APPENDICES

Appendix A

Determination of HCl reduction from copyrolysis of PVC with cattle manure

The percentage of HCl reduction was calculated from the amount of the remaining sodium hydroxide in absorber. The remaining sodium hydroxide in absorber was analyzed by titration with hydrochloric acid using phenolphthalein as an indicator. The calculation of percentage of HCl reduction is shown in an example below.

Example the calculation of percentage of HCl reduction at the heating rate of 1^oC/min, reaction temperature of 250^oC, reaction time of 60 min, and PVC:cattle manure of 1:5

Determination of the mol of HCl released from pyrolysis of PVC

Amount of PVC powder 0.1027 g

Amount of NaOH (solution 300 ml)

Flask No.1 2.2015 g

Flask No.2 2.3788 g

Flask No.3 2.3758 g

Volume of titration (ml)

Flask No	First	Second	Average
1	6.25	6.20	6.225
2	6.90	6.90	6.900
3	6.75	6.70	6.725

Concentration of hydrochloric acid 0.28583 mol/l

Flask No.1 mol of NaOH before reaction 2.3683 / 40 = 0.0592075 mol (A)

mol of NaOH after reaction (sampling 10ml)

(0.28583 x 6.225) x300 / 1000 = 0.053378752 mol (B)

mol of HCl released = mol of NaOH disappeared = (A) – (B)

= 0.0016587475 mol

Flask No.2 similar calculation with Flask No.1

mol of HCl reased = 0.0017287975 mol

Flask No.3

mol of HCl reased = 0.00030319 mol

Total HCl released = 0.003690735 mol

Mol of HCl released per weight of PVC = 359.3704966 mol/g

Determination of the mol of HCl released from pyrolysis of PVC and cattle manure mixture (1:5)

Amount of PVC powder 0.1021 g

Amount of NaOH (solution 300 ml)

Flask No.1	2.2132 g
Flask No.2	2.2262 g
Flask No.3	2.3817 g

Volume of titration (ml)

Flask No	First	Second	Average
1	5.20	5.15	5.175
2	5.30	5.30	5.300
3	5.50	5.50	5.500

Concentration of hydrochloric acid 0.34939 mol/l

Flask No.1 mol of NaOH before reaction 2.2132 / 40 = 0.055533 mol (A)

mol of NaOH after reaction (sampling 10ml)

(0.34939 x 5.175) x 300 / 1000 = 0.054242797 mol (B)

mol of HCl released = mol of NaOH disappeared = (A) – (B)

= 0.0010872025 mol

Flask No.2 similar calculation with Flask No.1

mol of HCl released = 0.00189315 mol

Flask No.3

mol of HCl released = 0.00010199 mol

Total HCl released = 0.0030823425 mol

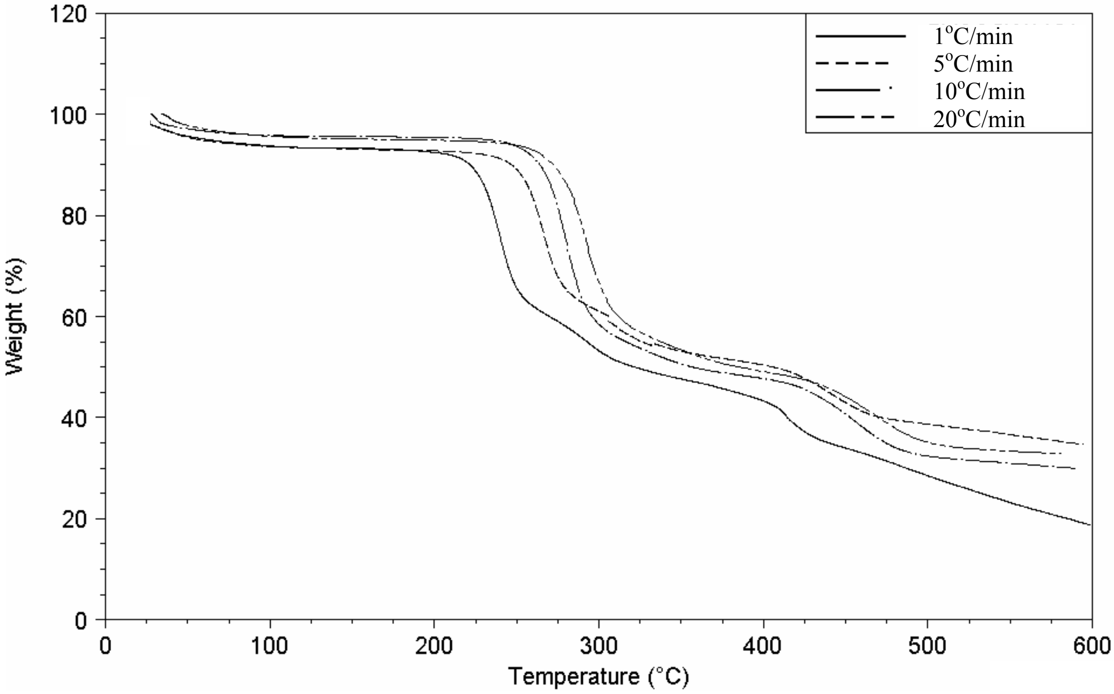
mol of HCl released per weight of PVC = 296.9501445 mol/g

Therefore, the percentage of HCl reduction was

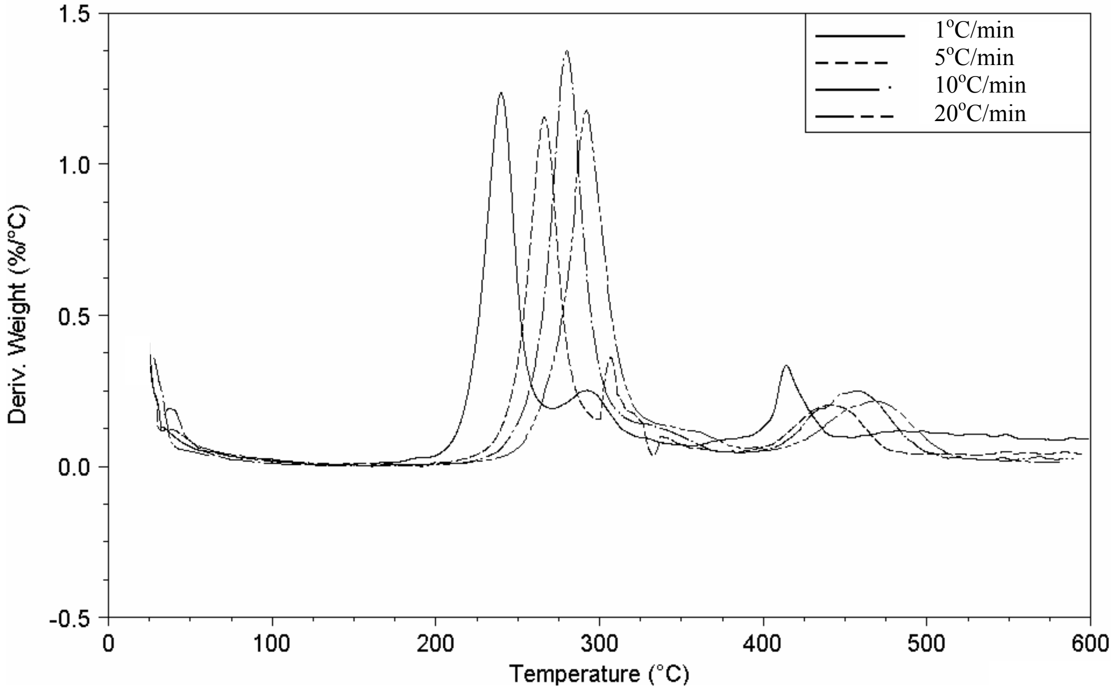
(359.3704966 - 296.9501445) x100 / 359.3704966 = 17.37%

Appendix B

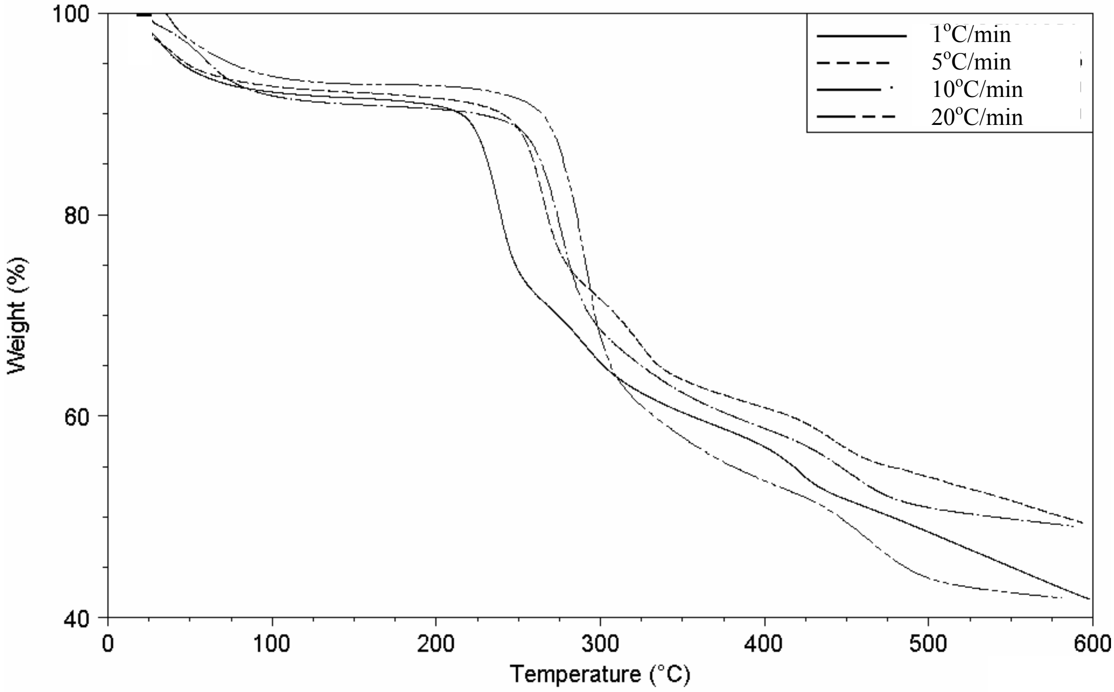
Thermogravimetric data for investigating kinetic parameters



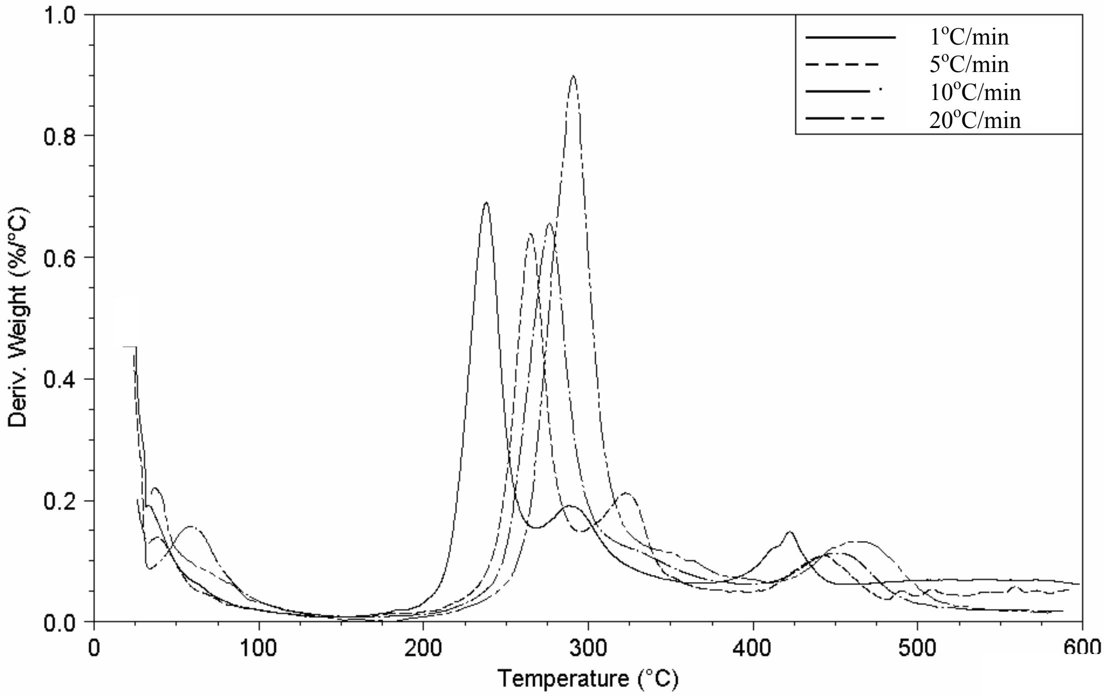
<u>Appendix Figure B1</u> Thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:1



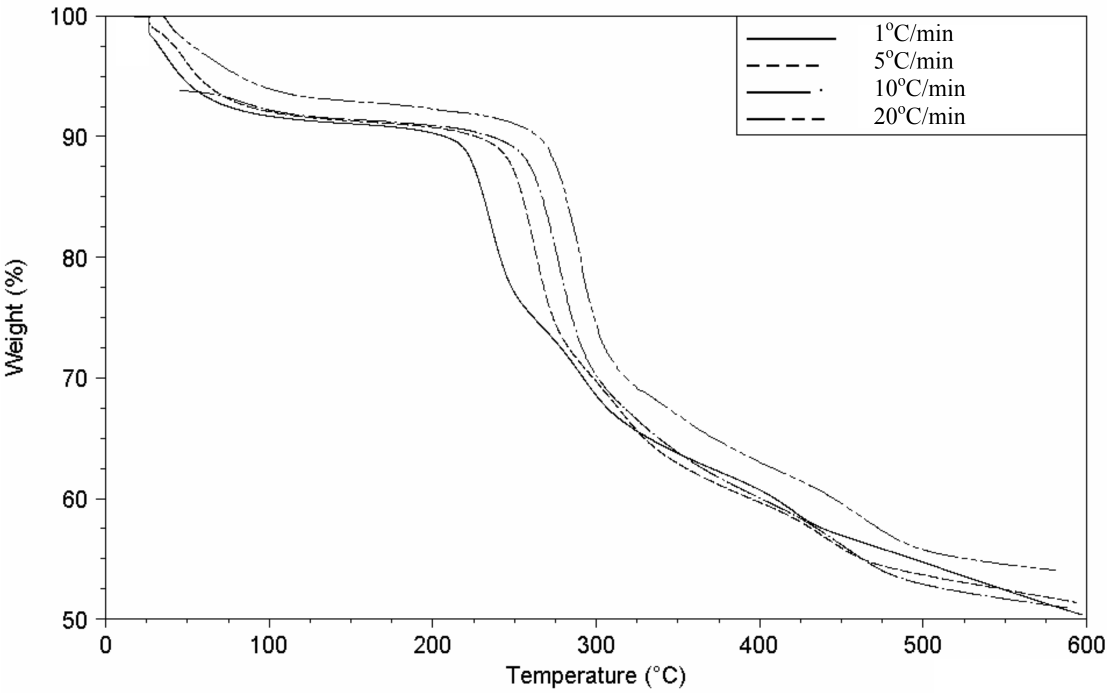
<u>Appendix Figure B2</u> Differential weight of thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:1



