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## APPENDICES

### Appendix A Characterization of vegetable oils. (All Analysis done by Thailand Institute of Scientific and Technological Research)

**Table A1** Density Measurement

	Crude Palm Kernel Oil	Crude Coconut Oil
Density, g/ml	0.908	0.909

**Table A2** Kinetic Viscosity Measurement

	Crude Palm Kernel Oil	Crude Coconut Oil
Kinetic Viscosity, mm <sup>2</sup> /s	28.65	24.85

**Table A3** Free fatty acid determination

	Crude Palm Kernel Oil			Crude Coconut Oil		
	1	2	3	1	2	3
Wt. Oil, g	5.06	5.03	5.03	4.99	5.04	5.00
Conc. NaOH, N	0.2	0.2	0.2	0.2	0.2	0.2
V NaOH used, ml	0.1	0.1	0.1	2.85	2.85	5.5
FFA(% Lauric acid)	0.079	0.079	0.079	2.280	2.258	2.196
<b>Average FFA</b>	0.08			2.25		
<b>Amount needed to neutralize oil</b>						
mg NaOH/ g oil	0.16			4.51		
g NaOH/100 g oil	0.016			0.451		

Formula:

$$\text{FFA (\% Lauric acid)} = (\text{ml. Alkali} \times \text{N} \times 56.1) / (\text{weight of sample} \times 2.81)$$

$$\text{Amount needed to neutralize oil} = \text{FFA, \%} \times 2.81 \times 40 / 56.1$$

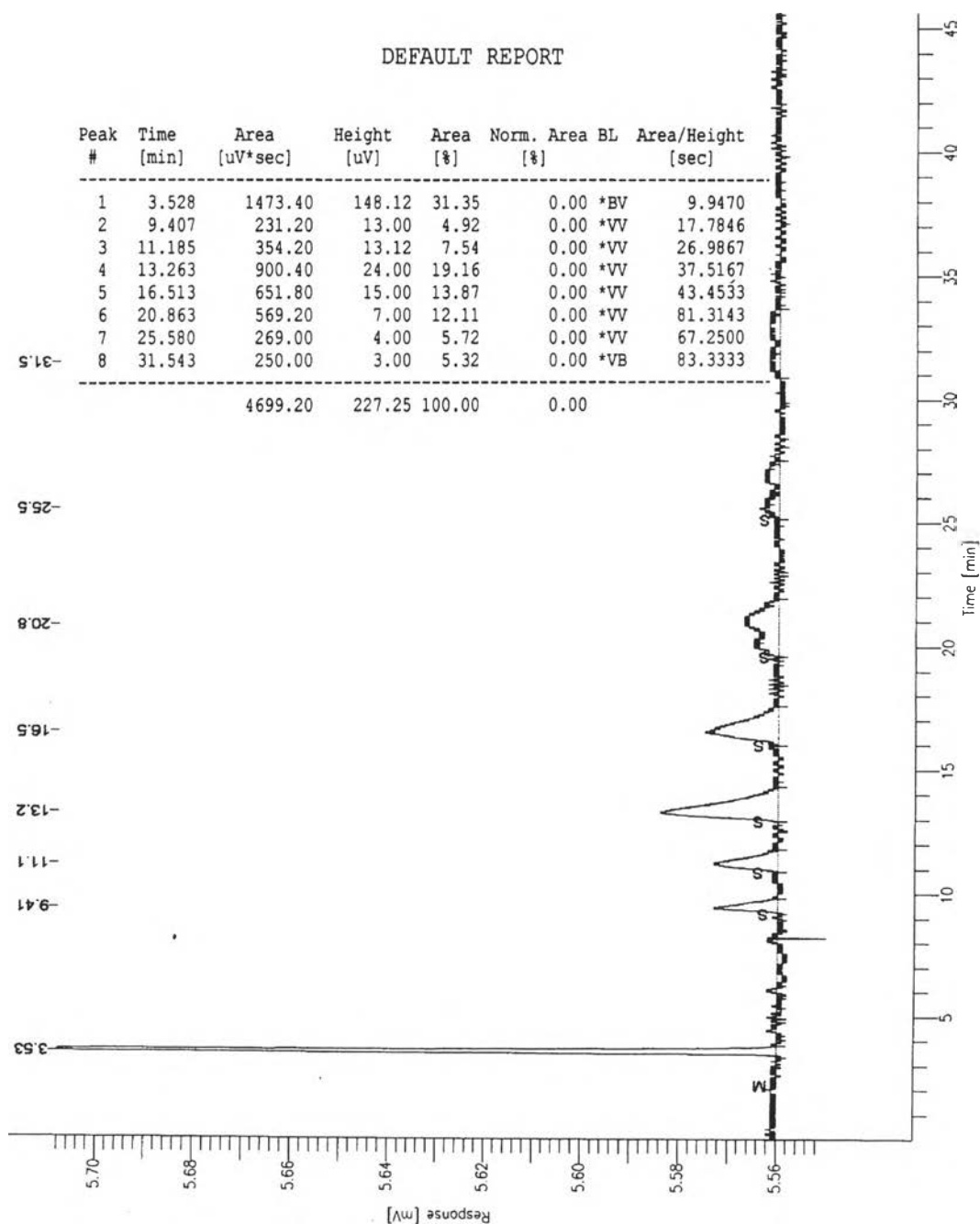
**Table A4** Moisture content measurement

	<b>Palm Kernel Oil</b>	<b>Coconut Oil</b>
<b>Moisture Content, %</b>	0.09	0.17

**Table A5** Molecular weight determination

<b>Fatty acid</b>	<b>Structure</b>	<b>FA PKO</b>	<b>FA CCO</b>	<b>MW acid</b>	<b>MW PKO</b>	<b>MW CCO</b>
Caprylic	8:00	0.0267	0.064	144.21	3.85	9.23
Capric	10:00	0.0346	0.058	172.26	5.96	9.99
Lauric	12:00	0.4945	0.481	200.31	99.05	96.35
Myristic	14:00	0.1608	0.19	228.36	36.72	43.39
Palmitic	16:00	0.0774	0.089	256.42	19.85	22.82
palmitoleic	16:01	0.0007	0.001	254.4	0.18	0.25
Stearic	18:00	0.0193	0.028	284.47	5.49	7.97
Oleic	18:01	0.1411	0.059	282.5	39.86	16.67
Linoleic	18:02	0.0236	0.014	280.77	6.63	3.93
Linolenic	18:03	-	-	278.4	-	-
Arachidic	20:00	0.0009	0.001	312.5	0.28	0.31
total		0.9796	0.985		217.87	210.91
					222.41	214.12
		<b>MW of vegetable oil</b>			708.22	683.36

## Appendix B HPLC chromatograms of biodiesel products.

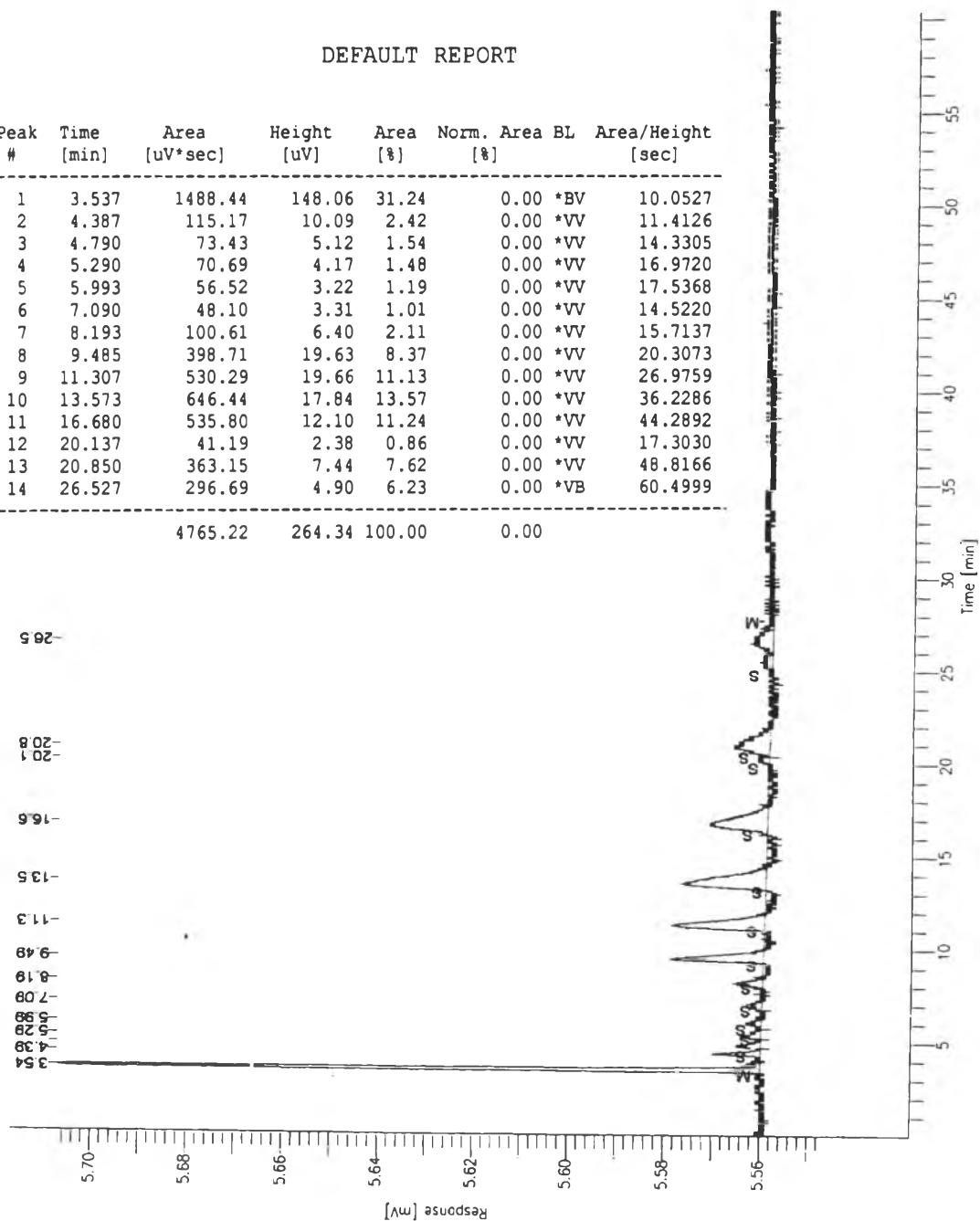


**Figure B1** Crude palm kernel oil.

Condition: 6:1 methanol:oil, 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.537	1488.44	148.06	31.24	0.00	*BV	10.0527
2	4.387	115.17	10.09	2.42	0.00	*VV	11.4126
3	4.790	73.43	5.12	1.54	0.00	*VV	14.3305
4	5.290	70.69	4.17	1.48	0.00	*VV	16.9720
5	5.993	56.52	3.22	1.19	0.00	*VV	17.5368
6	7.090	48.10	3.31	1.01	0.00	*VV	14.5220
7	8.193	100.61	6.40	2.11	0.00	*VV	15.7137
8	9.485	398.71	19.63	8.37	0.00	*VV	20.3073
9	11.307	530.29	19.66	11.13	0.00	*VV	26.9759
10	13.573	646.44	17.84	13.57	0.00	*VV	36.2286
11	16.680	535.80	12.10	11.24	0.00	*VV	44.2892
12	20.137	41.19	2.38	0.86	0.00	*VV	17.3030
13	20.850	363.15	7.44	7.62	0.00	*VV	48.8166
14	26.527	296.69	4.90	6.23	0.00	*VB	60.4999
		4765.22	264.34	100.00	0.00		

