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APPENDIX A

Table A.1 Tensile strength of commercial ABS and ABS blends with fire retardants.

Composition	Specimen	Width (mm)	Thick (mm)	Tensile strength (kgf/cm ²)
Commercial ABS	1	12.84	3.10	486.6
	2	12.82	3.10	485.9
	3	12.85	3.15	485.2
	Mean	12.84	3.12	485.9
	S.D.	-	-	0.7
ABS with 20% BTBPE + 4% ZHS + 5% CPE	1	12.86	3.10	510.2
	2	12.86	3.12	512.2
	3	12.84	3.10	503.9
	Mean	12.85	3.11	508.8
	S.D.	-	-	4.3
ABS with 20% BTBPE + 6% ZHS + 3% CPE	1	12.86	3.10	494.2
	2	12.85	3.10	496.8
	3	12.85	3.12	490.7
	Mean	12.85	3.11	493.9
	S.D.	-	-	3.1
ABS with 20% BTBPE + 6% ZHS + 5% CPE	1	12.85	3.10	497.3
	2	12.85	3.12	502.1
	3	12.87	3.12	502.4
	Mean	12.86	3.11	500.6
	S.D.	-	-	2.9

Table A.1 (Continued)

Composition	Specimen	Width (mm)	Thick (mm)	Tensile strength (kgf/cm ²)
ABS with 20% BTBPE + 4% ZS + 5% CPE	1	12.89	3.09	502.2
	2	12.86	3.10	505.3
	3	12.87	3.10	509.9
	Mean	12.87	3.10	505.8
	S.D.	-	-	3.9
ABS with 20% BTBPE + 6% ZS + 3% CPE	1	12.87	3.08	505.4
	2	12.86	3.10	500.9
	3	12.86	3.10	505.8
	Mean	12.86	3.09	504.0
	S.D.	-	-	2.7
ABS with 20% BTBPE + 6% ZS + 5% CPE	1	12.85	3.10	489.2
	2	12.87	3.11	486.5
	3	12.85	3.10	501.3
	Mean	12.86	3.10	492.3
	S.D.	-	-	7.9

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Table A.2 Impact resistance of commercial ABS and ABS blends with fire retardants.

Composition	Specimen	Width (mm)	Swing up angle (β)	Impact strength (kgf-cm/cm ²)
Commercial ABS	1	3.18	120.6	9.53
	2	3.18	120.6	9.53
	3	3.18	120.8	9.36
	Mean	3.18	120.7	9.47
	S.D.	-	-	0.1
ABS with 20% BTBPE + 4% ZHS + 5% CPE	1	3.18	119.8	10.20
	2	3.18	119.4	10.53
	3	3.18	120.0	10.03
	Mean	3.18	119.7	10.25
	S.D.	-	-	0.4
ABS with 20% BTBPE + 6% ZHS + 3% CPE	1	3.18	120.4	9.69
	2	3.18	120.2	9.86
	3	3.18	120.2	9.86
	Mean	3.18	120.3	9.80
	S.D.	-	-	0.1
ABS with 20% BTBPE + 6% ZHS + 5% CPE	1	3.18	120.2	10.02
	2	3.18	120.2	10.02
	3	3.17	120.2	10.06
	Mean	3.18	120.2	10.03
	S.D.	-	-	0.3

Table A.2 (Continued)

Composition	Specimen	Width (mm)	Swing up angle (β)	Impact strength (kgf-cm/cm ²)
ABS with 20% BTBPE + 4% ZS + 5% CPE	1	3.18	119.2	10.70
	2	3.18	119.0	10.86
	3	3.18	119.4	10.52
	Mean	3.18	119.2	10.69
	S.D.	-	-	0.2
ABS with 20% BTBPE + 6% ZS + 3% CPE	1	3.18	120.6	9.53
	2	3.17	120.5	9.63
	3	3.17	120.6	9.56
	Mean	3.17	120.6	9.57
	S.D.	-	-	0.1
ABS with 20% BTBPE + 6% ZS + 5% CPE	1	3.18	119.8	10.20
	2	3.18	119.9	10.13
	3	3.18	120.0	10.03
	Mean	3.18	119.9	10.12
	S.D.	-	-	0.1

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Table A.3 Hardness (R-scale) of commercial ABS and ABS blends with fire retardants.

Composition	Specimen	C	L	R	Hardness	
Commercial ABS	1	94.0	94.6	94.6	94.4	
	2	94.2	94.5	94.3	94.3	
	3	94.5	94.8	94.4	94.6	
					Mean	94.4
					S.D.	0.12
ABS with 20% BTBPE + 4% ZHS + 5% CPE	1	95.9	96.1	96.2	96.4	
	2	96.1	96.0	96.3	96.1	
	3	96.0	96.0	96.3	96.1	
					Mean	96.2
					S.D.	0.17
ABS with 20% BTBPE + 6% ZHS + 3% CPE	1	98.3	98.5	98.5	98.4	
	2	98.6	98.8	98.8	98.7	
	3	98.6	98.7	98.9	98.7	
					Mean	98.6
					S.D.	0.17
ABS with 20% BTBPE + 6% ZHS + 5% CPE	1	96.6	96.5	96.6	96.6	
	2	96.6	96.6	96.3	96.5	
	3	96.4	96.6	96.8	96.6	
					Mean	96.6
					S.D.	0.05

Table A.3 (Continued)

Composition	Specimen	C	L	R	Hardness	
ABS with 20% BTBPE + 4% ZS + 5% CPE	1	96.5	96.9	96.7	96.7	
	2	96.6	97.0	96.4	96.7	
	3	96.6	97.0	96.9	96.8	
					Mean	96.7
					S.D.	0.09
ABS with 20% BTBPE + 6% ZS + 3% CPE	1	99.2	98.8	99.2	99.1	
	2	99.3	99.5	99.5	99.4	
	3	99.3	99.6	99.5	99.5	
					Mean	99.3
					S.D.	0.22
ABS with 20% BTBPE + 6% ZS + 5% CPE	1	97.4	97.4	97.6	97.5	
	2	97.2	97.6	97.6	97.5	
	3	97.4	97.4	97.3	97.4	
					Mean	97.4
					S.D.	0.06

Remark : C = Central

L = Left

R = Right

Table A.4 Heat distortion temperature of commercial ABS and ABS blends with fire retardants.

Composition	Specimen	Temp (°)	Mean	S.D.
Commercial ABS	1	75.4	75.2	2.8
	2	75.8		
	3	74.5		
ABS with 20% BTBPE + 4% ZHS + 5% CPE	1	75.3	74.4	0.8
	2	73.7		
	3	74.1		
ABS with 20% BTBPE + 6% ZHS + 3% CPE	1	74.4	74.2	0.2
	2	74.3		
	3	74.0		
ABS with 20% BTBPE + 6% ZHS + 5% CPE	1	73.8	73.8	0.1
	2	73.8		
	3	73.9		
ABS with 20% BTBPE + 4% ZS + 5% CPE	1	74.3	73.8	0.4
	2	73.6		
	3	73.5		
ABS with 20% BTBPE + 6% ZS + 3% CPE	1	74.5	74.2	2.0
	2	74.6		
	3	73.6		
ABS with 20% BTBPE + 6% ZS + 5% CPE	1	74.2	73.8	0.4
	2	73.8		
	3	73.4		

