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Fast Pyrolysis of Halogenated Plastics Recovered from Waste Computers

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ABSTRACT

The disposal of waste computers is an issue that is gaining increasing interest around the world. In this paper, results from the fast pyrolysis in a fluidized bed reactor of three different waste computer monitor casings composed of mainly acrylonitrile-butadiene-styrene (ABS) copolymer and two different waste computer body casings composed of mostly poly(vinyl chloride) (PVC) type polymers are presented. Preliminary characterization of the waste plastics was investigated using coupled thermogravimetric analysis-Fourier transform infrared spectrometry (TGA-FT-IR). The results showed that the plastics decomposed in two stages. For the ABS-containing monitor casings, aromatic and aliphatic material were released in the first and second stages. The PVC-containing computer body casing samples showed a first-stage evolution of HCl and a second stage evolution of aromatic and aliphatic material and further HCl. In addition, each of the five plastics was fast-pyrolyzed in a laboratory-scale fluidized bed reactor at 500 °C. The fluidized bed pyrolysis led to the conversion of most of the plastics to pyrolysis oil, although the two PVC computer body cases produced large quantities of HCl. The pyrolysis oils were characterized by GC-MS and it was found that they were chemically very heterogeneous and contained a wide range of aliphatic, aromatic, halogenated, oxygenated, and nitrogenated compounds.

TABLES AND FIGURES

Table 1. Characteristics of the waste plastics

Waste Plastic Sample	Country of Origin	Date	Main Material	Abbreviation
Computer Monitor Back Cover	Taiwan	1994	ABS Co-polymer	MO1
Computer Monitor Back Cover	Indonesia	1995	ABS Co-polymer	MO2
Computer Monitor Back Cover	Taiwan	1991	ABS Co-polymer	MO3
Computer Body Casing	-	1997	PVC	CT1
Computer Body Casing	-	1997	PVC	CT2

Table 2 Elemental composition of the waste plastic computer body and monitor cases

Element	MO1 (wt%)	MO2 (wt%)	MO3 (wt%)	CT1 (wt%)	CT2 (wt%)
N	3.1	3.0	3.5	0.3	0.0
C	68.9	69.2	70.3	55.4	43.4
H	6.5	6.4	6.7	6.6	5.6
S	1.0	0.0	0.8	1.2	1.1
O	3.0	2.8	2.5	1.6	2.0
Br	10.3	10.2	10.5	0.0	0.0
Cl	1.1	2.6	0.9	32.8	43.1
Ca	0.1	0.1	0.1	0.2	2.1
Fe	0.0	0.0	0.0	0.0	0.0
Sb	4.5	4.5	3.9	0.0	0.0
Ti	1.4	1.2	1.0	1.8	2.7

Table 3. Total mass balance, bromine, and chlorine balances from the fluidised bed pyrolysis of the waste plastics

	Product	MO1	MO2	MO3	CT1	CT2
Mass (%)	Char	4.3	3.8	11.1	6.4	19.8
	Oil	91.8	91.0	85.4	55.1	35.9
	Gas	3.9	5.2	3.5	38.5	44.3
Bromine (%)	Char	0.0	0.0	0.0	0.0	0.0
	Oil	98.8	95.9	98.1	0.0	0.0
	Gas	1.2	4.1	1.9	0.0	0.0
Chlorine (%)	Char	0.0	0.0	0.0	0.0	2.6
	Oil	94.3	72.8	63.2	6.0	1.8
	Gas	5.7	27.2	36.8	94.0	95.5

Table 4. Composition of the pyrolysis gases derived from the fluidised bed pyrolysis of waste plastics

Gas	MO1 (Vol %)	MO2 (Vol %)	MO3 (Vol %)	CT1 (Vol %)	CT2 (Vol %)
Hydrogen	0.8	0.3	0.6	0.1	0.1
Carbon monoxide	29.9	15.1	26.7	0.0	0.0
Carbon dioxide	N/D	N/D	N/D	N/D	N/D
Methane	6.7	3.2	6.0	1.0	1.1
Ethene	9.2	3.7	6.5	1.5	0.7
Ethane	7.6	3.4	6.2	1.5	1.0
Propene	5.4	3.2	6.5	1.4	0.8
Propane	2.8	1.4	2.5	1.3	0.6
Butene + butadiene	21.4	27.0	23.3	4.3	2.0
$HBr + Br_2$	3.4	6.5	4.9	0.0	0.0
$HCl + Cl_2$	9.2	34.8	13.4	87.9	93.0
Butane	3.7	1.4	3.3	1.0	0.6

Table 5 Components identified by GC-MS in the pyrolysis oil of MO1

RT (min)	SI (%)	CAS	Name	Concentration (%)	Peak #
GC-FID only		107 - 13 - 1	acrylonitrile	2.7	
GC-FID only		71 - 43 - 2	benzene	21.9	
GC-FID only		108 -88 - 3	toluene	1.3	
9.1	99	100 - 41 - 4	Ethylbenzene	4.9	1
11.3	97	100 - 42 - 5	Styrene	13.4	2
15.1	97	98 - 82 - 8	Cumene	0.6	3
20.3	92	98 - 83 - 9	α-Methylstyrene	0.1	
21.4	97	108 - 95 - 2	Phenol	0.5	4
21.7	93	4013 - 34 - 7	(1-Methoxyethyl)benzene	0.1	
22.5	92	300 - 57 - 2	2-Propenylbenzene	0.1	
22.6	94	611 - 15 - 4	2-Methylstyrene	0.1	
25.1	92	1572 - 52 - 7	α-Methyleneglutaronitrile	0.1	
25.9	91	1120 - 21 - 4	Undecane	0.1	
27.5	94	140 - 29 - 4	Benzyl nitrile	0.1	
28.4	96	1823 - 91 - 2	alpha-methyl-benzeneacetonitrile	0.1	
28.7	94	91 - 20 - 3	Naphthalene	0.2	
28.9	94	1885 - 38 - 7	trans-3-Phenylpropenonitrile	0.1	
29.1	91	112 - 41 - 4	1-Dodecene	<0.1	
30.5	98	99 - 89 - 8	4-Isopropylphenol	0.5	5
32.7	95	90 - 12 - 0	1-Methylnaphthalene	0.2	
33.5	98	2046 - 18 - 6	Benzenebutanenitrile	5.9	6
33.9	91	5590 - 14 - 7	Cyclopropanecarbonitrile	0.1	
34.9	94	13360 - 61 - 7	1-Pentadecene	0.1	
37.3	90	644 - 08 - 6	4-Methyldiphenyl	0.1	
37.6	96	613 - 46 - 7	2-Naphthalenecarbonitrile	0.2	
38.2	92	103 - 29 - 7	Bibenzyl	0.1	
39.9	91	74339 - 50 - 7	Dodecyl trichloroacetate	0.1	
41.3	97	1081 - 75 - 0	1,3-Diphenylpropane	2.3	7
41.4	93	132 - 75 - 2	1-Naphthaleneacetonitrile	0.6	
42.6	94	103 - 30 - 0	1,2-Diphenylethene	0.2	
44.3	96	6362-80-7	2,4-Diphenyl-4-methyl-1-pentene	3.3	8
44.6	91	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.8	
45.2	94	22768 - 22 - 5	2,4-Diphenyl-4-methyl-2(E)-pentene	2.3	9
46.5	91	629 - 79 - 8	Hexadecanenitrile	0.3	
46.6	91	86544 - 79 - 8	1,3-Diphenyl-3-methylcyclopropene	0.3	
47.0	96	112 - 39 - 0	Methyl hexadecanoate	0.8	10
48.0	81	612 - 94 - 2	Naphthalene, 2-phenyl-	0.7	11
49.8	96	4998 - 48 - 5	2-(2H-Benzotriazol-2-yl)-5-methylphenol	0.5	
50.8	96	112 - 61 - 8	Methyl octadecanoate	1.4	12
51.7	74	-	1-phenyl-1(3-phenyl-3butenyl)cyclopropane	3.6	13
53.3	76	-	unknown	1.9	14
54.2	84	1889 - 67 - 4	Benzene, 1,1'-(1,1,2,2-tetramethyl-1,2-ethanediyl)bis-	1.7	15
56.9	86	6362-80-7	2,4-Diphenyl-4-methyl-1-pentene	2.5	16
57.8	85	6362-80-7	2,4-Diphenyl-4-methyl-1-pentene	1.8	17
59.2	92	1889 - 67 - 4	2,3-Dimethyl-2,3-diphenylbutane	0.4	
			TOTAL	**78.8**	