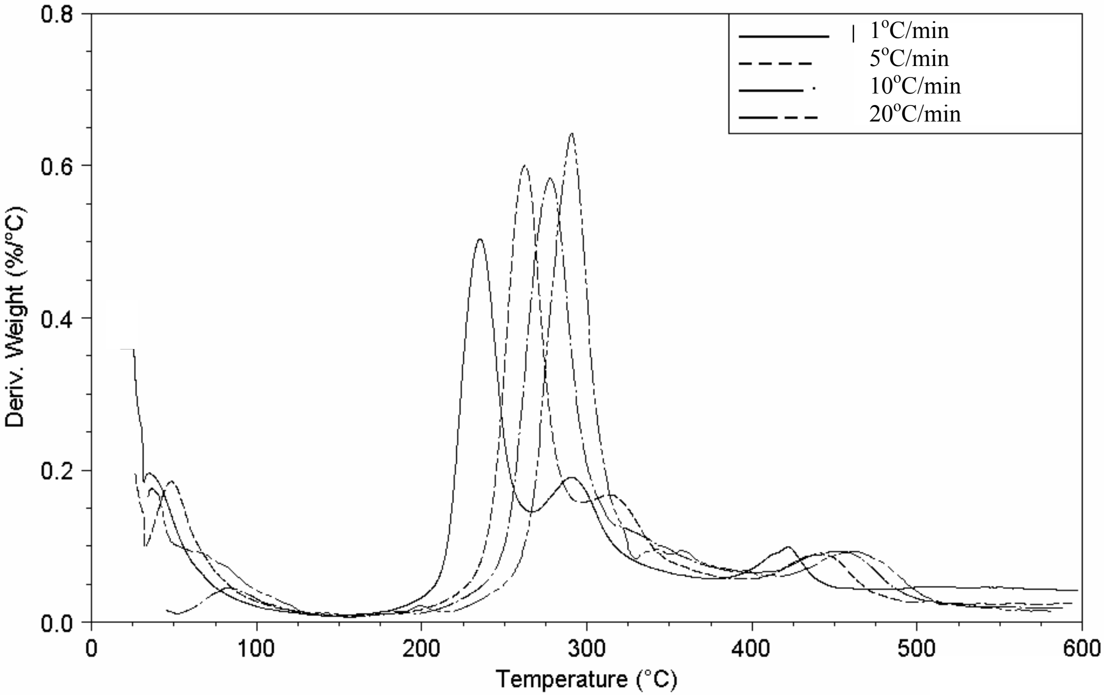
Appendix Figure B3 Thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:3



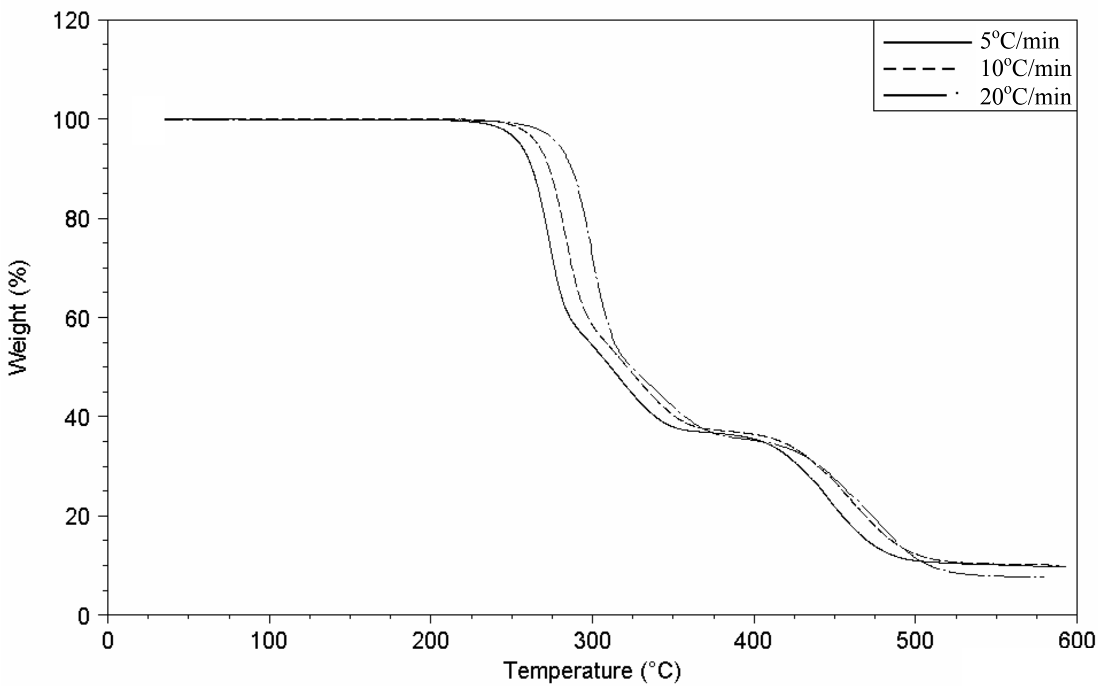
Appendix Figure B4 Differential weight of thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:3



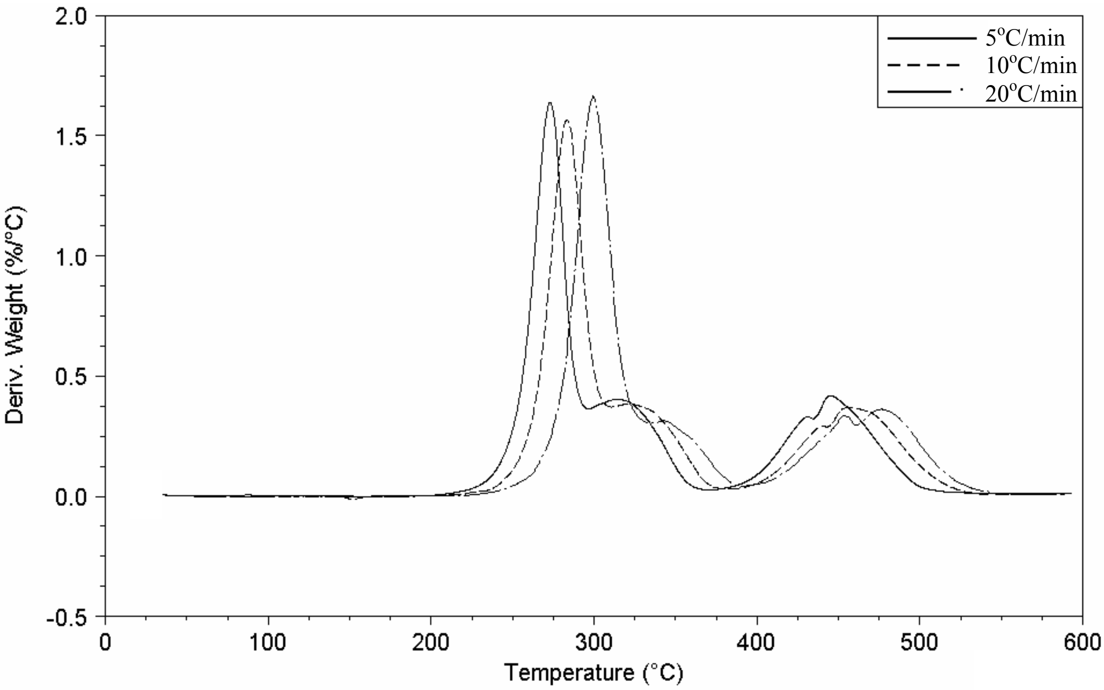
Appendix Figure B5 Thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:5



Appendix Figure 6 Differential weight of thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:5



Appendix Figure B7 Thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:0



Appendix Figure B8 Differential weight of thermal decomposition profile of PVC and cattle manure mixture at various heating rates, and PVC: cattle manure ratio of 1:0

Appendix C

Experimental data from dynamic degradation

Appendix Table C1 α-T data of copyrolysis of PVC and cattle manure mixture at the ratio of 1:0

α	ln(β/T_5)	1/T_5	ln(β/T_{10})	1/T_{10}	ln(β/T_{20})	1/T_{20}
0.05	9.47332	0.001894	-8.86396	0.001855	-8.26411	0.001813
0.1	9.53312	0.001866	-8.91929	0.00183	-8.32456	0.001785
0.15	9.56543	0.001852	-8.94978	0.001816	-8.35606	0.001771
0.2	9.59111	0.00184	-8.97512	0.001805	-8.38269	0.001759
0.25	9.61302	0.00183	-8.996	0.001795	-8.40027	0.00175
0.3	9.63506	0.00182	-9.01951	0.001784	-8.42214	0.00174
0.35	9.66071	0.001808	-9.04557	0.001772	-8.4441	0.00173
0.4	9.70311	0.001789	-9.08623	0.001754	-8.47069	0.001718
0.45	9.78669	0.00175	-9.15878	0.001721	-8.50592	0.001702
0.5	9.87195	0.001712	-9.24304	0.001682	-8.566	0.001675
0.55	9.95051	0.001676	-9.32627	0.001644	-8.6631	0.001631
0.6	10.0421	0.001634	-9.42183	0.001601	-8.76237	0.001586
0.65	10.3978	0.001475	-9.76196	0.00145	-9.00764	0.001477
0.7	10.5085	0.001427	-9.86878	0.001403	-9.18136	0.001401
0.75	10.5747	0.001398	-9.93805	0.001374	-9.2553	0.001369
0.8	10.6299	0.001374	-9.99687	0.001348	-9.32377	0.00134
0.85	10.6974	0.001345	-10.0665	0.001319	-9.38195	0.001315

Appendix Table C2 α-T data of copyrolysis of PVC and cattle manure mixture at the ratio of 1:1

α	$\ln(\beta/T_1)$	$1/T_1$	$\ln(\beta/T_5)$	$1/T_5$	$\ln(\beta/T_{10})$	$1/T_{10}$	$\ln(\beta/T_{20})$	$1/T_{20}$
0.05	-11.8485	0.002674	-10.875	0.001946	-9.79452	0.002361	-9.55943	0.001878
0.1	-12.4111	0.002018	-10.9174	0.001905	-10.2337	0.001896	-9.61499	0.001826
0.15	-12.4432	0.001986	-10.9382	0.001885	-10.2843	0.001848	-9.6404	0.001803
0.2	-12.461	0.001969	-10.9532	0.001871	-10.3063	0.001828	-9.65657	0.001789
0.25	-12.4747	0.001955	-10.9644	0.00186	-10.3209	0.001815	-9.66905	0.001778
0.3	-12.4864	0.001944	-10.9737	0.001852	-10.3317	0.001805	-9.67969	0.001768
0.35	-12.498	0.001932	-10.9829	0.001843	-10.3425	0.001795	-9.69027	0.001759
0.4	-12.5153	0.001916	-10.994	0.001833	-10.3551	0.001784	-9.69905	0.001751
0.45	-12.5552	0.001878	-11.0068	0.001821	-10.3675	0.001773	-9.70953	0.001742
0.5	-12.6271	0.001812	-11.0231	0.001807	-10.3852	0.001757	-9.72342	0.00173

Appendix Table C3 α-T data of copyrolysis of PVC and cattle manure mixture at the ratio of 1:3

α	$\ln(\beta/T_1)$	$1/T_1$	$\ln(\beta/T_5)$	$1/T_5$	$\ln(\beta/T_{10})$	$1/T_{10}$	$\ln(\beta/T_{20})$	$1/T_{20}$
0.05	-11.4504	0.003263	-9.84751	0.003252	-9.25581	0.003091	-8.57499	0.003072
0.1	-11.5921	0.00304	-9.98268	0.00304	-9.35531	0.002941	-8.78756	0.002762
0.15	-12.2798	0.002155	-10.6355	0.002193	-9.5486	0.00267	-9.53677	0.001899
0.2	-12.4212	0.002008	-10.8963	0.001925	-10.1877	0.00194	-9.60217	0.001838
0.25	-12.4471	0.001982	-10.9325	0.00189	-10.2526	0.001878	-9.62592	0.001817
0.3	-12.4649	0.001965	-10.9514	0.001873	-10.2787	0.001854	-9.6422	0.001802
0.35	-12.4806	0.001949	-10.9663	0.001859	-10.2953	0.001838	-9.65657	0.001789
0.4	-12.5	0.001931	-10.9811	0.001845	-10.31	0.001825	-9.66905	0.001778
0.45	-12.5306	0.001901	-10.9995	0.001828	-10.3245	0.001812	-9.67969	0.001768
0.5	-12.5905	0.001845	-11.0321	0.001799	-10.339	0.001799	-9.69203	0.001757

<u>Appendix Table C4</u> α-T data of copyrolysis of PVC and cattle manure mixture at the ratio of 1:5

α	$\ln(\beta/T_1)$	$1/T_1$	$\ln(\beta/T_5)$	$1/T_5$	$\ln(\beta/T_{10})$	$1/T_{10}$	$\ln(\beta/T_{20})$	$1/T_{20}$
0.05	-11.4472	0.003268	-9.90521	0.00316	-9.23093	0.00313	-8.56884	0.003082
0.1	-11.5304	0.003135	-9.98875	0.00303	-9.31069	0.003008	-8.72013	0.002857
0.15	-11.6986	0.002882	-10.1655	0.002774	-9.3845	0.002899	-9.03414	0.002442
0.2	-12.3455	0.002086	-10.8138	0.002006	-9.52982	0.002695	-9.54246	0.001894
0.25	-12.4212	0.002008	-10.9021	0.001919	-10.1226	0.002004	-9.60951	0.001832
0.3	-12.4452	0.001984	-10.9269	0.001896	-10.2507	0.00188	-9.63317	0.00181
0.35	-12.4669	0.001963	-10.9438	0.00188	-10.2916	0.001842	-9.6494	0.001795
0.4	-12.4844	0.001946	-10.9588	0.001866	-10.3154	0.00182	-9.66371	0.001783
0.45	-12.5115	0.001919	-10.9756	0.00185	-10.3443	0.001794	-9.67615	0.001771
0.5	-12.5589	0.001874	-10.994	0.001833	-10.3869	0.001756	-9.68851	0.001761

Appendix D

Product yields, distillation products, and fraction of chlorinated hydrocarbon of copyrolyzed oil

Appendix Table D1 The product yields of pyrolyzed oils from pyrolysis of PVC-containing plastic mixture with and without cattle manure.

Sample	Oil yield	Solid yield	Gas Yield	Synergistic of oil	Synergistic of solid	Synergistic of gas
Without manure	68.14	3	28.86	-	-	-
With manure	43.76	33.8	22.44	-16.90	23.24	13.15

Appendix Table D2 The distillation products of pyrolyzed oils from pyrolysis of PVC-containing plastic mixture with and without cattle manure.

Sample	Gasoline (%)	Kerosene (%)	Diesel (%)	Residue (%)
Without manure	53.53	12.30	22.78	11.39
With manure	57.69	6.73	22.12	13.46

Appendix Table D3 The peak areas of NMR and fractions of chlorinated hydrocarbon of pyrolyzed oils from pyrolysis of PVC-containing plastic mixture with and without cattle manure.

