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APPENDICES

Appendix A Scanning Electron Microscopy Micrographs

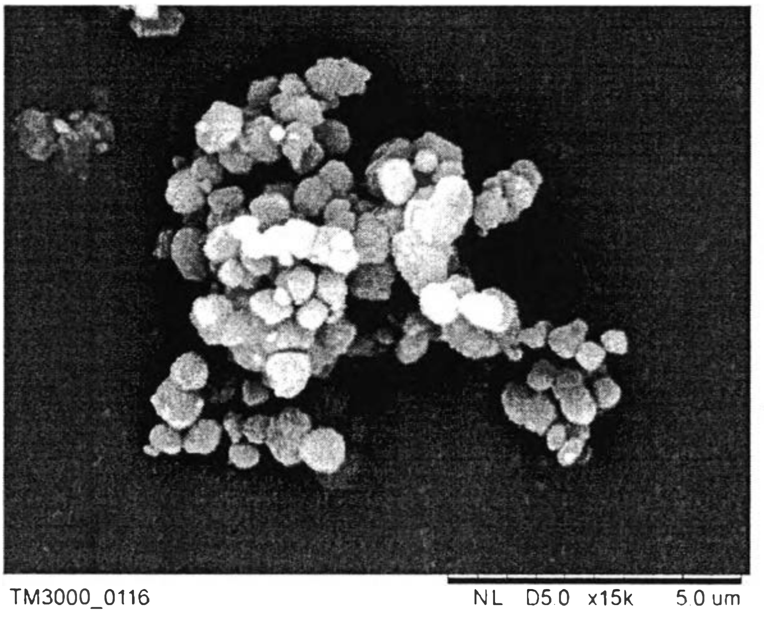

Figure A1 SEM image of HZ11(75) (15.0 kV×10.0k).

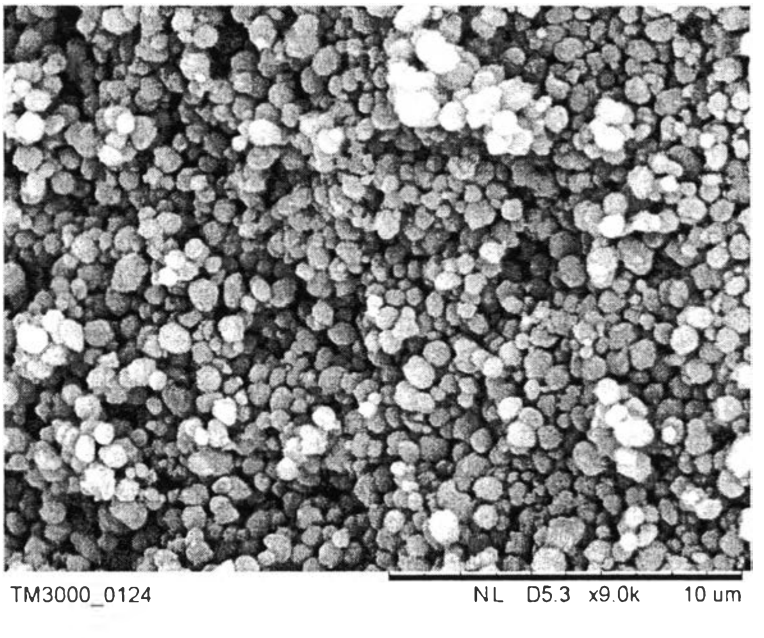

Figure A2 SEM image of P/HZ11(75) (15.0 kV×10.0k).

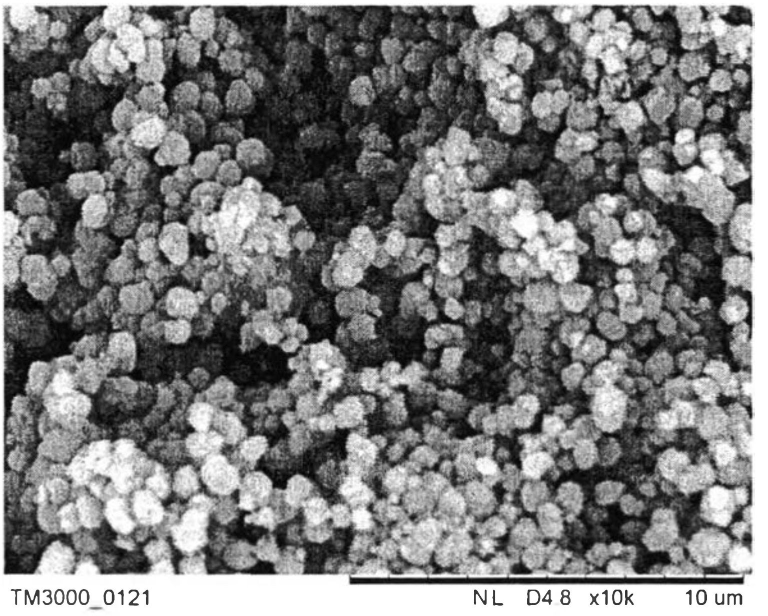

Figure A3 SEM image of Sb/HZ11(75) (15.0 kV×10.0k).

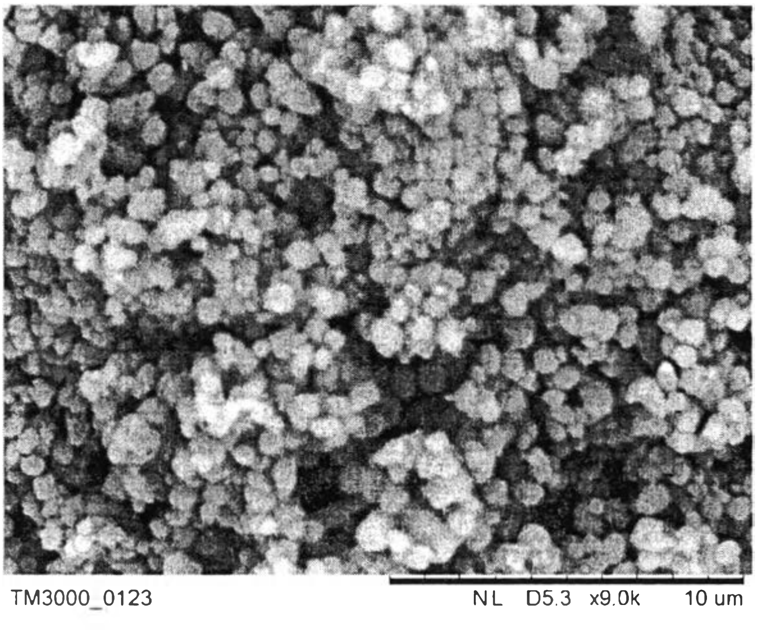

Figure A4 SEM image of Bi/HZ11(75) (15.0 kV×10.0k).

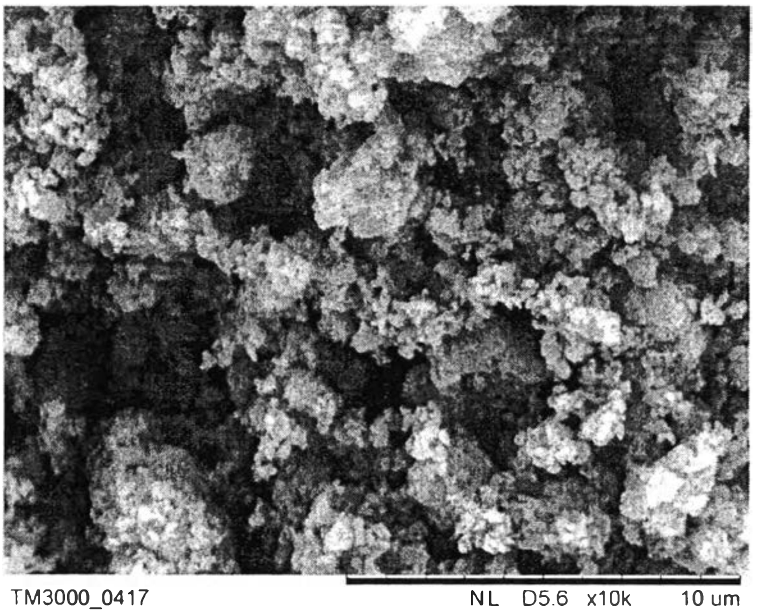

Figure A5 SEM image of HZ5(30) (15.0 kV×10.0k).