Table 6 Components identified by GC-MS in the pyrolysis oil of MO2

RT (min)	SI (%)	CAS	Name	Concentration (%)	Peak #
GC-FID only		107-13-1	acrylonitrile	3.0	
GC-FID only		71-43-2	benzene	20.5	
GC-FID only		108-88-3	toluene	2.3	
8.3	96	108 - 90 - 7	chlorobenzene	0.1	
9.2	99	100 - 41 - 4	Ethylbenzene	3.2	1
11.4	98	100 - 42 - 5	Styrene	16.5	2
20.3	93	98 - 83 - 9	A-Methylstyrene	0.1	
21.7	94	4013 - 34 - 7	(1-methoxyethyl)Benzene	0.3	
22.6	95	637 - 50 - 3	1-propenylbenzene	0.1	
25.2	92	1572 - 52 - 7	2-Methyleneglutaronitrile	0.1	
25.9	94	1120 - 21 - 4	Undecane	0.1	
27.5	97	140 - 29 - 4	Benzyl nitrile	0.1	
28.7	97	91 - 20 - 3	Naphthalene	0.1	
28.9	93	1885 - 38 - 7	trans-3-Phenylpropenonitrile	0.1	
29.1	91	2437 - 56 - 1	1-Tridecene	0.1	
32.3	92	119 - 65 - 3	Isoquinoline	0.1	
32.7	95	91 - 57 - 6	2-methylnaphthalene	0.1	
33.4	97	2046 - 18 - 6	Benzenebutanenitrile	5.7	3
34.9	90	13360 - 61 - 7	1-Pentadecene	0.1	
37.6	95	86 - 53 - 3	1-Naphthalenecarbonitrile	0.1	
38.2	92	103 - 29 - 7	Bibenzyl	0.1	
38.3	90	86 - 53 - 3	1-Naphthalenecarbonitrile	0.1	
40.3	93	93 - 96 - 9	α-Methyl benzyl ether	0.1	
41.3	97	1081 - 75 - 0	1,3-Diphenylpropane	1.9	4
41.4	93	132 - 75 - 2	1-Naphthaleneacetonitrile	0.4	
42.6	95	103 - 30 - 0	(E)-Stilbene	0.2	
43.7	92	-	(l-Erythro-2,3-diphenyl)-2-butanol	3.1	5
44.1	92	7614 - 93 - 9	1,3-Diphenyl-1-butene	2.6	6
44.3	93	6362-80-7	2,4-Diphenyl-4-methyl-1-pentene	0.9	
44.6	92	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.6	
44.9	91	20669 - 52 - 7	1,2-Dihydro-3-phenylnaphthalene	0.4	
45.2	94	22768 - 22 - 5	2,4-Diphenyl-4-methyl-2(E)-pentene	2.1	
45.4	77	-	Bis-(2-methylbenzyl)-methylenisonitril	5.4	7
48.0	88	35465 - 71 - 5	2-Phenylnaphthalene	1.4	8
50.4	92	723 - 98 - 8	1H-Cyclopenta[l]phenanthrene, 2,3-dihydro-	0.8	
50.6	82	13754 - 10 - 4	1,2-Propanediol, 3-benzyloxy-1,2 diacetyl-	4.4	9
50.8	93	112 - 61 - 8	Methyl octadecanoate	0.2	
51.3	95	92 - 06 - 8	m-Terphenyl	0.3	
51.7	74	-	Cyclopropane, 1-phenyl-1(3-phenyl-3-butenyl)-	4.2	10
53.2	76	-	unknown	2.5	11
57.2	79	32461 - 31 - 7	2-Oxazolidinone, 4-phenyl-5-p-tolyl-, trans-	1.6	12
58.4	71	7614 - 93 - 9	1,3-Diphenyl-1-butene	2.7	13
59.6	77	-	1-Propene, 3-(2-cyclopentenyl)-2-methyl-1,1-diphenyl-	0.8	14
			TOTAL	**86.9**	