Sample	Total peak area	Peak area of chlorinated hydrocarbon	Fraction of chlorinated hydrocarbon
Without manure	9.237	0.309	0.033
With manure	8.098	0.149	0.018

Appendix E

The experimental results from upgrading the copyrolyzed oil

Appendix Table E1 The product yields from upgrading the copyrolyzed oil

Type of catalyst	silica alumina: metal oxide	Feed rate (ml/h)	Yield		
			1	2	3
Silica alumina	-	10	34.5	35.01	-
Silica alumina	-	30	73.21	69.49	-
Silica alumina	-	50	74.91	71.91	-
Silica alumina + ZnO	1:1	10	48.78	40.07	-
Silica alumina + ZnO	1:1	30	59.71	67.92	53.34
Silica alumina + ZnO	1:1	50	76.89	68.16	-
Silica alumina + ZnO	1:2	10	44.5	49.55	-
Silica alumina + ZnO	1:2	30	54.51	57.8	-
Silica alumina + ZnO	1:2	50	62.03	60.57	-
Silica alumina + Fe_2O_3	1:1	30	30.92	38.23	-
Silica alumina + Fe_2O_3	1:1	50	44.96	47.81	-

Appendix Table E2 The distillation product yields from upgrading the copyrolyzed oil

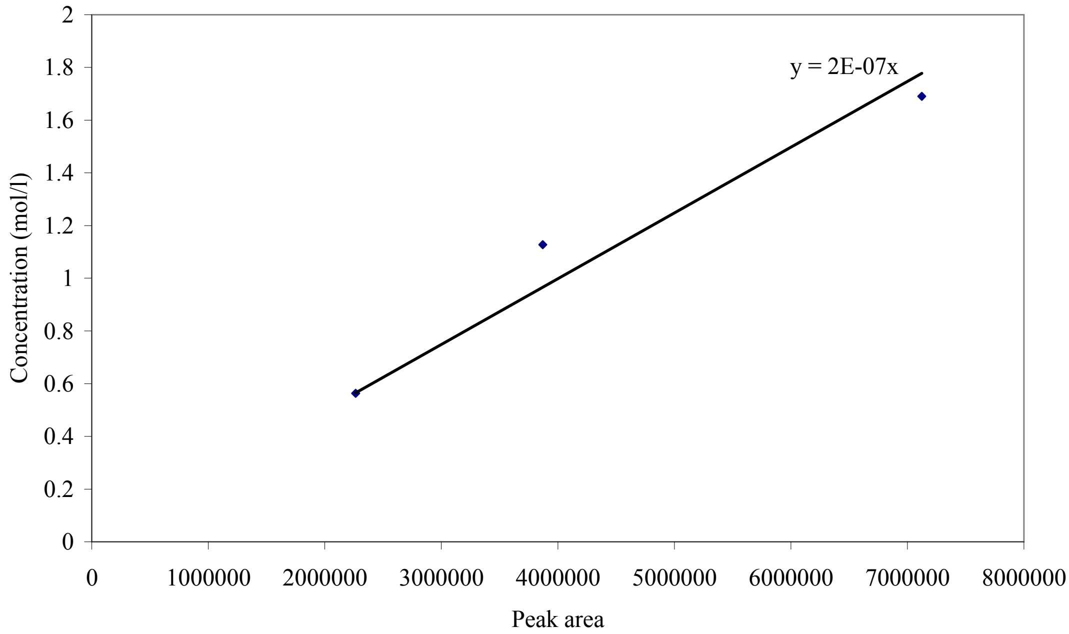
Type of catalyst	silica alumina :metal oxide	Feed rate (ml/h)	Gasoline (%)	Kerosene (%)	Diesel (%)	Residue (%)
Silica alumina	-	10	48.49	15.15	18.18	18.18
Silica alumina	-	30	49.46	10.75	29.03	10.75
Silica alumina	-	50	51.06	11.70	30.85	6.38
Silica alumina + ZnO	1:1	10	53.57	9.82	26.79	9.82
Silica alumina + ZnO	1:1	30	52.74	19.32	24.45	3.48
Silica alumina + ZnO	1:1	50	51.83	9.96	25.39	12.82
Silica alumina + ZnO	1:2	10	38.46	21.15	21.15	19.23
Silica alumina + ZnO	1:2	30	50	14	18	18
Silica alumina + ZnO	1:2	50	46.82	13.38	31.77	8.03
Silica alumina + Fe_2O_3	1:1	30	64.82	17.59	8.33	9.26
Silica alumina + Fe_2O_3	1:1	50	55.17	17.93	11.72	15.17

Appendix Table E3 The peak areas from NMR analysis and fractions of chlorinated hydrocarbon in the upgraded oil

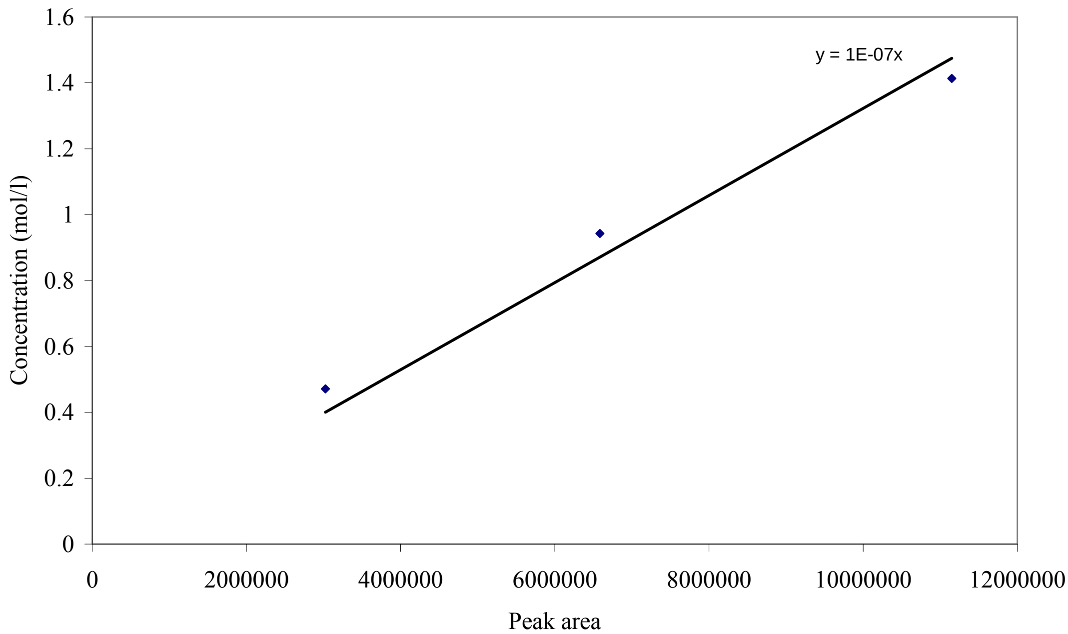
Type of catalyst	silica alumina:metal oxide	Feed rate (ml/h)	Fraction of chlorinated hydrocarbon		
			1	2	3
Silica alumina	-	10	0.0115	0.0148	-
Silica alumina	-	30	0.0118	0.0138	-
Silica alumina	-	50	0.018	0.015	-
Silica alumina + ZnO	1:1	10	0.015	0.013	-
Silica alumina + ZnO	1:1	30	0.006	0.011	0.01
Silica alumina + ZnO	1:1	50	0.016	0.013	-
Silica alumina + ZnO	1:2	10	0.015	0.013	-
Silica alumina + ZnO	1:2	30	0.017	0.014	-
Silica alumina + ZnO	1:2	50	0.015	0.015	-
Silica alumina + Fe_2O_3	1:1	30	0.009	0.01	-
Silica alumina + Fe_2O_3	1:1	50	0.015	0.012	-

Appendix F

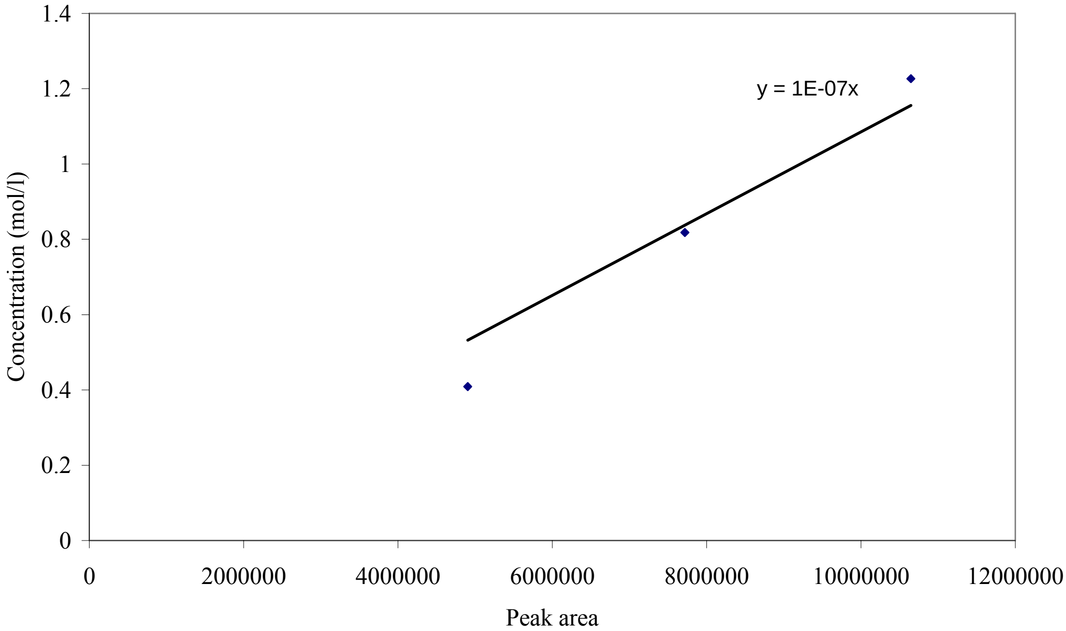
The standard curve of benzene, toluene, and xylene from gas chromatograph



Appendix Figure F1 Standard curve of benzene



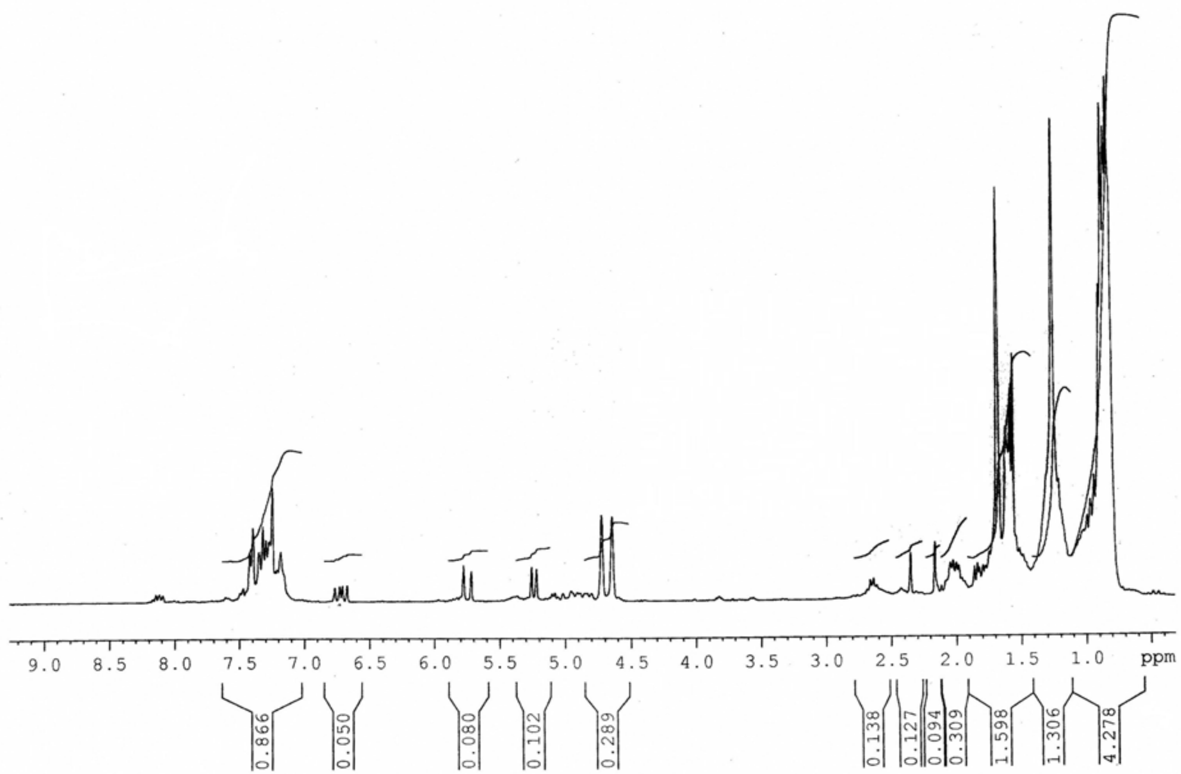
Appendix Figure F2 Standard curve of toluene



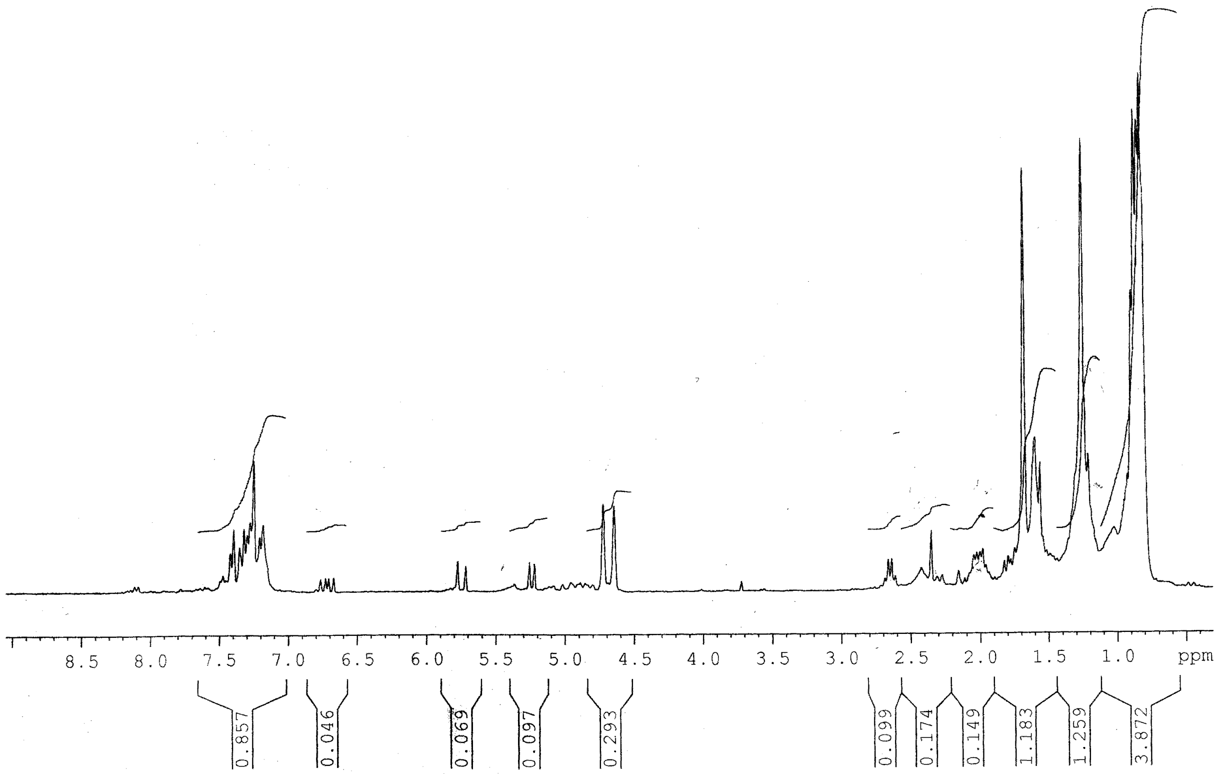
Appendix Figure F3 Standard curve of xylene

Appendix G

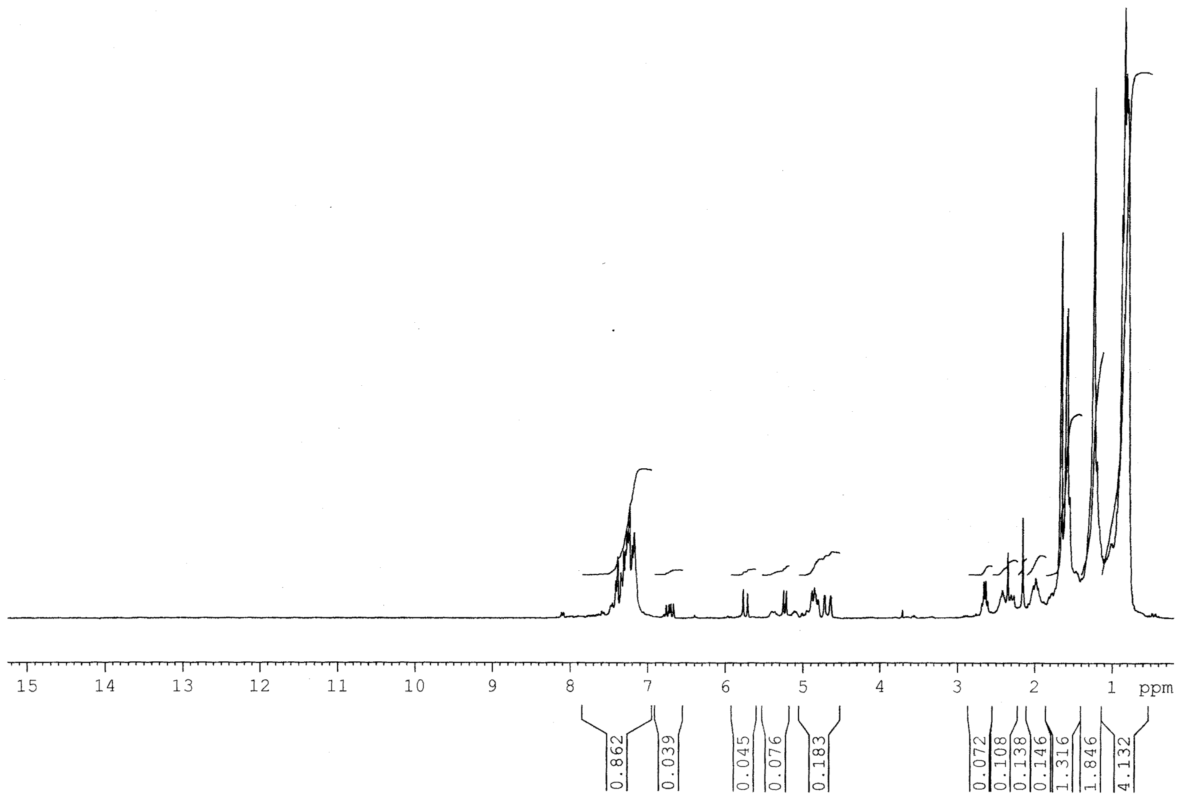
Nuclear Magnetic Resonance (NMR) pattern of copyrolyzed oil and gasoline fraction



