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APPENDICES

APPENDIX A

2³ factorial design experimental data

Table A-1 2³ factorial design experimental data for catalytic cracking of waste lubricating oil over Fe/AC

Condition			Product yield (wt%)			%recovered				
Temp (°C)	Pressure (bar)	%Fe/AC (wt%)	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue
375	5	1	83.69	16.03	0.28	1.62	1.14	13.10	13.59	70.55
425	5	1	69.12	29.55	1.33	33.96	14.57	29.41	6.34	15.72
375	10	1	80.82	18.08	1.10	2.82	2.40	19.32	15.89	60.11
425	10	1	63.36	35.43	1.21	37.92	15.21	28.75	5.93	12.19
375	5	5	70.81	26.36	2.83	7.84	7.00	27.83	11.77	45.56
425	5	5	58.32	39.14	2.54	40.71	16.93	30.07	4.91	7.38
375	10	5	80.89	17.80	1.31	5.21	3.04	20.14	15.21	56.40
425	10	5	58.88	38.89	2.23	42.91	15.91	26.91	4.49	9.78

Table A-2 2³ factorial design experimental data for catalytic cracking of waste lubricating oil over CoMo/Al₂O₃

Condition			Product yield (wt%)			%recovered				
Temp (°C)	Pressure (bar)	%Fe/AC (wt%)	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue
375	5	1	89.70	10.15	0.15	1.42	2.33	21.06	16.19	59.00
425	5	1	63.48	34.33	2.19	32.89	12.48	22.12	4.53	27.98
375	10	1	87.16	12.54	0.30	3.34	3.49	20.59	14.08	58.50
425	10	1	60.21	37.31	2.48	35.10	13.48	29.74	5.20	16.48
375	5	5	76.18	21.48	2.34	3.14	2.57	21.42	16.65	56.22
425	5	5	60.11	36.57	3.32	37.00	16.84	28.69	4.89	12.58
375	10	5	79.33	18.59	2.09	3.47	2.83	18.87	15.23	59.60
425	10	5	55.10	41.58	3.32	43.16	17.42	29.79	4.20	5.43

Table A-3 2³ factorial design experimental data for catalytic cracking of waste lubricating oil over HZSM-5

Condition			Product yield (wt%)			%recovered				
Temp (°C)	Pressure (bar)	%HZSM-5 (wt%)	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue
375	5	0.1	89.19	10.68	0.13	1.41	2.06	13.49	15.96	67.08
425	5	0.1	73.83	24.18	1.99	16.83	6.89	24.20	7.10	44.98
375	10	0.1	86.43	9.16	4.41	2.43	5.05	23.13	13.84	55.55
425	10	0.1	70.58	27.63	1.79	17.24	7.16	25.28	7.36	42.96
375	5	1.0	81.08	18.00	0.92	4.20	3.09	12.46	13.59	66.66
425	5	1.0	62.59	34.72	2.69	32.91	14.45	28.14	3.51	20.99
375	10	1.0	85.24	13.19	1.57	2.40	3.71	19.11	15.28	59.50
425	10	1.0	58.67	40.12	1.21	38.20	14.10	26.20	5.24	16.26

APPENDIX B

Univariate experimental data

Table B-1 Univariate experimental data for catalytic cracking of waste lubricating oil over Fe/AC

condition			Product yield (wt%)			%recovered					overall composition in liquid product (wt%)			sum of 3 composition (wt%)
Temp (°C)	Pressure (bar)	%Fe/AC (wt%)	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	
375	5	1	83.69	16.03	0.28	1.62	1.14	13.10	13.59	70.55	1.36	0.95	10.96	13.27
375	5	3	82.65	14.47	2.88	2.48	2.31	18.39	15.93	60.89	2.05	1.91	15.20	19.16
375	5	5	80.81	16.36	2.83	7.84	7	27.83	11.77	45.56	6.34	5.66	22.49	34.48
390	5	1	82.92	16.38	0.7	2.77	1.64	13.59	12.75	69.25	2.30	1.36	11.27	14.93
390	5	3	87.66	11.99	0.35	3.85	2.13	13.89	11.96	68.17	3.37	1.87	12.18	17.42
390	5	5	79.55	18.58	1.87	7.1	6.9	27.5	11.78	46.72	5.65	5.49	21.88	33.01
410	5	1	80.37	19.16	0.47	7.48	4.86	21.14	11.19	55.33	6.01	3.91	16.99	26.91
410	5	3	68.41	30.11	1.48	8.9	5.32	20.17	10.11	55.5	6.09	3.64	13.80	23.53
410	5	5	75.38	22.9	1.72	18.93	10.32	29.79	9.59	31.37	14.27	7.78	22.46	44.50
425	5	1	69.12	29.55	1.33	33.96	14.57	29.41	6.34	15.72	23.47	10.07	20.33	53.87
425	5	3	60.31	37.16	2.53	36.84	16.34	27.92	4.85	14.05	22.22	9.85	16.84	48.91
425	5	5	58.32	39.14	2.54	40.71	16.93	30.07	4.91	7.38	23.74	9.87	17.54	51.15