Table 7 Components identified by GC-MS in the pyrolysis oil of MO3

RT (min)	SI (%)	CAS	Name	Concentration (%)	Peak #
GC-FID only		107-13-1	acrylonitrile	0.6	
GC-FID only		71-43-2	benzene	1.5	
GC-FID only		108 - 88 - 3	Toluene	2.2	
9.5	98	100 - 41 - 4	Ethylbenzene	7.6	1
12.0	98	100 - 42 - 5	Styrene	25.0	2
15.9	98	98 - 82 - 8	Cumene	1.8	
21.4	98	108 - 95 - 2	Phenol	0.3	3
22.9	94	873 - 49 - 4	cyclopropylbenzene	0.1	
24.3	91	104 - 51 - 8	butylbenzene	<0.1	
25.0	90	98 - 86 - 2	Acetophenone	0.1	
26.2	90	15869 - 93 - 9	3,5-dimethyloctane	<0.1	
26.7	92	768 - 00 - 3	cis-2-Phenyl-2-butene	<0.1	
27.5	90	1587 - 04 - 8	1-methyl-2-(2-propenyl)Benzene	<0.1	
27.7	93	140 - 29 - 4	Benzyl nitrile	0.1	
28.3	93	612 - 17 - 9	1,4-Dihydronaphthalene	0.1	
28.7	97	1823 - 91 - 2	α-methylBenzeneacetonitrile	0.1	
29.0	98	91 - 20 - 3	Naphthalene	0.1	
29.1	95	1885 - 38 - 7	trans-3-Phenylpropenonitrile	0.1	
30.6	97	99 - 89 - 8	4-(1-Methylethyl)phenol	0.3	4
32.7	90	935 - 44 - 4	1-Phenyl-1-cyclopropanecarbonitrile	0.1	
32.9	96	90 - 12 - 0	1-methylNaphthalene,	0.1	
33.7	98	2046 - 18 - 6	Benzenebutanenitrile	4.2	5
34.2	91	5590 - 14 - 7	2-Phenylcyclopropanecarbonitrile	0.1	
34.8	93	56851 - 51 - 5	(1,3-dimethyl-3-butenyl)Benzene	0.4	6
36.0	83	122057 - 61 - 8	Bicyclo[4.2.0]octa-1,3,5-triene, 7-(3-butenyl)-	0.5	7
37.6	94	644 - 08 - 6	4-Methylbiphenyl	<0.1	
41.6	97	1081 - 75 - 0	1,3-Diphenylpropane	1.4	8
41.6	94	132 - 75 - 2	1-Naphthaleneacetonitrile	0.3	
42.8	96	103 - 30 - 0	(E)-Stilbene	0.1	
43.4	90	3282 - 18 - 6	1-Phenylcyclopropyl)benzene	0.3	
44.3	92	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.2	
44.6	98	6362-80-7	2,4-Diphenyl-4-methyl-1-pentene	2.7	9
44.8	91	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.4	
45.5	93	22768 - 22 - 5	2,4-Diphenyl-4-methyl-2(E)-pentene	0.6	
45.6	78	2412 - 58 - 0	1-Methyl-3,4-dihydroisoquinoline	1.8	10
47.3	96	112 - 39 - 0	Methyl hexadecanoate	0.4	
47.4	81	55044 - 97 - 8	1,1'-[oxybis(methylene)]bis[4-ethylBenzene	0.4	11
50.8	81	10304 - 81 - 1	(2-chloropropyl)Benzene	1.2	12
51.1	95	112 - 61 - 8	Methyl octadecanoate	0.5	
52.0	73	-	Cyclopropane, 1-phenyl-1(3-phenyl-3-butenyl)-	3.0	13
52.3	95	629 - 97 - 0	Docosane	0.1	
53.5	76	-	unknown	0.9	14
54.5	83	1889 - 67 - 4	2,3-Dimethyl-2,3-diphenylbutane	1.3	15
57.1	86	-	2,4-Diphenyl-4-methyl-1-pentene	0.9	16
			TOTAL	**61.7**	

Table 8 Components identified by GC-MS in the pyrolysis oil of CT1

RT (min)	SI (%)	CAS	Name	Concentration (%)	Peak #
GC-FID only		71-43-2	benzene	20.3	
GC-FID only		108-88-3	toluene	1.0	
8.8	98	108 - 90 - 7	chlorobenzene	0.2	
9.7	99	100 - 41 - 4	Ethylbenzene	3.1	1
12.0	97	100 - 42 - 5	Styrene	8.3	2
20.1	92	98 - 83 - 9	α-Methylstyrene	0.1	
21.5	96	4013 - 34 - 7	(1-methoxyethyl)Benzene	0.5	
23.6	95	35275 - 62 - 8	1-chloro-2,3-dihydro-1H-Indene	<0.1	
24.7	94	672 - 65 - 1	(1-chloroethyl)benzene	0.2	
25.3	91	935 - 67 - 1	(1-methoxy-1-methylethyl)benzene	0.6	3
27.7	94	140 - 29 - 4	Benzyl nitrile	0.1	
28.3	94	612 - 17 - 9	1,4-Dihydronaphthalene	0.2	
29.0	98	91 - 20 - 3	Naphthalene	0.2	
29.4	91	112 - 41 - 4	1-Dodecene	<0.1	
32.2	98	2046 - 18 - 6	Benzenebutanenitrile	1.4	4
32.9	95	90 - 12 - 0	1-methylnaphthalene	0.5	
33.2	98	2046 - 18 - 6	Benzenebutanenitrile	3.7	5
34.8	90	56851 - 51 - 5	(1,3-dimethyl-3-butenyl)benzene	0.1	
34.8	95	92 - 52 - 4	Biphenyl	0.1	
35.1	94	1120 - 36 - 1	1-Tetradecene	0.2	
37.6	90	643 - 93 - 6	3-Methylbiphenyl	<0.1	
37.9	92	629 - 62 - 9	Pentadecane	0.1	
38.4	93	103 - 29 - 7	Bibenzyl	<0.1	
39.9	93	86 - 73 - 7	Fluorene	0.1	
40.1	92	52132 - 58 - 8	Chloro-acetic acid hexadecyl ester	0.2	
41.5	97	1081 - 75 - 0	1,3-Diphenylpropane	1.3	6
42.2	93	1520 - 44 - 1	(3-Phenylbutyl)benzene	0.2	
42.5	90	629 - 78 - 7	Heptadecane	0.1	
42.8	95	103 - 30 - 0	(E)-Stilbene	0.1	
43.1	93	124 - 10 - 7	Methyl tetradecanoate	0.1	
43.2	90	1889 - 67 - 4	2,3-Dimethyl-2,3-diphenylbutane	0.1	
44.5	91	6362 - 80 - 7	2,4-Diphenyl-4-methyl-1-pentene	0.8	
44.8	92	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.5	
44.9	84	32461 - 31 - 7	2-Oxazolidinone, 4-phenyl-5-p-tolyl-, trans-	1.9	7
45.5	93	22768 - 22 - 5	2,4-Diphenyl-4-methyl-2(E)-pentene	0.3	
45.6	78	2412 - 58 - 0	1-Methyl-3,4-dihydroisoquinoline	1.3	8
46.8	92	629 - 79 - 8	Hexadecanenitrile	0.5	
47.3	96	112 - 39 - 0	Methyl hexadecanoate	3.2	9
49.2	94	1731 - 92 - 6	methyl heptadecanoate	0.1	
50.6	93	2345 - 29 - 1	8-Octadecenoic acid, methyl ester	0.7	
51.1	96	112 - 61 - 8	Methyl octadecanoate	3.0	10
52.0	73	-	unknown	1.8	11
52.1	91	111 - 06 - 8	Butyl hexadecanoate	0.3	
53.3	75	-	1-Propene, 3-(2-cyclopentenyl)-2-methyl-1,1-diphenyl-	0.7	12
58.7	71	7614 - 93 - 9	1,3-Diphenyl-1-butene	0.1	13
			TOTAL	**58.3**	