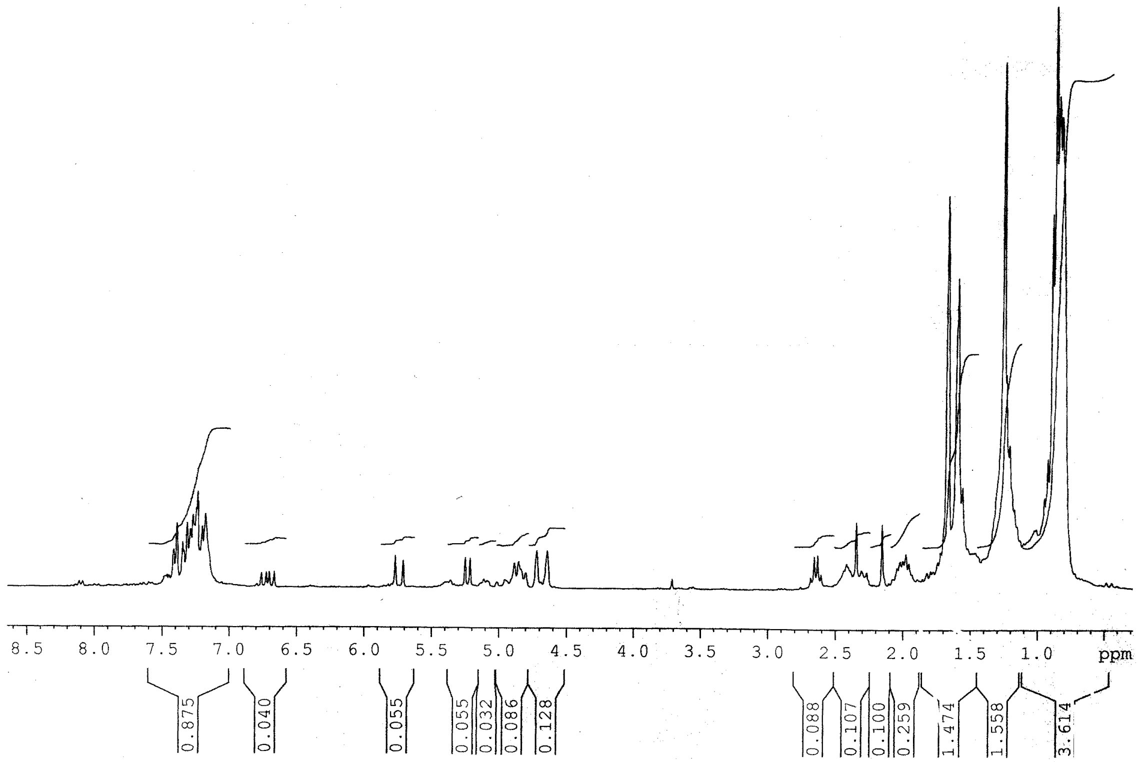
Appendix Figure G1 NMR pattern of the pyrolyzed oil from pyrolysis of PVC-containing plastic mixture (without manure)



Appendix Figure G2 NMR pattern of the copyrolyzed oil from copyrolysis of PVC-containing plastic mixture and manure

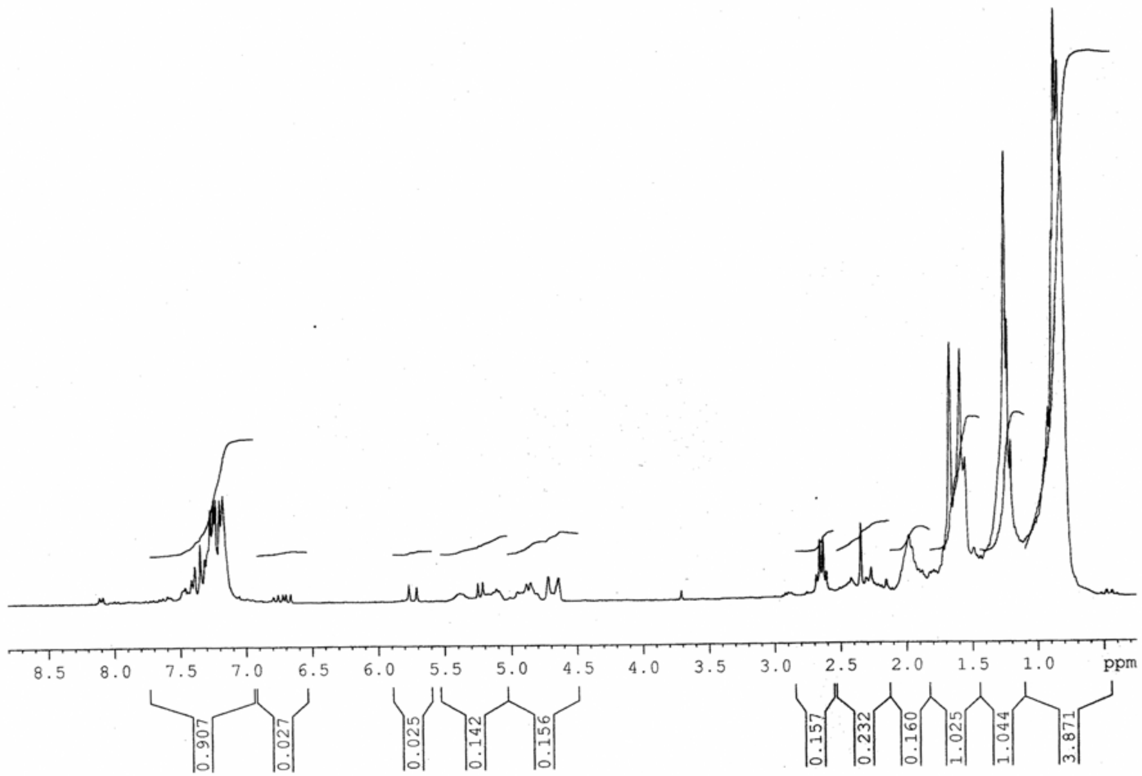


Appendix Figure G3 NMR pattern of the oil from upgrading by silica alumina at feed rate of 10 ml/h.

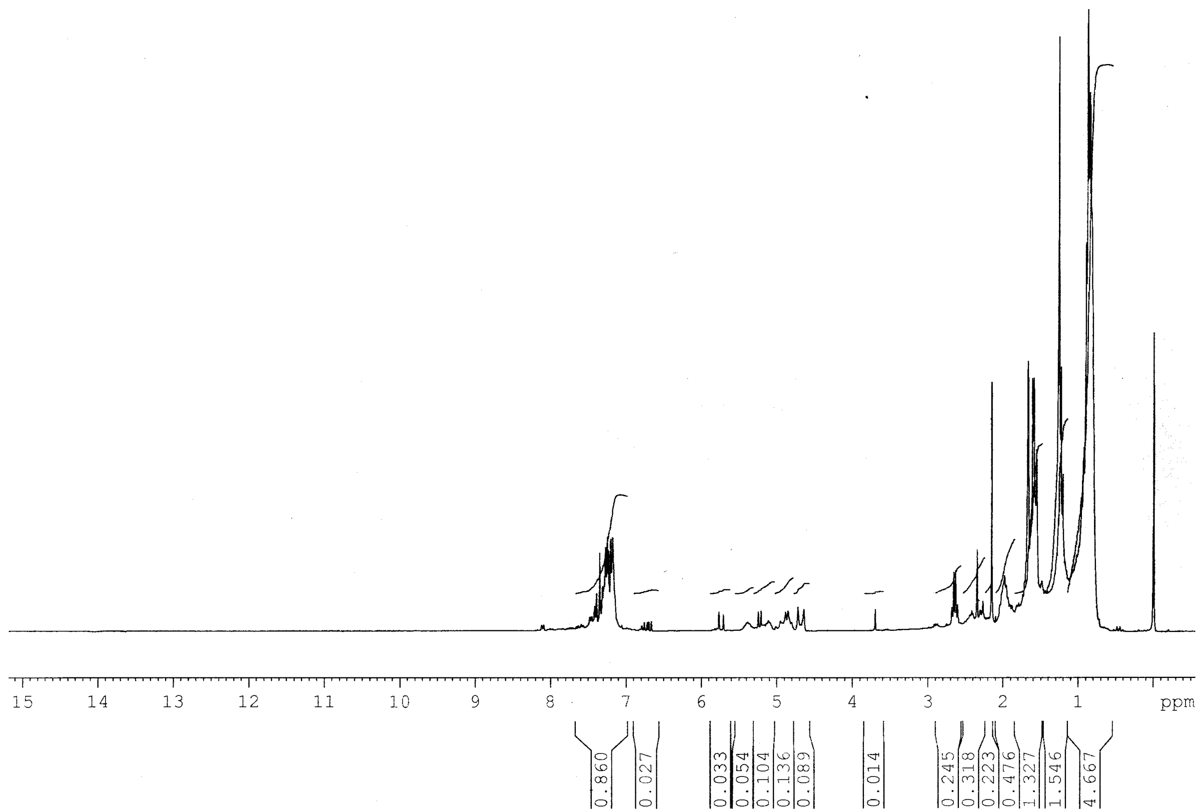


Appendix Figure G4 NMR pattern of the oil from upgrading by silica alumina at feed rate of 30 ml/h.

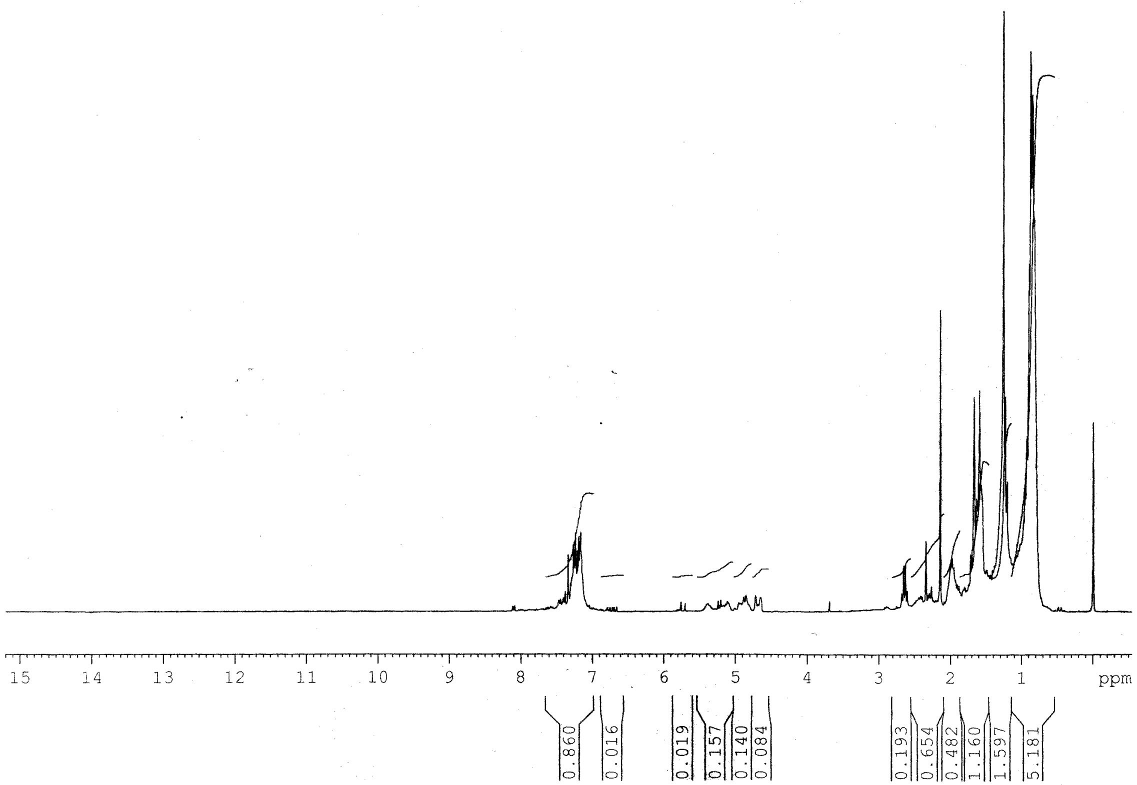
Appendix Figure G5 NMR pattern of the oil from upgrading by silica alumina at feed rate of 50 ml/h.



Appendix Figure G6 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:1 and feed rate of 10 ml/h.

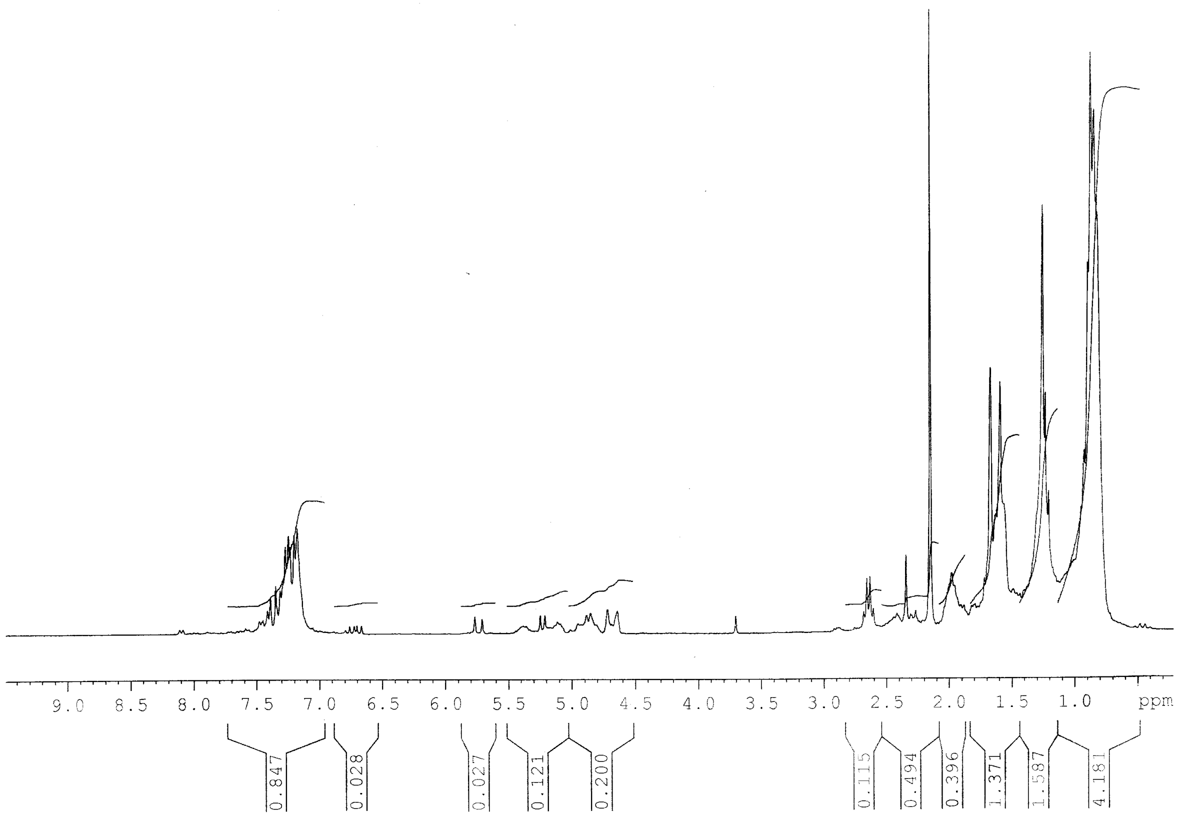


Appendix Figure G7 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:1 and feed rate of 30 ml/h.