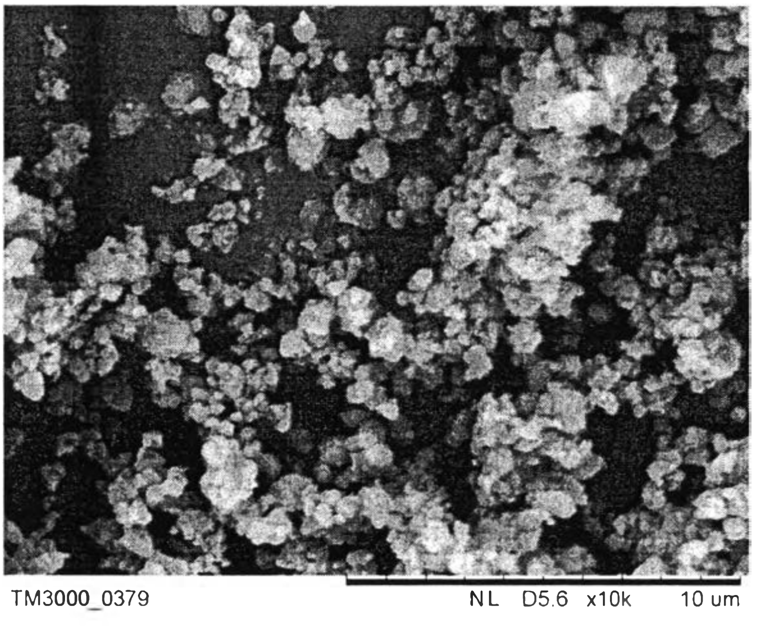

Figure A6 SEM image of HZ5(80) (15.0 kV×10.0k).

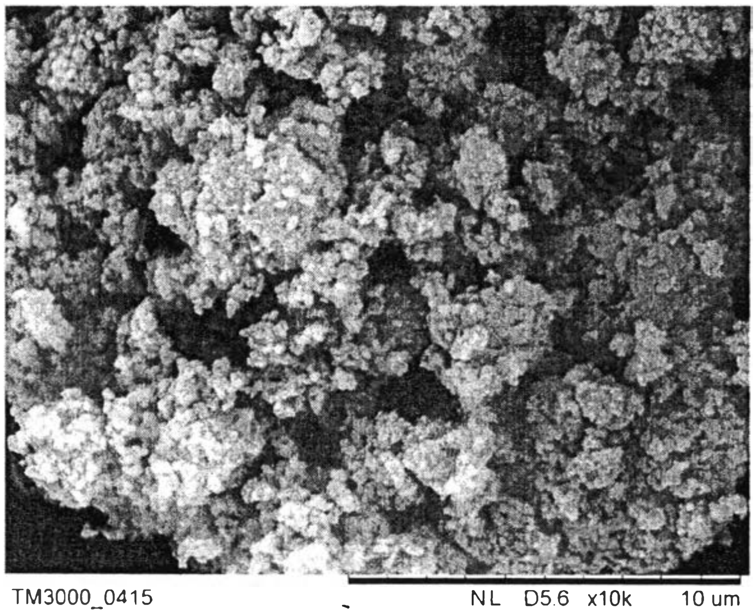

Figure A7 SEM image of HBeta(27) (15.0 kV×10.0k).

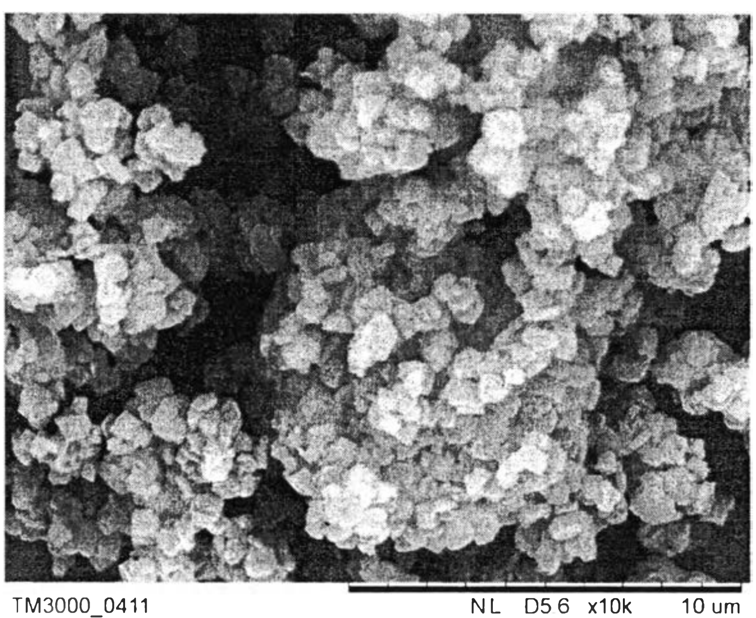

Figure A8 SEM image of HY(30) (15.0 kV×10.0k).

Appendix B Product Distribution and Product Yield Calculations

$$\text{Yield (wt \%)} = \frac{\text{Total weight of any products}}{\text{Total weight of converted bioethanol}} \times 100$$

Table B1 Product distribution and product yields from HZ5(30), P/HZ5(30), Sb/HZ5(30), and Bi/HZ5(30) catalysts

Catalyst	**HZ5(30)**	**P/HZ5(30)**	**Sb/HZ5(30)**	**Bi/HZ5(30)**
Ethanol conversion (wt %)	99.5	99.0	99.3	97.8
Feed ethanol (ml/h)	2.00	2.00	2.00	2.00
Feed ethanol (ml)	16.6	17.5	17.5	17.7
Feed ethanol (g)*	13.1	13.8	13.8	14.0
Converted ethanol (g)	13.1	13.7	13.7	13.7
Product distribution (g)				
Oil	0.92	0.48	1.55	2.56
Gas	9.64	9.60	10.3	8.0
Water	2.49	3.63	1.85	3.09
Other**	0.06	0.13	0.10	0.31
Product yield (wt %)				
Oil	7.07	3.52	11.3	18.7
Gas	73.9	70.0	75.2	58.6
Water	19.1	26.4	13.5	22.6

*Ethanol concentration is 99.5 v/v %

**Unconverted bio-ethanol

Table B2 Product distribution and product yields from HBeta(27), P/HBeta(27), Sb/HBeta(27), and Bi/HBeta(27) catalysts

Catalyst	**HBeta(27)**	**P/HBeta(27)**	**Sb/HBeta(27)**	**Bi/ HBeta(27)**
Ethanol conversion (wt %)	96.7	99.1	98.5	99.7
Feed ethanol (ml/h)	2.00	2.00	2.00	2.00
Feed ethanol (ml)	16.9	16.0	17.3	16.6
Feed ethanol (g)*	13.3	12.6	13.7	13.1
Converted ethanol (g)	12.9	12.5	13.5	13.1
Product distribution (g)				
Oil	0.21	0.55	0.68	0.62
Gas	10.5	9.71	9.52	9.30
Water	2.13	2.23	3.27	3.14
Other**	0.44	0.12	0.20	0.04
Product yield (wt %)				
Oil	1.60	4.43	5.06	4.74
Gas	80.7	70.9	69.4	68.0
Water	16.3	16.3	23.9	23.0