Table 9 Components identified by GC-MS in the pyrolysis oil of CT2

RT (min)	SI (%)	CAS #	Name	Concentration (%)	Peak #
GC-FID only		71-43-2	benzene	0.1	
GC-FID only		108-88-3	toluene	0.2	
8.4	97	108 - 90 - 7	chlorobenzene	0.1	
9.3	98	100 - 41 - 4	Ethylbenzene	<0.1	1
11.4	98	100 - 42 - 5	Styrene	1.1	2
23.2	96	104 - 76 - 7	2-Ethyl-1-hexanol	0.4	3
23.3	94	95 - 13 - 6	Indene	0.1	
25.4	89	935 - 67 - 1	(1-methoxy-1-methylethyl)benzene	1.0	4
25.9	92	1120 - 21 - 4	Undecane	0.2	
27.2	91	824 - 22 - 6	2,3-dihydro-4-methyl-1H-Indene	0.1	
27.6	91	3454 - 07 - 7	4-Ethylstyrene	0.1	
27.8	90	2177 - 47 - 1	2-Methylindene	0.4	
28.1	95	612 - 17 - 9	1,4-Dihydronaphthalene	0.2	
28.7	98	91 - 20 - 3	Naphthalene	1.3	5
32.7	96	90 - 12 - 0	1-methylnaphthalene	0.4	
33.4	98	2046 - 18 - 6	Benzenebutanenitrile	1.3	6
34.6	96	92 - 52 - 4	Biphenyl	0.2	
35.1	91	1127 - 76 - 0	1-ethylnaphthalene	<0.1	
37.5	93	13360 - 61 - 7	1-Pentadecene	0.1	
38.3	90	111 - 82 - 0	Methyl dodecanoate	0.1	
39.7	93	86 - 73 - 7	Fluorene	0.2	
39.9	93	13360 - 61 - 7	1-Pentadecene	0.2	
40.1	92	643 - 58 - 3	2-Methylbiphenyl	0.2	
41.3	96	1081 - 75 - 0	1,3-Diphenylpropane	0.9	7
42.5	90	1430 - 97 - 3	2-Methylfluorene	0.2	
42.6	92	103 - 30 - 0	(E)-Stilbene	0.1	
42.9	96	124 - 10 - 7	Methyl tetradecanoate	0.5	
44.1	95	120 - 12 - 7	Anthracene	0.5	
45.0	93	7132 - 64 - 1	Methyl pentadecanoate	0.3	
46.4	91	779 - 02 - 2	9-Methylanthracene	0.2	
47.0	96	112 - 39 - 0	Methyl hexadecanoate	4.0	8
49.0	95	1731 - 92 - 6	methyl heptadecanoate	0.3	
50.3	93	2345 - 29 - 1	8-Octadecenoic acid, methyl ester	1.5	
50.8	96	112 - 61 - 8	Methyl octadecanoate	7.6	9
51.7	74	-	1-phenyl-1(3-phenyl-3-butenyl)cyclopropane	0.9	10
57.1	84	24468 - 13 - 1	dl-2-Ethylhexyl chloroformate	0.6	11
61.8	97	111 - 02 - 4	2,6,10,15,19,23-Hexamethyl-2,6,10,14,18,22-Tetracosahexaene	0.5	12
			TOTAL	**25.6**	

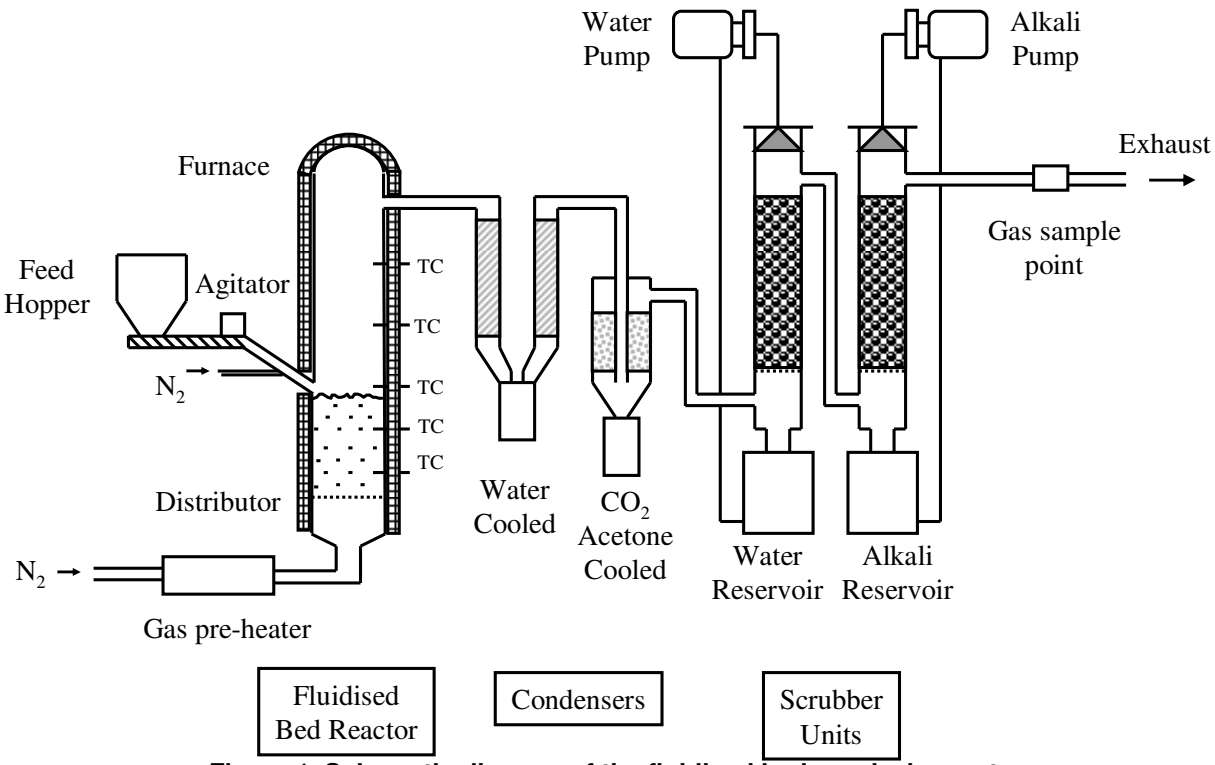

Figure 1. Schematic diagram of the fluidised bed pyrolysis reactor.