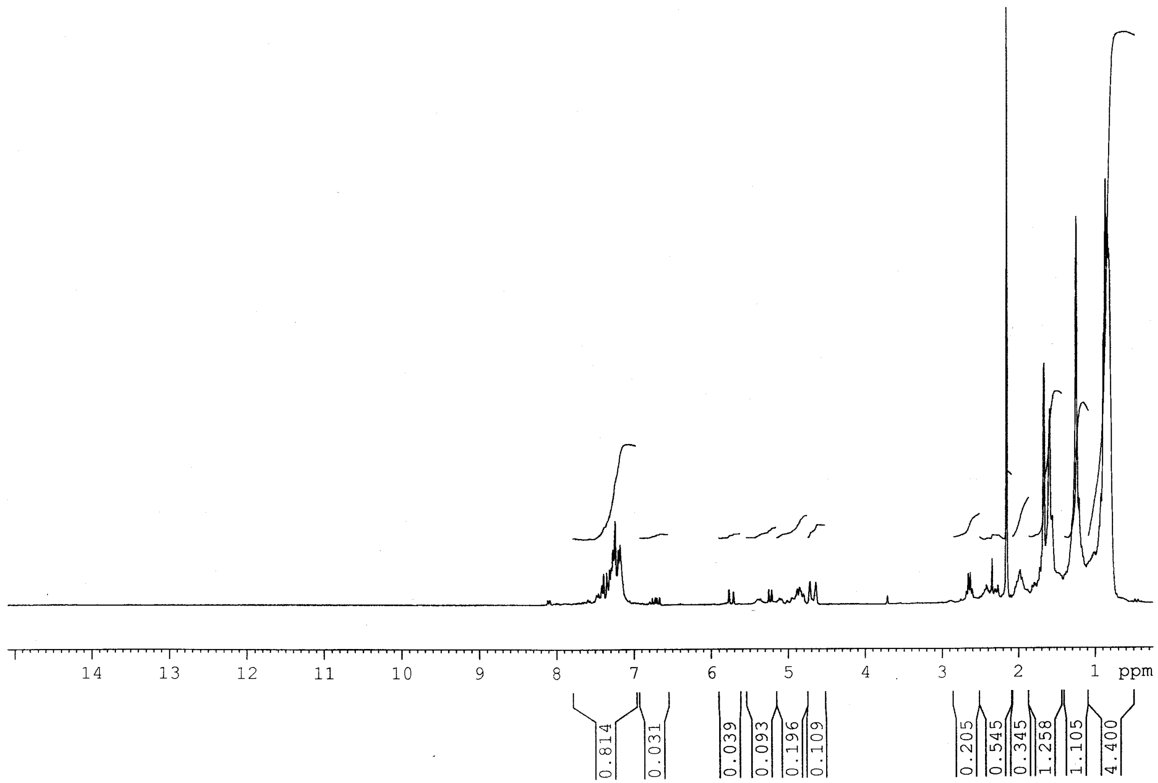


Appendix Figure G8 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:1 and feed rate of 50 ml/h.

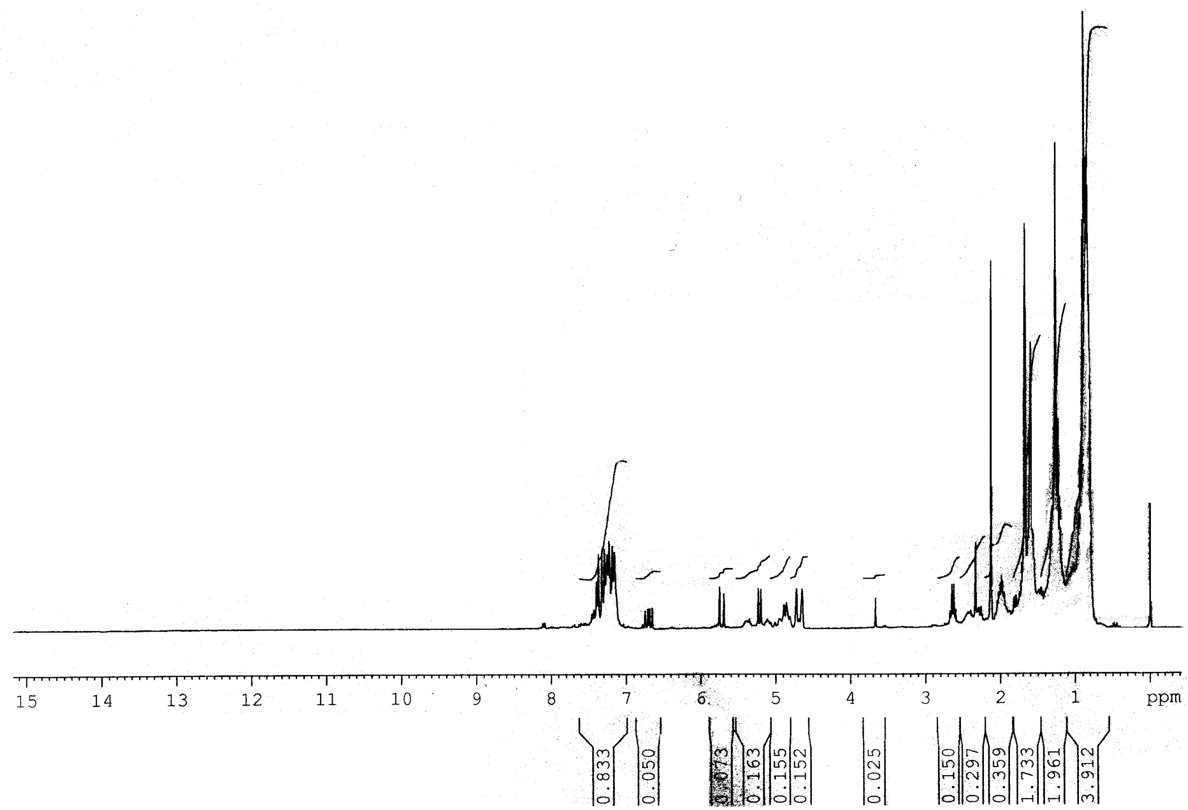
Appendix Figure G9 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 10 ml/h.



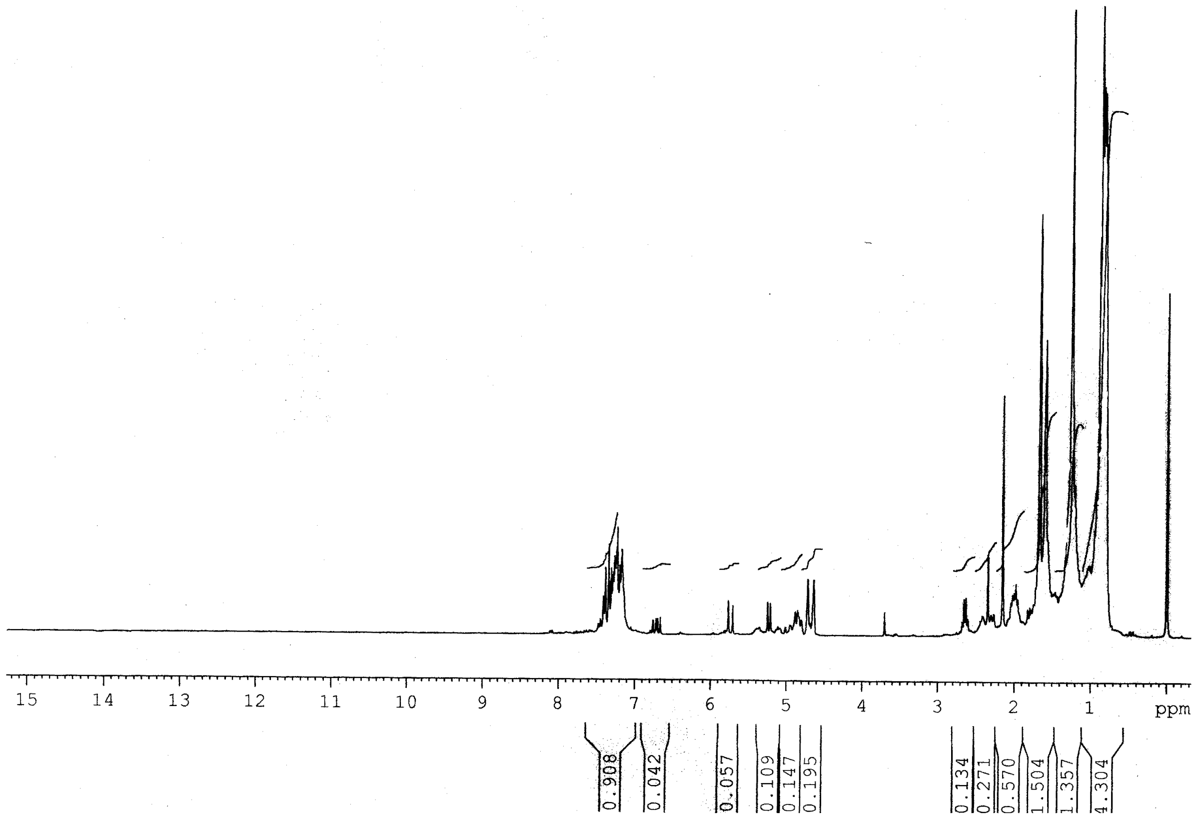
Appendix Figure G10 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 30 ml/h.



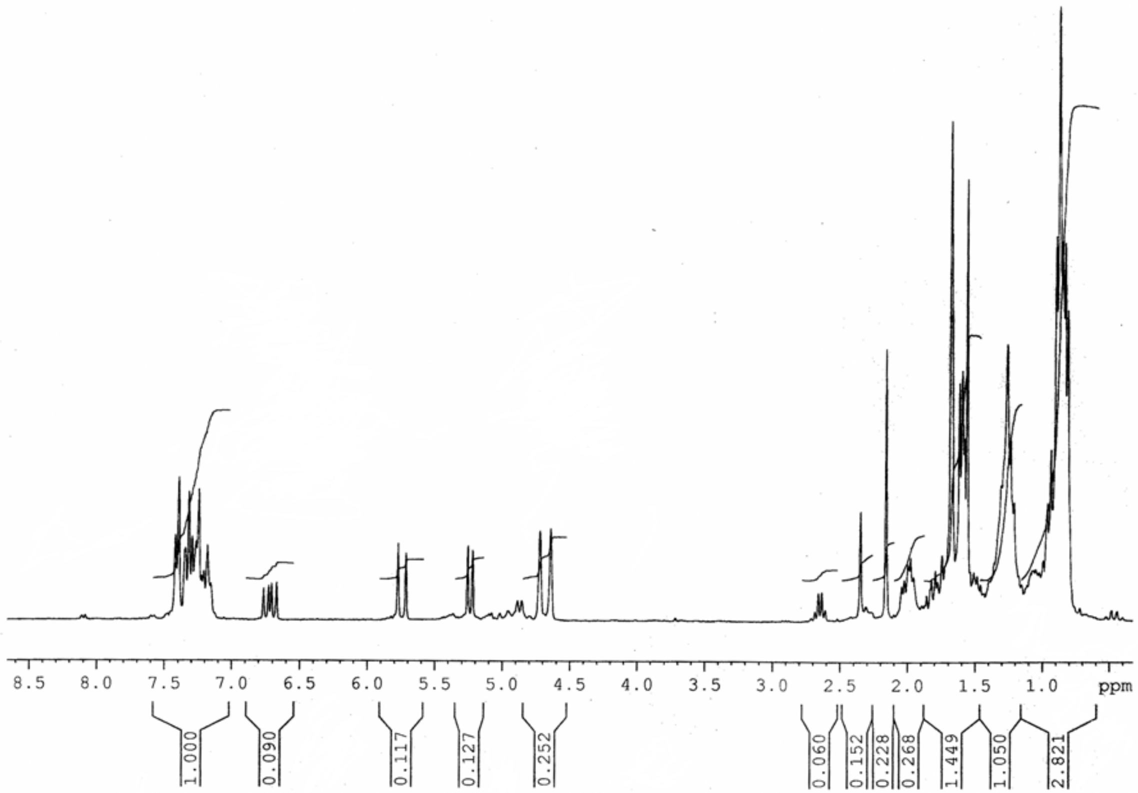
Appendix Figure G11 NMR pattern of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 50 ml/h.



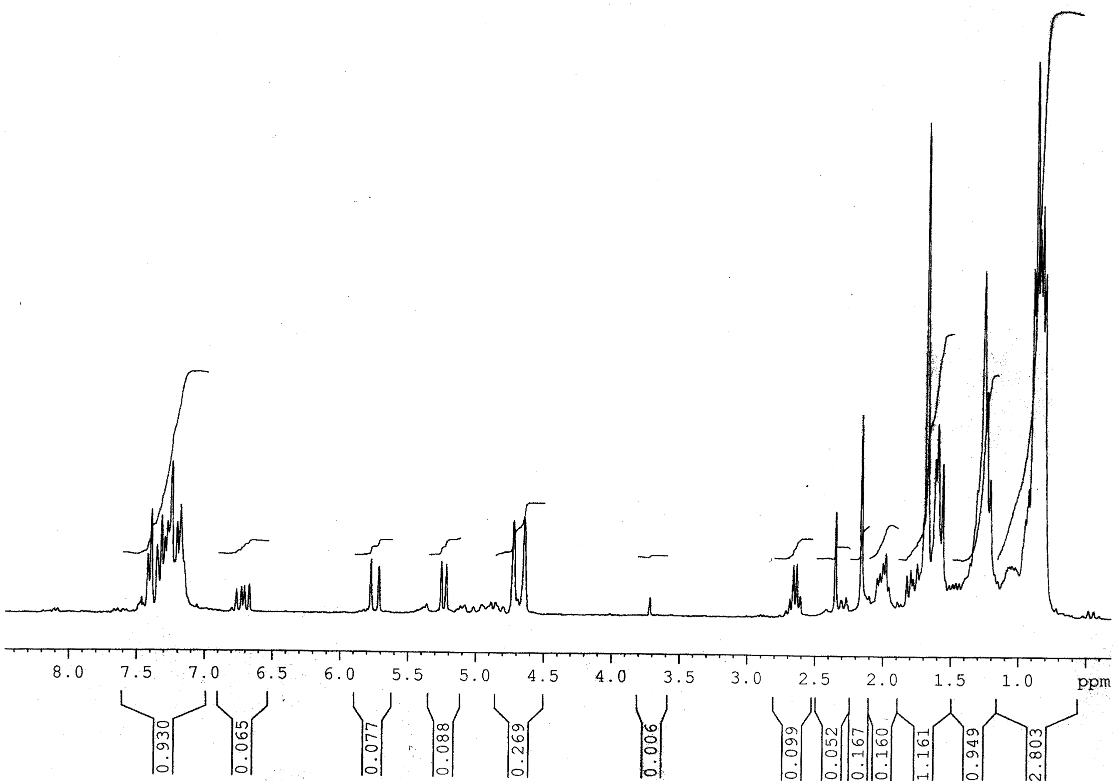
Appendix Figure G12 NMR pattern of the oil from upgrading by silica alumina-Fe_2O_3 catalyst at the ratio of 1:1 and feed rate of 30 ml/h.