*Ethanol concentration is 99.5 v/v %

**Unconverted bio-ethanol

Table B3 Product distribution and product yields from HY(30), P/HY(30), Sb/HY(30), and Bi/HY(30) catalysts

Catalyst	HY(30)	P/HY(30)	Sb/HY(30)	Bi/HY(30)
Ethanol conversion (wt %)	99.5	99.0	99.3	97.8
Feed ethanol (ml/h)	2.00	2.00	2.00	2.00
Feed ethanol (ml)	17.0	17.2	17.2	15.6
Feed ethanol (g)*	13.4	13.6	13.6	12.3
Converted ethanol (g)	13.4	13.5	13.5	12.1
Product distribution (g)				
Oil	0.46	0.48	0.62	0.72
Gas	11.1	11.6	10.4	8.79
Water	1.79	1.36	2.49	2.56
Other**	0.07	0.13	0.10	0.28
Product yield (wt %)				
Oil	3.47	3.55	4.62	6.00
Gas	85.0	84.9	75.7	64.3
Water	13.7	9.9	18.2	18.7

*Ethanol concentration is 99.5 v/v %

**Unconverted bio-ethanol

Table B4 Product distribution and product yields from HZ5(80), P/HZ5(80), Sb/HZ5(80), and Bi/HZ5(80) catalysts

Catalyst	HZ5(80)	P/HZ5(80)	Sb/HZ5(80)	Bi/HZ5(80)
Ethanol conversion (wt %)	97.7	99.1	98.1	99.0
Feed ethanol (ml/h)	2.00	2.00	2.00	2.00
Feed ethanol (ml)	15.9	15.5	15.8	16.0
Feed ethanol (g)*	12.6	12.3	12.5	12.6
Converted ethanol (g)	12.3	12.2	12.2	12.5
Product distribution (g)				
Oil	1.50	0.54	1.71	2.31
Gas	7.97	9.31	8.55	8.34
Water	2.82	2.31	1.96	1.86
Other**	0.29	0.11	0.23	0.13
Product yield (wt %)				
Oil	12.17	4.45	14.01	18.50
Gas	61.1	67.9	62.3	61.0
Water	21.6	16.8	14.3	13.6

*Ethanol concentration is 99.5 v/v %

**Unconverted bio-ethanol

Table B5 Product distribution and product yields from HZ11(75), P/HZ11(75), Sb/HZ11(75), and Bi/HZ11(75) catalysts

Catalyst	HZ11(75)	P/ HZ11(75)	Sb/ HZ11(75)	Bi/ HZ11(75)
Ethanol conversion (wt %)	95.5	98.0	95.6	96.8
Feed ethanol (ml/h)	2.00	2.00	2.00	2.00
Feed ethanol (ml)	15.6	17.9	15.6	15.9
Feed ethanol (g)*	12.3	14.2	12.3	12.5
Converted ethanol (g)	11.8	13.9	11.7	12.1
Product distribution (g)				
Oil	0.52	0.61	0.46	0.55
Gas	7.93	10.8	8.86	9.72
Water	3.30	2.52	2.43	1.85
Other**	0.55	0.28	0.54	0.41
Product yield (wt %)				
Oil	4.41	4.38	3.92	4.53
Gas	60.8	78.4	64.5	71.1
Water	25.3	18.4	17.7	13.5

*Ethanol concentration is 99.5 v/v %

**Unconverted bio-ethanol

Appendix C Compositions in Gas Products

Table C1 Gas composition as a function of time on stream for HZ5(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	12.0	19.9	17.8	17.6	15.4	12.4	11.8
CO2	0.00	12.1	8.35	8.11	9.42	7.83	7.01	6.76
Ethylene	100	12.1	11.8	12.9	15.6	15.5	16.0	17.1
Ethane	0.00	21.1	13.8	13.3	12.6	12.8	11.8	11.8
Propylene	0.00	3.25	2.39	2.71	6.51	4.17	3.81	4.09
Propane	0.00	38.8	41.1	41.6	33.4	39.8	41.6	41.1
Butylene	0.00	0.76	1.59	2.11	2.71	2.85	3.68	3.90
Butane	0.00	0.00	1.14	1.45	2.11	1.63	3.60	3.58
Σ	100	100	100	100	100	100	100	100

Table C2 Gas composition as a function of time on stream for P/HZ5(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	2.98	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	94.8	92.7	96.5	96.8	97.2	97.2	97.4	97.4
Ethane	0.00	0.78	0.70	0.67	0.65	0.65	0.64	0.65
Propylene	5.15	2.70	2.07	1.79	1.49	1.45	1.34	1.25
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butane	0.00	0.80	0.73	0.72	0.65	0.67	0.65	0.66
Σ	100	100	100	100	100	100	100	100

Table C3 Gas composition as a function of time on stream for Sb/HZ5(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	35.6	16.4	18.7	15.5	14.3	13.5	12.5	7.36
CO2	19.6	14.1	10.6	9.53	9.11	8.81	8.14	4.98
Ethylene	6.10	10.6	11.7	13.7	15.4	15.5	17.2	32.7
Ethane	27.8	22.0	15.7	14.4	13.9	13.6	13.1	10.1
Propylene	0.00	2.73	3.14	3.75	4.44	4.63	5.04	10.7
Propane	10.9	34.2	37.4	39.1	38.3	38.4	38.1	28.3
Butylene	0.00	0.00	1.48	2.41	2.83	3.29	3.67	3.12
Butane	0.00	0.00	1.15	1.61	1.79	2.24	2.23	2.69
Σ	100	100	100	100	100	100	100	100

Table C4 Gas composition as a function of time on stream for Bi/HZ5(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	21.3	11.5	15.4	13.7	12.8	12.2	11.1	10.4
CO2	49.3	10.2	9.35	8.48	8.04	7.83	7.11	6.60
Ethylene	15.6	17.9	16.5	17.6	18.7	19.7	20.8	22.0
Ethane	13.8	13.2	12.6	12.4	12.4	12.4	12.3	12.2
Propylene	0.00	4.95	4.96	5.32	5.92	6.85	7.13	7.82
Propane	0.00	37.3	36.0	36.7	35.9	34.2	34.5	33.0
Butylene	0.00	3.04	3.08	3.54	3.84	4.16	4.39	4.54
Butane	0.00	1.92	2.10	2.27	2.40	2.69	2.64	3.36
Σ	100	100	100	100	100	100	100	100

Table C5 Gas composition as a function of time on stream for HBeta(27) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	24.5	10.6	6.20	3.71	3.55	2.55	1.88	1.51
CO2	34.2	2.95	1.67	1.07	0.00	0.00	0.00	0.00
Ethylene	19.9	30.2	58.1	73.2	79.1	84.2	89.1	90.2
Ethane	10.5	20.8	17.3	11.5	10.0	7.54	5.58	4.33
Propylene	10.8	2.90	3.85	4.26	4.23	3.91	3.47	2.99
Propane	0.0	26.5	10.8	3.95	2.48	1.47	0.00	0.54
Butylene	0.0	2.88	2.05	1.00	0.59	0.35	0.00	0.00
Butane	0.0	3.12	0.00	1.31	0.00	0.00	0.00	0.47
Σ	100	100	100	100	100	100	100	100

Table C6 Gas composition as a function of time on stream for P/HBeta(27) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	12.9	1.06	0.93	0.76	0.00	0.00	0.00	0.00
CO2	8.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	59.1	88.1	90.9	94.1	95.3	96.1	95.9	96.6
Ethane	7.95	2.84	2.84	2.43	2.23	1.89	1.76	1.71
Propylene	6.36	4.62	3.33	2.72	2.43	2.03	1.86	1.72
Propane	4.52	1.76	0.92	0.00	0.00	0.00	0.00	0.00
Butylene	0.94	0.88	0.48	0.00	0.00	0.00	0.00	0.00
Butane	0.00	0.78	0.58	0.00	0.00	0.00	0.43	0.00
Σ	100	100	100	100	100	100	100	100