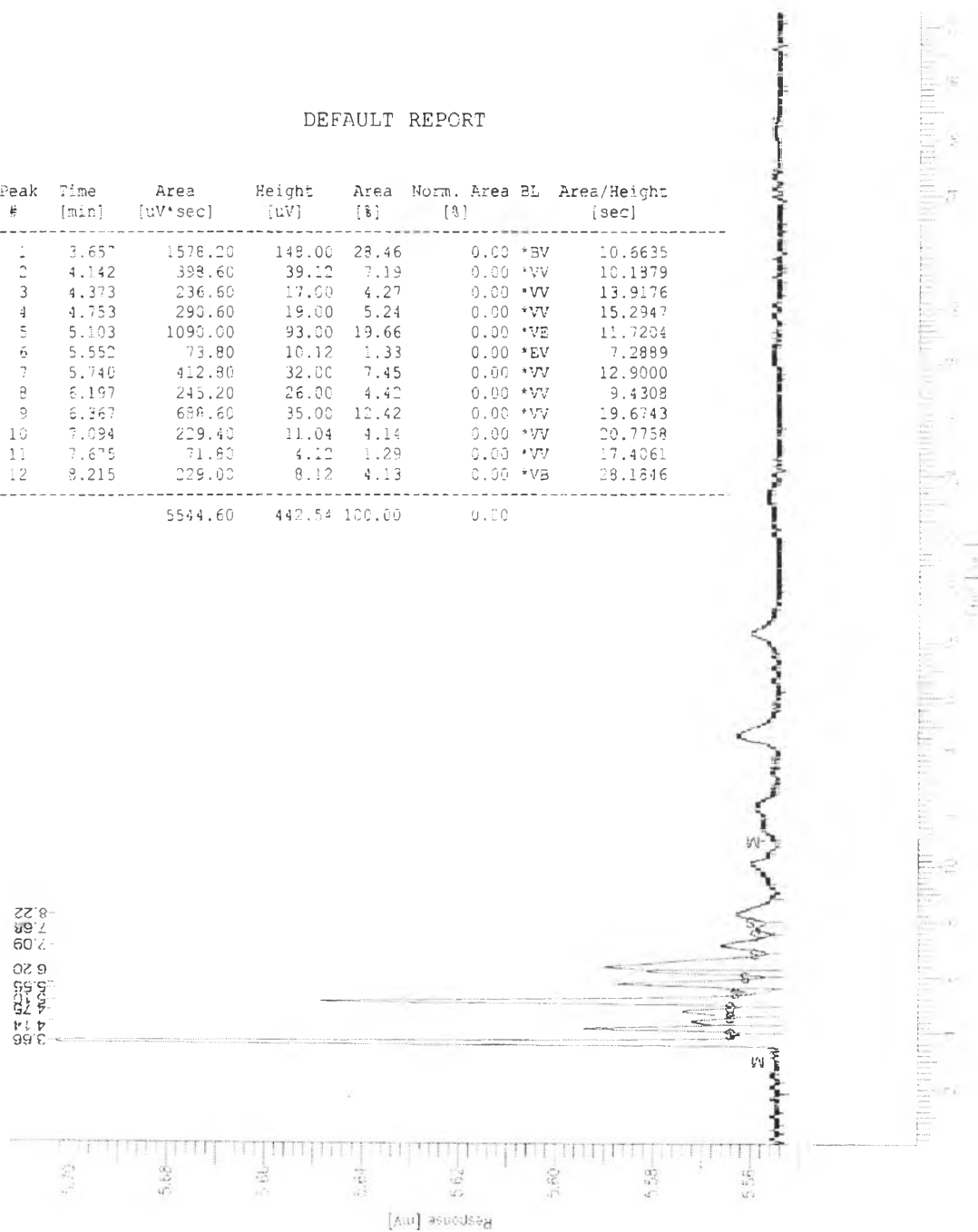


**Figure B2** Crude coconut oil.

Condition: 6:1 methanol:oil, 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	BL	Area/Height [sec]
1	3.657	1578.20	148.00	28.46	0.00	*BV	10.6635
2	4.142	398.60	39.12	7.19	0.00	*VV	10.1879
3	4.373	236.60	17.00	4.27	0.00	*VV	13.9176
4	4.753	290.60	19.00	5.24	0.00	*VV	15.2947
5	5.103	1090.00	93.00	19.66	0.00	*VE	11.7204
6	5.552	73.80	10.12	1.33	0.00	*EV	7.2889
7	5.740	412.80	32.00	7.45	0.00	*VV	12.9000
8	6.197	245.20	26.00	4.42	0.00	*VV	9.4308
9	6.367	688.60	35.00	12.42	0.00	*VV	19.6743
10	7.094	229.40	11.04	4.14	0.00	*VV	20.7758
11	7.675	71.80	4.12	1.29	0.00	*VV	17.4061
12	8.215	229.00	8.12	4.13	0.00	*VB	28.1646
		5544.60	442.54	100.00	0.00		



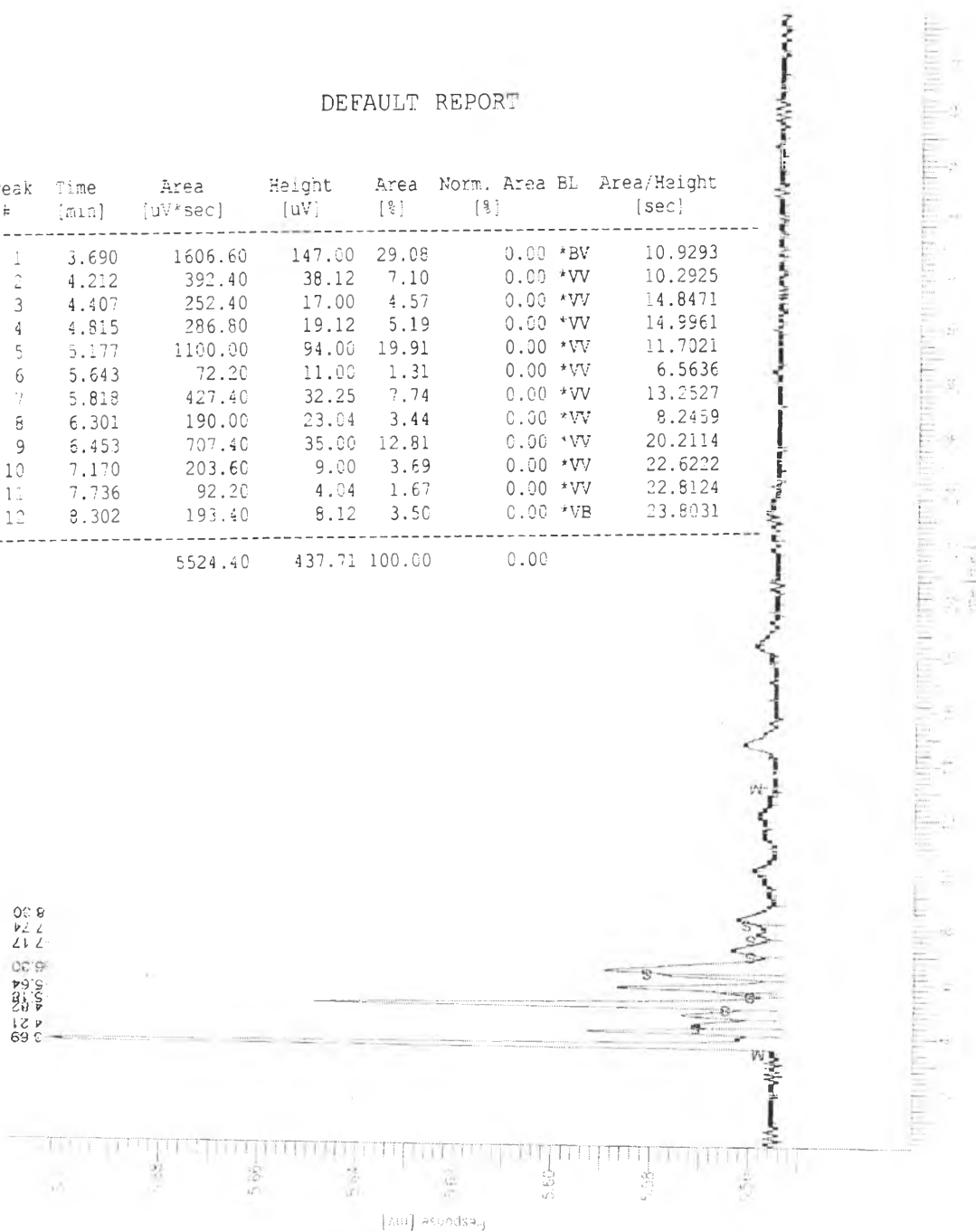
**Figure B3** PKO experimental no.1.