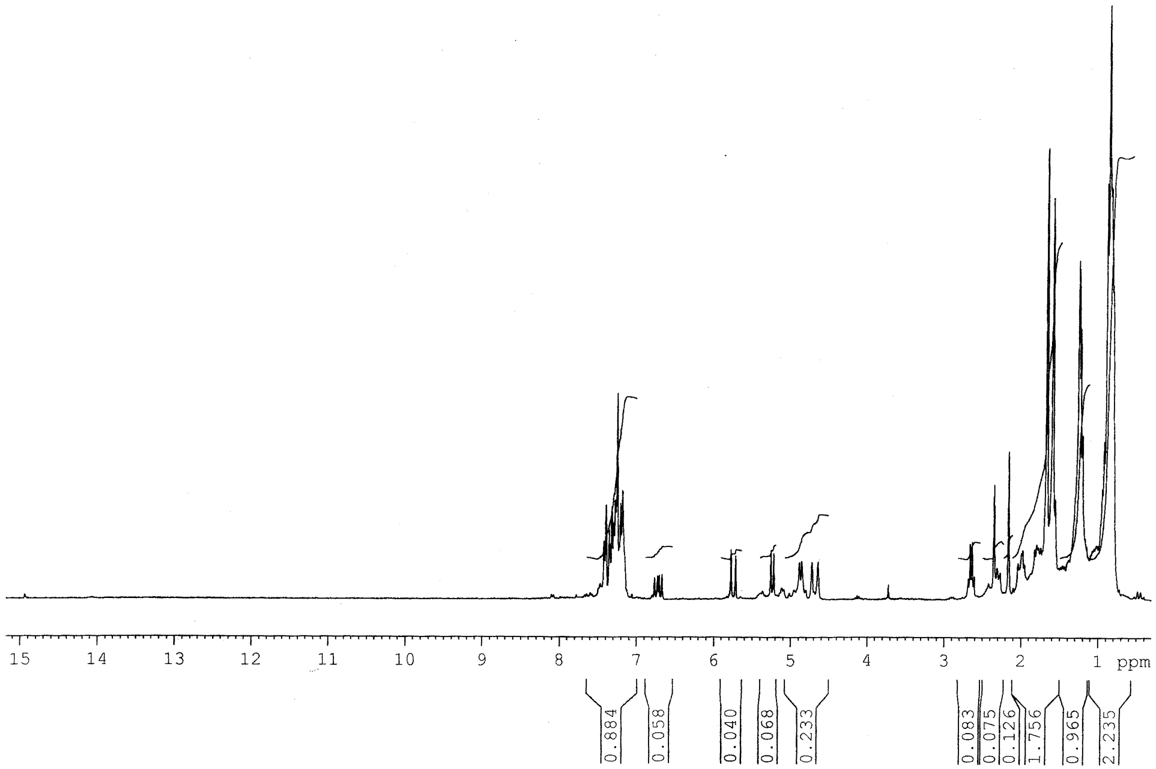
Appendix Figure G13 NMR pattern of the oil from upgrading by silica alumina-Fe_2O_3 catalyst at the ratio of 1:1 and feed rate of 50 ml/h.



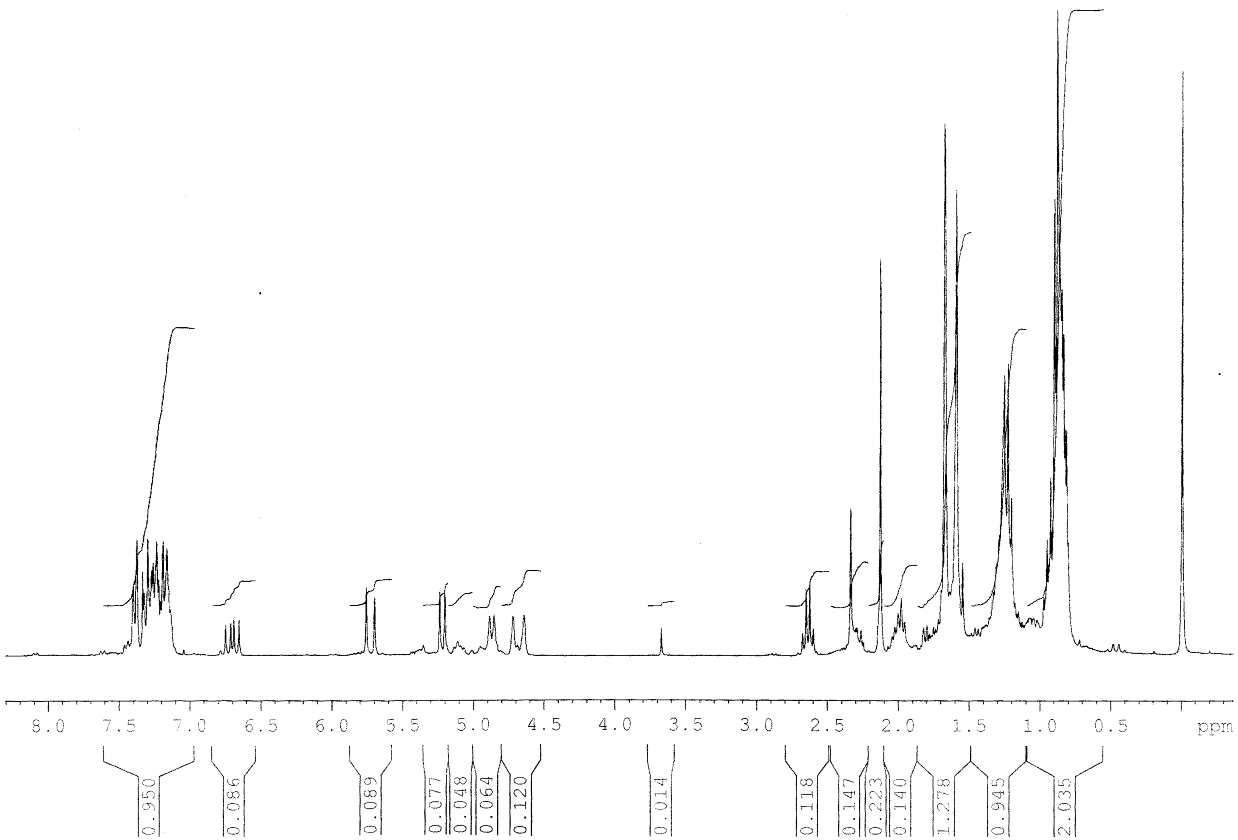
Appendix Figure G14 NMR pattern of gasoline fraction of pyrolyzed oil from pyrolysis of PVC-containing plastic mixture (without manure)



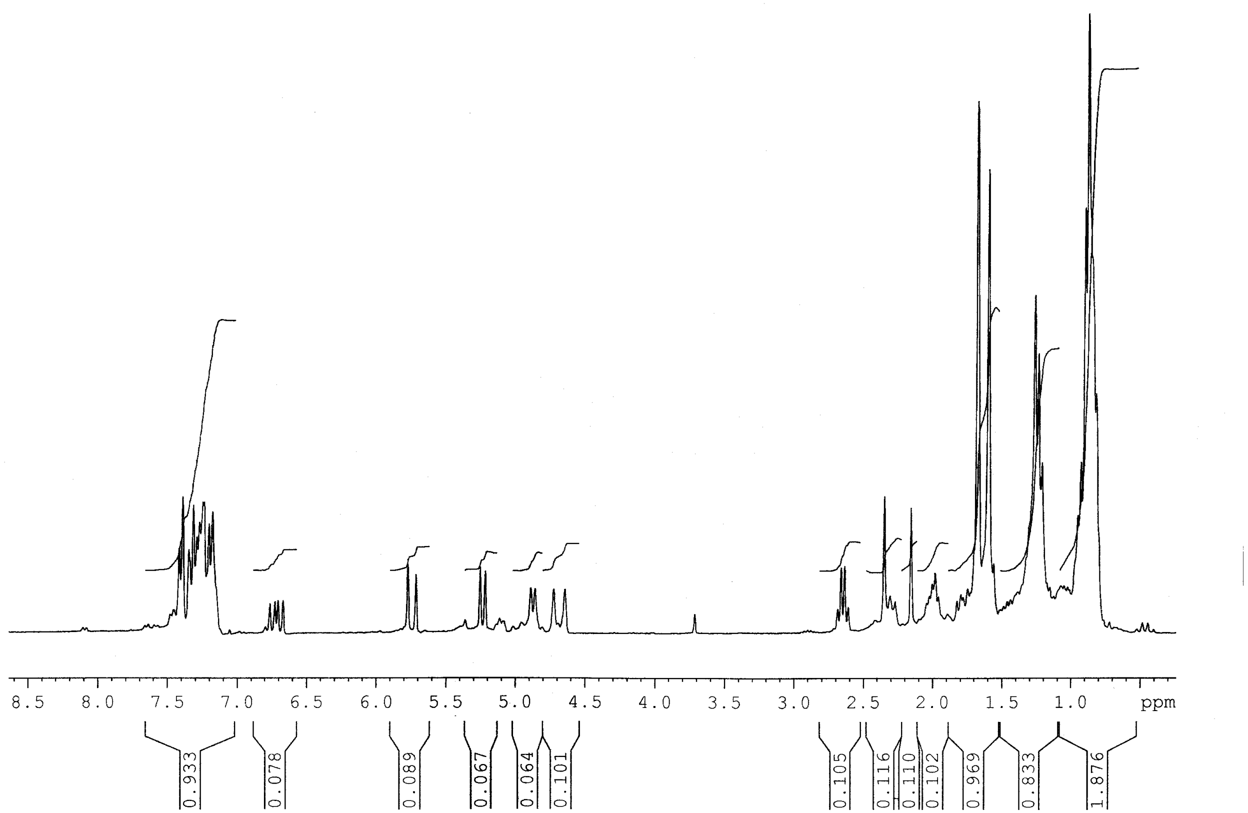
Appendix Figure G15 NMR pattern of gasoline fraction of copyrolyzed oil from copyrolysis of PVC-containing plastic mixture and manure



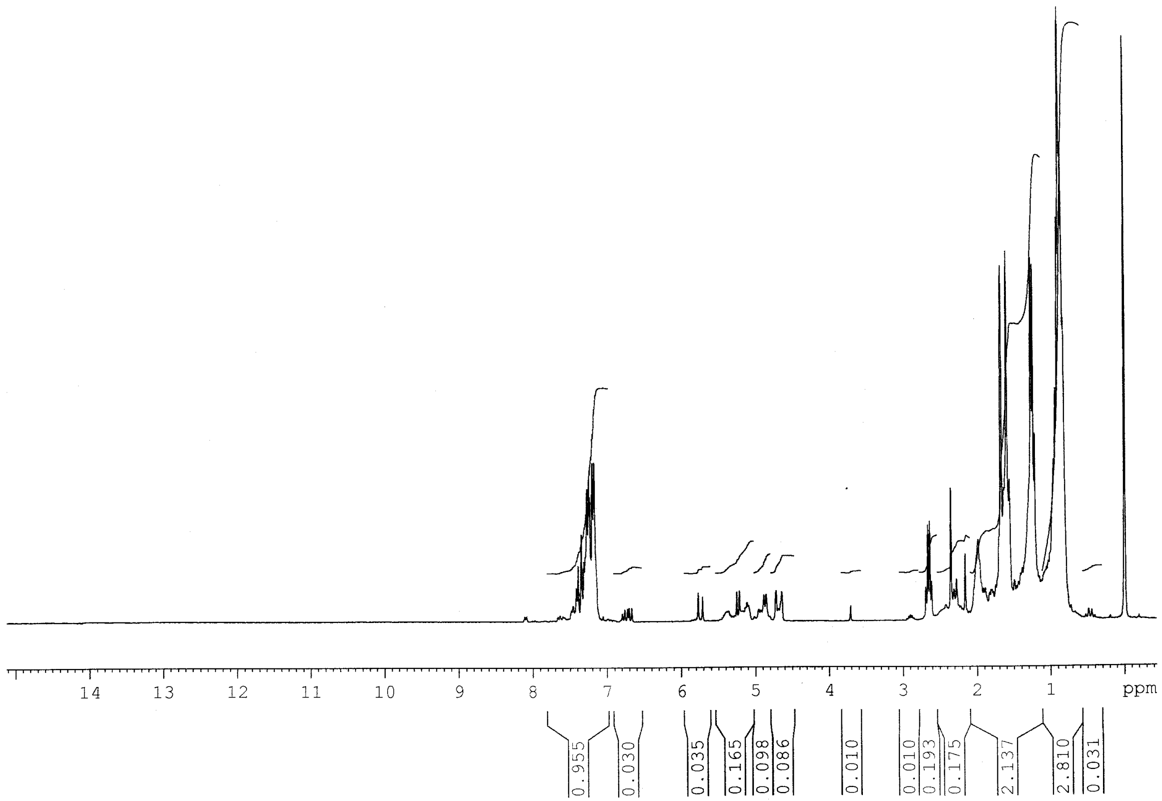
Appendix Figure G16 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina at feed rate of 10 ml/h.



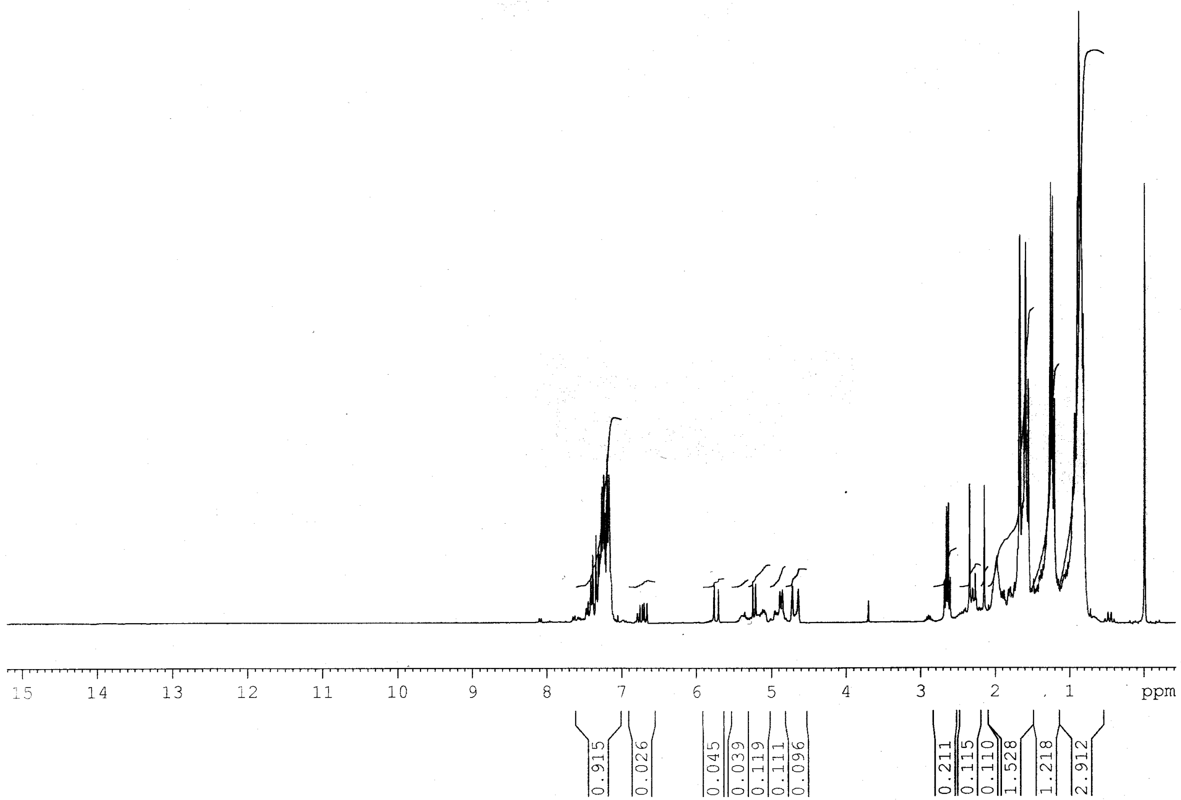
Appendix Figure G17 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina at feed rate of 30 ml/h.