Table B-2 Univariate experimental data for catalytic cracking of waste lubricating oil over CoMo/Al₂O₃

condition			Product yield (wt%)			%recovered					overall composition in liquid product (wt%)			sum of 3
Temp (°C)	pressure (bar)	%CoMo (wt%)	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	composition (wt%)
375	5	1	89.7	10.15	0.15	2.42	2.33	21.06	16.19	58	2.17	2.09	18.89	23.15
375	5	3	84.94	16.23	1.25	2.78	2.45	21.24	16.42	57.11	2.36	2.08	18.04	22.48
375	5	5	76.18	21.48	2.34	3.14	2.57	21.42	16.65	56.22	2.39	1.96	16.32	20.67
390	5	1	80.24	18.29	1.47	12.25	7.14	20.02	13.34	47.25	9.83	5.73	16.06	31.62
390	5	3	80.17	21.21	1.62	13.98	8.69	22.54	14.62	40.17	11.21	6.97	18.07	36.24
390	5	5	73.37	24.49	2.14	15.16	10.36	23.69	14.96	35.83	11.12	7.60	17.38	36.11
410	5	1	75.4	23.13	1.47	18.1	10.38	30.47	10.16	30.89	13.65	7.83	22.97	44.45
410	5	3	69.34	28.68	1.98	23.53	12.53	29.65	11.53	22.76	16.32	8.69	20.56	45.56
410	5	5	68.29	29.36	2.35	27.7	14.65	28.69	12.36	16.6	18.92	10.00	19.59	48.51
425	5	1	63.48	34.33	2.19	32.89	12.48	22.12	4.53	27.98	20.88	7.92	14.04	42.84
425	5	3	62.22	35.33	2.45	34.14	14.28	25.31	4.67	21.57	21.24	8.89	15.75	45.87
425	5	5	60.11	36.57	3.32	37.00	16.84	28.69	4.89	12.58	22.24	10.12	17.25	49.61

Table B-3 Univariate experimental data for catalytic cracking of waste lubricating oil over HZSM-5

condition			Product yield (wt%)			%recovered					overall composition in liquid product (wt%)			sum of 3 composition (wt%)
Temp (°C)	Pressure (bar)	%HZSM-5 (wt%)	liquid	gas (wt%)	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	
375	5	0.1	89.19	10.68	0.126	1.41	2.06	13.49	15.96	67.08	1.26	1.84	12.03	15.13
375	5	0.5	84.43	15.08	0.49	2.92	3.58	14.03	13.38	66.09	2.47	3.02	11.85	17.33
375	5	1.0	81.08	18.00	0.92	4.20	3.09	12.46	13.59	66.66	3.41	2.51	10.10	16.01
390	5	0.1	86.93	12.64	0.43	6.30	5.00	12.22	13.5	62.98	5.48	4.35	10.62	20.45
390	5	0.5	84.92	14.51	0.57	12.51	5.56	20.2	12.44	49.29	10.62	4.72	17.15	32.50
390	5	1.0	78.31	20.81	0.88	15.98	5.21	21.33	12.16	45.32	12.51	4.08	16.70	33.30
410	5	0.1	77.69	20.50	1.81	9.50	3.91	10.79	9.80	66.00	7.38	3.04	8.38	18.80
410	5	0.5	76.50	22.12	1.38	18.12	4.41	22.18	11.5	43.79	13.86	3.37	16.97	34.20
410	5	1.0	70.79	26.71	2.50	27.54	8.12	16.55	3.16	44.63	19.50	5.75	11.72	36.96
425	5	0.1	73.83	24.18	1.99	16.83	6.89	24.2	7.1	44.98	12.43	5.09	17.87	35.38
425	5	0.5	71.32	27.25	1.43	19.27	9.04	26.59	8.84	36.26	13.74	6.45	18.96	39.15
425	5	1.0	62.59	34.72	2.69	32.91	14.45	28.14	3.51	20.99	20.60	9.04	17.61	47.25

Table B-4 Effect of reaction time on product yield and composition in liquid product catalytic cracking of waste lubricating oil over Fe/AC

(Temperature 425 °C, pressure 5 bar and amount of Fe/AC 5 wt%)

Reaction time (minute)	Product yield (wt%)			%recovered					Overall composition in liquid product (wt%)			Sum of three composition (wt%)
	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	
10	87.43	11.55	1.02	8.71	6.98	17.16	4.19	62.96	7.62	6.10	15.00	28.72
30	82.77	15.72	1.51	17.16	11.45	23.72	4.99	42.68	14.20	9.48	19.63	43.31
60	58.32	39.14	2.54	40.71	16.93	30.07	4.91	7.38	23.74	9.87	17.54	51.15
90	52.67	45.54	1.79	41.73	17.34	31.16	4.47	5.30	21.98	9.13	16.41	47.52

Table B-5 Effect of reaction time on product yield and composition in liquid product catalytic cracking of waste lubricating oil over CoMo/Al₂O₃ (Temperature 425 °C, pressure 5 bar and amount of CoMo/Al₂O₃ 5 wt%)

Reaction time (minute)	Product yield (wt%)			%recovered					Overall composition in liquid product (wt%)			Sum of three composition (wt%)
	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	
10	79.33	16.94	3.23	12.14	8.15	18.86	14.39	46.46	9.69	6.51	15.02	31.25
30	69.80	28.06	2.14	25.43	10.21	22.23	8.95	33.18	17.75	7.13	15.52	40.39
60	60.11	36.57	3.32	37.00	16.84	28.69	4.89	12.58	22.24	10.12	17.25	49.61
90	56.64	40.57	2.79	40.35	17.85	29.48	3.89	8.43	22.85	10.11	16.70	49.66

Table B-6 Effect of reaction time on product yield and composition in liquid product catalytic cracking of waste lubricating oil over HZSM-5

(Temperature 425 °C, pressure 5 bar and amount of HZSM-5 1 wt%)