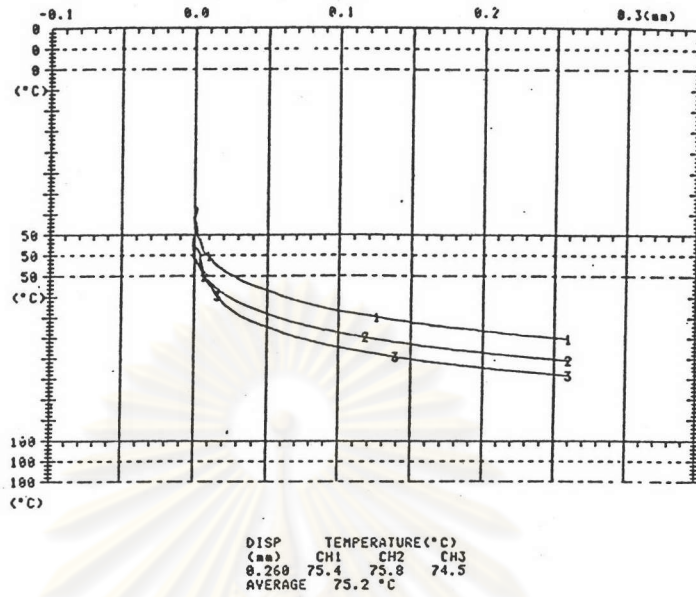


Figure A.1 HDT of commercial ABS

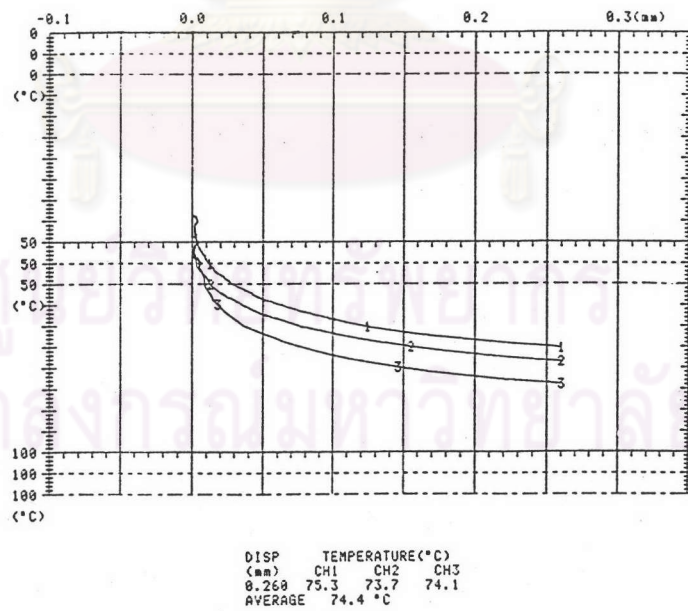


Figure A.2 HDT of ABS with 20% BTBPE, 4% ZHS and 5% CPE

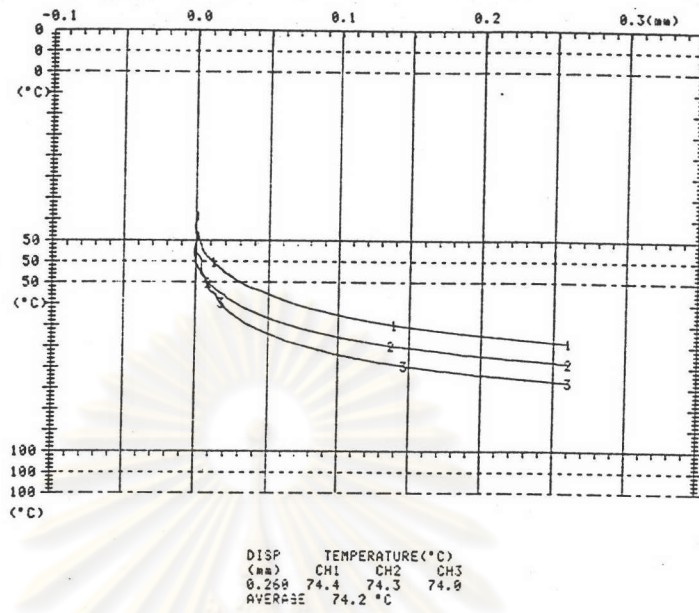


Figure A.3 HDT of ABS with 20% BTBPE, 6% ZHS and 3% CPE

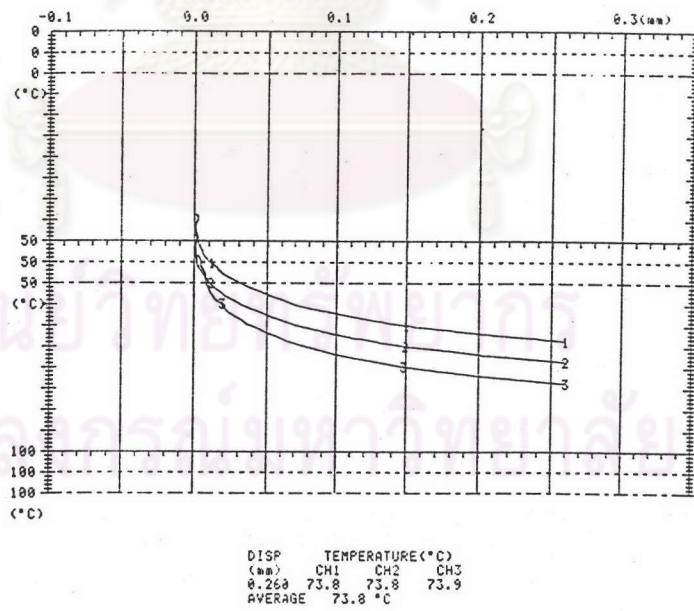


Figure A.4 HDT of ABS with 20% BTBPE, 6% ZHS and 5% CPE

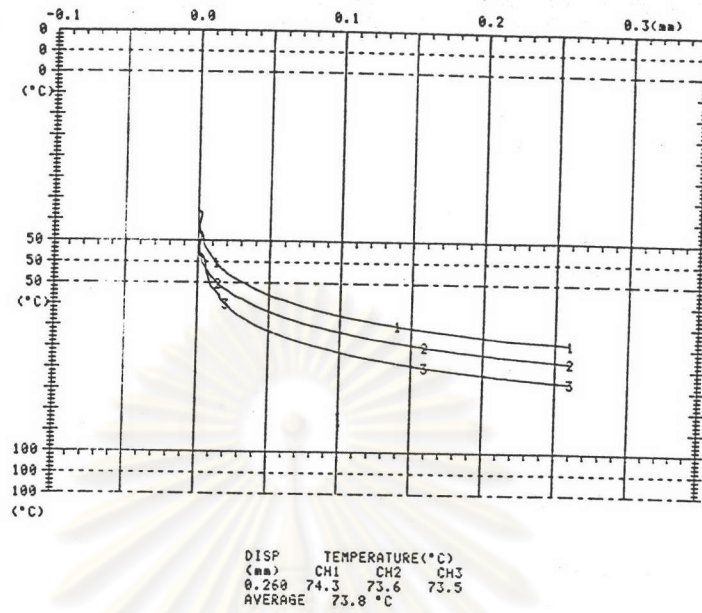


Figure A.5 HDT of ABS with 20% BTBPE, 4% ZS and 5% CPE

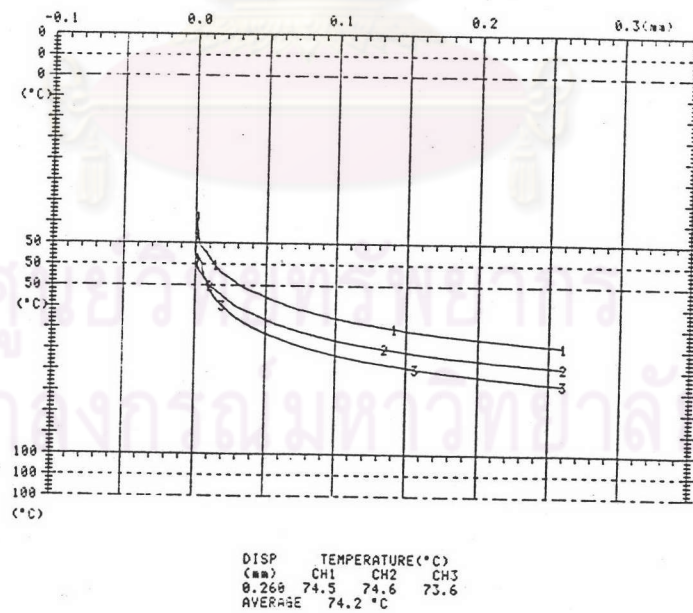


Figure A.6 HDT of ABS with 20% BTBPE, 6% ZS and 3% CPE

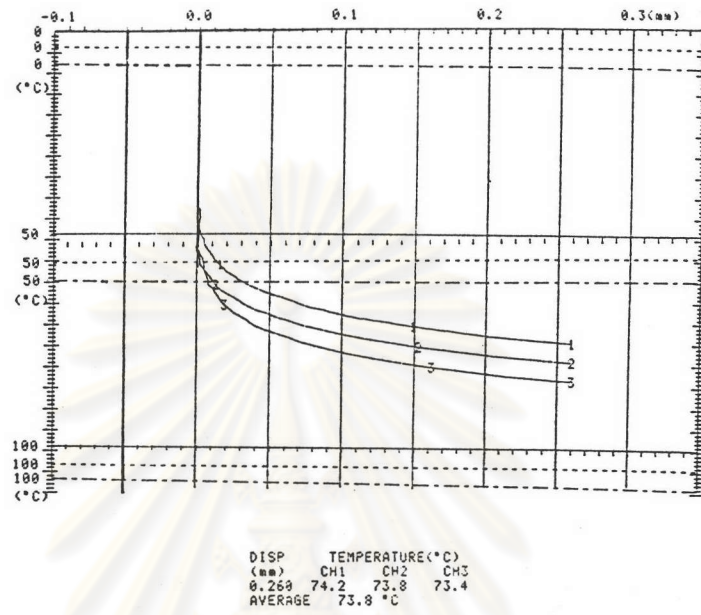


Figure A.7 HDT of ABS with 20% BTBPE, 6% ZS and 5% CPE

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APPENDIX B

Calculation the percent of elements in residues

Table B.1 Determination of Sn from sample

- ABS with 18% BTBPE and 4% ZHS

- ABS with 18% BTBPE and 4% ZS

additive	Std Sn			ZHS			ZS		
	1	2	3	1	2	3	1	2	3
no.									
weight (g)	0.0050	0.0050	0.0051	0.0644	0.0609	0.0621	0.0638	0.0652	0.0607
area	1263	551	1175	3304	1334	3546	2311	1072	2477
time at (min)	0	0	0	9.15	9.45	9.30	4.45	4.45	4.45
% Sn	-	-	-	3.76	3.81	4.67	1.91	1.99	2.36
char yield				10.61%			9.90%		
platic origin				0.6070			0.6444		
Sn (add)				0.0100			0.0131		
Sn (after)				0.0024			0.0013		
%Sn residue				14.12%			9.16%		

Table B.2 Determination of Sn from sample

- ABS with 18% BTBPE, 4% ZHS and 3% CPE

- ABS with 18% BTBPE, 4% ZS and 3% CPE

additive	Std Sn			ZHS			ZS		
	1	2	3	1	2	3	1	2	3
no.									
weight (g)	0.0052	0.0053	0.0051	0.0600	0.0647	0.0605	0.0606	0.0605	0.0600
area	1532	1432	830	3470	3305	1837	1212	1190	568
time at (min)	0	0	0	4.45	4.45	5.00	10.00	10.00	10.00
% Sn	-	-	-	2.61	2.52	2.53	1.33	1.42	1.14
char yield				16.68%			16.27%		
platic origin				0.3627			0.3725		
Sn (add)				0.0059			0.0076		
Sn (after)				0.0015			0.0008		
%Sn residue				25.93%			10.53%		