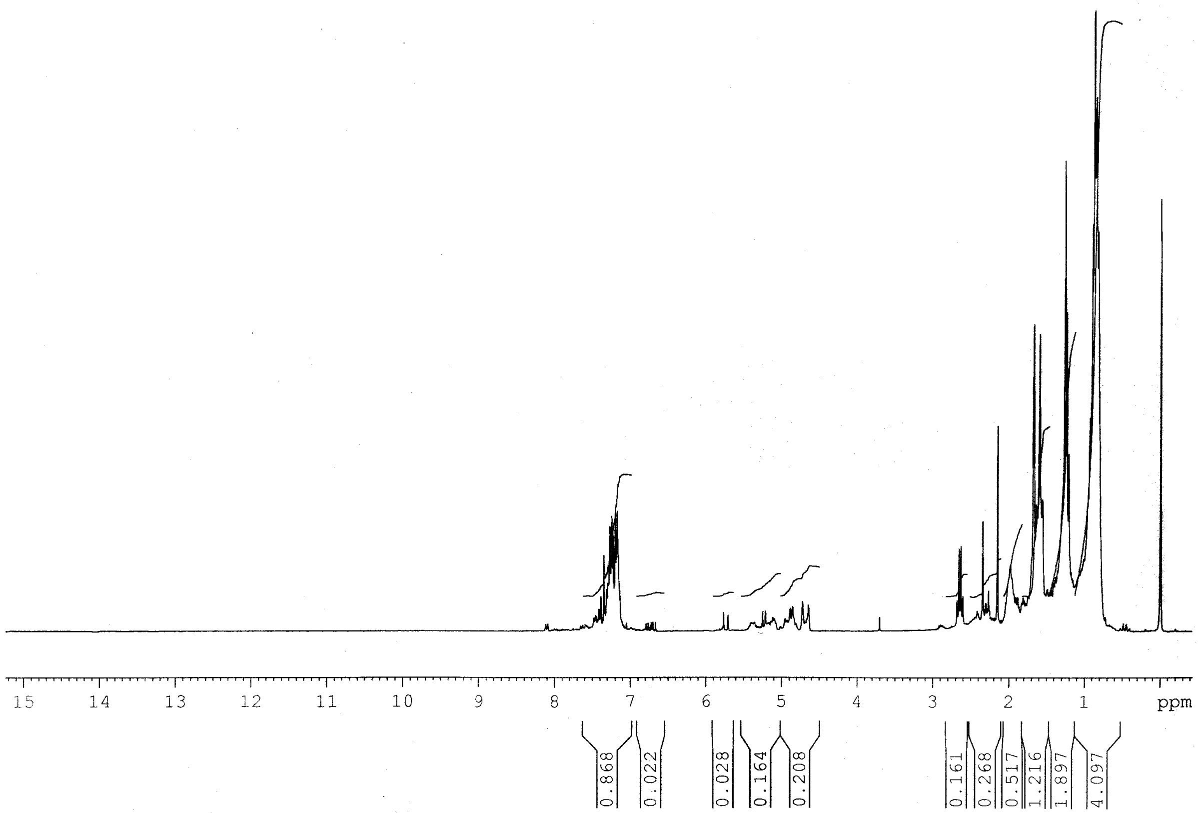
<u>Appendix Figure G18</u> NMR pattern of gasoline fraction of the oil from upgrading by silica alumina at feed rate of 50 ml/h.



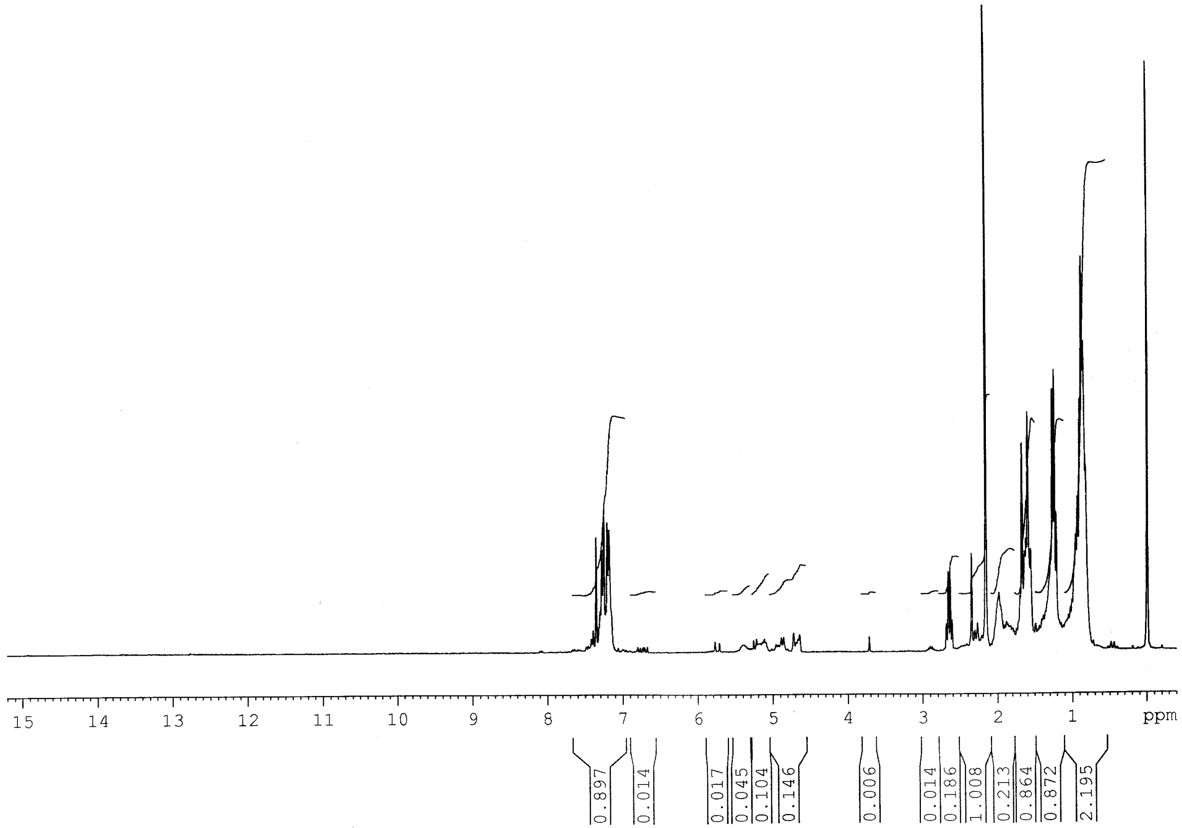
Appendix Figure G19 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:1 and feed rate of 10 ml/h.



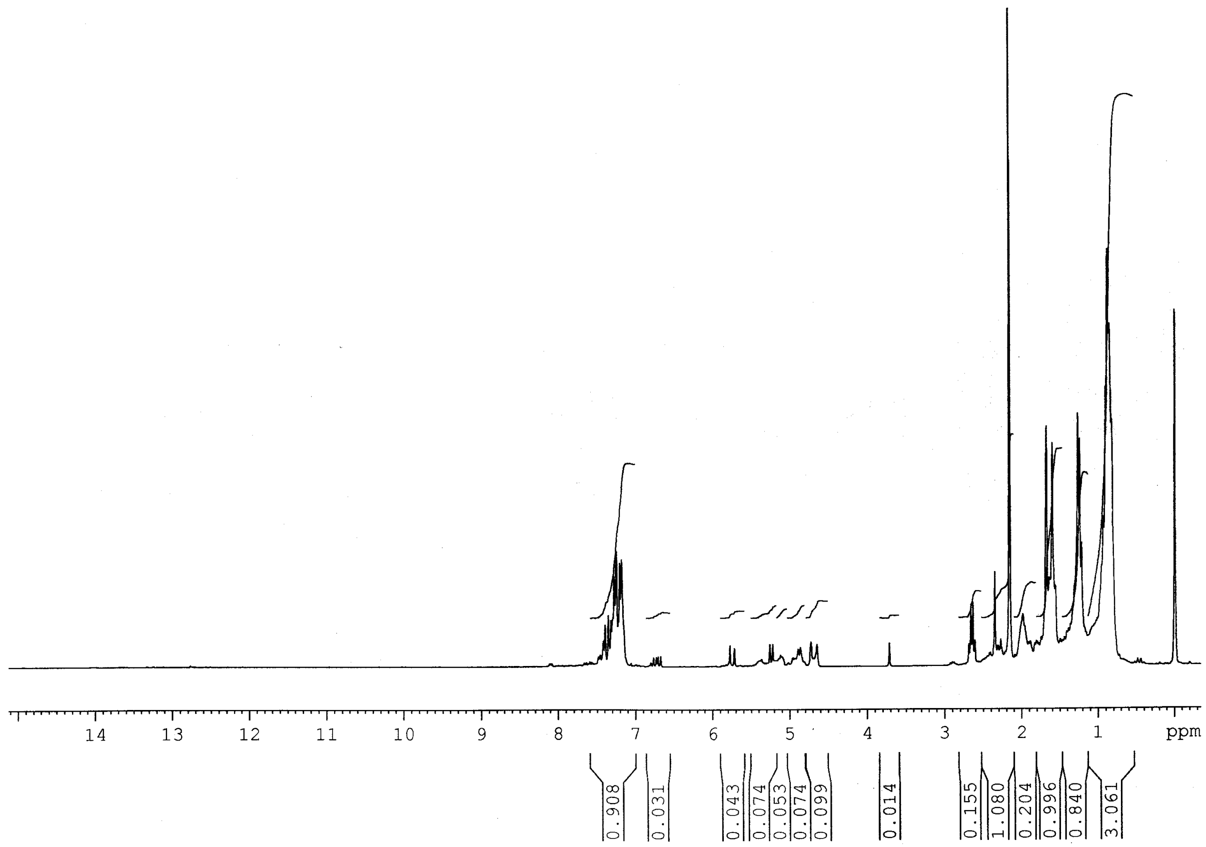
Appendix Figure G20 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:1 and feed rate of 30 ml/h.



Appendix Figure G21 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO at the ratio of 1:1 and feed rate of 50 ml/h.

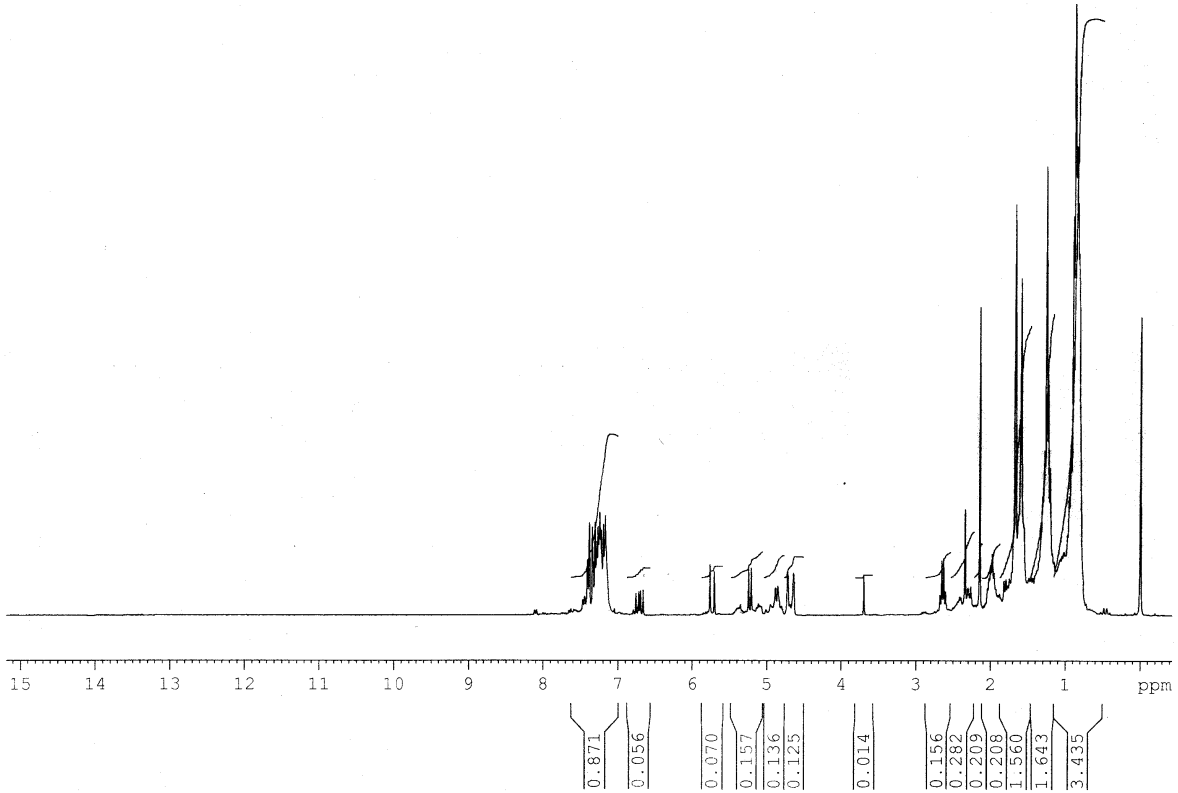


Appendix Figure G22 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 10 ml/h.

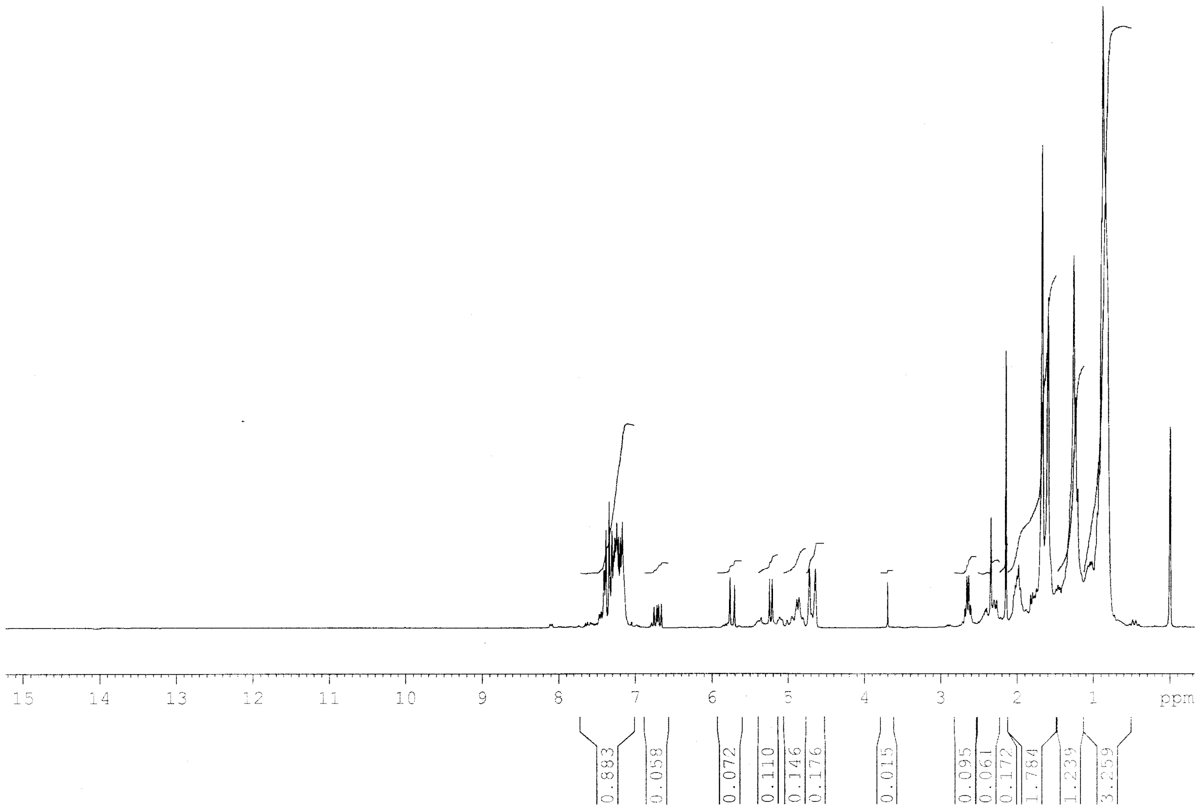


Appendix Figure G23 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 30 ml/h.

Appendix Figure G24 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-ZnO catalyst at the ratio of 1:2 and feed rate of 50 ml/h.



Appendix Figure G25 NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-Fe_2O_3 catalyst at the ratio of 1:1 and feed rate of 30 ml/h.