Reaction time (minute)	Product yield (wt%)			%recovered					Overall composition in liquid product (wt%)			Sum of three composition (wt%)
	liquid	gas	solid	gasoline	kerosene	light gas oil	gas oil	long residue	gasoline	kerosene	light gas oil	
10	87.43	11.55	1.02	8.71	6.98	17.16	4.19	62.96	7.62	6.10	15.00	28.72
30	82.77	15.72	1.51	17.16	11.45	23.72	4.99	42.68	14.20	8.07	19.63	43.31
60	62.59	34.72	2.69	32.91	14.45	22.14	3.51	26.99	20.60	9.04	17.61	47.25
90	60.67	35.54	3.79	32.73	17.34	28.16	3.47	18.30	19.86	10.52	17.08	47.46

APPENDIX C

Kinetic experimental data

Table C-1 Kinetic data for catalytic cracking of waste lubricating oil over Fe/AC (Pressure 5 bar and amount of Fe/AC 5 wt%)

Temperature (°C)	Time (minute)	Gas yield (wt%)	Solid yield (wt%)	Composition in liquid product (wt%)					Long residue
				Gasoline	Kerosene	Light gas oil	Gas oil		
390	10	10.33	1.32	1.76	1.26	5.46	4.70	75.17	
	20	11.03	2.02	3.48	2.54	7.54	4.65	68.74	
	30	12.03	1.68	4.75	3.31	9.01	5.19	64.02	
	40	14.16	1.52	5.20	3.93	11.43	6.37	57.39	
	50	14.28	1.17	5.51	5.28	15.88	7.69	50.18	
	90	19.84	1.87	5.65	5.49	21.88	9.37	37.17	
410	10	11.22	1.26	5.51	4.34	12.80	3.49	61.38	
	20	12.91	1.43	6.85	5.52	13.71	4.26	57.90	
	30	16.24	0.25	7.82	5.29	13.07	4.89	54.10	
	40	19.16	0.47	7.42	6.42	16.20	5.32	46.61	
	50	21.87	1.47	12.04	8.03	15.33	6.75	37.57	
	90	24.04	1.72	14.27	7.78	22.46	7.23	23.65	
425	10	11.55	1.02	7.62	6.10	15.00	3.66	55.05	
	20	16.22	1.31	11.50	8.07	17.36	3.87	41.68	
	30	15.72	1.51	14.20	9.48	19.63	4.13	35.33	
	40	24.92	3.32	20.90	8.94	18.05	3.65	20.21	
	50	31.41	4.13	22.90	8.80	17.92	3.33	11.51	
	90	39.14	2.54	23.74	9.87	17.54	2.86	4.30	
		45.54	1.79	21.96	9.13	16.41	2.35	2.79	

Table C-2 Kinetic data for catalytic cracking of waste lubricating oil over CoMo/Al₂O₃ (Pressure 5 bar and amount of CoMo/Al₂O₃ 5 wt%)

Temperature (°C)	Time (minute)	Gas yield (wt%)	Solid yield (wt%)	Composition in liquid product (wt%)				
				Gasoline	Kerosene	Light gas oil	Gas oil	Long residue
390	10	15.62	0.99	2.49	1.53	16.53	12.71	50.13
	20	15.90	0.75	2.85	1.94	16.72	13.49	48.34
	30	16.57	0.98	2.59	2.12	17.66	13.73	46.35
	40	17.04	1.20	4.37	2.85	16.83	13.15	44.56
	50	20.52	1.46	10.75	4.74	18.93	10.42	33.18
	60	24.49	2.14	11.12	7.60	17.38	10.98	26.29
410	90	27.89	2.09	11.75	7.76	16.99	9.35	24.18
	10	17.48	1.76	4.93	4.22	15.85	12.59	43.17
	20	17.79	2.04	6.93	5.08	16.59	11.93	39.64
	30	18.29	1.47	9.01	5.60	18.58	10.94	36.11
	40	22.79	1.45	10.64	6.11	19.45	9.36	30.19
	50	25.42	0.66	11.67	7.33	21.41	8.41	25.10
425	60	29.36	2.35	18.92	10.00	19.59	8.44	11.34
	90	31.58	3.04	18.50	10.61	20.00	7.77	8.49
	10	16.94	3.23	9.69	6.51	15.06	11.49	37.09
	20	22.06	2.14	12.55	7.25	15.32	7.78	32.90
	30	28.06	2.14	17.75	7.13	15.52	6.25	23.16
	40	28.47	2.26	19.03	7.62	16.30	4.77	21.55
425	50	32.44	2.31	19.78	7.59	14.78	3.82	19.27
	60	36.57	3.32	22.24	10.12	17.25	2.94	7.56
	90	40.57	2.79	22.85	10.11	16.70	2.20	4.77

Table C-3 Kinetic data for catalytic cracking of waste lubricating oil over HZSM-5 (Pressure 5 bar and amount of HZSM-5 1 wt%)