Table C7 Gas composition as a function of time on stream for Sb/HBeta(27) catalyst

	Composition (mol %)							
Component	**@60 min**	**@120 min**	**@180 min**	**@240 min**	**@300 min**	**@360 min**	**@420 min**	**@480 min**
CH4	12.6	9.37	5.35	2.88	2.19	1.82	1.20	1.12
CO2	8.09	3.81	1.94	1.22	1.03	0.91	0.76	0.71
Ethylene	57.9	47.8	66.5	80.2	85.5	88.3	92.3	93.0
Ethane	7.79	20.7	14.76	8.79	6.43	5.09	3.06	2.72
Propylene	6.23	2.57	3.48	3.74	3.45	3.13	2.28	2.03
Propane	4.43	12.8	5.91	2.12	1.13	0.73	0.00	0.00
Butylene	0.92	1.62	1.18	0.55	0.30	0.00	0.00	0.00
Butane	1.99	1.38	0.85	0.48	0.00	0.00	0.40	0.40
Σ	100	100	100	100	100	100	100	100

Table C8 Gas composition as a function of time on stream for Bi/HBeta(27) catalyst

	Composition (mol %)							
Component	**@60 min**	**@120 min**	**@180 min**	**@240 min**	**@300 min**	**@360 min**	**@420 min**	**@480 min**
CH4	0	14.0	4.08	2.55	1.90	1.90	1.47	1.36
CO2	0	2.91	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	100	46.8	77.5	86.5	90.2	91.6	93.5	94.2
Ethane	0	21.5	11.3	6.92	4.98	4.53	3.46	2.95
Propylene	0	1.86	2.74	2.60	2.29	1.93	1.57	1.51
Propane	0	12.4	3.58	1.16	0.60	0.00	0.00	0.00
Butylene	0	0.60	0.78	0.31	0.00	0.00	0.00	0.00
Butane	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C9 Gas composition as a function of time on stream for HY(30) catalyst

Component	Composition (mol %)							
	@60 min	**@120 min**	**@180 min**	**@240 min**	**@300 min**	**@360 min**	**@420 min**	**@480 min**
CH4	25.3	12.9	11.4	7.87	5.99	4.10	2.94	3.42
CO2	26.0	3.17	3.04	2.58	2.30	2.06	1.85	2.45
Ethylene	14.5	28.7	36.3	53.2	63.9	74.2	80.8	79.6
Ethane	26.3	42.7	42.8	31.8	24.0	16.3	11.5	12.2
Propylene	7.92	1.40	1.26	1.91	2.17	2.46	2.30	2.33
Propane	0.00	8.74	4.61	2.65	1.62	0.94	0.57	0.00
Butylene	0.00	1.39	0.61	0.00	0.00	0.00	0.00	0.00
Butane	0.00	0.98	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C10 Gas composition as a function of time on stream for P/HY(30) catalyst

Component	Composition (mol %)							
	@60 min	**@120 min**	**@180 min**	**@240 min**	**@300 min**	**@360 min**	**@420 min**	**@480 min**
CH4	11.4	2.28	0.95	0.88	0.74	0.62	0.66	0.00
CO2	7.26	2.25	1.17	1.15	1.02	0.92	1.00	1.07
Ethylene	69.1	88.6	93.6	94.0	94.8	95.4	95.1	95.6
Ethane	6.66	3.70	2.31	2.23	1.99	1.76	1.85	1.90
Propylene	-5.59	2.72	1.60	1.46	1.22	1.12	1.14	1.20
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butylene	0.00	0.49	0.33	0.30	0.22	0.23	0.22	0.23
Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C11 Gas composition as a function of time on stream for Sb/HY(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	3.9	11.3	6.49	3.23	4.31	1.67	0.66	1.37
CO2	1.80	1.91	1.27	0.99	1.59	0.85	1.00	1.06
Ethylene	80.3	39.0	61.6	79.5	78.7	89.2	95.1	91.8
Ethane	9.27	37.6	26.0	13.1	13.1	6.46	1.85	4.52
Propylene	2.94	1.61	2.15	2.30	2.33	1.60	1.14	1.22
Propane	1.17	6.29	2.10	0.65	0.00	0.00	0.00	0.00
Butylene	0.61	1.24	0.38	0.22	0.00	0.26	0.22	0.00
Butane	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C12 Gas composition as a function of time on stream for Bi/HY(30) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	12.0	5.78	3.15	4.26	1.86	1.50	1.31
CO2	0.00	1.93	1.21	0.93	0.00	0.00	0.00	1.01
Ethylene	100	43.4	66.7	80.0	80.8	88.7	91.0	91.2
Ethane	0.00	34.5	21.9	12.2	12.5	7.14	5.49	4.62
Propylene	0.00	1.46	2.42	2.32	2.47	1.68	1.41	1.22
Propane	0.00	5.07	1.73	0.61	0.00	0.00	0.00	0.00
Butylene	0.00	0.76	0.31	0.25	0.00	0.00	0.00	0.00
Butane	0.00	0.99	0.00	0.57	0.00	0.64	0.60	0.66
Σ	100	100	100	100	100	100	100	100

Table C13 Gas composition as a function of time on stream for HZ5(80) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	23.4	18.7	17.2	14.7	12.0	10.2	8.99
CO2	0.00	0.00	1.91	2.36	3.20	3.27	3.27	3.18
Ethylene	100	17.4	15.0	15.4	16.9	19.1	21.0	22.7
Ethane	0.00	14.1	12.9	12.8	12.4	11.8	11.4	11.1
Propylene	0.00	4.74	3.57	3.55	4.68	5.34	6.16	7.17
Propane	0.00	39.1	44.9	45.3	44.5	44.1	42.7	40.9
Butylene	0.00	1.27	1.55	1.78	2.50	3.18	3.75	4.14
Butane	0.00	0.00	1.47	1.54	1.11	1.28	1.54	1.81
Σ	100	100	100	100	100	100	100	100

Table C14 Gas composition as a function of time on stream for P/HZ5(80) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	2.24	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	100	95.9	98.6	98.6	98.7	98.6	98.6	98.6
Ethane	0.00	0.67	0.52	0.51	0.51	0.54	0.53	0.55
Propylene	0.00	0.88	0.62	0.59	0.00	0.00	0.00	0.00
Propane	0.00	0.00	0.00	0.00	0.54	0.60	0.57	0.56
Butylene	0.00	0.32	0.29	0.28	0.24	0.27	0.28	0.29
Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C15 Gas composition as a function of time on stream for Sb/HZ5(80) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	26.4	19.2	18.2	15.5	13.2	12.1	11.1
CO2	0.00	0.00	4.37	5.25	5.44	5.45	5.24	5.17
Ethylene	100	43.4	14.4	16.6	18.2	20.1	21.7	23.7
Ethane	0.00	30.2	13.2	13.0	11.9	11.1	10.5	10.4
Propylene	0.00	0.00	3.64	4.55	5.87	7.02	8.35	9.45
Propane	0.00	0.00	41.1	38.5	38.0	36.9	34.9	34.0
Butylene	0.00	0.00	2.22	2.18	2.98	3.70	4.28	4.60
Butane	0.00	0.00	1.88	1.67	2.18	2.62	2.94	1.63
Σ	100	100	100	100	100	100	100	100