Condition: 6:1 methanol:oil, 200 °C, 50 bars, 350 rpm



## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.690	1606.60	147.00	29.08	0.00	*BV	10.9293
2	4.212	392.40	38.12	7.10	0.00	*VV	10.2925
3	4.407	252.40	17.00	4.57	0.00	*VV	14.8471
4	4.815	286.80	19.12	5.19	0.00	*VV	14.9961
5	5.177	1100.00	94.00	19.91	0.00	*VV	11.7021
6	5.643	72.20	11.00	1.31	0.00	*VV	6.5636
7	5.818	427.40	32.25	7.74	0.00	*VV	13.2527
8	6.301	190.00	23.04	3.44	0.00	*VV	8.2459
9	6.453	707.40	35.00	12.81	0.00	*VV	20.2114
10	7.170	203.60	9.00	3.69	0.00	*VV	22.6222
11	7.736	92.20	4.04	1.67	0.00	*VV	22.8124
12	8.302	193.40	8.12	3.50	0.00	*VB	23.8031
		5524.40	437.71	100.00	0.00		

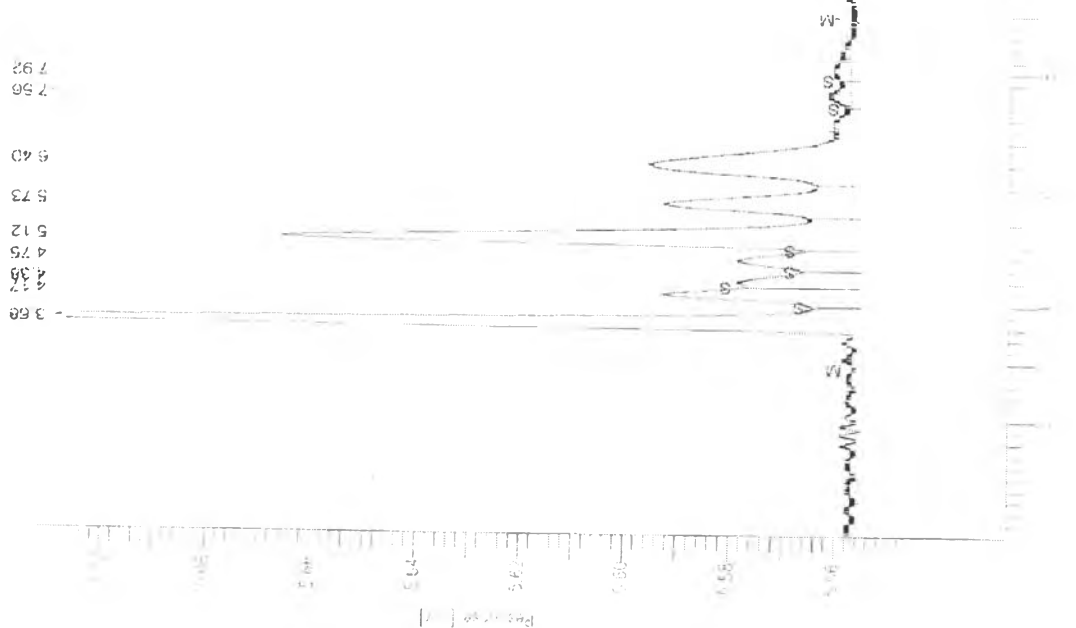


**Figure B4** PKO experiment no.2.

Condition: 6:1 methanol:oil, 3 wt% of  $ZrO_2$ , 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area/Height [sec]
1	3.683	1773.97	151.87	28.07	0.00	*BV 11.6908
2	4.167	462.94	35.79	7.32	0.00	*VV 12.9346
3	4.378	294.80	21.89	4.66	0.00	*VV 13.4728
4	4.748	334.51	21.82	5.29	0.00	*VV 15.3309
5	5.115	1396.64	108.76	25.26	0.00	*VV 14.6805
6	5.727	648.42	35.53	10.26	0.00	*VV 18.2486
7	6.403	1057.69	38.42	16.73	0.00	*VV 27.5292
8	7.557	72.15	4.23	1.14	0.00	*VV 17.6579
9	7.923	79.38	3.17	1.26	0.00	*VB 25.0506
		6320.49	421.47	100.00	0.00	

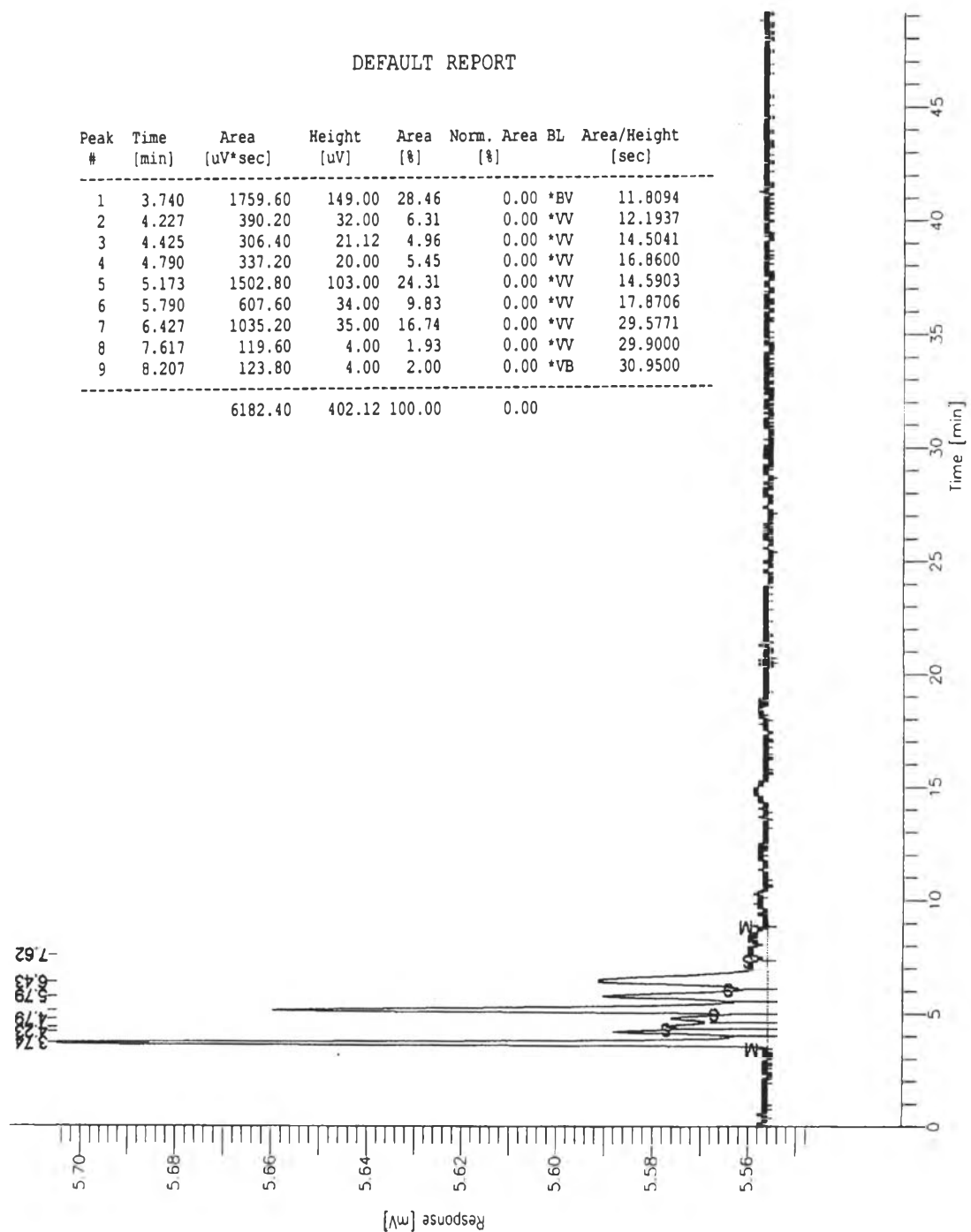


**Figure B5** PKO experiment no.3.

Condition: 6:1 methanol:oil,3 wt% of ZnO, 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [ $\mu\text{V}\cdot\text{sec}$ ]	Height [ $\mu\text{V}$ ]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.740	1759.60	149.00	28.46	0.00	*BV	11.8094
2	4.227	390.20	32.00	6.31	0.00	*VV	12.1937
3	4.425	306.40	21.12	4.96	0.00	*VV	14.5041
4	4.790	337.20	20.00	5.45	0.00	*VV	16.8600
5	5.173	1502.80	103.00	24.31	0.00	*VV	14.5903
6	5.790	607.60	34.00	9.83	0.00	*VV	17.8706
7	6.427	1035.20	35.00	16.74	0.00	*VV	29.5771
8	7.617	119.60	4.00	1.93	0.00	*VV	29.9000
9	8.207	123.80	4.00	2.00	0.00	*VB	30.9500
		6182.40	402.12	100.00	0.00		