<u>Appendix Figure G26</u> NMR pattern of gasoline fraction of the oil from upgrading by silica alumina-Fe_2O_3 catalyst at the ratio of 1:1 and feed rate of 50 ml/h.

Appendix H

Economic Analysis

The economic analysis was studied at the optimum conditions. Gasoline and diesel oil fractions were products of interest. This analysis calculated the operation cost and compared with gasoline and diesel oil prices at present (August, 2006).

Operating cost for 1 month

- Electric power of the heating furnace was 2 kW operated 7 hours a batch.

  2 x 7 = 14 kW.h

- Electric power of the compressor was 1.2 kWatt operated 7 hours a batch.

  1.2 x 7 = 8.4 kW.h

Total electricity unit is (14+8.4) = 22.4 unit / batch. In this calculation, we operated 30 batches a month and used electricity 672 units/month.

Appendix Table H1 Electricity rate of Provincial Electricity Authority Thailand

Electricity unit	Electricity rate (THB/unit)
First 150 units	1.8047
151- 400 units	2.7781
More than 400 units	2.978

Electricity rate for small company of Provincial Electricity Authority Thailand is shown in Appendix Table 10. The calculation of electricity cost is shown below.

First 150 units	1.8047 x 150 = 270.705 THB
151 – 400 units	2.7781 x 250 = 694.525 THB
More than 400 units	2.978 x 272 = 810.016 THB

Total electricity cost	1775.246	THB
Utility cost (gasket, gas etc)	100	THB
Total cost	1875.246	THB /month

From experimental results, gasoline obtained was 30 ml/batch and diesel oil was 11.5 ml/ batch, therefore, we obtained gasoline 900 ml/month (900ml/month x 30.19 THB/1000ml = 27.17 THB/month) and diesel oil 345ml/month (345 ml/month x 27.54 THB/1000 ml = 9.50 THB/month), however, the total operating cost was 1875.246 THB /month. When this total operating cost was compared with the oil prices, it showed a large difference in the expense and product values. However, in the industrial scale, electricity was not used but the gas products and waste materials were used for heating reaction. Therefore, the operating cost can be reduced.

Appendix I

Data analysis of the difference of mean

The data of oil yields and fractions of chlorinated hydrocarbon were analyzed using analysis of variance (ANOVA) and least square difference (LSD) to check the difference of means and rank them.

The analysis of variance was applied at level of significance 90% which α = 0.1. The hypothesis of ANOVA is shown below:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \ldots = \mu_n$$

H_1: The μ are not all equal.

If H_0 is rejected, the means will be different. In case the means show differences, the means are ranked by LSD method.

Appendix Table I1 Analysis of variance

Source	DF	SS	MS	F	P
treatment	a-1	SS_t	SS_t/a-1	MS_t/MS_E	-
Error	N-a	SS_E	SS_E/N-a		
Total	N-1	SS_T			

N = number of experiment

a = number of treatment

$$SS_T = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \overline{y})^2$$

$$SS_E = n\sum_{i=1}^{a}(\overline{y}_{i.} - \overline{y})^2$$

$$SS_t = SS_T - SS_E$$

<u>Example</u> Oil yields obtained from upgrading by silica alumina-Fe_2O_3

<u>Appendix Table I2</u> Experimental results of oil yields obtained from upgrading by silica alumina-Fe_2O_3

Feed rate (ml/h)	Sample size (n)	1	2	Total y_i	Average Y_i
30	2	30.92	38.23	69.15	34.58
50	2	44.96	47.81	92.77	46.39
	N = 4			161.92	40.49

SS_T $= (30.92)^2 + (38.23)^2 + (44.96)^2 + (47.81)^2 - (161.92)^2/4$

$= 170.3$

SS_t $= 1/2\,(69.15)^2 + 1/2\,(92.77)^2 - (161.92)^2/4$

$= 139.5$

SS_E $= 170.3 - 139.5$

$= 30.8$

MS_t $= 139.5 / (2 - 1)$

$= 139.5$

MS_E $= 30.8 / (4 - 2)$

$= 15.4$

F_0 $= 139.5 / 15.4$

$= 9.06$

From statistical table $F_{0.1,1,2} = 8.53$, $F_0 > F_{0.1,1,2}$, H_0 was rejected. The average mean of oil yields was different.

After checking the difference of mean, the means of oil yields were ranked by LSD method as shown below:

$$LSD = t_{\alpha/2}\sqrt{MS_E\left(\frac{1}{n_i}+\frac{1}{n_j}\right)}$$

At level of significance of 90%, $\alpha = 0.1$

$t_{0.05} = 2.92$ (degree of freedom = 4 – 2 = 2)

LSD (n_i=2, n_j=2) = 44.68

Feed rate (ml/h)	30	50
Sample mean of oil yield	34.58	46.39

The difference of mean of oil yield between 30ml/h and 50ml/h is less than LSD, therefore, this calculation can conclude that the oil yield decreased in the order: feed rate of 50 ml/h > 30 ml/h.

1. **Oil yields obtained from upgrading by silica alumina at feed rates of 30 and 50ml/h**

Feed rate (ml/h)	Sample size (n)	Oil yield (%)
30	2	73.21, 69.49
50	2	74.91, 71.91

Analysis of variance

Source	DF	SS	MS	F	P
Factor	1	4.24	4.24	0.74	0.479
Error	2	11.42	5.71		
Total	3	15.66			

P > 0.1, this analysis accepts H_0. The average means were not different.

2. **Oil yields obtained from upgrading by silica alumina-ZnO at feed rates of 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Oil yield (%)
30	3	59.71, 67.92, 53.34
50	2	76.89, 68.16

Analysis of variance

Source	DF	SS	MS	F	P
Factor	1	178.7	178.7	3.70	0.150
Error	3	145.0	48.3		
Total	4	323.6			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

3. **Oil yields obtained from upgrading by silica alumina at feed rates of 10, 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Oil yield (%)
10	2	34.0, 35.01
30	2	73.21, 69.49
50	2	74.91, 71.91

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	1916.93	958.47	241.04	0.000
Error	3	11.93	3.98		
Total	5	1928.86			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=2) = 9.36

Oil yields: at 50 ml/h > at 30 ml/h ≥ at 10ml/h

4. **<u>Oil yields obtained from upgrading by silica alumina-ZnO at the ratio of 1:1 and feed rates of 10, 30 and 50 ml/h</u>**

Feed rate (ml/h)	Sample size (n)	Oil yield (%)
10	2	48.78, 40.07
30	3	59.71, 67.92, 53.34
50	2	76.89, 68.16

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	795.5	397.7	8.70	0.035
Error	4	182.9	45.7		
Total	6	978.4			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=2) = 97.43

LSD (n_i=2, n_j=2) = 88.94

Oil yields: at 50 ml/h ≥ at 30 ml/h ≥ at 10ml/h

5. **<u>Oil yields obtained from upgrading by silica alumina-ZnO at the ratio of 1:2 and feed rates of 10, 30 and 50 ml/h</u>**

Feed rate (ml/h)	Sample size (n)	Oil yield (%)
10	2	44.5, 49.55
30	2	54.51, 57.80
50	2	62.03, 60.57

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	209.07	104.53	16.31	0.024
Error	3	19.23	6.41		
Total	5	228.30			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=2) = 15.08

Oil yields: at 50 ml/h ≥ at 30 ml/h ≥ at 10ml/h

6. **Oil yields obtained from upgrading by various ratios of composite catalyst at feed rate of 10 ml/h**

Silica alumina:ZnO	Sample size (n)	Oil yield (%)
1:0	2	34.0, 35.01
1:1	2	48.78, 40.07
1:2	2	44.5, 49.55

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	174.6	87.3	5.12	0.108
Error	3	51.2	17.1		
Total	5	225.8			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

7. **Oil yields obtained from upgrading by various ratios of composite catalyst at feed rate of 30 ml/h**

Silica alumina:ZnO	Sample size (n)	Oil yield (%)
1:0	2	73.21, 69.49
1:1	3	59.71, 67.92, 53.34
1:2	2	54.51, 57.80

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	251.0	125.5	4.21	0.104
Error	4	119.2	29.8		
Total	6	370.2			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

8. **<u>Oil yields obtained from upgrading by various ratios of composite catalyst at feed rate of 50 ml/h</u>**

Silica alumina:ZnO	Sample size (n)	Oil yield (%)
1:0	2	74.91, 71.91
1:1	2	76.89, 68.16
1:2	2	62.03, 60.57

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	182.3	91.1	6.26	0.085
Error	3	43.7	14.6		
Total	5	226.0			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=2) = 15.08

Oil yields: at silica alumina $\geq$ at 1:1 $\geq$ at 1:2

9. **<u>Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina at feed rates of 30 and 50 ml/h</u>**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
30	2	0.0118, 0.0138
50	2	0.018, 0.015

Analysis of variance

Source	DF	SS	MS	F	P
Factor	1	0.0000137	0.0000137	4.21	0.177
Error	2	0.0000065	0.0000032		
Total	3	0.0000202			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

10. **<u>Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina-ZnO at feed rates of 30 and 50 ml/h</u>**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
30	3	0.006, 0.011, 0.010
50	2	0.016, 0.013

Analysis of variance

Source	DF	SS	MS	F	P
Factor	1	0.0000363	0.0000363	5.89	0.094
Error	3	0.0000185	0.0000062		
Total	4	0.0000548			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=3) = 0.0000132

Fraction of chlorinated hydrocarbon: at 50 ml/h > at 30 ml/h

11. **Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina-Fe_2O_3 at feed rates of 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
30	2	0.009, 0.010
50	2	0.015, 0.012

Analysis of variance

Source	DF	SS	MS	F	P
Factor	1	0.0000160	0.0000160	6.40	0.127
Error	2	0.0000050	0.0000025		
Total	3	0.0000210			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

12. **Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina at feed rates of 10, 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
10	2	0.0150, 0.0148
30	2	0.0118, 0.0138
50	2	0.018, 0.015

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	0.0000138	0.0000069	3.17	0.182
Error	3	0.0000065	0.0000022		
Total	5	0.0000203			

$P > 0.1$, this analysis accepts H_0. The average means were not different.

13. **Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina-ZnO at the ratio of 1:1 and feed rates of 10, 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
10	2	0.015, 0.013
30	3	0.006, 0.011, 0.010
50	2	0.016, 0.013

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	0.0000475	0.0000237	4.63	0.091
Error	4	0.0000205	0.0000051		
Total	6	0.0000680			

$P < 0.1$, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=3) = 0.00000997

LSD (n_i=2, n_j=2) = 0.0000109

Fraction of chlorinated hydrocarbon: at 50 ml/h > at 10 ml/h > at 30 ml/h

14. **Fraction of chlorinated hydrocarbon in upgraded oil using silica alumina-ZnO at the ratio of 1:2 and feed rates of 10, 30 and 50 ml/h**

Feed rate (ml/h)	Sample size (n)	Cl-hydrocarbon
10	2	0.015, 0.013
30	2	0.017, 0.014
50	2	0.015, 0.015

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	0.0000023	0.0000012	0.54	0.631
Error	3	0.0000065	0.0000022		
Total	5	0.0000088			

P > 0.1, this analysis accepts H_0. The average means were not different.

15. **Fraction of chlorinated hydrocarbon in upgraded oil using various ratios of composite catalyst at feed rate of 10 ml/h**

Silica alumina:ZnO	Sample size (n)	Cl-hydrocarbon
1:0	2	0.0150, 0.0148
1:1	2	0.015, 0.013
1:2	2	0.015, 0.013

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	0.0000011	0.0000005	0.40	0.700
Error	3	0.0000040	0.0000013		
Total	5	0.0000051			

P > 0.1, this analysis accepts H_0. The average means were not different.

16. **Fraction of chlorinated hydrocarbon in upgraded oil using various ratios of composite catalyst at feed rate of 30 ml/h**

Silica alumina:ZnO	Sample size (n)	Cl-hydrocarbon
1:0	2	0.0118, 0.0138
1:1	3	0.006, 0.011, 0.010
1:2	2	0.017, 0.014

Analysis of variance

Source	DF	SS	MS	F	P
Factor	2	0.0000528	0.0000264	5.15	0.078
Error	4	0.0000205	0.0000051		
Total	6	0.0000733			

P < 0.1, this analysis rejects H_0. The average means were different in significantly.

LSD (n_i=2, n_j=3) = 0.00000997

LSD (n_i=2, n_j=2) = 0.0000109

Fraction of chlorinated hydrocarbon: at 1:2 > at silica alumina > at 1:1

17. <u>Fraction of chlorinated hydrocarbon in upgraded oil using various ratios of composite catalyst at feed rate of 50 ml/h</u>

Silica alumina:ZnO	Sample size (n)	Cl-hydrocarbon
1:0	2	0.018, 0.015
1:1	2	0.016, 0.013
1:2	2	0.015, 0.015

Analysis of variance

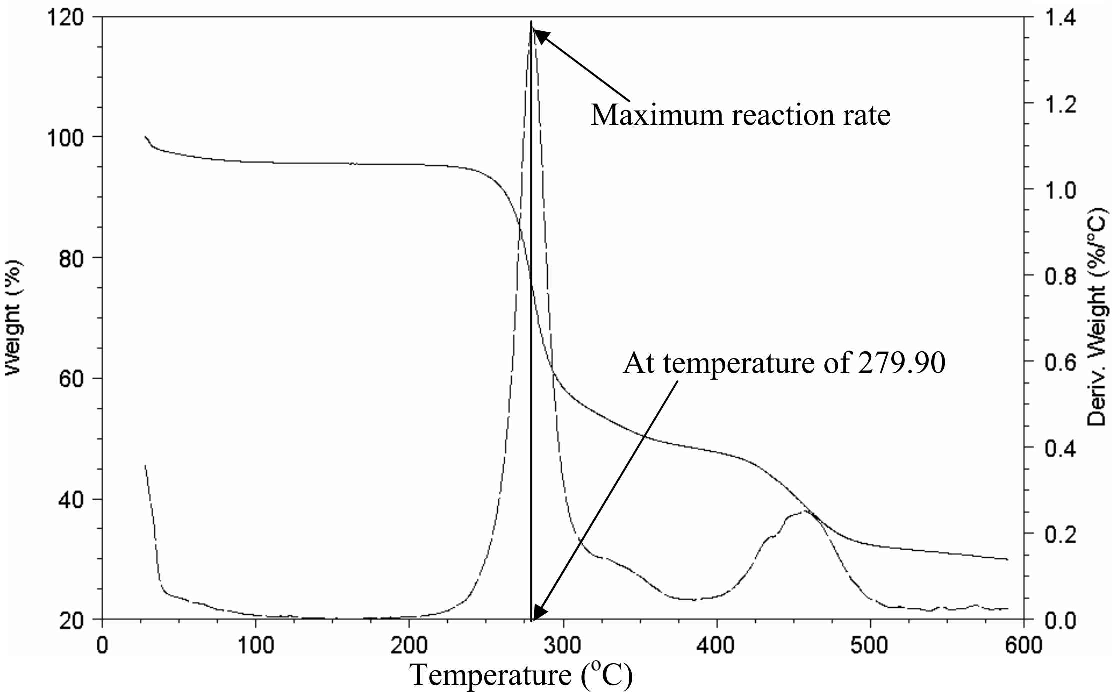
Source	DF	SS	MS	F	P
Factor	2	0.0000043	0.0000022	0.72	0.555
Error	3	0.0000090	0.0000030		
Total	5	0.0000133			

P > 0.1, this analysis accepts H_0. The average means were not different.

Appendix J

Determination of conversion at maximum reaction rate

Example Determination of the conversion at maximum reaction rate of PVC and cattle manure mixture, PVC:cattle manure (1:1), and heating rate of 10°C/min.



Appendix Figure J1 Thermal gravimetry profile and differential of thermal gravimetry of PVC and cattle manure mixture, PVC:cattle manure (1:1), heating rate of 10°C/min.

Appendix Figure 38 shows the maximum rate at the temperature of 279.90°C where the conversion at this temperature was 0.28. Therefore, the conversion at maximum reaction rate of PVC:cattle manure (1:1) and heating rate of 10°C/min was 0.28.