Table C16 Gas composition as a function of time on stream for Bi/HZ5(80) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	25.8	22.4	19.2	22.1	18.9	17.0	16.5
CO2	0.00	6.58	0.00	5.38	0.00	4.83	4.54	4.48
Ethylene	100	31.3	38.0	28.3	30.4	24.2	23.1	23.6
Ethane	0.00	20.3	21.3	17.2	17.2	15.9	15.2	15.1
Propylene	0.00	4.75	0.00	5.95	6.08	5.66	6.13	6.27
Propane	0.00	11.2	18.3	24.0	24.3	29.2	32.4	32.4
Butylene	0.00	0.00	0.00	0.00	0.00	1.38	1.69	1.66
Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Σ	100	100	100	100	100	100	100	100

Table C17 Gas composition as a function of time on stream for HZ11(75) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	23.3	7.33	1.92	1.52	1.32	1.19	1.12	1.02
CO2	0.00	2.09	1.65	1.40	1.25	1.17	1.11	1.03
Ethylene	50.7	50.2	58.9	63.9	68.0	70.6	75.1	75.8
Ethane	12.7	4.00	3.47	3.14	2.93	2.81	2.76	2.60
Propylene	13.2	30.3	28.0	24.7	21.7	19.8	18.4	16.5
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butylene	0.00	0.99	0.69	0.48	0.37	0.29	0.00	1.74
Butane	0.00	5.06	5.39	4.91	4.41	4.14	1.51	1.38
Σ	100	100	100	100	100	100	100	100

Table C18 Gas composition as a function of time on stream for P/HZ11(75) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	6.69	26.2	12.1	10.9	9.55	8.29	7.63	7.69
CO2	4.41	4.53	4.68	3.78	3.16	2.52	2.36	2.37
Ethylene	72.9	57.6	68.5	71.8	73.9	78.2	78.3	75.0
Ethane	2.90	2.52	2.90	2.81	2.76	2.67	2.71	2.75
Propylene	7.18	6.71	7.67	6.74	6.12	4.75	4.91	4.76
Propane	3.40	0.00	0.00	0.00	0.00	0.00	0.00	4.99
Butylene	1.43	1.46	0.92	1.14	1.60	1.38	1.72	1.29
Butane	1.05	0.92	3.24	2.83	2.89	2.18	2.36	1.11
Σ	100	100	100	100	100	100	100	100

Table C19 Gas composition as a function of time on stream for Sb/HZ11(75) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	2.25	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	100	82.0	80.2	80.6	83.4	84.4	84.9	86.2
Ethane	0.00	1.12	1.20	1.15	1.03	1.03	0.96	0.92
Propylene	0.00	12.6	15.9	15.5	14.3	13.4	12.0	11.0
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butylene	0.00	1.23	1.66	1.65	0.50	0.48	1.28	1.15
Butane	0.00	0.80	1.12	1.10	0.74	0.71	0.86	0.77
Σ	100	100	100	100	100	100	100	100

Table C20 Gas composition as a function of time on stream for Bi/HZ11(75) catalyst

Component	Composition (mol %)							
	@60 min	@120 min	@180 min	@240 min	@300 min	@360 min	@420 min	@480 min
CH4	0.00	11.8	1.43	1.19	1.09	0.89	0.80	0.00
CO2	0.00	2.48	1.29	1.16	1.07	0.00	0.00	0.00
Ethylene	100	62.9	73.3	75.8	78.4	82.9	84.5	86.3
Ethane	0.00	2.92	2.21	2.07	1.98	1.78	1.72	1.69
Propylene	0.00	15.5	18.8	17.0	15.0	12.5	11.2	10.3
Propane	0.00	2.59	0.00	0.00	0.00	0.00	0.00	0.00
Butylene	0.00	1.80	1.81	1.67	1.50	1.21	1.12	1.04
Butane	0.00	0.00	1.16	1.06	0.92	0.74	0.71	0.66
Σ	100	100	100	100	100	100	100	100

Appendix D Compositions in Liquid Products

Table D1 Oil compositions from HZ5(30), P/HZ5(30), Sb/HZ5(30), and Bi/HZ5(30) catalysts

Component	Composition (wt%)			
	HZ5(30)	**P/HZ5(30)**	**Sb/HZ5(30)**	**Bi/HZ5(30)**
Oxygenate	0.18	18.60	0.29	1.27
Non-aromatic	10.45	5.27	2.55	3.71
Benzene	1.28	7.48	0.56	0.25
Toluene	3.70	4.98	7.25	5.30
o-Xylene	6.52	6.10	1.37	7.48
m-Xylene	9.87	2.59	8.58	7.73
p-Xylene	4.66	2.55	4.30	5.04
Ethylbenzene	1.03	1.29	3.55	1.98
C9	26.35	2.23	38.78	28.62
C10+	35.96	48.92	32.77	38.61
BTEX/total aromatics	0.30	0.33	0.26	0.29
p-Xylene/total aromatics	0.172	0.102	0.168	0.181

Table D2 Oil compositions from HBeta(27), P/HBeta(27), Sb/HBeta(27), and, Bi/HBeta(27) catalysts

Component	Composition (wt %)			
	HBeta(27)	**P/HBeta(27)**	**Sb/HBeta(27)**	**Bi/HBeta(27)**
Oxygenate	1.03	3.63	1.02	1.43
Non-aromatic	0.00	0.00	0.44	0.57
Benzene	30.02	29.25	8.95	14.76
Toluene	34.83	27.40	21.66	23.73
o-Xylene	9.26	3.80	11.06	9.32
m-Xylene	10.67	5.56	14.91	11.86
p-Xylene	8.33	4.46	10.90	9.96
Ethylbenzene	1.18	1.41	3.32	3.15
C9	2.70	4.51	16.44	15.29
C10+	1.97	19.97	11.30	9.93
BTEX/total aromatics	0.95	0.75	0.72	0.74
p-Xylene/total aromatics	0.088	0.062	0.154	0.137

Table D3 Oil compositions from HY(30), P/HY(30), Sb/HY(30), and, Bi/HY(30) catalysts

Component	Composition (wt %)			
	HY(30)	P/HY(30)	Sb/HY(30)	Bi/HY(30)
Oxygenate	0.71	7.31	7.38	13.87
Non-aromatic	3.52	1.87	1.27	1.10
Benzene	44.90	45.62	42.81	32.81
Toluene	31.34	18.00	21.38	19.08
o-Xylene	4.40	3.88	5.32	6.31
m-Xylene	5.12	4.02	6.19	6.20
p-Xylene	3.85	2.92	4.75	5.16
Ethylbenzene	1.27	1.02	1.38	1.35
C9	0.88	2.66	1.86	5.13
C10+	4.00	12.69	7.67	8.98
BTEX/total aromatics	0.95	0.83	0.90	0.83
p-Xylene/total aromatics	0.042	0.039	0.058	0.073

Table D4 Oil composition from HZ5(80), P/HZ5(80), Sb/HZ5(80), and Bi/HZ5(80) catalysts

Component	Composition (wt %)			
	HZ5(80)	P/ HZ5(80)	Sb/ HZ5(80)	Bi/ HZ5(80)
Oxygenate	0.01	25.94	0.00	0.14
Non-aromatic	9.76	0.00	15.00	22.6
Benzene	0.24	0.00	3.39	0.00
Toluene	9.54	1.76	29.47	9.61
o-Xylene	15.24	7.70	5.04	3.92
m-Xylene	14.80	2.74	2.54	2.62
p-Xylene	5.79	6.93	6.43	6.14
Ethylbenzene	5.08	2.75	16.52	12.8
C9	25.49	7.75	13.62	15.5
C10+	14.05	44.43	8.00	26.6
BTEX/total aromatics	0.56	0.30	0.75	0.53
p-Xylene/total aromatics	0.114	0.317	0.101	0.175

Table D5 Oil composition from HZ11(75), P/HZ11(75), Sb/HZ11(75), and Bi/HZ5(75) catalysts