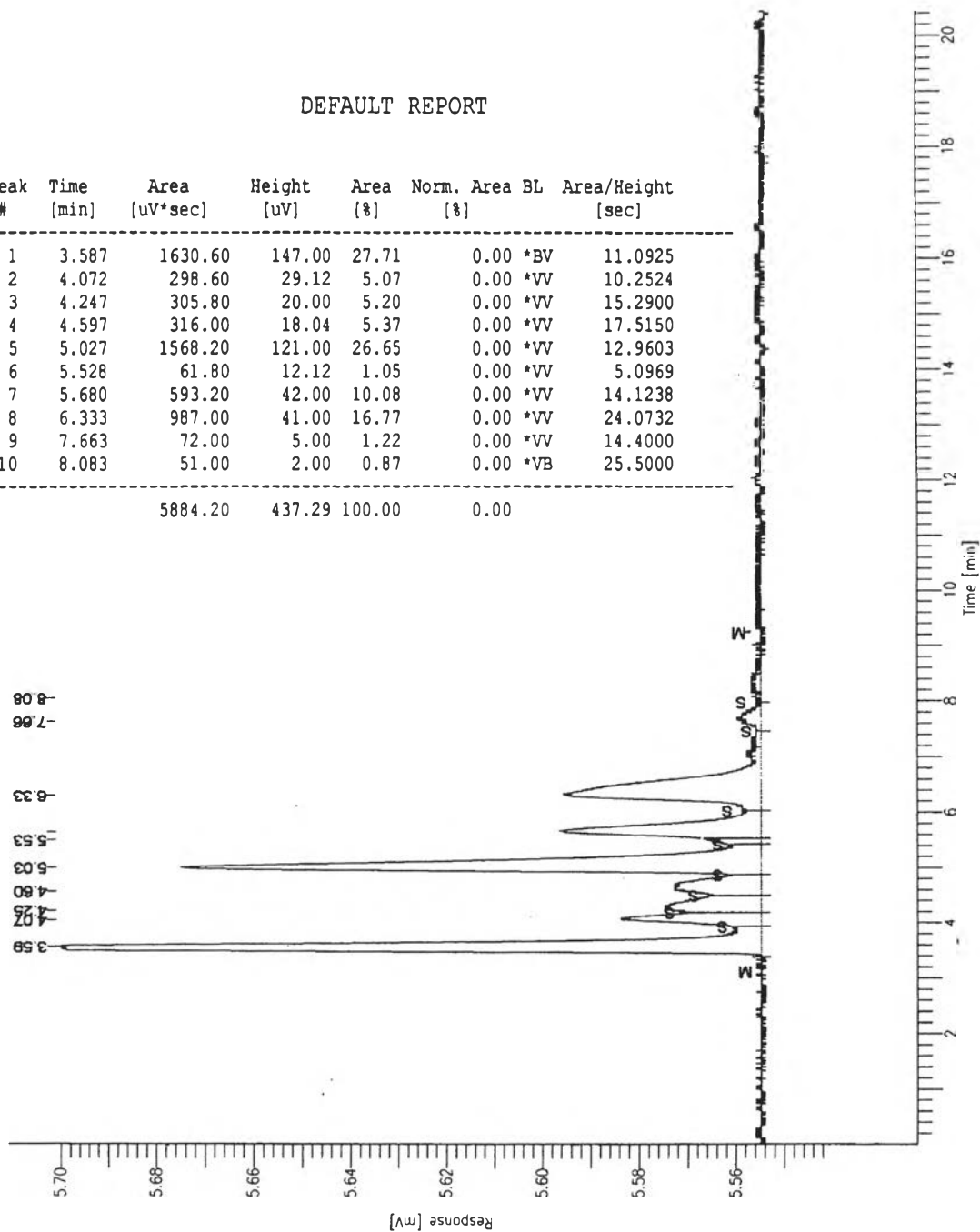


**Figure B6** PKO experiment no.4.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{SO}_4^{2-}/\text{SnO}_2$ , 200 °C, 50 bars, 350 rpm

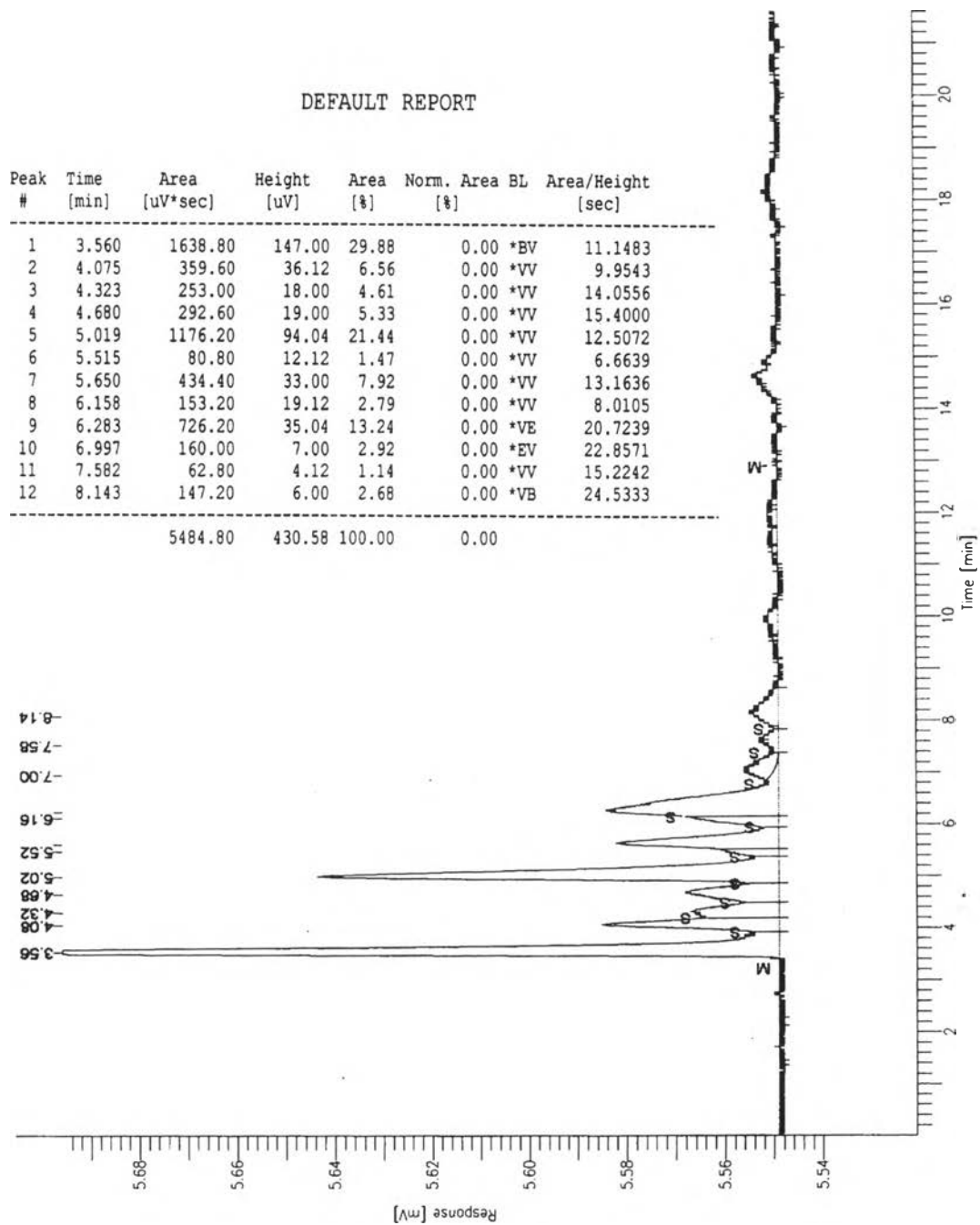
## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	BL	Area/Height [sec]
1	3.587	1630.60	147.00	27.71	0.00	*BV	11.0925
2	4.072	298.60	29.12	5.07	0.00	*VV	10.2524
3	4.247	305.80	20.00	5.20	0.00	*VV	15.2900
4	4.597	316.00	18.04	5.37	0.00	*VV	17.5150
5	5.027	1568.20	121.00	26.65	0.00	*VV	12.9603
6	5.528	61.80	12.12	1.05	0.00	*VV	5.0969
7	5.680	593.20	42.00	10.08	0.00	*VV	14.1238
8	6.333	987.00	41.00	16.77	0.00	*VV	24.0732
9	7.663	72.00	5.00	1.22	0.00	*VV	14.4000
10	8.083	51.00	2.00	0.87	0.00	*VB	25.5000
		5884.20	437.29	100.00	0.00		



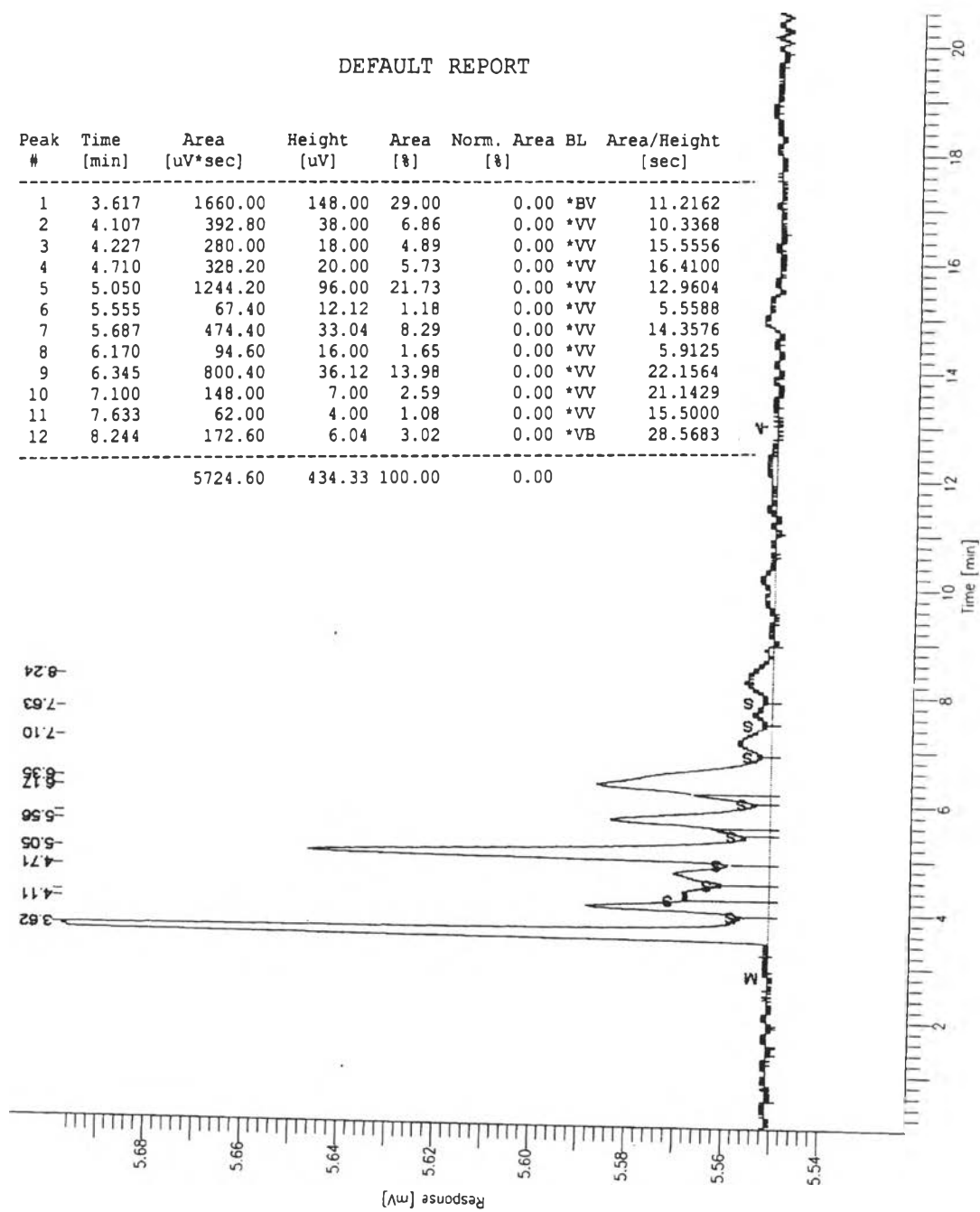
**Figure B7** PKO experiment no.5.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{SO}_4^{2-}/\text{ZrO}_2$ , 200 °C, 50 bars, 350 rpm