Temperature (°C)	Time (minute)	Gas yield (wt%)	Solid yield (wt%)	Composition in liquid product (wt%)				
				Gasoline	Kerosene	Light gas oil	Gas oil	Long residue
390	10	10.33	1.32	1.76	1.26	5.46	13.54	66.33
	20	11.03	2.02	3.48	2.54	7.54	10.74	62.66
	30	12.03	1.68	4.75	3.31	9.01	11.23	57.98
	40	14.16	1.52	5.20	3.93	11.43	11.43	52.33
	50	14.28	1.17	6.98	4.44	13.34	11.84	47.96
	60	20.81	0.88	12.51	4.08	16.70	9.52	35.49
410	90	25.74	1.83	14.33	7.62	12.64	8.29	29.56
	10	11.22	1.26	5.51	4.34	9.29	5.24	63.13
	20	12.91	1.43	6.85	5.52	10.28	4.26	58.75
	30	16.24	0.25	7.82	5.29	13.07	4.06	53.26
	40	19.16	0.47	7.42	6.42	12.99	3.71	49.83
	50	21.87	1.47	12.04	6.50	13.03	2.91	42.17
425	60	26.71	2.50	19.50	5.75	11.72	2.24	31.59
	90	29.52	2.10	19.42	7.86	12.66	2.69	25.75
	10	11.55	1.02	7.62	6.10	15.00	3.66	55.05
	20	16.22	1.31	11.50	8.07	17.36	3.87	41.68
	30	15.72	1.51	14.20	9.48	19.63	4.13	35.33
	40	24.92	3.32	13.73	8.94	18.05	3.65	27.39
425	50	26.41	2.13	13.95	9.75	19.87	3.69	24.20
	60	34.72	2.69	20.60	9.04	13.86	2.20	16.89
	90	35.54	3.79	19.86	10.52	17.08	2.11	11.10

APPENDIX D

Product analysis by GC-MS

Table D-1 Hydrocarbon components detected in liquid product from waste lubricating oil feedstock.

No.	Compound	Formula	Classification
1.	3,3,5-Trimethyl heptane	$C_{10}H_{22}$	n-Alkane C_{10}
2.	3,3,4-Trimethyl decane	$C_{13}H_{28}$	n-Alkane C_{13}
3.	Hexadecane	$C_{16}H_{34}$	n-Alkane C_{16}
4.	Heptadecane	$C_{17}H_{36}$	n-Alkane C_{17}
5.	Octadecane	$C_{18}H_{38}$	n-Alkane C_{18}
6.	Nonadecane	$C_{19}H_{40}$	n-Alkane C_{19}
7.	Eicosane	$C_{20}H_{42}$	n-Alkane C_{20}
8.	Heneicosane	$C_{21}H_{44}$	n-Alkane C_{21}
9.	Docosane	$C_{22}H_{46}$	n-Alkane C_{22}
10.	Tetracosane	$C_{24}H_{50}$	n-Alkane C_{24}
11.	Octacosane	$C_{28}H_{58}$	n-Alkane C_{28}
12.	Nonacosane	$C_{29}H_{60}$	n-Alkane C_{29}
13.	Hentriacontane	$C_{31}H_{64}$	n-Alkane C_{31}
14.	Tetratriacontane	$C_{34}H_{70}$	n-Alkane C_{34}
15.	Cyclohexane	C_6H_{12}	Cycloalkane
16.	Naphthalene	$C_{10}H_8$	Naphthalene
17.	1,3-Dimethyl naphthalene	$C_{12}H_{12}$	Alkyl-naphthalene
18.	1,2-Dimethyl naphthalene	$C_{12}H_{12}$	Alkyl-naphthalene

Table D-1 Hydrocarbon components detected in liquid product from waste lubricating oil feedstock (Continued).

No.	Compound	Formula	Classification
19.	Dodecamethyl cyclohexasiloxane	$C_{12}H_{36}O_6Si_6$	Siloxane
22.	Tetradecamethyl cycloheptasiloxane	$C_{14}H_{42}O_7Si_7$	Siloxane
21.	Eicosamethyl cyclodecasiloxane	$C_{20}H_{60}O_{10}Si_{10}$	Siloxane
22.	Hexadecamethyl cyclooctasiloxane	$C_{16}H_{48}O_8Si_8$	Siloxane
23.	Acetaldehyde	C_2H_4O	Aldehyde
24.	N-dl-Alanylglycine	$C_5H_{10}N_2O_3$	Nitrogen compound
25.	dl-Phynylephrine	$C_9H_{13}NO_2$	Nitrogen compound
26.	Dibutyl phthalate	$C_{16}H_{22}O_4$	Aromatic ester
27.	Butyl cyclohexyl ester phthalic acid	$C_{18}H_{24}O_4$	Aromatic ester
28.	Butyl-2-ethylhexyl ester -1,2-benzenedicarboxylic acid	$C_{20}H_{30}O_4$	Aromatic ester
29.	1-Cyclohexylethanamines	$C_8H_{17}N$	Nitrogen compound
30.	2-Undecanone	$C_{10}H_{20}O$	Aliphatic ketone
31.	5-(2-thienyl)-2-acetylthiophene	$C_{10}H_8OS_2$	Sulfur compound
32.	2,4-Di-tert-butylphenyl benzoate	$C_{21}H_{26}O_2$	Aromatic ester
33.	Nonyl ester chloroacetic acid	$C_{11}H_{21}ClO_2$	Halogen compound
34.	2-Methyl-1-hexene	C_7H_{14}	Alkene C ₇
35.	Fluorene	$C_{13}H_{10}$	Polyaromatic
36.	Phenanthrene	$C_{14}H_{10}$	Polyaromatic
37.	Anthracene	$C_{14}H_{10}$	Polyaromatic

Table D-2 Components detected in liquid product from cracking of waste lubricating oil over Fe/AC catalyst.