Component	Composition (wt %)			
	HZ11(75)	**P/ HZ11(75)**	**Sb/ HZ11(75)**	**Bi/ HZ11(75)**
Oxygenate	0.04	7.03	0.03	0.00
Non-aromatic	14.0	12.85	1.77	3.89
Benzene	1.98	3.19	15.03	8.21
Toluene	2.94	0.05	29.40	9.25
o-Xylene	12.83	9.74	10.66	21.81
m-Xylene	22.1	13.58	22.04	23.22
p-Xylene	13.2	15.86	9.77	4.78
Ethylbenzene	5.2	11.71	4.94	11.12
C9	22.2	18.50	6.36	17.14
C10+	5.57	7.49	0.00	0.59
BTEX/total aromatics	0.68	0.68	0.94	0.82
p-Xylene/total aromatics	0.226	0.293	0.106	0.061

Appendix E True Boiling Point Curves

Table E1 True boiling point curves from HZ5(30), P/HZ5(30), Sb/HZ5(30), Bi/HZ5(30)

% OFF	Boiling point (°C)			
	HZ5(30)	P/HZ5(30)	Sb/HZ5(30)	Bi/HZ5(30)
0	67.2	51.8	62.3	59.9
5	70	53.1	70.9	70.9
10	72.4	54.1	72.8	73.7
15	95.8	55.2	80.3	98.8
20	98.8	56.3	99.4	100.4
25	99.6	57.4	100.5	101.5
30	100.3	58.4	101.3	102.4
35	100.9	59.5	102	103.2
40	101.4	65.9	102.7	104
45	101.9	99.1	103.3	104.7
50	102.4	134.9	103.8	105.3
55	102.8	163.2	104.3	105.9
60	103.2	176.2	104.9	127.9
65	125.4	182.8	125.4	129.2
70	127	187.6	127.7	130.4
75	127.9	192.9	128.7	131.4
80	128.6	203.7	129.6	133.6
85	130.3	215.2	130.7	151.4
90	133.2	223.4	132.9	168.7
95	154.8	267.8	155.3	212.4
100	278.2	424.9	287.3	303.4

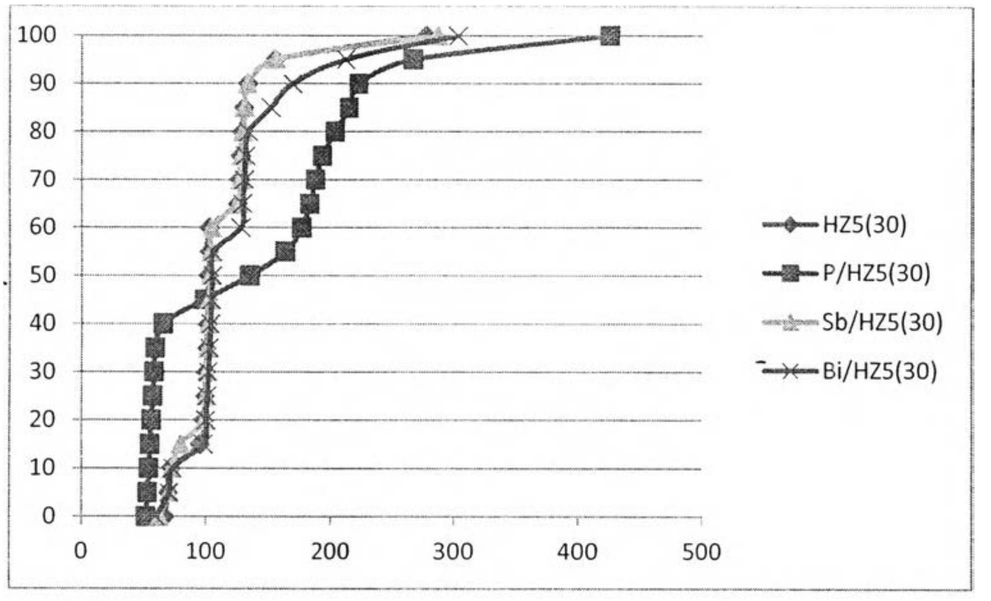

Figure E1 True boiling point curves from HZ5(30), P/HZ5(30), Sb/HZ5(30), Bi/HZ5(30).

Table E2 Petroleum cuts obtained from the HZ5(30), P/HZ5(30), Sb/HZ5(30), Bi/HZ5(30).

Fraction	Boiling point (°C)	wt %			
		HZ5(30)	P/HZ5(30)	Sb/HZ5(30)	Bi/HZ5(30)
Gasoline	<149	93.66	52.49	93.59	84.33
Kerosene	149-232	4.47	38.48	4.31	11.75
Gas oil	232-343	1.87	6.42	2.09	3.92
LVGO	343-371	0.00	0.89	0.00	0.00
HVGO	>371	0.00	1.72	0.00	0.00

Table E3 True boiling point curves from HBeta(27), P/ HBeta(27), Sb/ HBeta(27), Bi/ HBeta(27)

% OFF	Boiling point (°C)			
	HBeta(27)	P/HBeta(27)	Sb/HBeta(27)	Bi/HBeta(27)
0	62.3	53.3	52.6	52.4
5	63.4	54.3	55.6	54.3
10	64.4	55.4	93.2	61
15	65.5	56.5	98.3	90.4
20	72.2	59.3	101.2	98.4
25	73.3	75	123.3	101
30	74.8	98.6	124	123.7
35	99.2	103.4	125.4	124.8
40	99.6	127.5	128.3	126.9
45	101.2	140.9	130.3	129.3
50	125.1	171.3	146.1	145.6
55	126.8	184.3	152.6	151.2
60	129	194.7	156	154.7
65	133.4	203.3	172.5	166.1
70	159.2	207.1	190	180.4
75	186	214.1	196.7	193.8
80	212.2	228.6	216.8	201.8
85	230	243	239.5	210.8
90	254.3	270.9	257.6	230.1
95	314	349.3	283.5	267.2
100	524.7	522.1	434.8	498.3

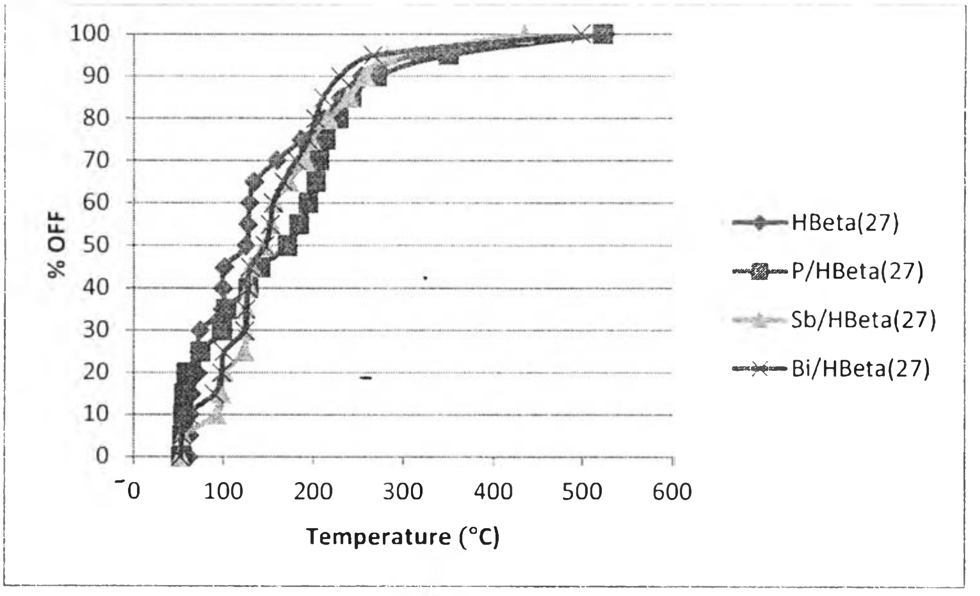

Figure E2 True boiling point curves from HBeta(27), P/ HBeta(27), Sb/ HBeta(27), Bi/ HBeta(27) catalysts.