**Figure B8** PKO experiment no.6.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{KNO}_3/\text{KLzeolite}$ , 200 °C, 50 bars, 350 rpm

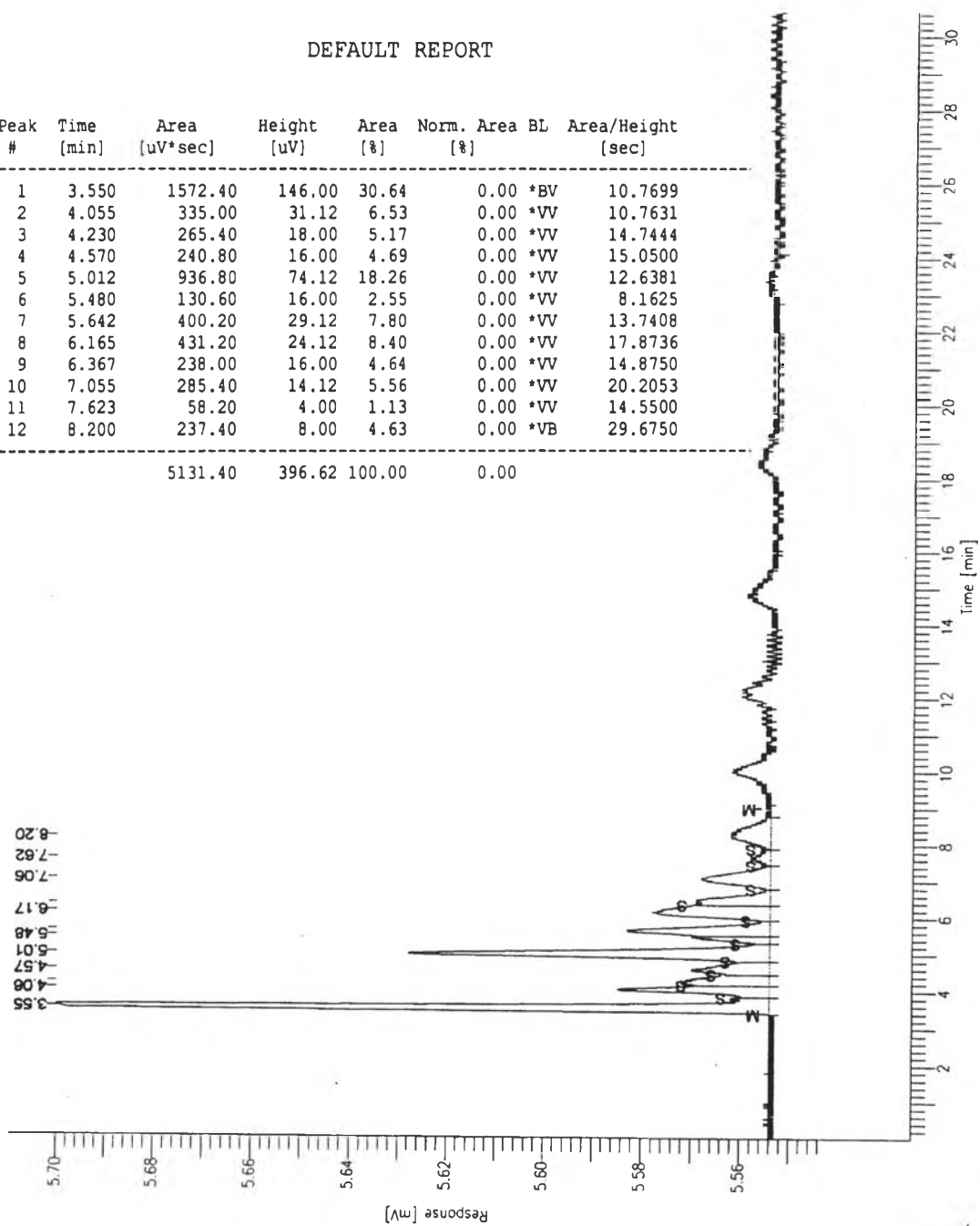


**Figure B9** PKO experiment no.7.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{KNO}_3/\text{ZrO}_2$ , 200 °C, 50 bars, 350 rpm

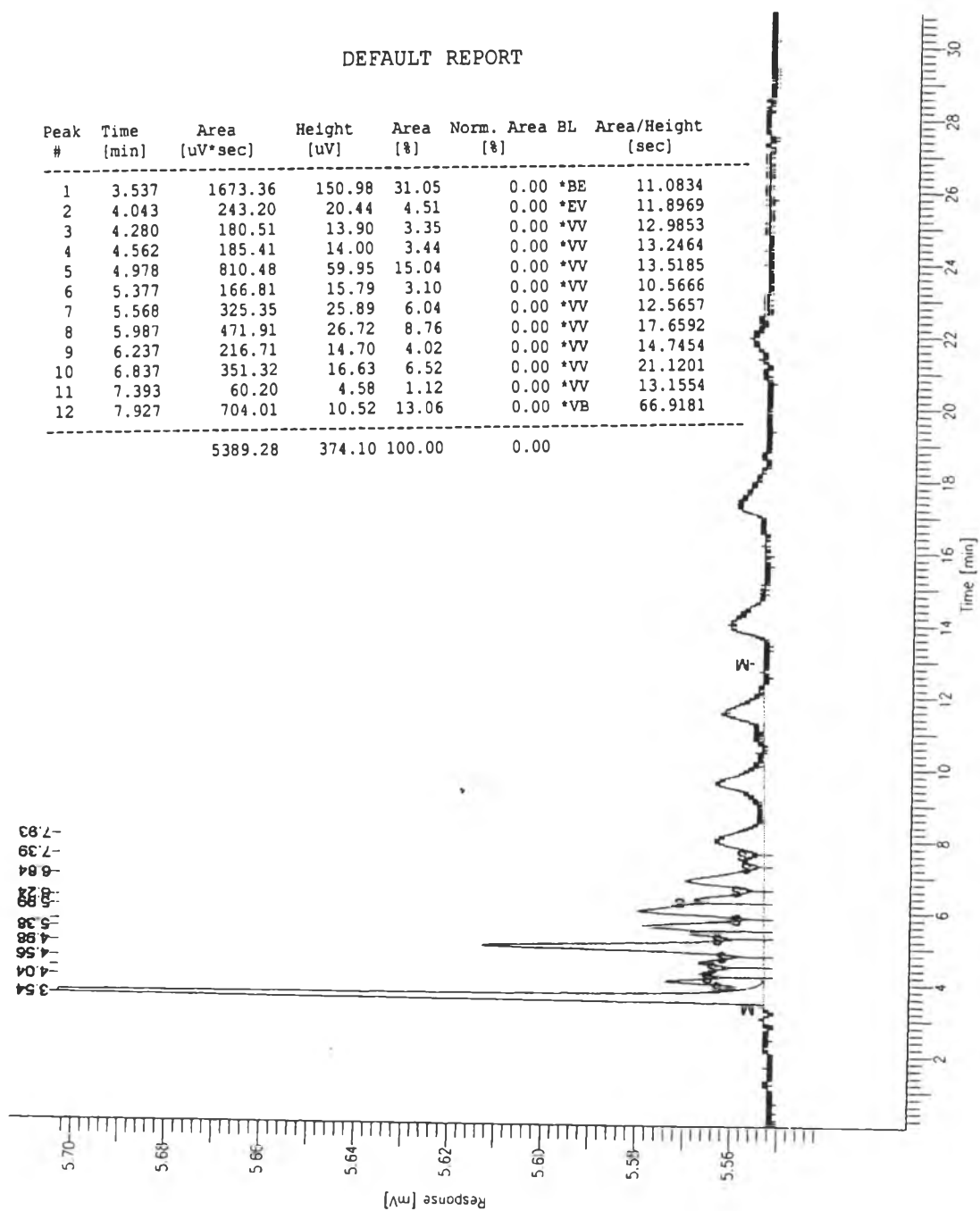
## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	BL	Area/Height [sec]
1	3.550	1572.40	146.00	30.64	0.00	*BV	10.7699
2	4.055	335.00	31.12	6.53	0.00	*VV	10.7631
3	4.230	265.40	18.00	5.17	0.00	*VV	14.7444
4	4.570	240.80	16.00	4.69	0.00	*VV	15.0500
5	5.012	936.80	74.12	18.26	0.00	*VV	12.6381
6	5.480	130.60	16.00	2.55	0.00	*VV	8.1625
7	5.642	400.20	29.12	7.80	0.00	*VV	13.7408
8	6.165	431.20	24.12	8.40	0.00	*VV	17.8736
9	6.367	238.00	16.00	4.64	0.00	*VV	14.8750
10	7.055	285.40	14.12	5.56	0.00	*VV	20.2053
11	7.623	58.20	4.00	1.13	0.00	*VV	14.5500
12	8.200	237.40	8.00	4.63	0.00	*VB	29.6750
		5131.40	396.62	100.00	0.00		