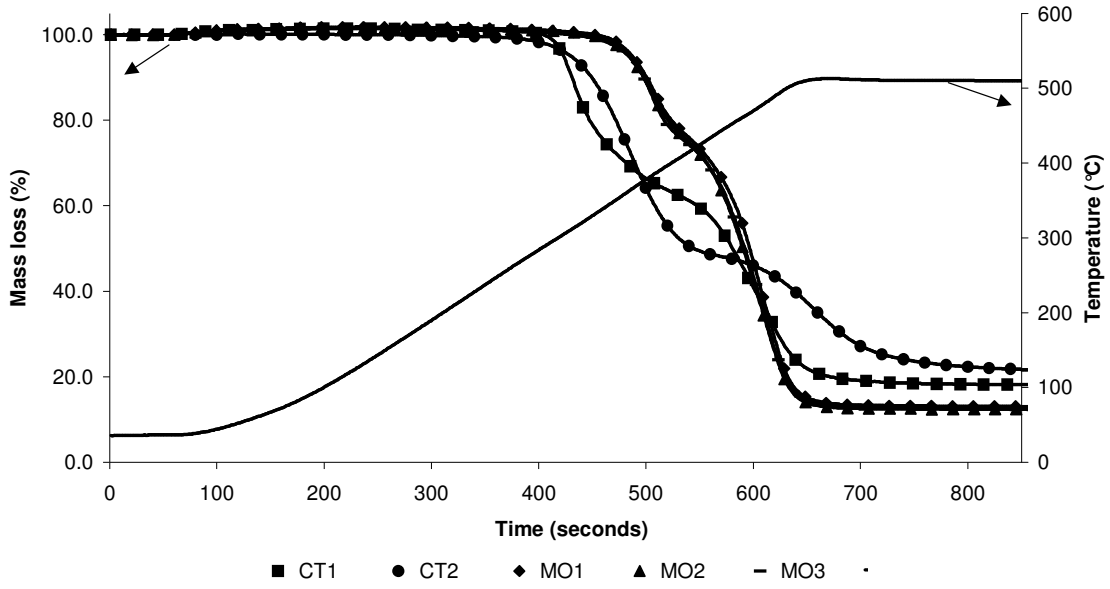

Figure 2. Thermogravimetric analysis of the five different plastics at a heating rate of 50 °C min^{-1} to a final temperature of 500 °C.

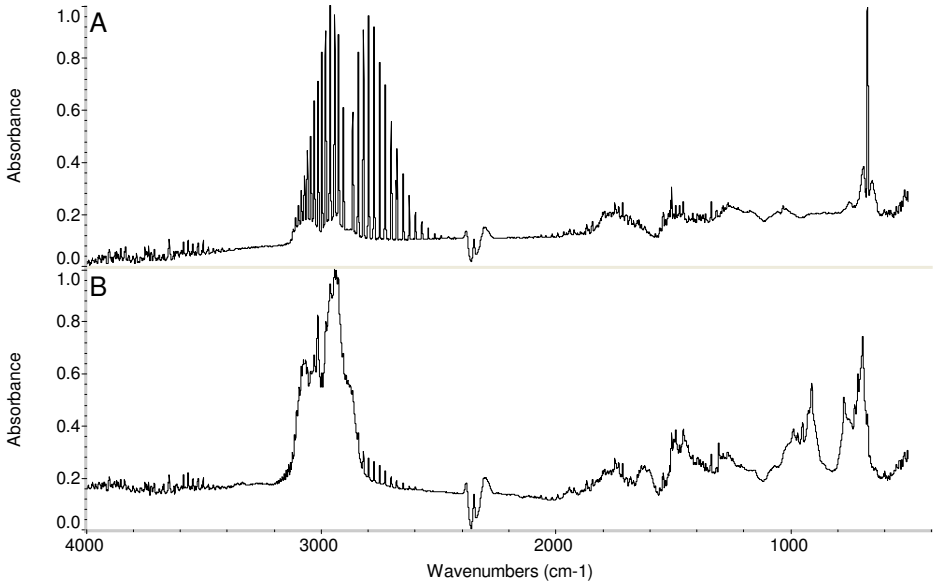

Figure 3. Fourier transform infra-red analysis of the evolved products derived from computer body casing sample CT1 at a thermogravimetric analysis temperature of 330 ℃ (A) and 485 ℃ (B).

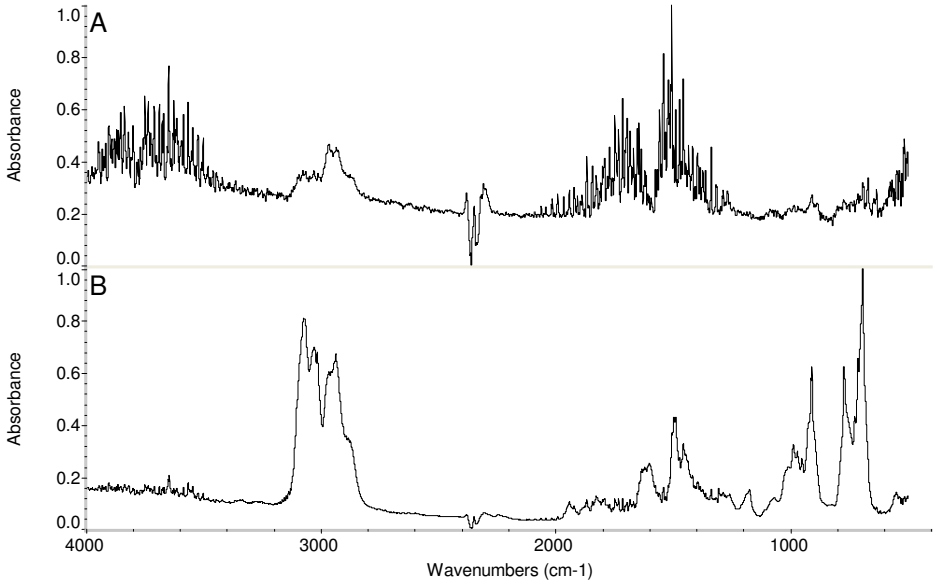

Figure 4. Fourier transform infra-red analysis of the evolved products derived from computer monitor casing sample MO1 at a thermogravimetric analysis temperature of 380 ℃ (A) and 485 ℃ (B).