Table E4 Petroleum cuts obtained from HBeta(27), P/ HBeta(27), Sb/ HBeta(27), Bi/ HBeta(27) catalysts.

Fraction	Boiling point (°C)	wt %			
		HBeta(27)	**P/ HBeta(27)**	**Sb/ HBeta(27)**	**Bi/ HBeta(27)**
Gasoline	<149	68.02	46.33	52.23	53.04
Kerosene	149-232	17.39	6.03	31.12	37.22
Gas oil	232-343	10.28	29.86	13.62	6.38
LVGO	343-371	0.66	6.98	0.93	0.61
HVGO	>371	3.65	10.80	2.11	2.75

Table E5 True boiling point curves from HY(30), P/HY(30), Sb/HY(30), and Bi/HY(30) catalysts.

% OFF	Boiling point (°C)			
	HY(30)	P/ HY(30)	Sb/ HY(30)	Bi/ HY(30)
0	58.2	56.3	52.8	52.6
5	59.9	58.6	54.3	55
10	61	59.9	55.4	56.1
15	62.1	61	56.5	57.6
20	63.2	62.1	57.6	58.6
25	64.2	63.2	58.6	59.7
30	65.3	64.2	59.7	60.8
35	66.4	65.3	60.8	61.9
40	67.5	66.4	61.9	62.9
45	68.5	73.9	62.9	64
50	69.6	174.2	64	65.1
55	70.7	226.6	65.1	66.2
60	71.7	352.3	66.2	67.2
65	72.8	363.8	67.2	68.3
70	73.9	374.4	68.3	69.4
75	75	384.6	73.3	72.2
80	76	392.2	97.1	75.4
85	91.9	402	177.9	133.1
90	243.9	414.2	214.3	227.6
95	518.6	442.4	267	263.4
100	569.1	564.6	568	570.1

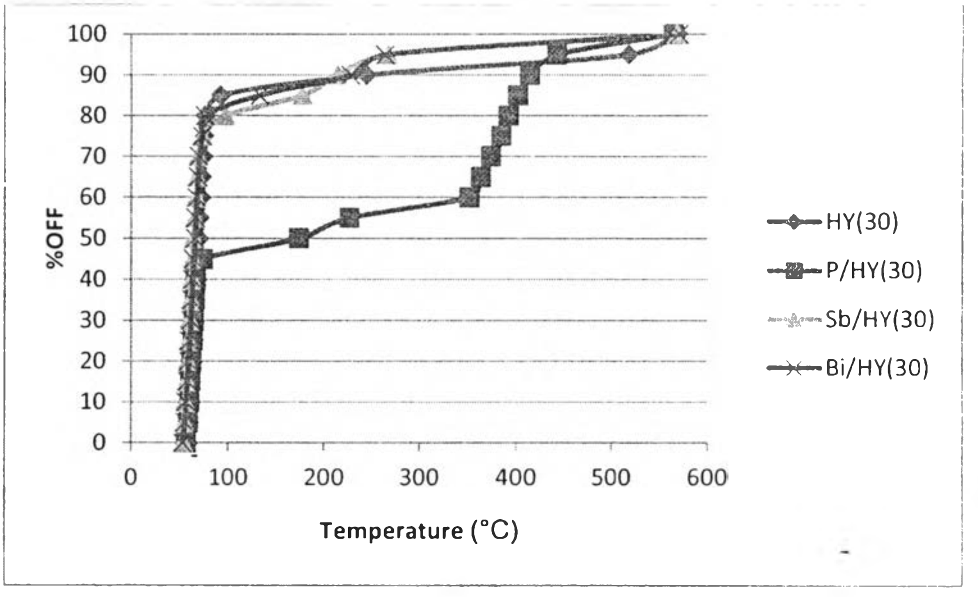

Figure E3 True boiling point curves from HY(30), P/HY(30), Sb/HY(30), and Bi/HY(30) catalysts.

Table E6 Petroleum cuts obtained from HY(30), P/HY(30), Sb/HY(30), and Bi/HY(30) catalysts.

Fraction	Boiling point (°C)	wt %			
		HY(30)	**P/HY(30)**	**Sb/HY(30)**	**Bi/HY(30)**
Gasoline	<149	86.88	48.74	83.21	85.84
Kerosene	149-232	2.73	6.77	8.47	4.77
Gas oil	232-343	2.20	4.11	4.58	5.68
LVGO	343-371	0.51	8.77	0.47	0.46
HVGO	>371	7.69	31.60	3.27	3.25

Table E7 True boiling point curves from HZ5(80), P/HZ5(80), and Sb/HZ5(80), Bi/HZ5(80) catalysts

% OFF	Boiling point (°C)			
	HZ5(80)	**P/HZ5(80)**	**Sb/HZ5(80)**	**Bi/HZ5(80)**
0	61.7	55	58.2	68.1
5	70.5	57.1	70.5	70.9
10	79.7	61.2	74.8	73
15	93.7	67	92.4	91.5
20	96.5	107.7	95.4	95.6
25	98.1	143.2	97.5	98.1
30	98.8	163.3	98.5	98.8
35	99.4	176.1	99.2	99.5
40	99.9	180.7	99.7	100.4
45	100.4	190.5	100.2	100.6
50	100.9	200	100.7	101.2
55	118.4	204.6	101.1	101.7
60	121.9	207.9	119	118.7
65	124.5	222.2	122.3	122.6
70	126.3	226.4	124.8	125.5
75	127	232.4	126.4	126.7
80	128.6	249.1	127.5	128.6
85	141.8	268.6	129	149.3
90	155.2	289.6	148.8	181.7
95	205.5	317.1	185.7	206.8
100	295.2	425.6	294.3	245

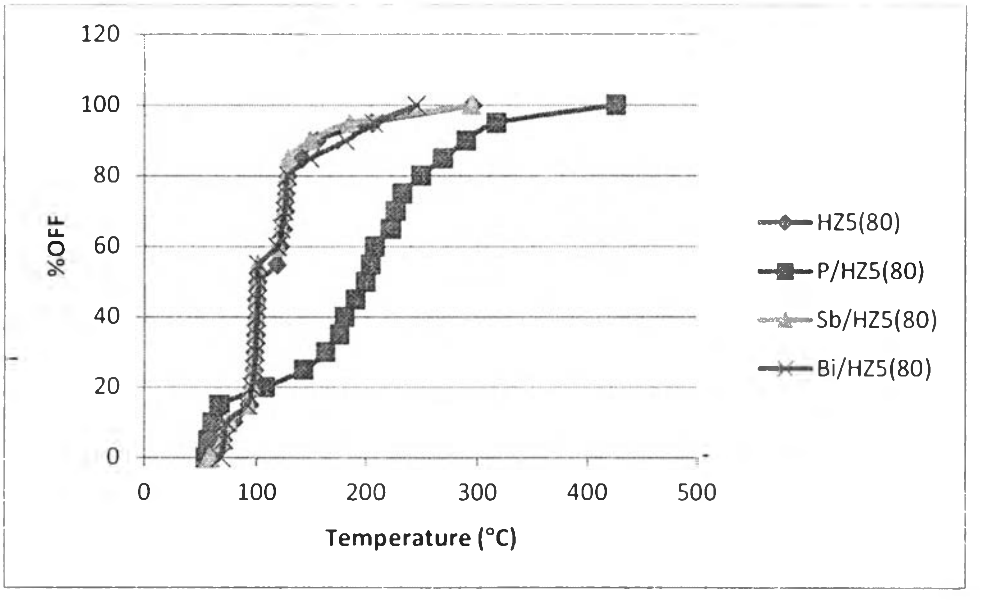

Figure E4 True boiling point curves from HZ5(80), P/HZ5(80), Sb/HZ5(80), and Bi/HZ5(80) catalysts.