**Figure B10** CCO experimental no.1.

Condition: 6:1 methanol:oil, 200 °C, 50 bars, 350 rpm



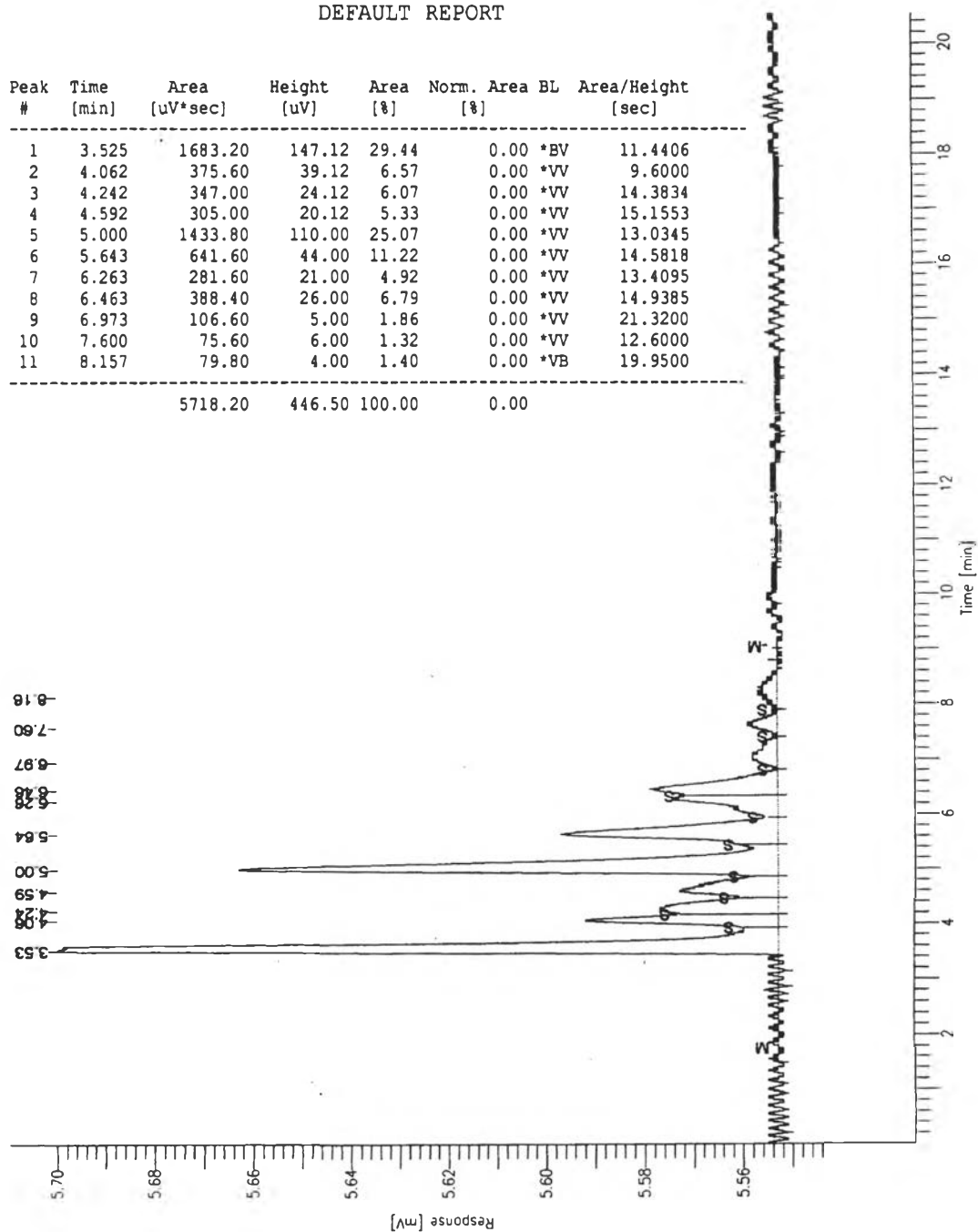
**Figure B11** CCO experiment no.2.

Condition: 6:1 methanol:oil, 3 wt% of  $ZrO_2$ , 200 °C, 50 bars, 350 rpm



## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	BL	Area/Height [sec]
1	3.525	1683.20	147.12	29.44	0.00	*BV	11.4406
2	4.062	375.60	39.12	6.57	0.00	*VV	9.6000
3	4.242	347.00	24.12	6.07	0.00	*VV	14.3834
4	4.592	305.00	20.12	5.33	0.00	*VV	15.1553
5	5.000	1433.80	110.00	25.07	0.00	*VV	13.0345
6	5.643	641.60	44.00	11.22	0.00	*VV	14.5818
7	6.263	281.60	21.00	4.92	0.00	*VV	13.4095
8	6.463	388.40	26.00	6.79	0.00	*VV	14.9385
9	6.973	106.60	5.00	1.86	0.00	*VV	21.3200
10	7.600	75.60	6.00	1.32	0.00	*VV	12.6000
11	8.157	79.80	4.00	1.40	0.00	*VB	19.9500
		5718.20	446.50	100.00	0.00		

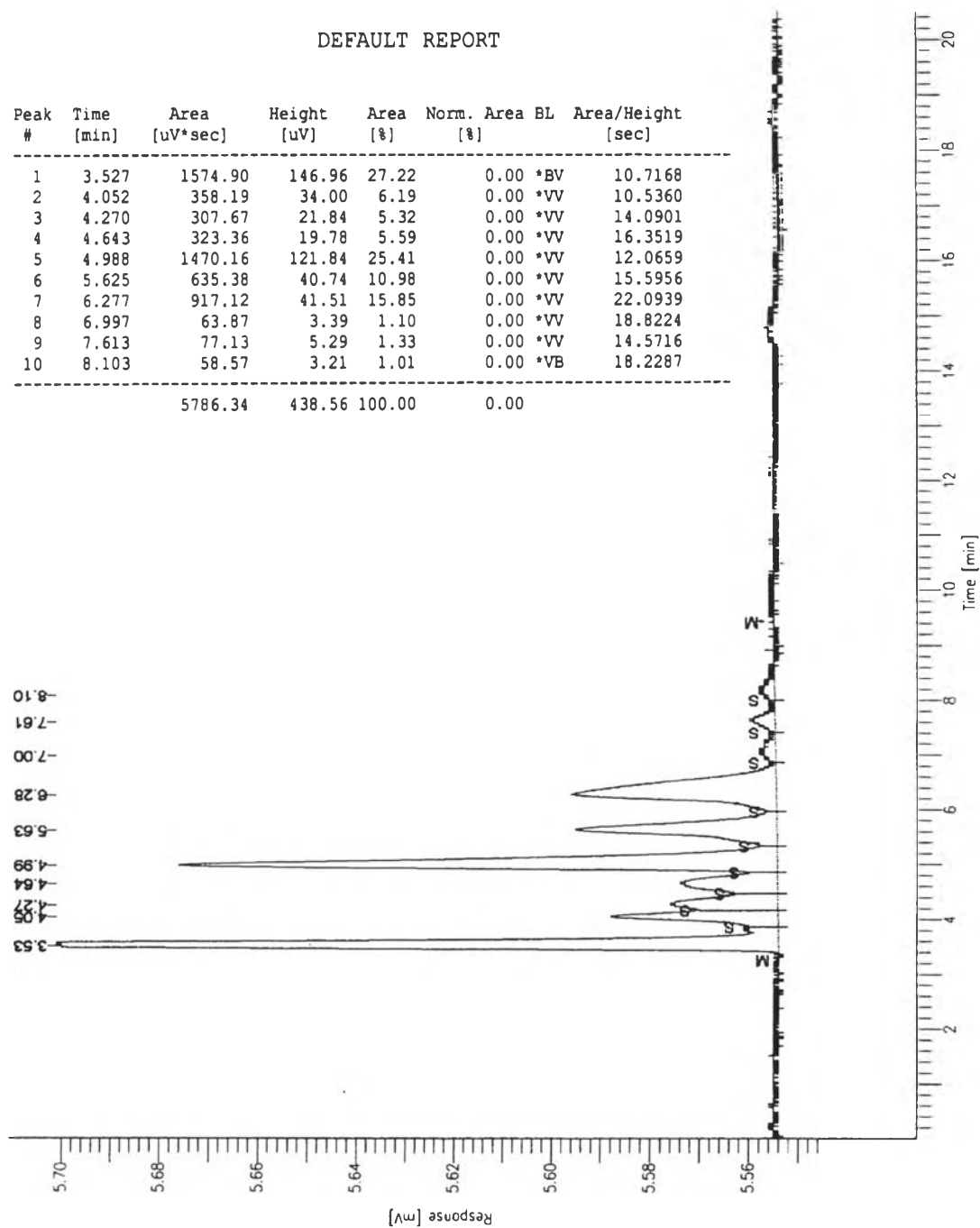


**Figure B12** PKO experiment no.3.

Condition: 6:1 methanol:oil, 3 wt% of ZnO, 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.527	1574.90	146.96	27.22	0.00	*BV	10.7168
2	4.052	358.19	34.00	6.19	0.00	*VV	10.5360
3	4.270	307.67	21.84	5.32	0.00	*VV	14.0901
4	4.643	323.36	19.78	5.59	0.00	*VV	16.3519
5	4.988	1470.16	121.84	25.41	0.00	*VV	12.0659
6	5.625	635.38	40.74	10.98	0.00	*VV	15.5956
7	6.277	917.12	41.51	15.85	0.00	*VV	22.0939
8	6.997	63.87	3.39	1.10	0.00	*VV	18.8224
9	7.613	77.13	5.29	1.33	0.00	*VV	14.5716
10	8.103	58.57	3.21	1.01	0.00	*VB	18.2287
		5786.34	438.56	100.00	0.00		