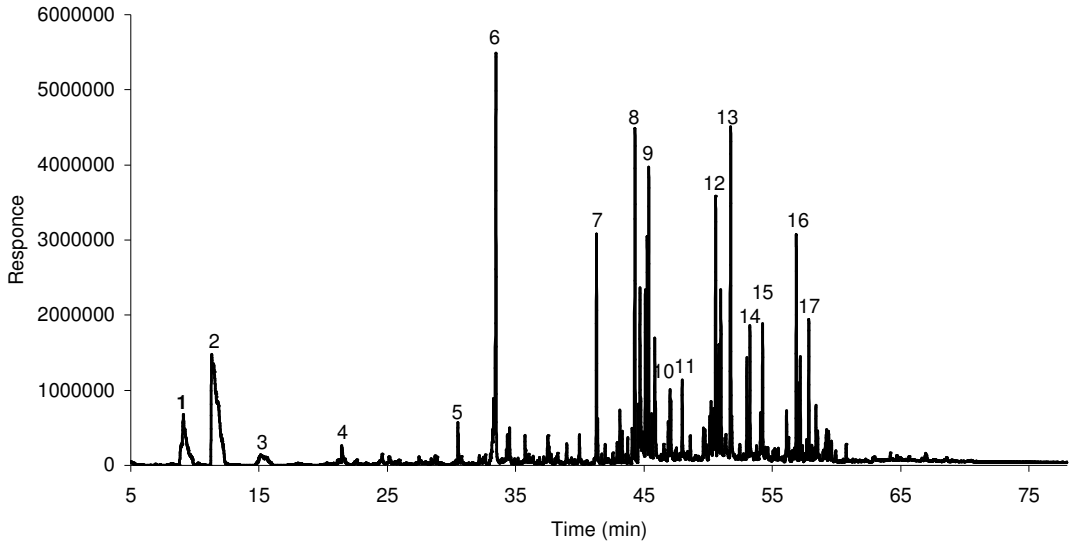

Figure 5. Total ion chromatogram from the gas chromatography-mass spectrometric analysis of the pyrolysis oil derived from the fluidised bed pyrolysis of computer monitor sample MO1 at 500 °C.

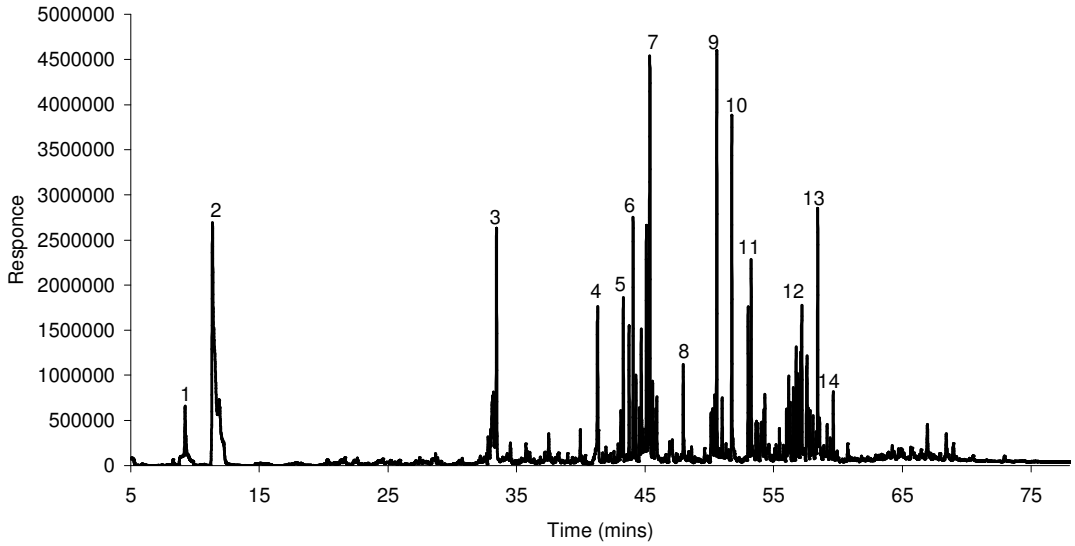

Figure 6. Total ion chromatogram from the gas chromatography-mass spectrometric analysis of the pyrolysis oil derived from the fluidised bed pyrolysis of computer monitor sample MO2 at 500 °C.

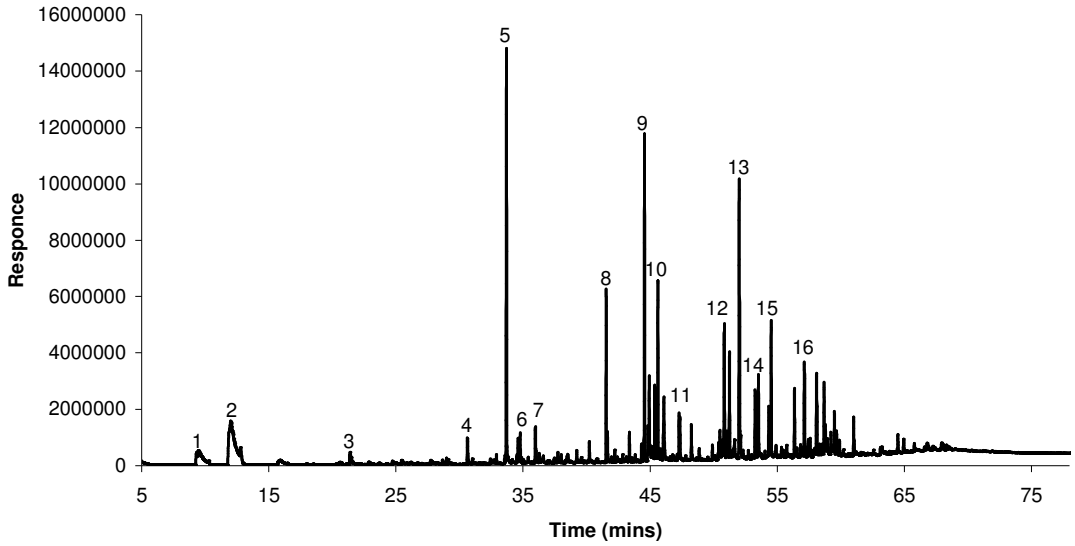

Figure 7. Total ion chromatogram from the gas chromatography-mass spectrometric analysis of the pyrolysis oil derived from the fluidised bed pyrolysis of computer monitor sample MO3 at 500 °C.