Standard Sn

Sample

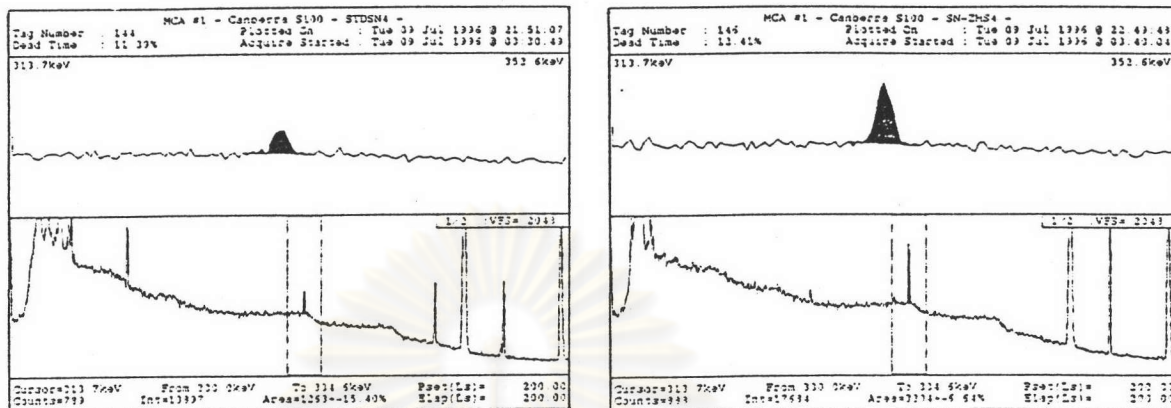


Figure B.1 NAA diagram of Sn element from
ABS sample with 18% BTBPE and 4% ZHS

Standard Sn

Sample

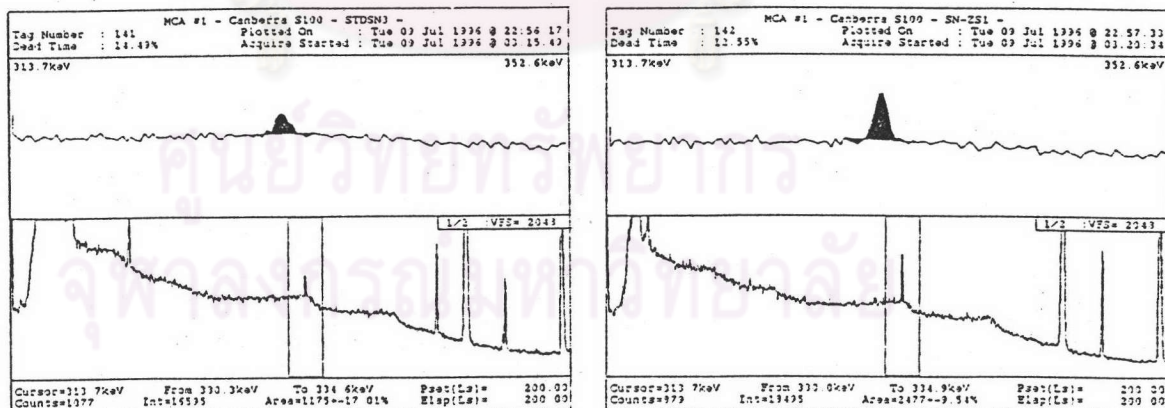


Figure B.2 NAA diagram of Sn element from
ABS sample with 18% BTBPE and 4% ZS

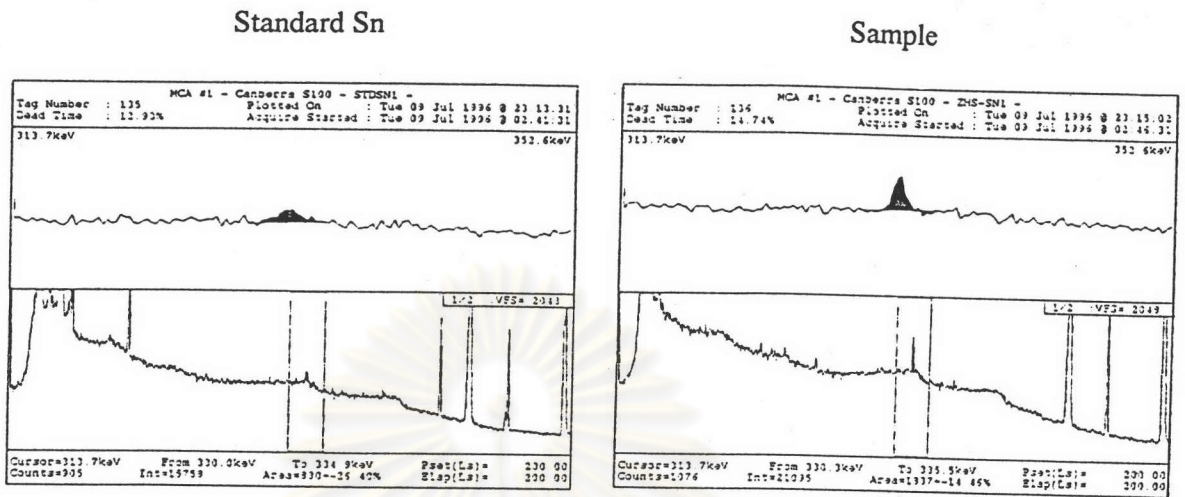


Figure B.3 NAA diagram of Sn element from ABS sample with 18% BTBPE, 4% ZHS and 3% CPE

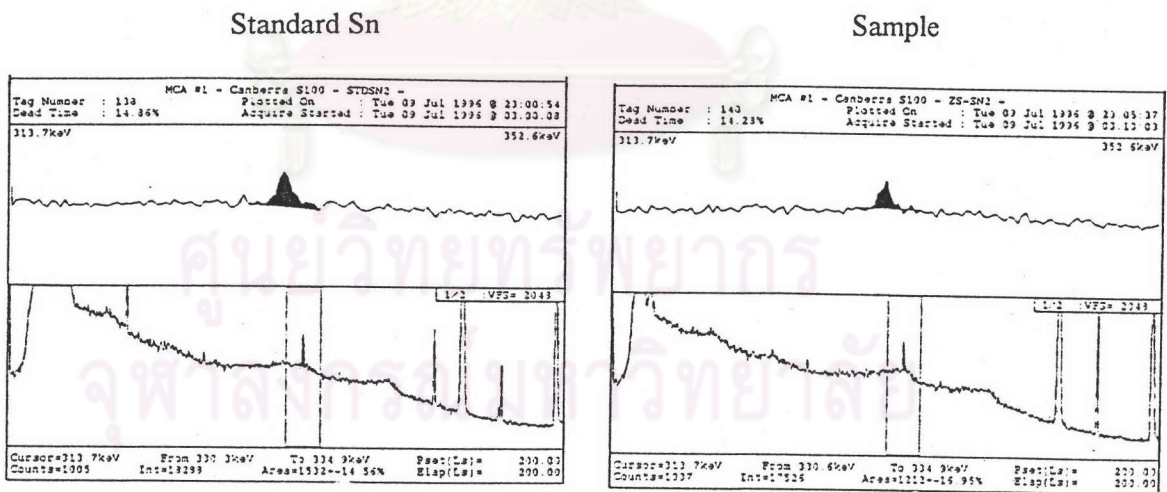


Figure B.4 NAA diagram of Sn element from ABS sample with 18% BTBPE, 4% ZS and 3% CPE

Example of calculation

From sample ABS with 18% BTBPE and 4% ZHS (Table B.1), determination %Sn according to the first time was calculated as follow :

$$A_o = Ae^{0.693T/t_{1/2}} \quad (3.4)$$

$$\begin{aligned} \text{ZHS 1,} \quad A_o &= 3304 e^{0.693 \times 9.25/9.5} \\ &= 6487.63 \end{aligned}$$

From equation 3.5 :

$$\%EX = \frac{C_{ex}}{C_{std}} \times \frac{W_{std}}{W_{ex}} \times \%STD$$

where :

%EX = % Element in sample

%STD = % Element in standard

C_{ex} = Count rate of sample

C_{std} = Count rate of standard

W_{ex} = Weight of sample

W_{std} = Weight of standard

$$\begin{aligned} \text{so that,} \quad \%Sn &= \frac{6487.63}{1263} \times \frac{0.0050}{0.0644} \times 9.42 \% \\ &= 3.76 \% \end{aligned}$$

Table B.3 Determination of Zn from sample

- ABS with 18% BTBPE and 4% ZHS

- ABS with 18% BTBPE and 4% ZS

additive	std ZnO		ZHS		ZS	
	1	2	1	2	1	2
no.						
weight (g)	0.00054	0.00053	0.06330	0.06167	0.05970	0.06040
area	1172	760	5592	3760	6483	4687
time (sec)	120	120	120	120	120	120
% Zn	-	-	3.27	3.42	4.02	4.35
char yield			10.61%		9.90%	
platic origin			0.5966		0.6030	
Zn (add)			0.0055		0.0068	
Zn (after)			0.0021		0.0024	
%Zn residue			38.18%		35.29%	

Table B.4 Determination of Zn from sample

- ABS with 18% BTBPE, 4% ZHS and 3% CPE

- ABS with 18% BTBPE, 4% ZS and 3% CPE

additive	std ZnO		ZHS		ZS	
	1	2	1	2	1	2
no.						
weight (g)	0.00051	0.00057	0.0601	0.0645	0.0615	0.0613
area	1197	816	3792	2983	5553	3735
time (sec)	120	120	120	120	120	120
% Zn	-	-	2.16	2.60	3.09	3.42
char yield			16.68%		16.27%	
platic origin			0.3868		0.3780	
Zn (add)			0.0036		0.0042	
Zn (after)			0.0017		0.0019	
%Zn residue			47.22%		45.24%	