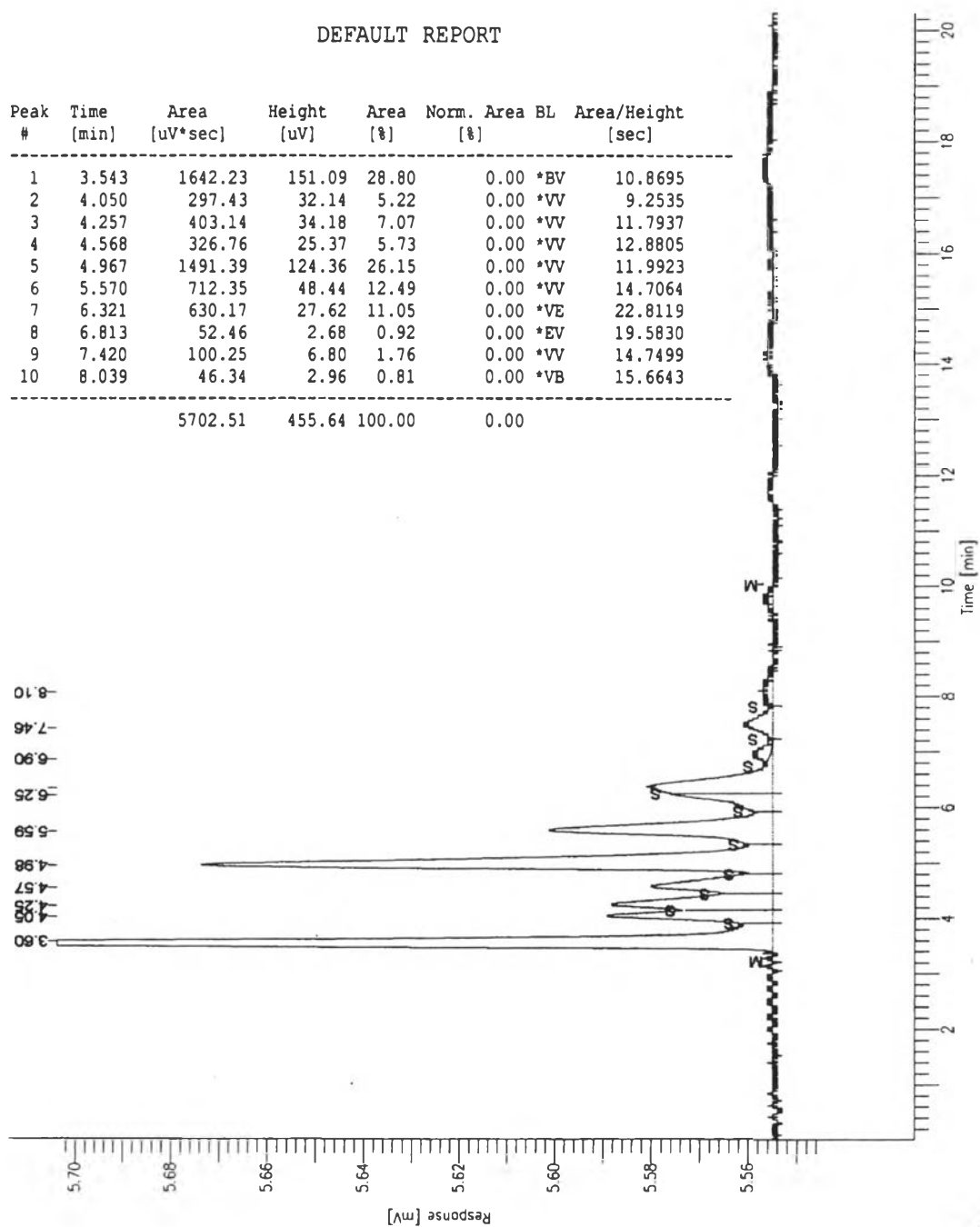


**Figure B13** CCO experiment no.4.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{SO}_4^{2-}/\text{SnO}_2$ , 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.543	1642.23	151.09	28.80	0.00	*BV	10.8695
2	4.050	297.43	32.14	5.22	0.00	*VV	9.2535
3	4.257	403.14	34.18	7.07	0.00	*VV	11.7937
4	4.568	326.76	25.37	5.73	0.00	*VV	12.8805
5	4.967	1491.39	124.36	26.15	0.00	*VV	11.9923
6	5.570	712.35	48.44	12.49	0.00	*VV	14.7064
7	6.321	630.17	27.62	11.05	0.00	*VE	22.8119
8	6.813	52.46	2.68	0.92	0.00	*EV	19.5830
9	7.420	100.25	6.80	1.76	0.00	*VV	14.7499
10	8.039	46.34	2.96	0.81	0.00	*VB	15.6643
		5702.51	455.64	100.00	0.00		

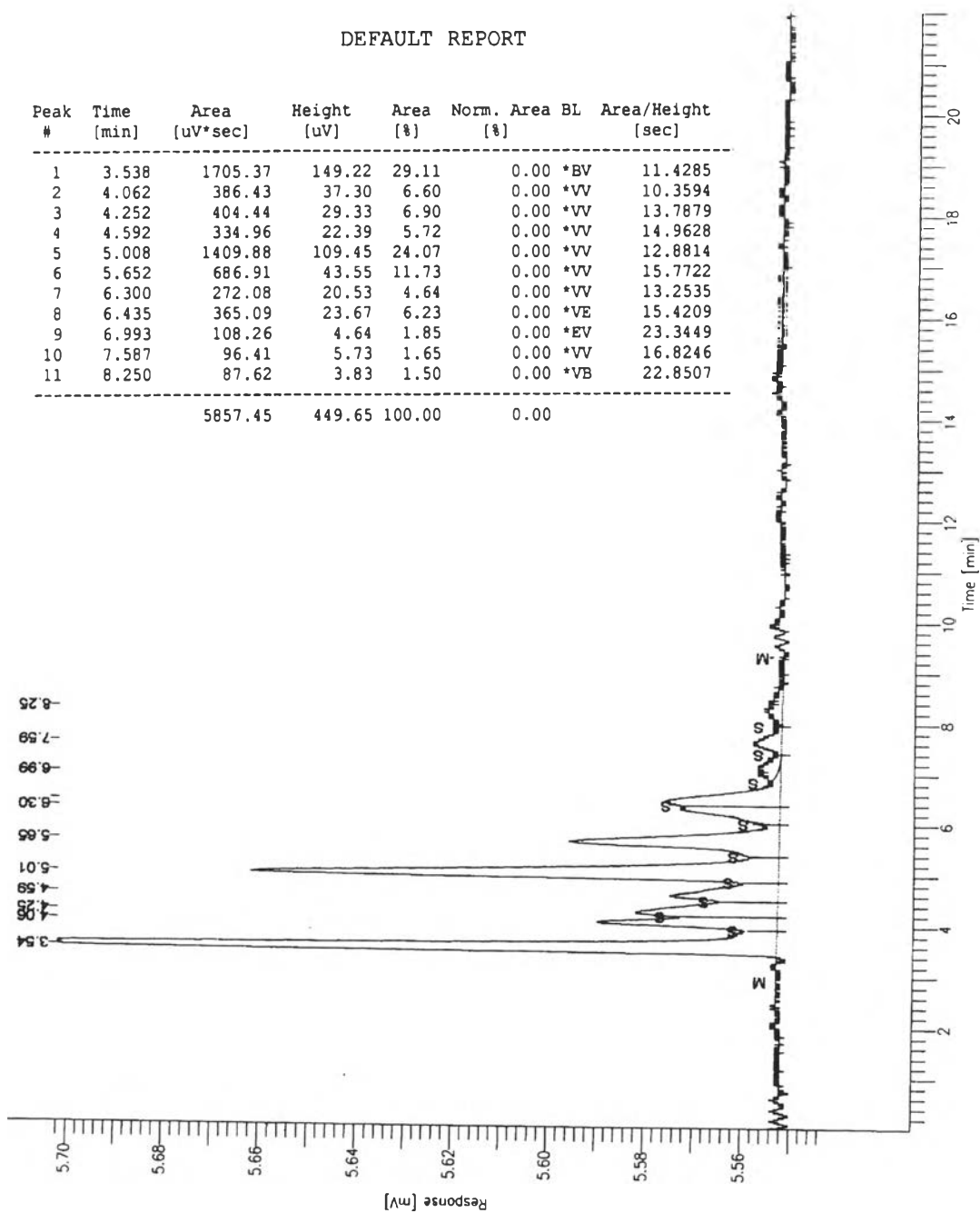


**Figure B14** CCO experiment no.5

Condition: 6:1 methanol:oil, 3 wt% of  $\text{SO}_4^{2-}/\text{ZrO}_2$ , 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [uV*sec]	Height [uV]	Area [%]	Norm. Area [%]	Area BL	Area/Height [sec]
1	3.538	1705.37	149.22	29.11	0.00	*BV	11.4285
2	4.062	386.43	37.30	6.60	0.00	*VV	10.3594
3	4.252	404.44	29.33	6.90	0.00	*VV	13.7879
4	4.592	334.96	22.39	5.72	0.00	*VV	14.9628
5	5.008	1409.88	109.45	24.07	0.00	*VV	12.8814
6	5.652	686.91	43.55	11.73	0.00	*VV	15.7722
7	6.300	272.08	20.53	4.64	0.00	*VV	13.2535
8	6.435	365.09	23.67	6.23	0.00	*VE	15.4209
9	6.993	108.26	4.64	1.85	0.00	*EV	23.3449
10	7.587	96.41	5.73	1.65	0.00	*VV	16.8246
11	8.250	87.62	3.83	1.50	0.00	*VB	22.8507
		5857.45	449.65	100.00	0.00		