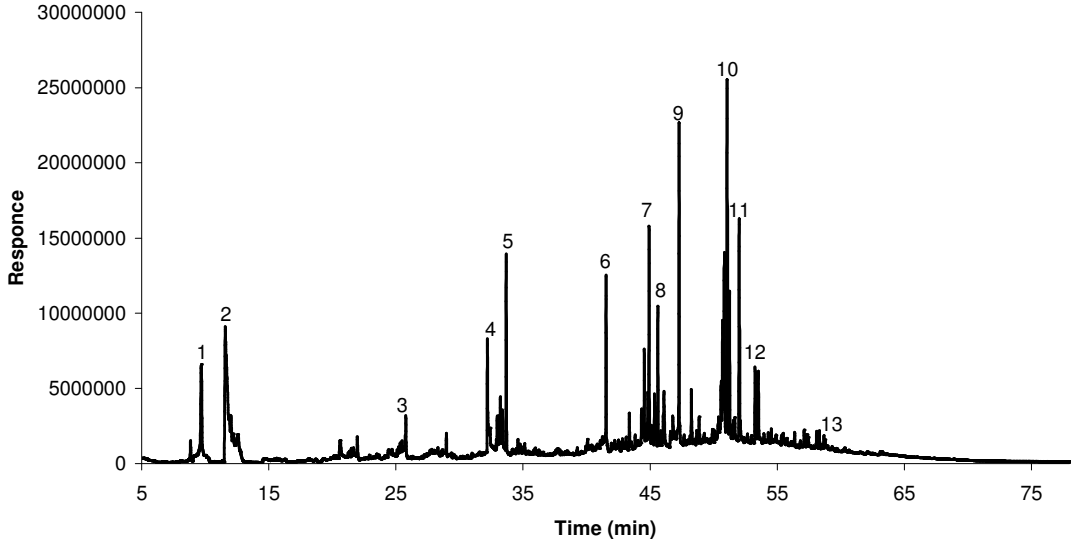

Figure 8. Total ion chromatogram from the gas chromatography-mass spectrometric analysis of the pyrolysis oil derived from the fluidised bed pyrolysis of computer body sample CT1 at 500 °C.

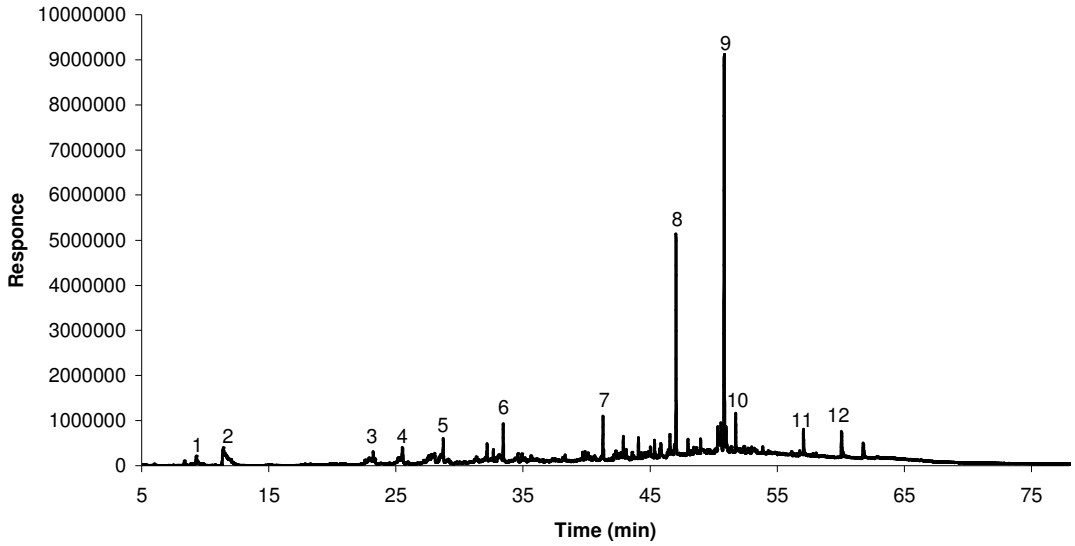

Figure 9. Total ion chromatogram from the gas chromatography-mass spectrometric analysis of the pyrolysis oil derived from the fluidised bed pyrolysis of computer body sample CT2 at 500 °C.

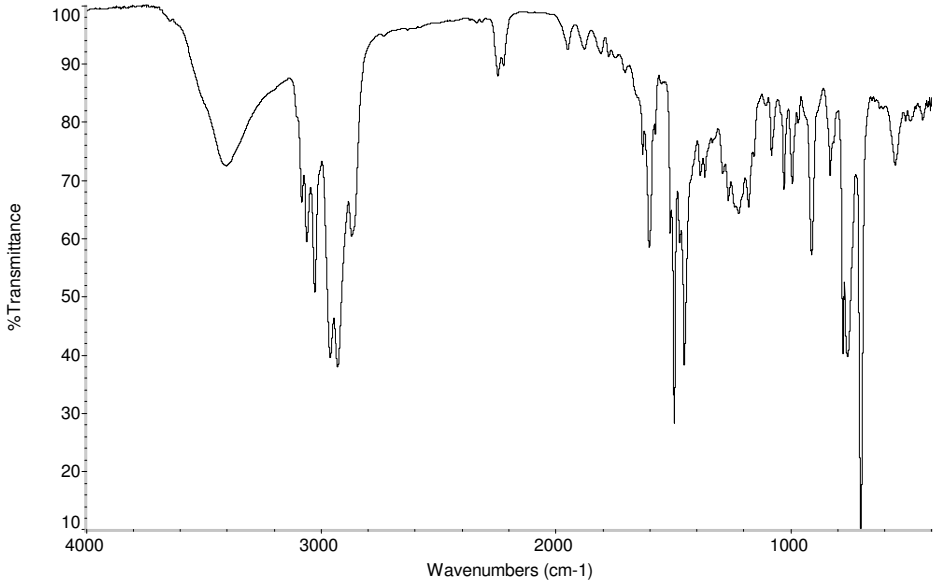

Figure 10. Fourier transform infra-red analysis of the pyrolysis oil derived from computer monitor sample MO1 pyrolysed at 500 °C in the fluidised bed reactor.

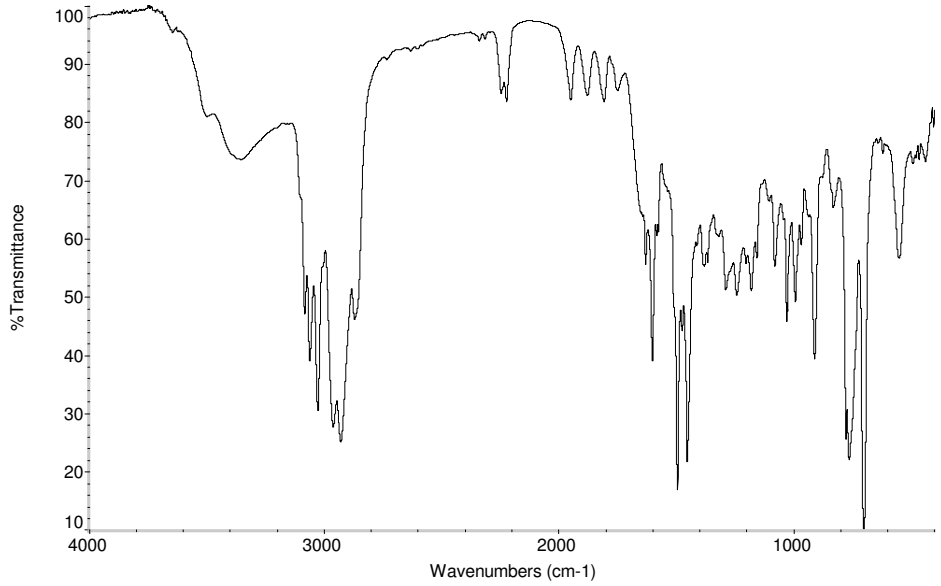

Figure 11. Fourier transform infra-red analysis of the pyrolysis oil derived from computer monitor sample MO2 pyrolysed at 500 °C in the fluidised bed reactor.