No.	Component	Formula	Classification
1.	n-Heptane	C_7H_{16}	n-Alkane C_7
2.	3-Methyl hexane	C_7H_{16}	iso-Alkane C_7
3.	2,4-Dimethyl hexane	C_8H_{18}	iso-Alkane C_8
4.	Toluene	C_7H_8	Alkyl-benzene
5.	n-Octane	C_8H_{18}	n-Alkane C_8
6.	Ethylbenzene	C_8H_{10}	Alkyl-benzene
7.	1,3-Dimethyl benzene	C_8H_{10}	Alkyl-benzene
8.	o-Xylene	C_8H_{10}	Alkyl-benzene
9.	n-Nonane	C_9H_{20}	n-Alkane C_9
10.	2,3,4-Trimethyl hexane	C_9H_{20}	Iso-Alkane C_9
11.	2,4-Dimethyl heptane	C_9H_{20}	Iso-Alkane C_9
12.	1-Ethyl-3methyl benzene	C_9H_{12}	Alkyl-benzene
13.	1,2,3-Trimethyl benzene	$C_{10}H_{22}$	Alkyl-benzene
14.	n-Decane	$C_{10}H_{22}$	n-Alkane C_{10}
15.	1,2,4-Trimethyl benzene	C_9H_{12}	Alkyl-benzene
16.	4-Ethyl-1,2-dimethyl benzene	$C_{10}H_{14}$	Alkyl-benzene
17.	n-Undecane	$C_{11}H_{24}$	n-Alkane C_{11}
18.	1-Phenyl-1-butene	$C_{10}H_{12}$	Alkyl-benzene
19.	Naphthalene	$C_{10}H_8$	Naphthalene

Table D-2 Components detected in liquid product from cracking of waste lubricating oil over Fe/AC catalyst (Continued.).

No.	Component	Formula	Classification
20.	1-Ethyl-2,3-dihydro-1-methyl-1H-Indene	$C_{11}H_{14}$	Naphthene.
21.	1-Ethyl-2,4,5-trimethyl benzene	$C_{11}H_{16}$	Alkyl-benzene
22.	Dodecane	$C_{12}H_{26}$	n-Alkane C_{12}
23.	Tridecane	$C_{13}H_{28}$	n-Alkane C_{13}
24.	1-Methyl naphthalene	$C_{11}H_{10}$	Alkyl-naphthalene
25.	2-Methyl naphthalene	$C_{11}H_{10}$	Alkyl-naphthalene
26.	Tetradecane	$C_{14}H_{30}$	n-Alkane C_{14}
27.	Pentadecane	$C_{15}H_{32}$	n-Alkane C_{15}
28.	Tetradecamethyl cycloheptasiloxane	$C_{14}H_{42}O_7Si_7$	Siloxane
29.	Hexadecamethyl-cyclohexasiloxane	$C_{16}H_{48}O_8Si_8$	Siloxane
30.	Octadecamethyl – cyclonanosiloxane	$C_{18}H_{54}O_9Si_9$	Siloxane
31.	Dibutyl phthalate	$C_{16}H_{22}O_4$	Aromatic ester
32.	Eicosamethyl cyclodecasiloxane	$C_{20}H_{60}O_{10}Si_{10}$	Siloxane

Table D-3 Components detected in liquid product from cracking of waste lubricating oil over CoMo/Al₂O₃ catalyst.

No.	Component	Formula	Classification
1.	n-Octane	C ₈ H ₁₈	n-Alkane C ₈
2.	2,4-Dimethyl hexane	C ₈ H ₁₈	iso-Alkane C ₈
3.	1,3-Dimethyl benzene	C ₈ H ₁₀	Alkyl-benzene
4.	n-Nonane	C ₉ H ₂₀	n-Alkane C ₉
5.	2,4-Dimethyl heptane	C ₉ H ₂₀	iso-Alkane C ₉
6.	2,3,4-Triimethyl hexane	C ₉ H ₂₀	iso-Alkane C ₉
7.	1-Ethyl-3-methyl benzene	C ₉ H ₁₂	Alkyl-benzene
8.	1,2,3-Trimethyl benzene	C ₉ H ₁₂	Alkyl-benzene
9.	n-Decane	C ₁₀ H ₂₂	n-Alkane C ₁₀
10.	1-Methyl-2-propyl benzene	C ₁₀ H ₁₄	Alkyl-benzene
11.	4-Ethyl-1,2-dimethyl benzene	C ₁₀ H ₁₄	Alkyl-benzene
12.	1-Ethyl-2,3-dimethyl benzene	C ₁₀ H ₁₄	Alkyl-benzene
13.	1,4-Diethyl benzene	C ₁₀ H ₁₄	Alkyl-benzene
14.	n-Undecane	C ₁₁ H ₂₄	n-Alkane C ₁₁
15.	1,2,3,4-Tetramethyl benzene	C ₁₀ H ₁₄	Alkyl-benzene
16.	1-Phenyl-1-butene	C ₁₀ H ₁₂	Alkyl-benzene
17.	1-Chloro-tetradecane	C ₁₄ H ₂₉ Cl	Haloalkane C ₁₄
18.	2,5-Heptaolecadione	C ₁₇ H ₃₂ O ₂	Aliphatic ketone
19.	6-Methyltetralin	C ₁₁ H ₁₄	Naphthene.

Table D-3 Components detected in liquid product from cracking of waste lubricating oil over CoMo/Al₂O₃ catalyst (Continued).