Standard ZnO

Sample

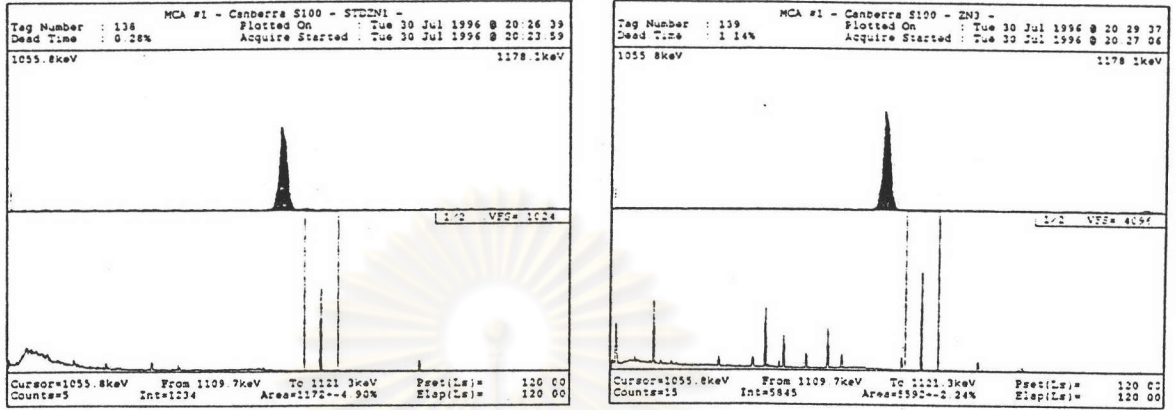


Figure B.5 NAA diagram of Zn element from ABS sample with 18% BTBPE and 4% ZHS

Standard ZnO

Sample

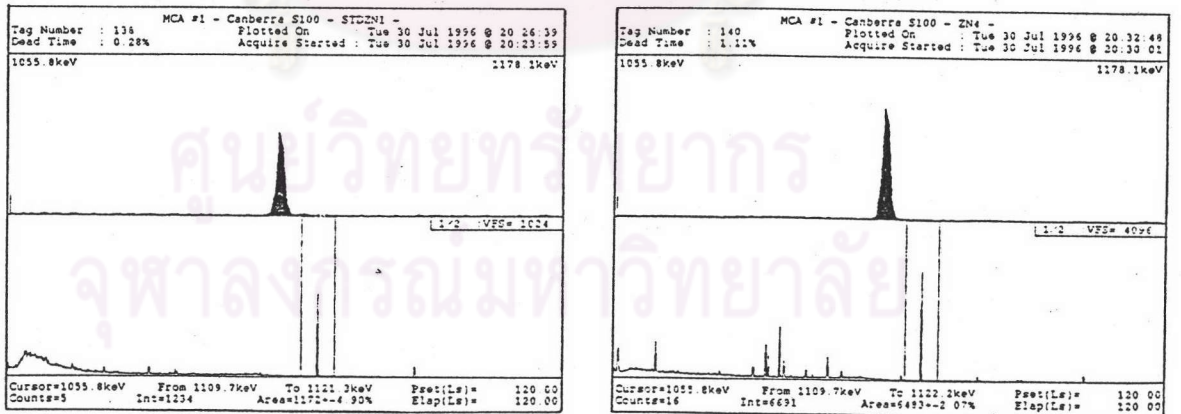


Figure B.6 NAA diagram of Zn element from ABS sample with 18% BTBPE and 4% ZS

Standard ZnO

Sample

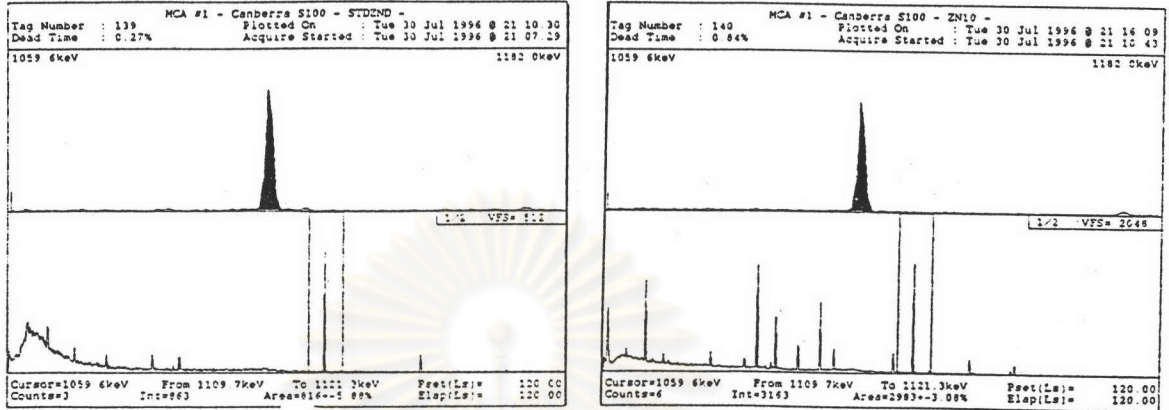


Figure B.7 NAA diagram of Zn element from ABS sample with 18% BTBPE, 4% ZHS and 3% CPE

Standard ZnO

Sample

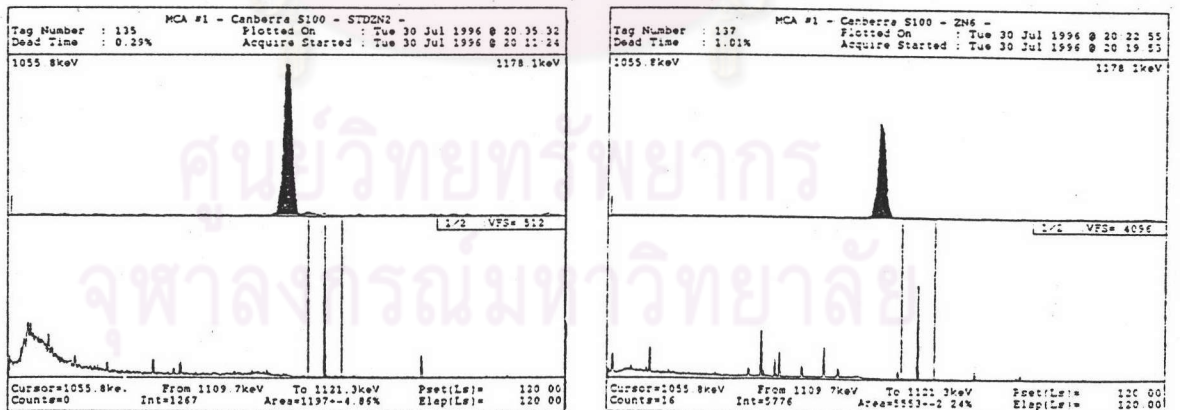


Figure B.8 NAA diagram of Zn element from ABS sample with 18% BTBPE, 4% ZS and 3% CPE

Table B.5 Determination of Br from sample

- ABS with 18% BTBPE and 4% ZHS

- ABS with 18% BTBPE and 4% ZS

additive	Std NH ₄ Br			ZHS			ZS		
	1	2	3	1	2	3	1	2	3
no.									
weight (g)	0.0061	0.0051	0.0057	0.0644	0.0609	0.0621	0.0638	0.0652	0.0607
area	13830	14970	14173	23365	28114	26148	16455	25585	21469
% Br	-	-	-	13.06	12.83	13.82	9.28	10.91	11.60
char yield				10.61%			9.90%		
platic origin				0.6070			0.6586		
Br (add)				0.0765			0.0830		
Br (after)				0.0084			0.0071		
%Br residue				10.98%			8.55%		

Table B.6 Determination of Br from sample

- ABS with 18% BTBPE, 4% ZHS and 3% CPE

- ABS with 18% BTBPE, 4% ZS and 3% CPE

additive	Std NH ₄ Br			ZHS + Cl			ZS + Cl		
	1	2	3	1	2	3	1	2	3
no.									
weight (g)	0.0053	0.0054	0.0050	0.0600	0.0647	0.0605	0.0606	0.0605	0.0600
area	14307	13084	13495	28596	27289	28043	27562	21534	23161
% Br	-	-	-	14.40	14.20	14.01	13.75	11.98	11.67
char yield				16.68%			16.27%		
platic origin				0.3879			0.3719		
Br (add)				0.0489			0.0469		
Br (after)				0.0092			0.0072		
%Br residue				18.79%			15.35%		