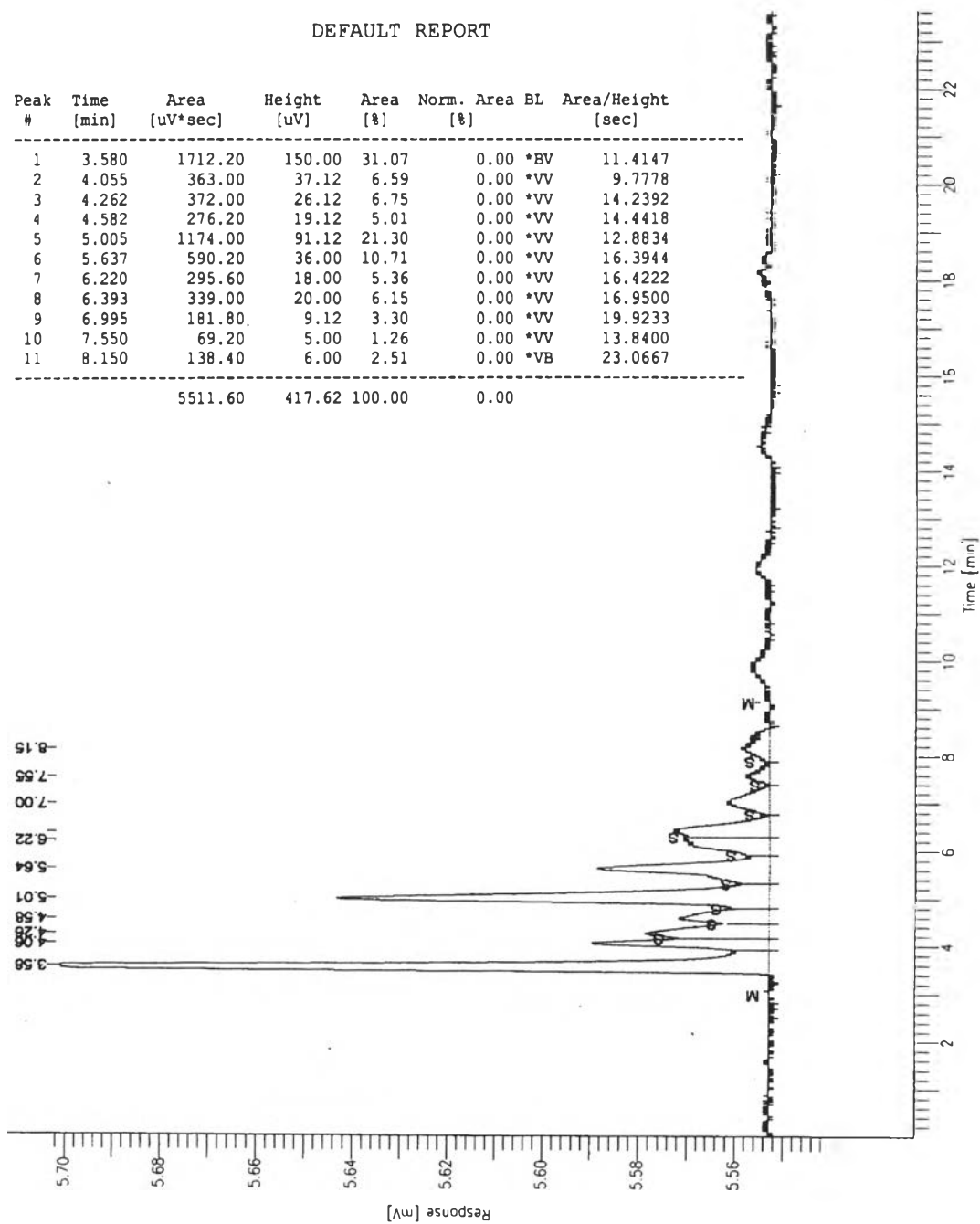


**Figure B15** CCO experiment no.6.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{KNO}_3/\text{KLzeolite}$ , 200 °C, 50 bars, 350 rpm

## DEFAULT REPORT

Peak #	Time [min]	Area [ $\mu\text{V}\cdot\text{sec}$ ]	Height [ $\mu\text{V}$ ]	Area [%]	Norm. Area [%]	BL	Area/Height [sec]
1	3.580	1712.20	150.00	31.07	0.00	*BV	11.4147
2	4.055	363.00	37.12	6.59	0.00	*VV	9.7778
3	4.262	372.00	26.12	6.75	0.00	*VV	14.2392
4	4.582	276.20	19.12	5.01	0.00	*VV	14.4418
5	5.005	1174.00	91.12	21.30	0.00	*VV	12.8834
6	5.637	590.20	36.00	10.71	0.00	*VV	16.3944
7	6.220	295.60	18.00	5.36	0.00	*VV	16.4222
8	6.393	339.00	20.00	6.15	0.00	*VV	16.9500
9	6.995	181.80	9.12	3.30	0.00	*VV	19.9233
10	7.550	69.20	5.00	1.26	0.00	*VV	13.8400
11	8.150	138.40	6.00	2.51	0.00	*VB	23.0667
		5511.60	417.62	100.00	0.00		



**Figure B16** CCO experiment no.7.

Condition: 6:1 methanol:oil, 3 wt% of  $\text{KNO}_3/\text{ZrO}_2$ , 200 °C, 50 bars, 350 rpm

**Appendix C Raw data for heterogeneous catalytic transesterification.**

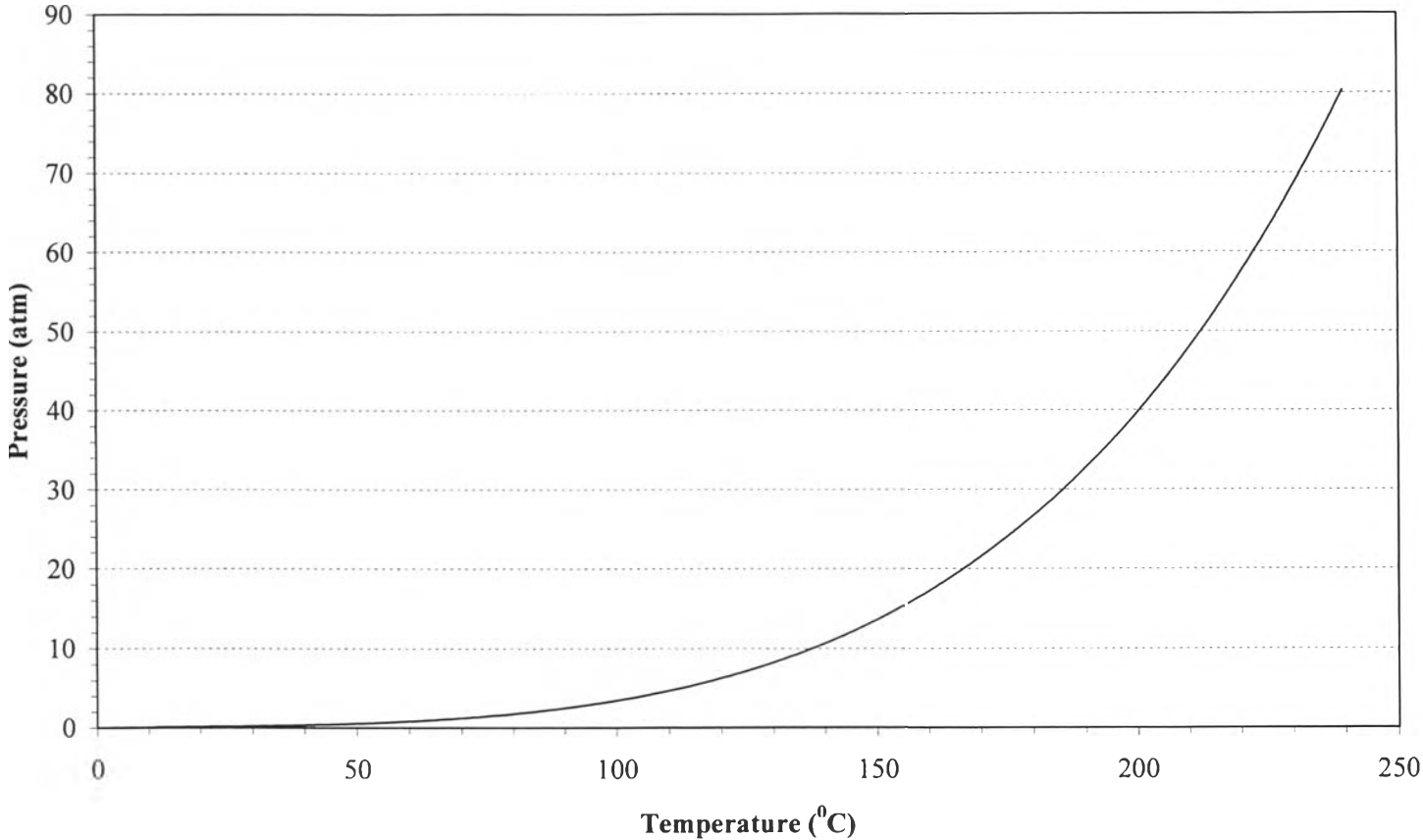
**Table C1** Crude palm kernel oil transesterification

Experiment No.	Catalyst	Wt. Oil (g)	Wt. Methanol (g)	Wt. Catalyst (g)	Wt. product (g)	M.E. Content (wt%)	M.E. Yield (wt%)
1	None	70.02	18.99	-	63.79	32.3	30.4
2	ZrO <sub>2</sub>	70.05	18.99	2.10	65.47	69.0	64.5
3	ZnO	70.09	19.04	2.11	61.07	98.9	86.1
4	SO <sub>4</sub> <sup>2-</sup> /SnO <sub>2</sub>	70.09	18.99	2.10	66.35	95.4	90.3
5	SO <sub>4</sub> <sup>2-</sup> /ZrO <sub>2</sub>	70.02	19.01	2.10	66.04	95.8	90.3
6	KNO <sub>3</sub> /KLzeolite	70.01	18.99	2.10	64.26	77.8	71.4
7	KNO <sub>3</sub> /ZrO <sub>2</sub>	70.02	19.02	2.10	66.55	78.3	74.4

**Table C2** Crude coconut oil transesterification

Experiment No.	Catalyst	Wt. Oil (g)	Wt. Methanol (g)	Wt. Catalyst (g)	Wt. product (g)	M.E. Content (%)	Conversion (%)
1	None	70.06	19.91	-	66.33	42.9	41.0
2	ZrO <sub>2</sub>	70.01	19.68	2.11	62.5	54.3	49.3
3	ZnO	70.01	19.80	2.10	65.23	83.2	77.5
4	SO <sub>4</sub> <sup>2-</sup> /SnO <sub>2</sub>	70.08	19.68	2.10	63.99	88.3	80.6
5	SO <sub>4</sub> <sup>2-</sup> /ZrO <sub>2</sub>	70.09	19.70	2.10	65.04	93.0	86.3
6	KNO <sub>3</sub> /KLzeolite	70.04	19.78	2.10	65.71	82.3	77.2
7	KNO <sub>3</sub> /ZrO <sub>2</sub>	70.01	19.70	2.10	64.89	70.7	65.5

**Appendix D Temperature – vapor pressure curve of methanol.**





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