No.	Component	Formula	Classification
20.	Dodecane	C ₁₂ H ₂₆	n-Alkane C ₁₂
21.	2,6-Dimethyl undecane	C ₁₃ H ₂₈	n-Alkane C ₁₃
22.	1-Ethyl-2,3-dihydro-1-methyl-1H-Indene	C ₁₂ H ₁₆	Naphthene
23.	Dodecamethyl cyclohexasiloxane	C ₁₂ H ₃₆ O ₆ Si ₆	Siloxane
24.	(2,3-Dimethyldecyl)-benzene	C ₁₈ H ₃₀	Alkyl-benzene
25.	Tetradecane	C ₁₄ H ₃₀	n-Alkane C ₁₄
26.	1,5-Dimethyl naphthalene	C ₁₂ H ₁₂	Alkyl-naphthalene
27.	Pentadecane	C ₁₅ H ₃₂	n-Alkane C ₁₅
28.	Hexadecane	C ₁₆ H ₃₄	n-Alkane C ₁₆
29.	Heptadecane	C ₁₇ H ₃₆	n-Alkane C ₁₇
30.	Octadecane	C ₁₈ H ₃₈	n-Alkane C ₁₈
31.	Dibutyl phthalate	C ₁₆ H ₂₂ O ₄	Aromatic ester
32.	Heneicosane	C ₂₁ H ₄₄	n-Alkane C ₂₁
33.	2,6,10,14-Trimethyl hexadecane	C ₂₀ H ₄₂	n-Alkane C ₂₁
34.	Eicosane	C ₂₀ H ₄₂	n-Alkane C ₂₀

Table D-4 Components detected in liquid product from cracking of waste lubricating oil over HZSM-5 catalyst.

No.	Component	Formula	Classification
1.	Toluene	C_7H_8	Alkyl-benzene
2.	n-Octane	C_8H_{18}	n-Alkane C_8
3.	2,4-Dimethyl hexane	C_8H_{18}	iso-Alkane C_8
4.	Ethylbenzene	C_8H_{10}	Alkyl-benzene
5.	1,3-Dimethyl benzene	C_8H_{10}	Alkyl-benzene
6.	o-Xylene	C_8H_{10}	Alkyl-benzene
7.	n-Nonane	C_9H_{20}	n-Alkane C_9
8.	2,4-Dimethyl heptane	C_9H_{20}	iso-Alkane C_9
9.	2,3,4-Trimethyl hexane	C_9H_{20}	iso-Alkane C_9
10.	1-Ethyl-3methyl benzene	C_9H_{12}	Alkyl-benzene
11.	1-Ethyl-2-methyl benzene	C_9H_{12}	Alkyl-benzene
12.	1,2,3-Trimethyl benzene	$C_{10}H_{22}$	Alkyl-benzene
13.	Decane	$C_{10}H_{22}$	Alkane- C_{10}
14.	4-Ethyl-1,2-dimethyl benzene	$C_{10}H_{14}$	Alkyl-benzene
15.	Undecane	$C_{11}H_{24}$	Alkane- C_{11}
16.	1,4-diethyl benzene	$C_{10}H_{14}$	Alkyl-benzene
	4-(1-Methylethyl)-benzaldehyde	$C_{10}H_{12}O$	Aromatic aldehyde
17.	Naphthalene	$C_{10}H_8$	Naphthalene

Table D-4 Components detected in liquid product from cracking of waste lubricating oil over HZSM-5 catalyst (Continued.).

No.	Component	Formula	Classification
18.	1-Ethyl-2,3-dihydro-1-methyl- 1-Indene	$C_{11}H_{14}$	Naphthene.
19.	3,3-dimethylbutyl benzene	$C_{12}H_{18}$	Alkyl-benzene
20.	Tridecane	$C_{13}H_{28}$	n-Alkane C_{13}
21.	Tetradecane	$C_{14}H_{30}$	n-Alkane C_{14}
22.	Pentadecane	$C_{15}H_{32}$	n-Alkane C_{15}
23.	Hexadecane	$C_{16}H_{34}$	n-Alkane C_{16}
24.	Heptadecane	$C_{17}H_{36}$	n-Alkane C_{17}
25.	Octadecane	$C_{18}H_{38}$	n-Alkane C_{18}
26.	Octadecamethyl - cyclonanosiloxane	$C_{18}H_{54}O_9Si_9$	Siloxane
27.	Eicosamethyl - cyclodecasiloxane	$C_{20}H_{60}O_{10}Si_{10}$	Siloxane