Standard NH₄Br

Sample

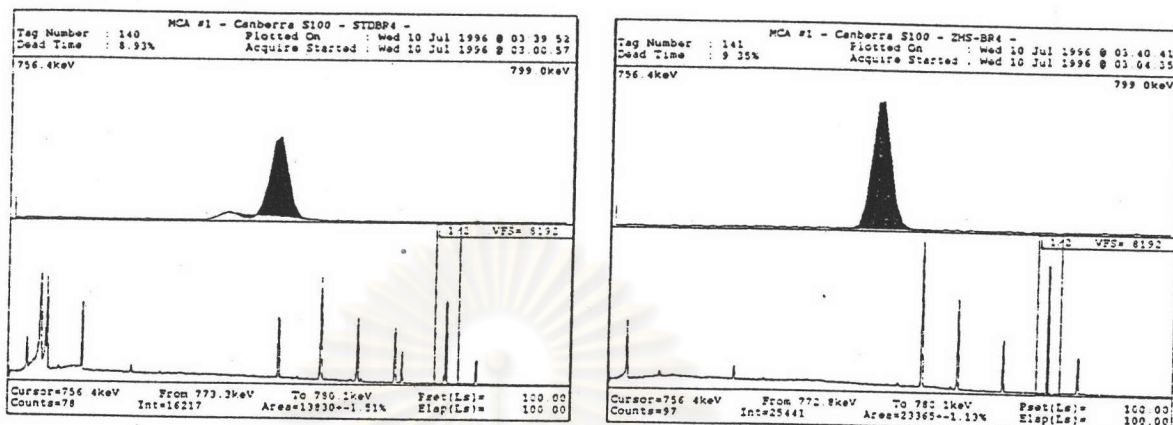


Figure B.9 NAA diagram of Br element from
ABS sampl with 18% BTBPE and 4% ZHS

Standard NH₄Br

Sample

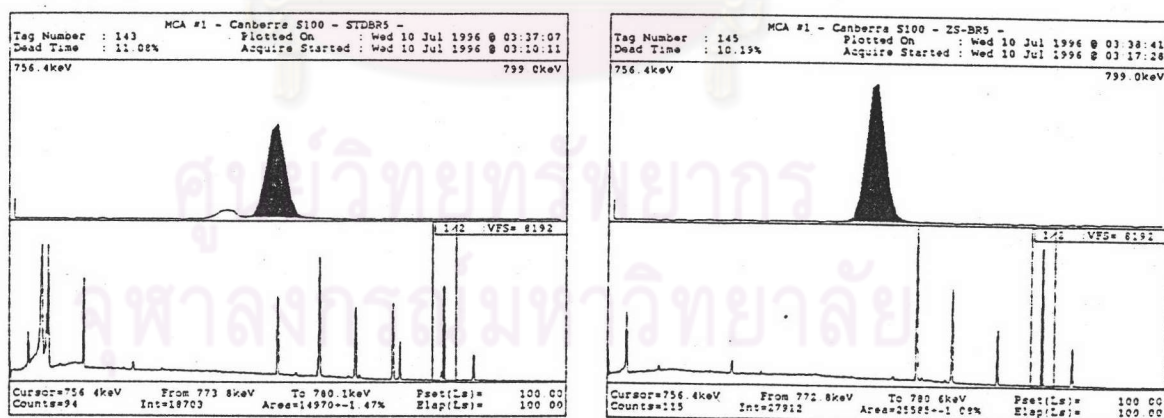


Figure B.10 NAA diagram of Br element from
ABS sample with 18% BTBPE and 4% ZS

Standard NH_4Br

Sample

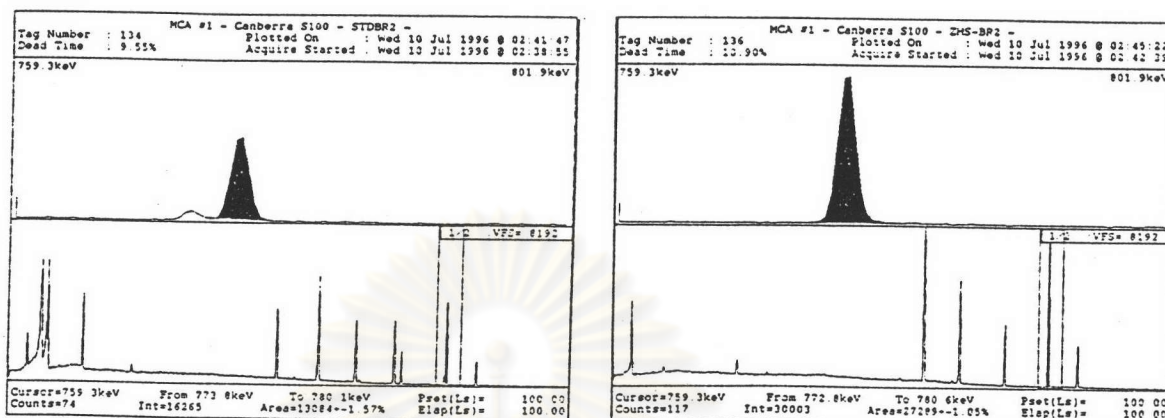


Figure B.11 NAA diagram of Br element from ABS sample with 18% BTBPE, 4% ZHS and 3% CPE

Standard NH_4Br

Sample

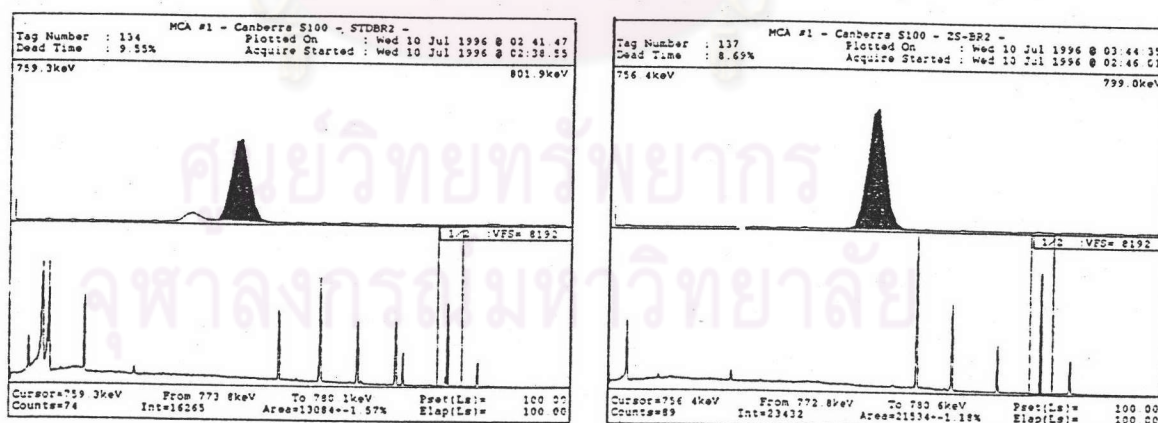


Figure B.12 NAA diagram of Br element from ABS sample with 18% BTBPE, 4% ZS and 3% CPE

Table B.7 Determination of Br from sample- ABS with 18% BTBPE and 4% Sb_2O_3 - ABS with 18% BTBPE, 4% Sb_2O_3 and 3% CPE

additive	Std. NH_4Br		Sb_2O_3		$\text{Sb}_2\text{O}_3 + \text{Cl}$	
	1	2	1	2	1	2
no.						
weight (g)	0.00500	0.00521	0.0508	0.0505	0.0508	0.0512
area	27958	25985	7835	7253	10781	10743
% Br	-	-	2.25	2.10	3.47	3.43
char yield			6.64%		11.47%	
platic origin			0.7651		0.4429	
Br (add)			0.0964		0.0558	
Br (after)			0.0011		0.0018	
%Br residue			1.14%		3.22%	

Table B.8 Determination of Sb from sample- ABS with 18% BTBPE and 4% Sb_2O_3 - ABS with 18% BTBPE, 4% Sb_2O_3 and 3% CPE

additive	Std. Sb_2O_4		Sb_2O_3		$\text{Sb}_2\text{O}_3 + \text{Cl}$	
	1	2	1	2	1	2
no.						
weight (g)	0.00379	0.00383	0.0508	0.0505	0.0508	0.0512
area	54053	45329	120584	95615	53395	50170
% Sb	-	-	13.18	10.51	7.03	6.56
char yield			6.64%		11.47%	
platic origin			0.7651		0.4429	
Sb (add)			0.0256		0.0148	
Sb (after)			0.0067		0.0036	
%Sb residue			26.17%		24.32%	

Standard NH₄Br

Sample

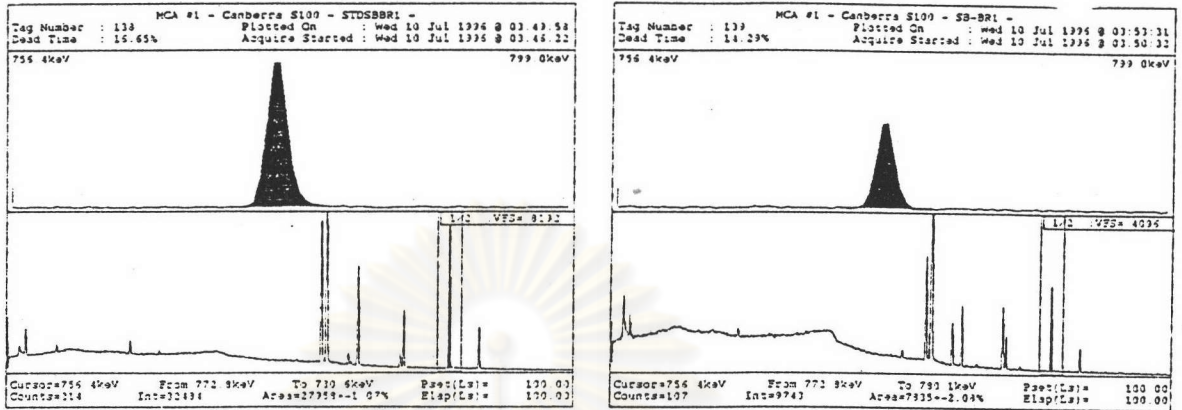


Figure B.13 NAA diagram of Br element from ABS sample with 18% BTBPE and 4% Sb₂O₃

Standard NH₄Br

Sample

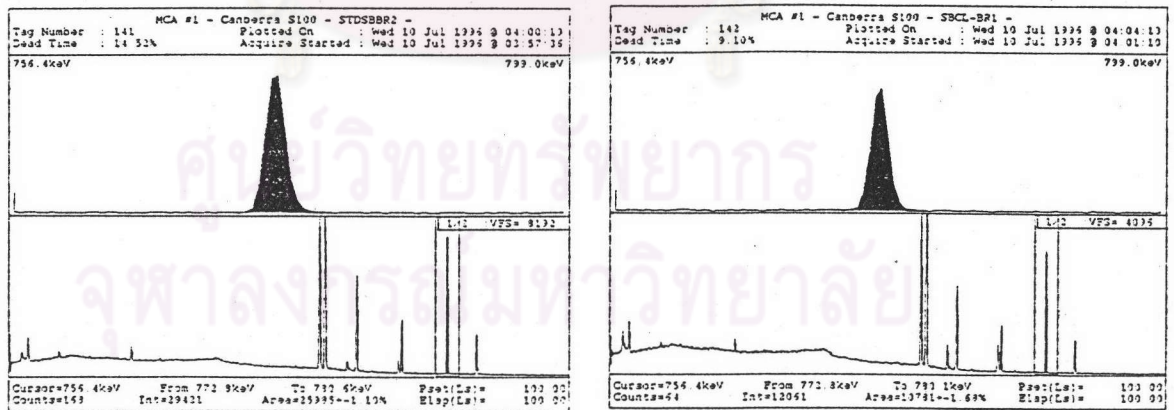


Figure B.14 NAA diagram of Br element from ABS sample with 18% BTBPE, 4% Sb₂O₃ and 3% CPE