Table E8 Petroleum cuts obtained from HZ5, 1BiHZ5, 2BiHZ5, 3BiHZ5, and 4BiHZ5 catalysts

Fraction	Boiling point (°C)	wt %			
		HZ5(80)	P/HZ5(80)	Sb/HZ5(80)	Bi/HZ5(80)
Gasoline	<149	84.1	69.0	69.8	69.9
Kerosene	149-232	11.3	23.3	24.5	22.7
Gas oil	232-343	1.73	5.46	3.28	4.87
LVGO	343-371	0.44	0.79	0.68	0.70
HVGO	>371	2.44	1.49	1.68	1.84

Table E9 True boiling point curves from HZ11(75), P/HZ11(75), and Sb/HZ11(75), Bi/HZ11(75) catalysts

% OFF	Boiling point (°C)			
	HZ11(75)	P/HZ11(75)	Sb/HZ11(75)	Bi/HZ11(75)
0	58.2	54.3	56.9	57.4
5	77.3	60.6	60.8	80.6
10	92.6	71.7	63.4	90.4
15	93.9	88.3	67.5	91.5
20	96.9	95.2	76	94.5
25	113.8	112.7	93.9	112.3
30	116	115.6	96	114.2
35	116.9	117.3	113.7	115.1
40	117.6	118.5	115.7	115.7
45	118	124.1	116.2	116.2
50	118.6	137.1	116.6	116.6
55	123.9	139.4	118.6	117
60	127.1	150.8	123.3	121.7
65	138.1	160.9	137	122.8
70	145.9	168.7	137.9	136.6
75	154.8	178.4	146.1	137.3
80	176	187.2	170.8	144.6
85	195.1	198	211.8	159.8
90	216.3	210.8	233.5	184.8
95	242.8	249.4	264.4	243.5
100	331.1	318.5	418.6	329.7

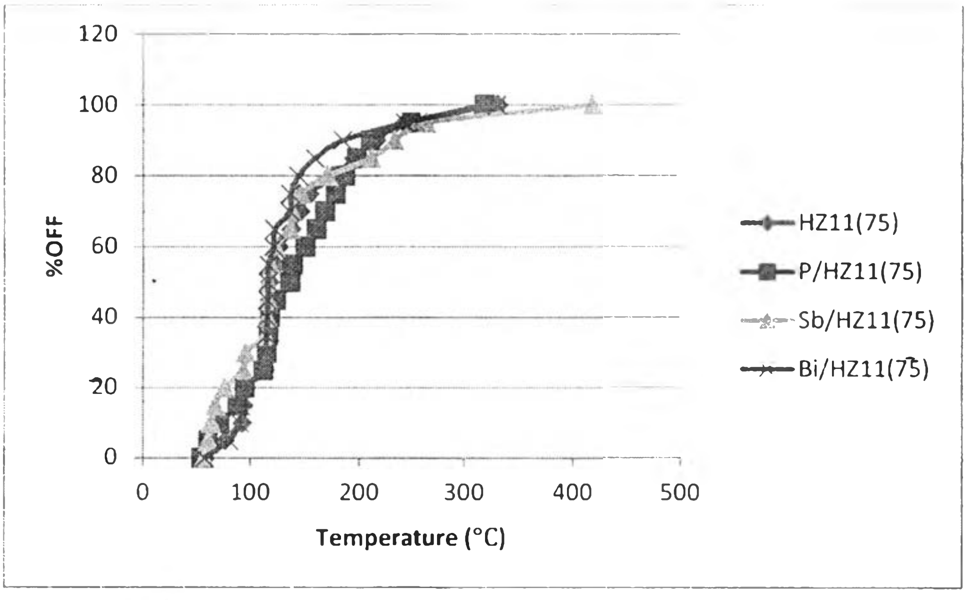

Figure E5 True boiling point curves from HZ11(75), P/HZ11(75), Sb/HZ11(75), and Bi/HZ11(75) catalysts.

Table E10 Petroleum cuts obtained from HZ11(75), P/HZ11(75), Sb/HZ11(75), and Bi/HZ11(75) catalysts

Fraction	Boiling point (°C)	wt %			
		HZ11(75)	**P/HZ11(75)**	**Sb/HZ11(75)**	**Bi/HZ11(75)**
Gasoline	<149	71.74	59.21	90.03	81.45
Kerosene	149-232	21.22	33.54	7.10	12.57
Gas oil	232-343	7.04	7.25	2.87	5.98
LVGO	343-371	0.00	0.00	0.00	0.00
HVGO	>371	0.00	0.00	0.00	0.00

Appendix F Xylene Isomer Spectra From GCxGC-MS/TOF

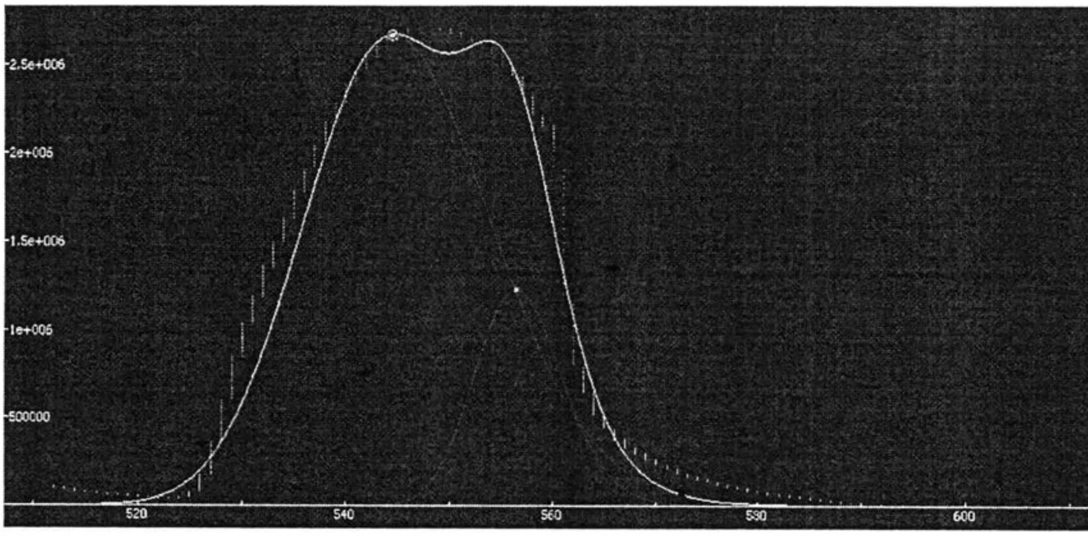

Figure F1 Deconvoluted peak of m,p-xylene from using GC×GC-MS/TOF.

Deconvoluted peak area = 2,621,351,427

p-Xylene peak area = 736,872,132

m-Xylene peak area = 1,884,479,295

wt.% of *p,m*-Xylene = 20.34 wt.%

wt.% of *p*-Xylene = 20.34x (736,872,132 /2,621,351,427) = 5.73 wt.%

wt.% of *m*-Xylene = 20.34x (1,884,479,295/2,621,351,427) =14.6 wt.%

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Proceedings:

1. Kittikarnchanaporn, J. , Jitkarnka, S. (2014). Effects of SiO_2/Al_2O_3 Ratio of HZSM-5 with Antimony Oxide Promoter for Dehydration of Bio-ethanol to Hydrocarbons. Proceedings of The 5th Research Symposium on Petrochemical and Materials Technology and The 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.
2. Kittikarnchanaporn, J. and Jitkarnka, S. (2014). Distillate Range of Hydrocarbon Production from Bio-ethanol Dehydration Using HY, HBeta, and HZSM-5 as Supports of Phosphorus Oxide. Proceedings of The 17th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Prague, Czech Republic.