APPENDIX E

GC-MS Chromatogram of liquid products

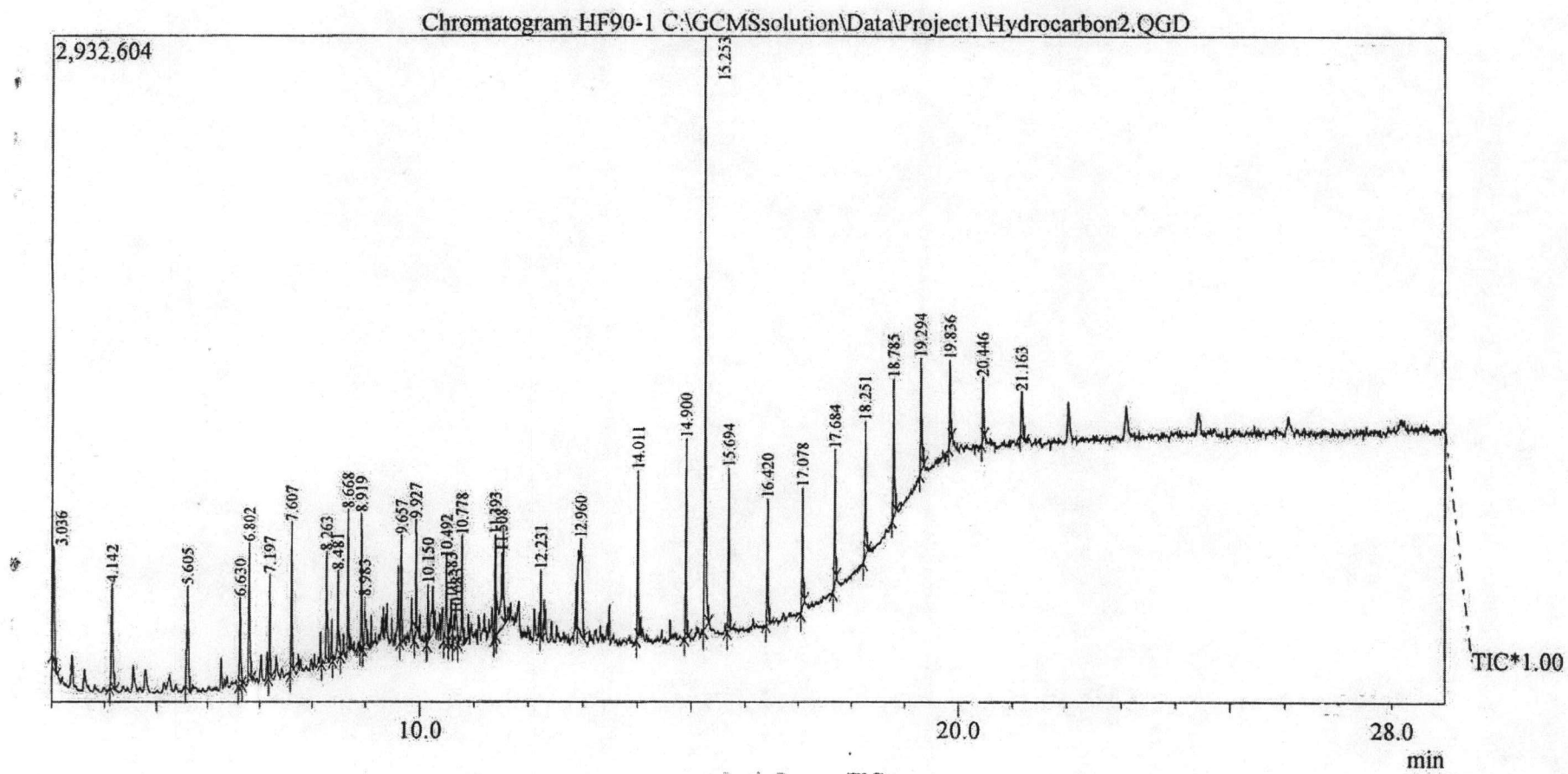


Figure E-1 GC-MS chromatogram of liquid product from catalytic cracking of waste lubricating oil over Fe/AC