Table B.9 Determination of Cl from sample

- ABS with 18% BTBPE, 4% ZHS and 3% CPE

- ABS with 18% BTBPE, 4% ZS and 3% CPE

additive	Std. NH_4Cl		ZHS		ZS	
	1	2	1	2	1	2
no.						
weight (g)	0.00049	0.00046	0.06028	0.06078	0.06041	0.06018
area	1083 (361)	1464 (488)	326	375	376	445
% Cl	-	-	0.14	0.11	0.19	0.12
char yield			16.68%		16.27%	
platic origin			0.36139		0.37130	
Cl (add)			0.0039		0.0040	
Cl (after)			0.000084		0.000115	
%Cl residue			2.16%		2.87%	

Table B.10 Determination of Cl from sample- ABS with 18% BTBPE, 4% Sb_2O_3 and 3% CPE

additive	Std. NH_4Cl			$\text{Sb}_2\text{O}_3 + \text{Cl}$		
	1	2	3	2	1	3
no.						
weight (g)	0.00044	0.00044	0.00046	0.06078	0.06041	0.06018
area	1059 (353)	1059 (353)	1233 (411)	287	297	387
% Cl	-	-		0.12	0.14	0.17
char yield				11.47		
platic origin				0.43740		
Cl (add)				0.0047		
Cl (after)				0.00007		
%Cl residue				1.43%		

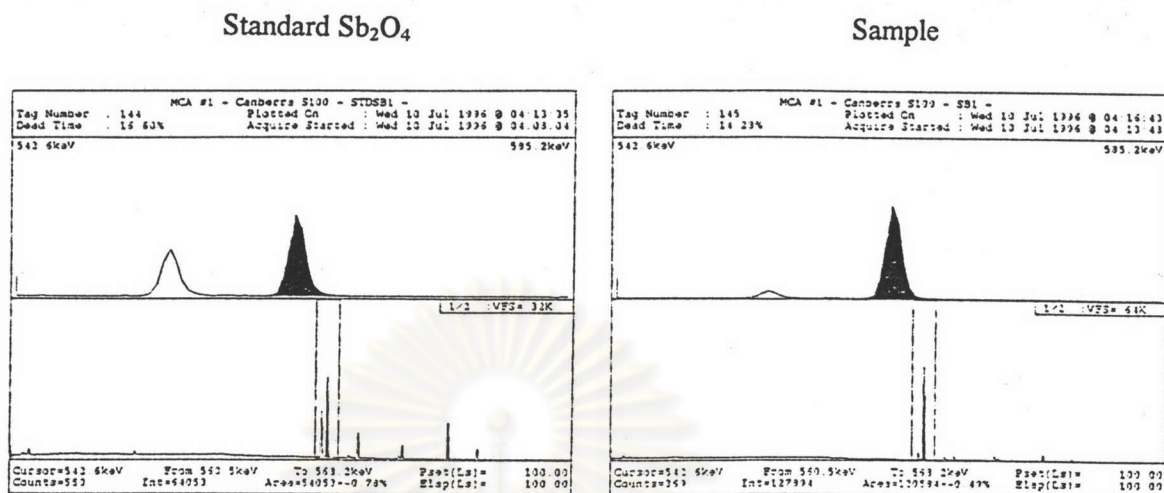


Figure B.15 NAA diagram of Sb element from ABS sample with 18% BTBPE and 4% Sb_2O_3

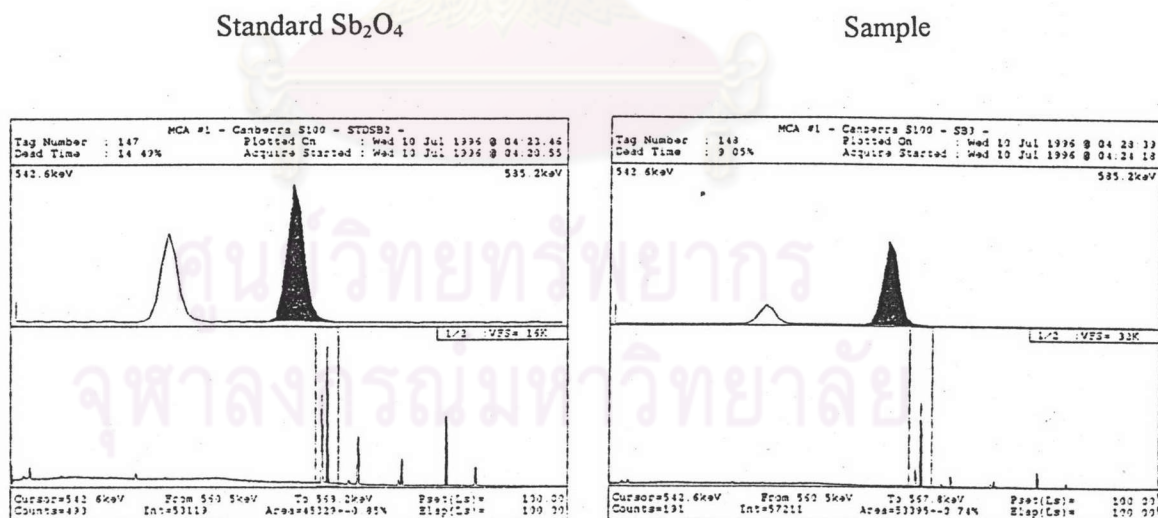
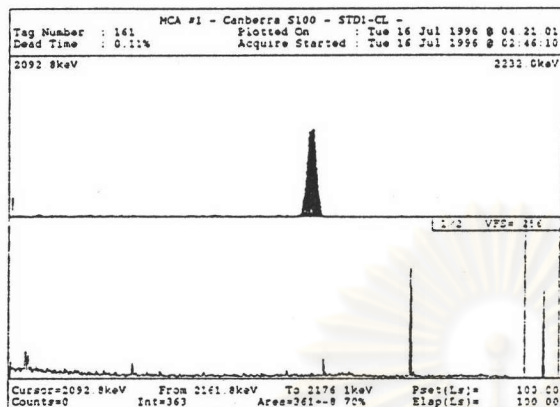


Figure B.16 NAA diagram of Sb element from ABS sample with 18% BTBPE, 4% Sb_2O_3 and 3% CPE

Standard NH_4Cl 

Sample

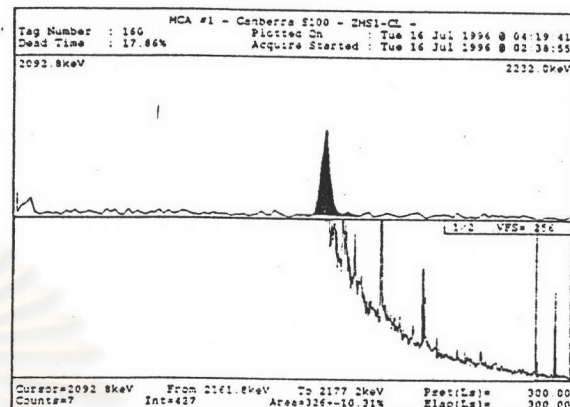
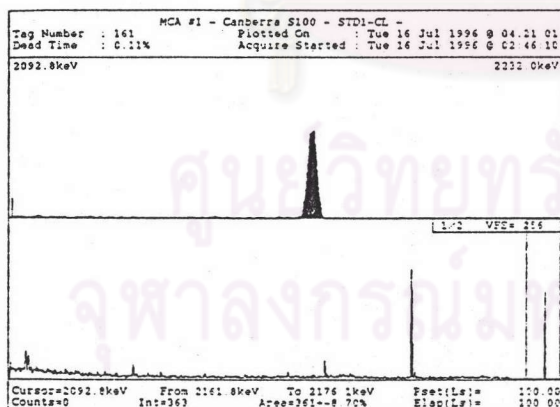


Figure B.17 NAA diagram of Cl element from ABS sample
 with 18% BTBPE, 4% ZHS and 3% CPE

Standard NH_4Cl 

Sample

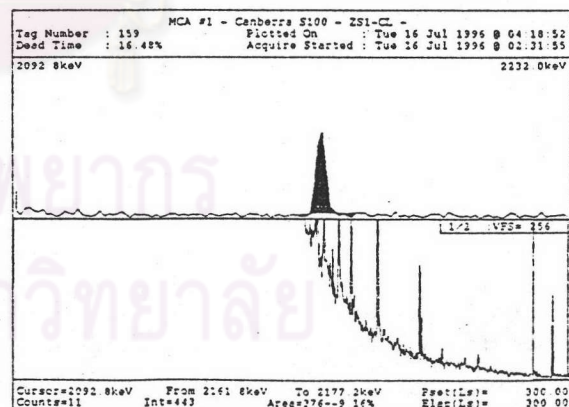


Figure B.18 NAA diagram of Cl element from ABS sample
 with 18% BTBPE, 4% ZS and 3% CPE

Standard NH₄Cl

Sample

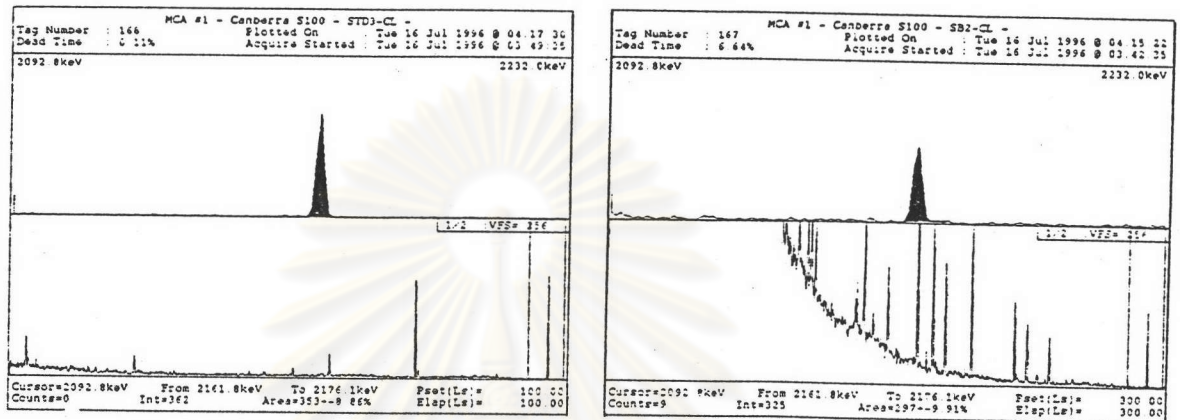


Figure B.19 NAA diagram of Cl element from ABS sample
with 18% BTBPE, 4% Sb₂O₃ and 3% CPE