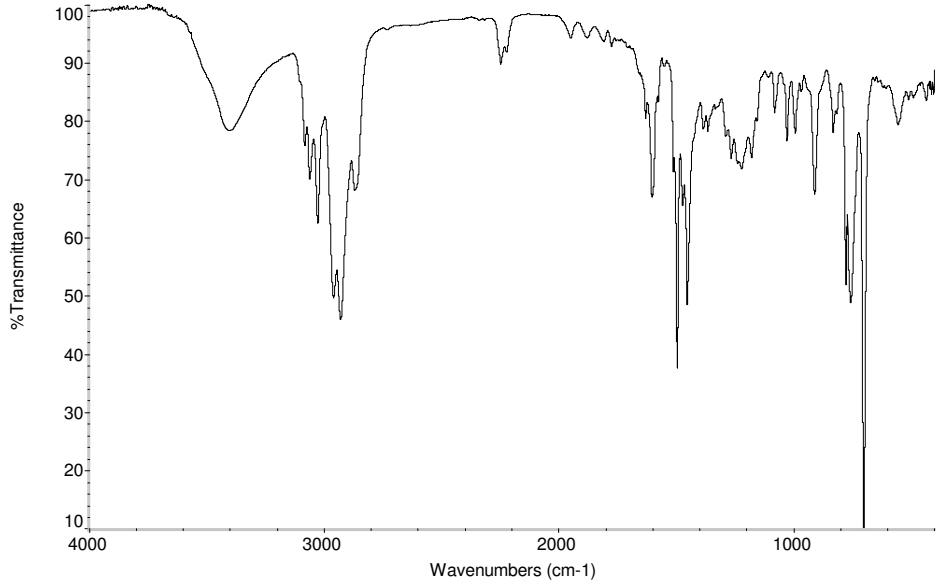

Figure 12. Fourier transform infra-red analysis of the pyrolysis oil derived from computer monitor sample MO3 pyrolysed at 500 °C in the fluidised bed reactor.

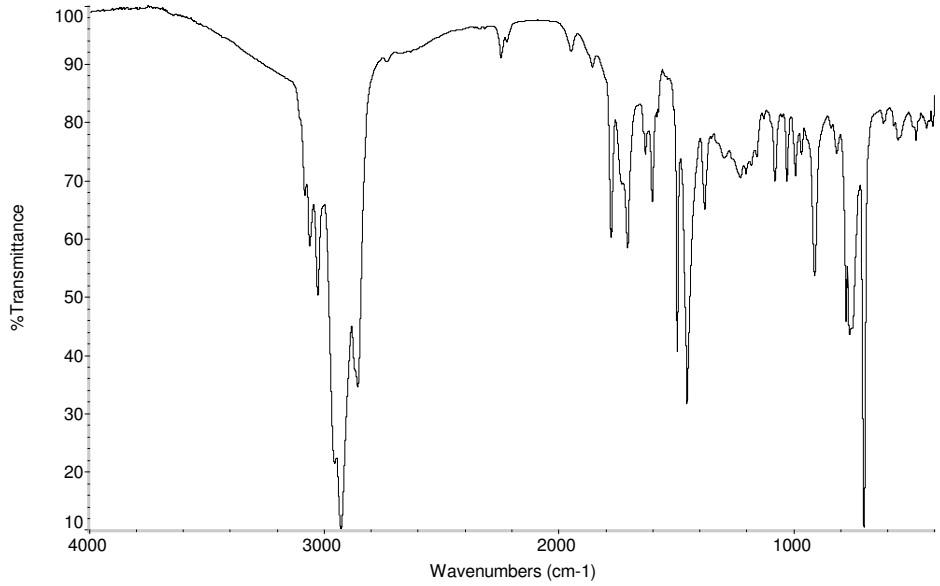

Figure 13. Fourier transform infra-red analysis of the pyrolysis oil derived from computer body sample CT1 pyrolysed at 500 °C in the fluidised bed reactor.

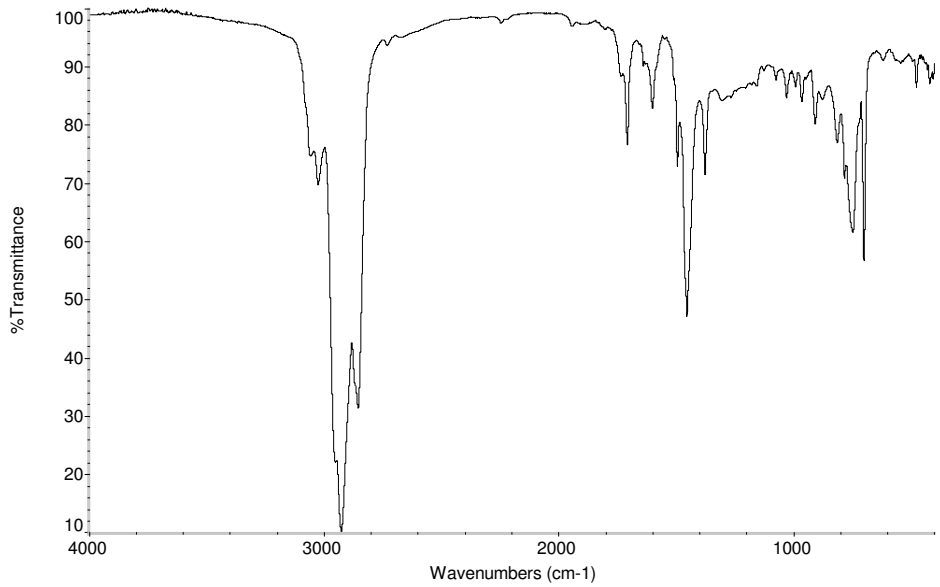

Figure 14. Fourier transform infra-red analysis of the pyrolysis oil derived from computer body sample CT2 pyrolysed at 500 °C in the fluidised bed reactor.