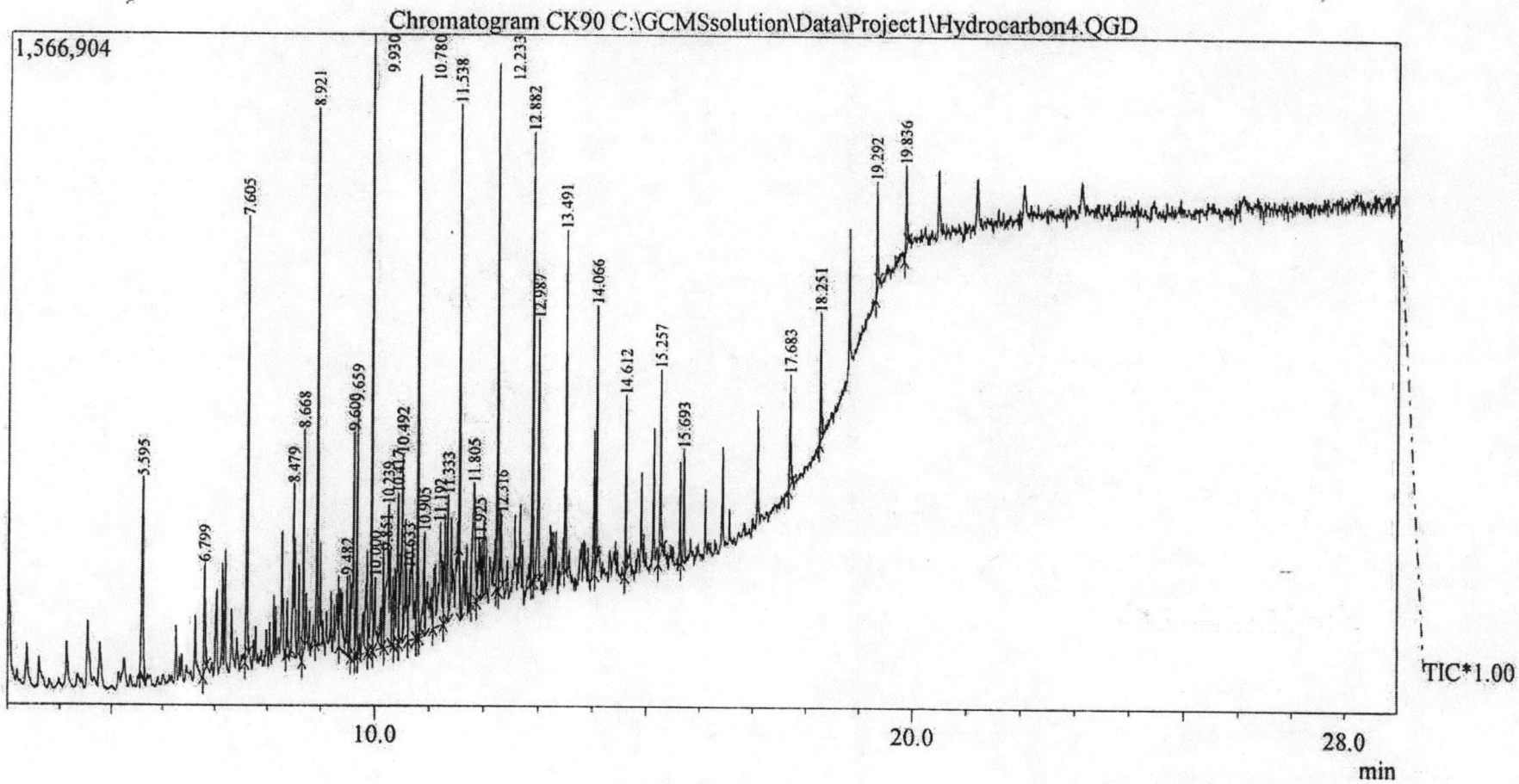


Figure E-2 GC-MS chromatogram of liquid product from catalytic cracking of waste lubricating oil over CoMo/Al₂O₃

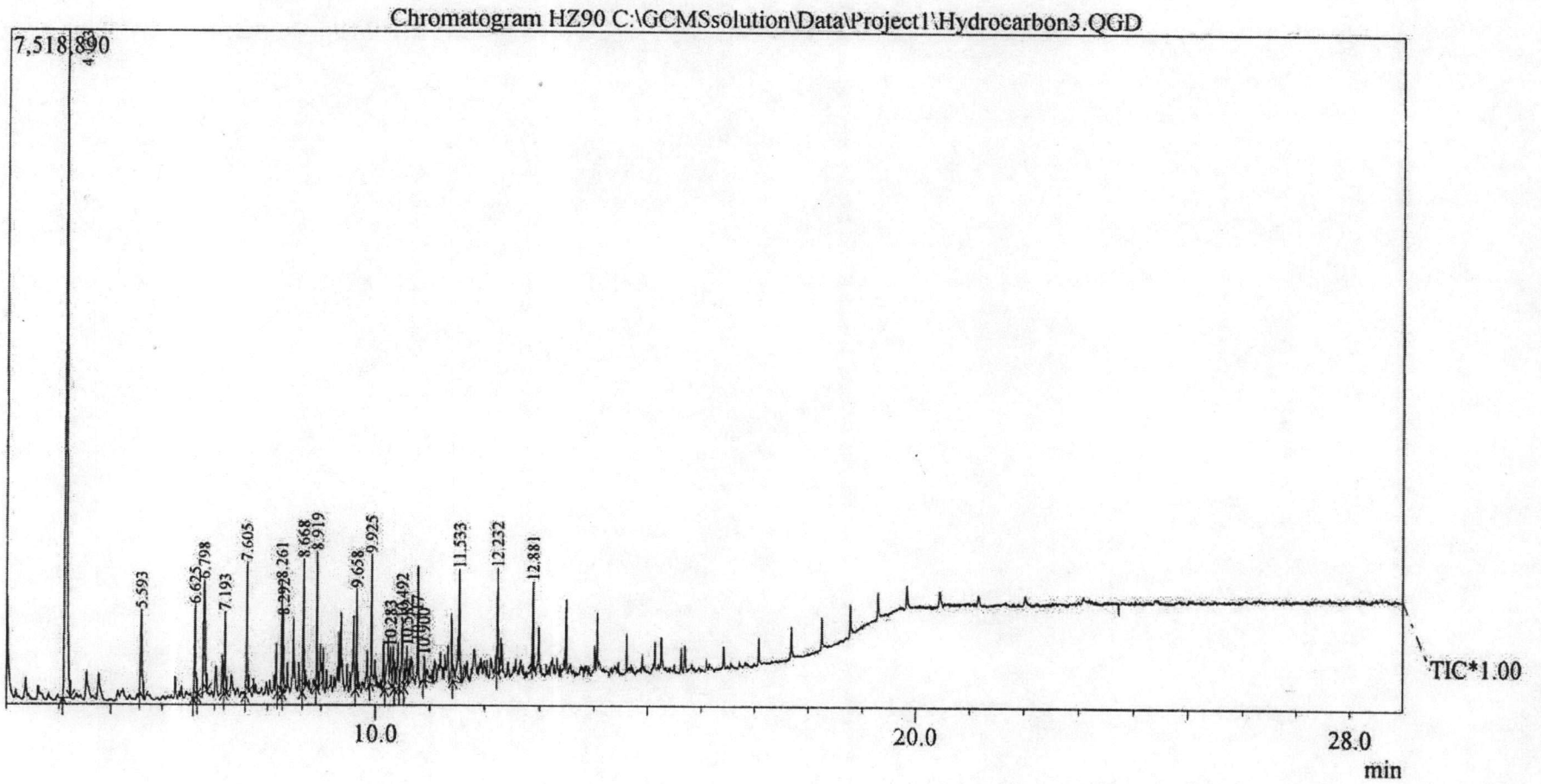


Figure E-3 GC-MS chromatogram of liquid product from catalytic cracking of waste lubricating oil over HZSM-5

BIOGRAPHY

Mr. Amnat Permsubscul was born on April 24, 1972 in Ratchaburi, Thailand. He received a Bachelor's degree of Science in Industrial Chemistry, Faculty of Science, Chiangmai University in 1994 and Master's degree of Engineering in Chemical Engineering, Faculty of Engineering, Chulalongkorn University in 1997. Since 2001, he has studied for Doctoral degree in Chemical Technology at the Faculty of Science, Chulalongkorn University.