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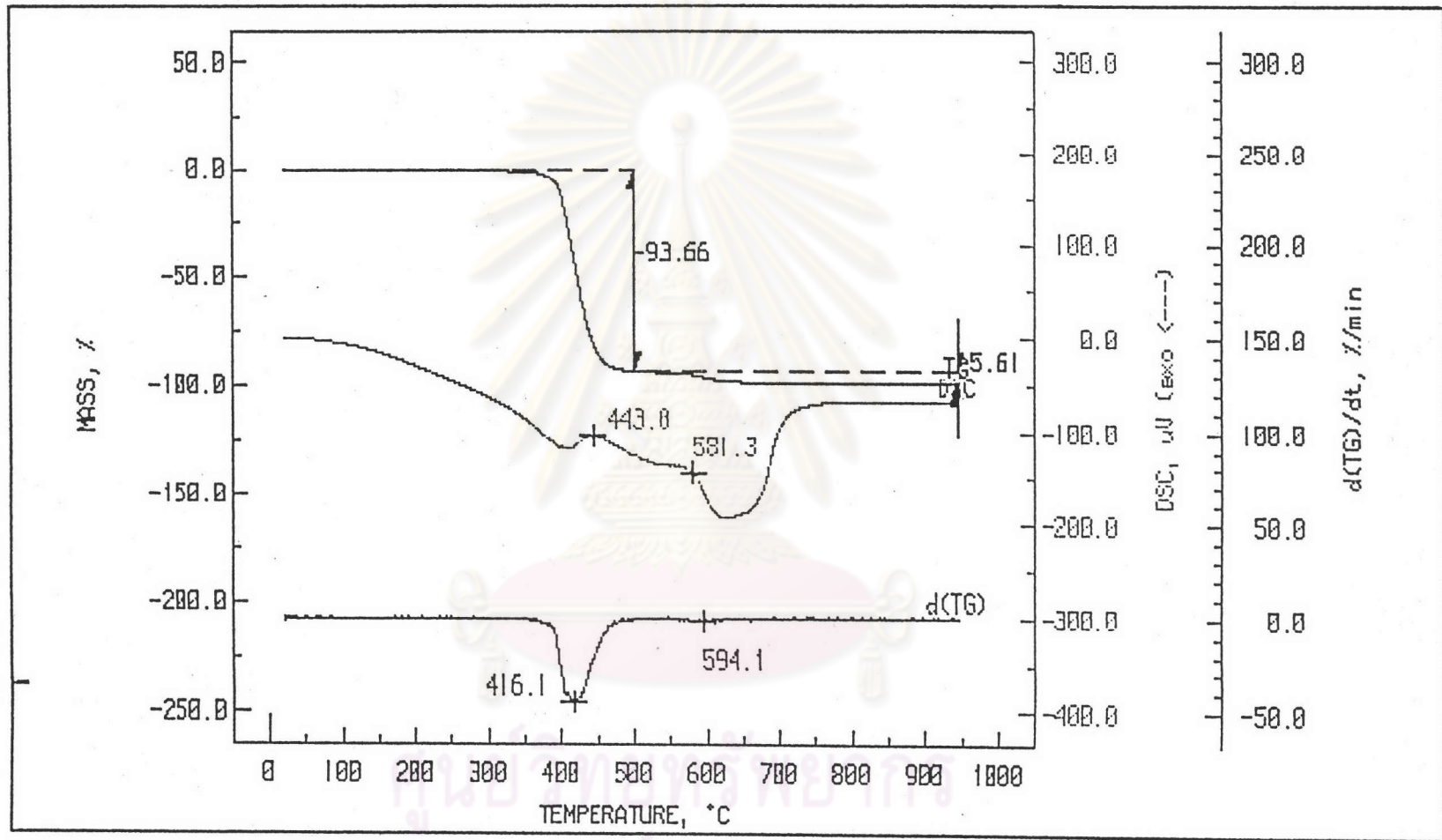


