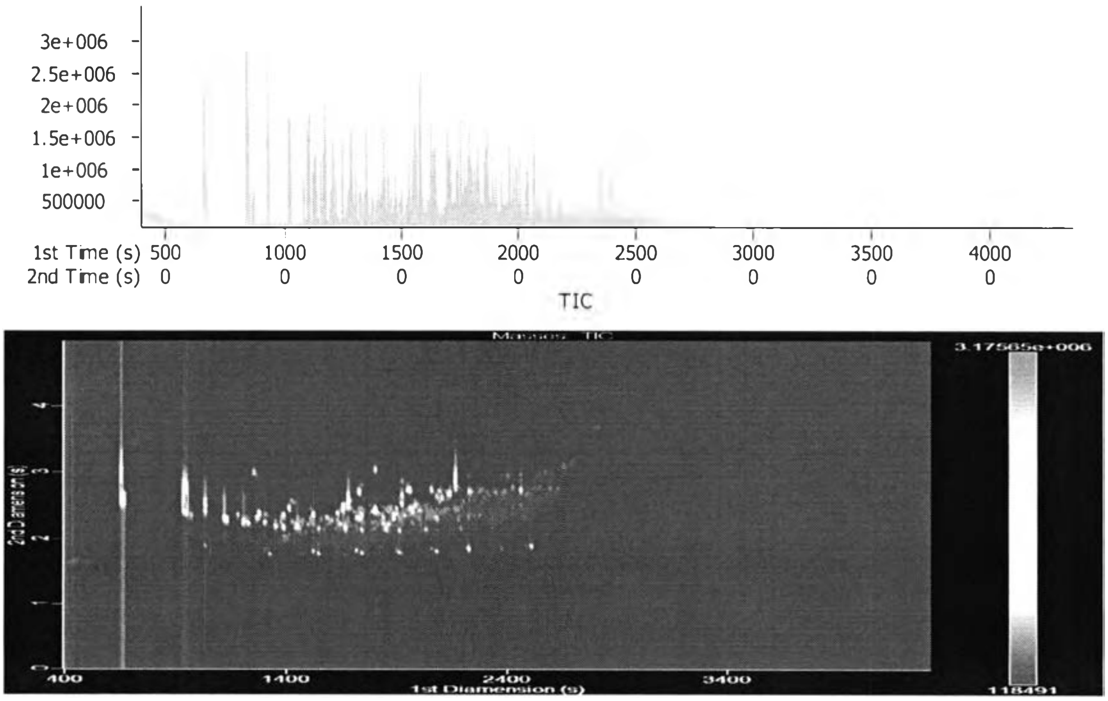

Figure F6 GCxGC-TOF/MS Chromatogram of core-shell composite of HY and MCM-41.

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Proceedings:

1. Namchot, W.; and Jitkarnka, S. (2015, April 21) Enhancement of valuable petrochemicals formation in waste tire- derived oil over 5 wt% NiKL. Proceeding of the 6th Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and the 21th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.
2. Namchot, W.; and Jitkarnka S. (2015, August 23 – 27) Upgrading of Waste Tyre-Derived Oil from Waste Tyre Pyrolysis over Ni Catalyst Supported on HZSM-5 Zeolite. Proceeding of the 18th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (PRES 2015), Kuching, Malaysia.

Presentation:

1. Namchot, W.; and Jitkarnka S. (2015, May 20 – 22) Sulphur Removal from Waste Tyre-Derived Oil and Enhanced Ethylbenzene Production over Ni catalysts Supported on MCM-41. Paper presented at the 1st Energy, Science and Technology Conference (EST 2015), Karlsruhe, Germany.