Figure B.20 TGA, DTG and DSC curves for ABS

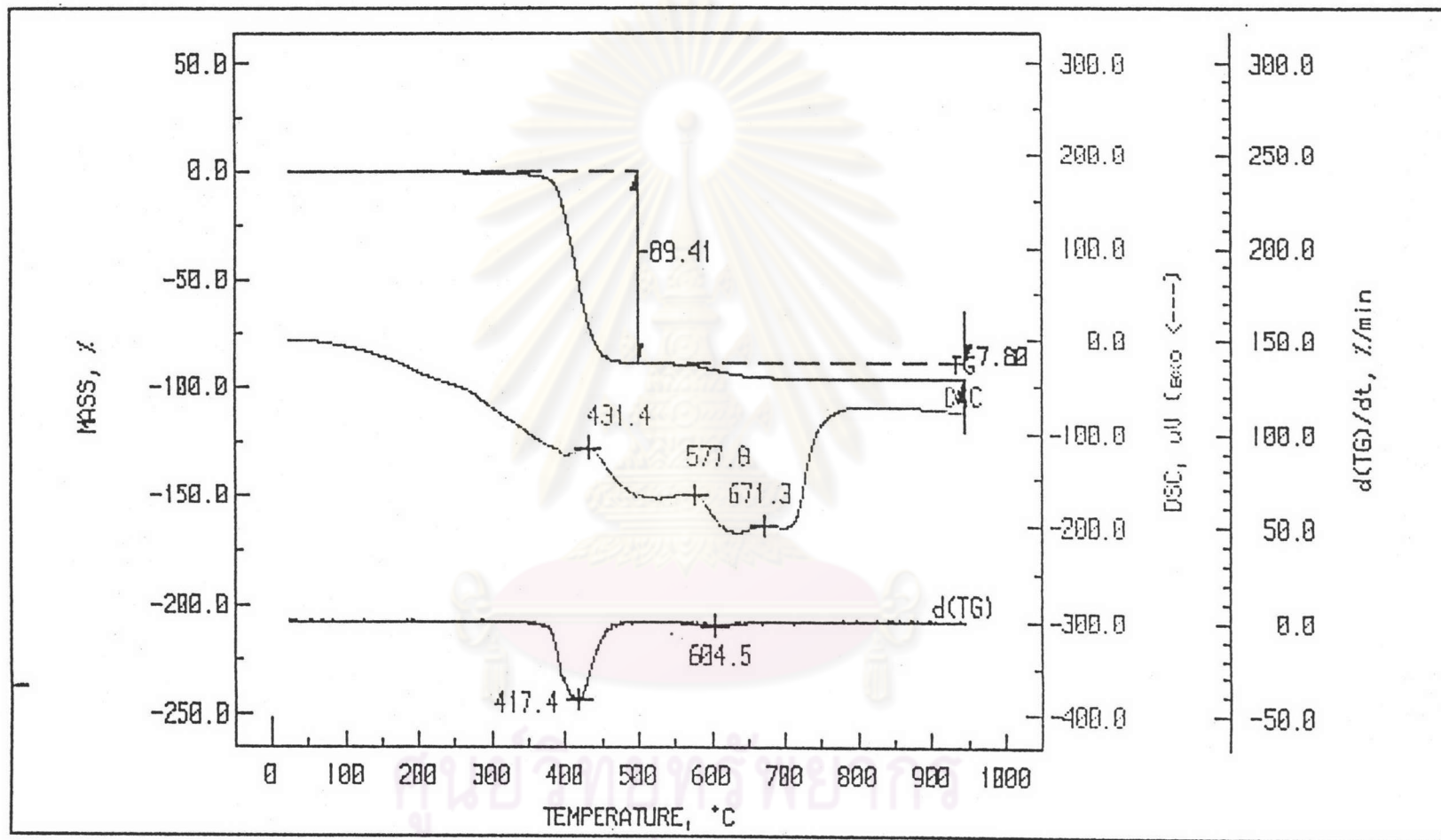


Figure B.21 TGA, DTG and DSC curves for ABS containing ZHS

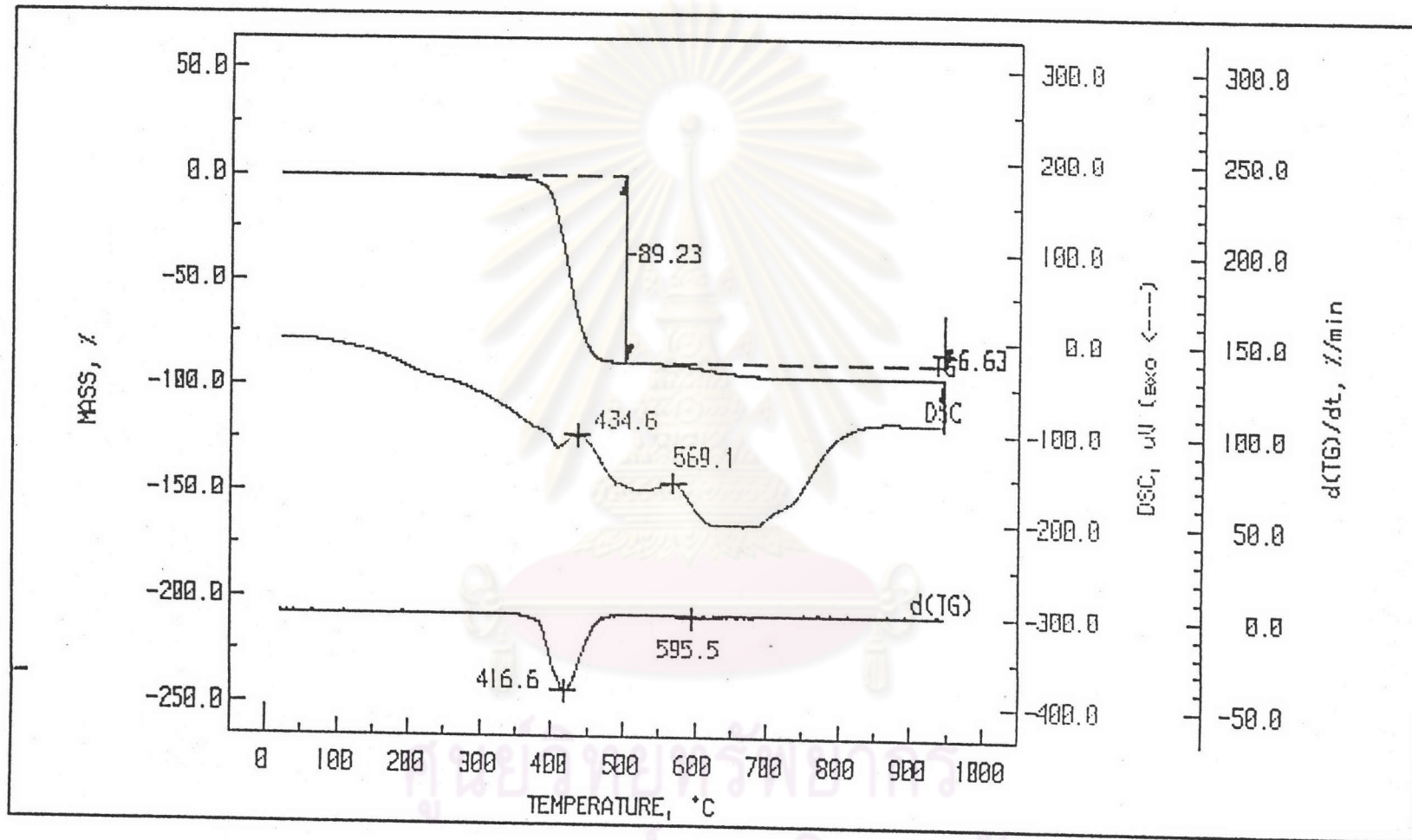


Figure B.22 TGA, DTG and DSC curves for ABS containing ZS

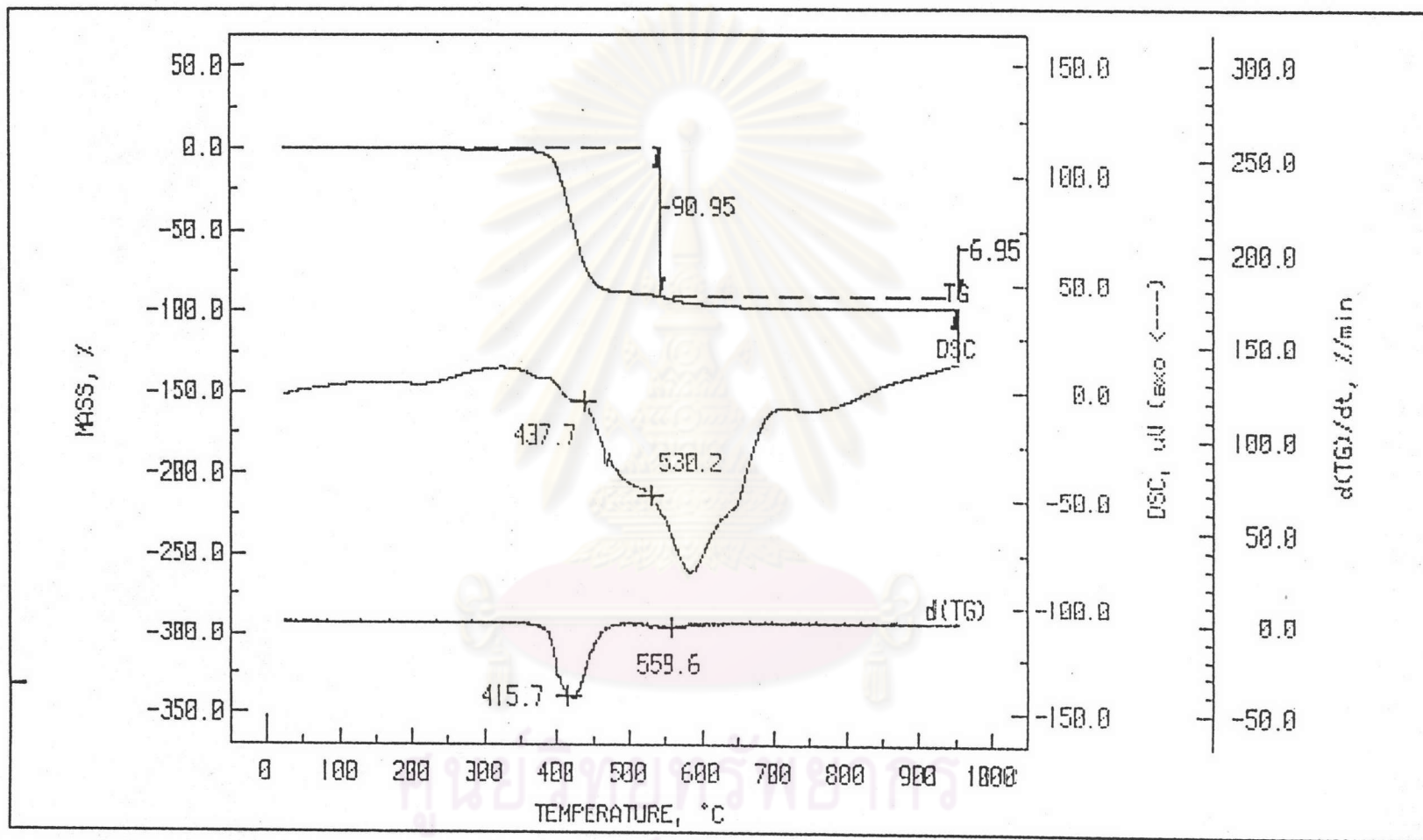


Figure B.23 TGA, DTG and DSC curves for ABS containing Sb_2O_3

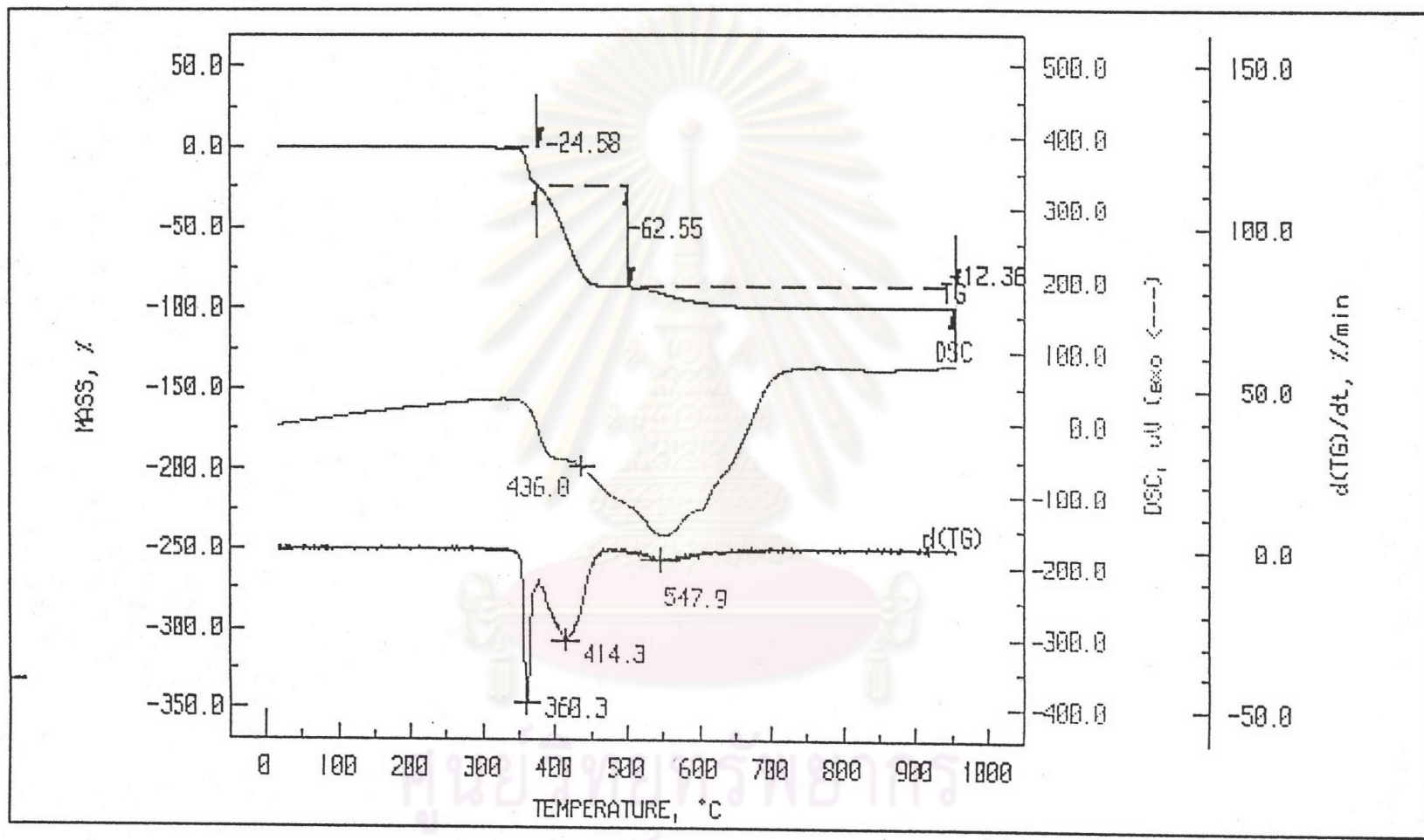


Figure B.24 TGA, DTG and DSC curves for ABS containing BTBPE

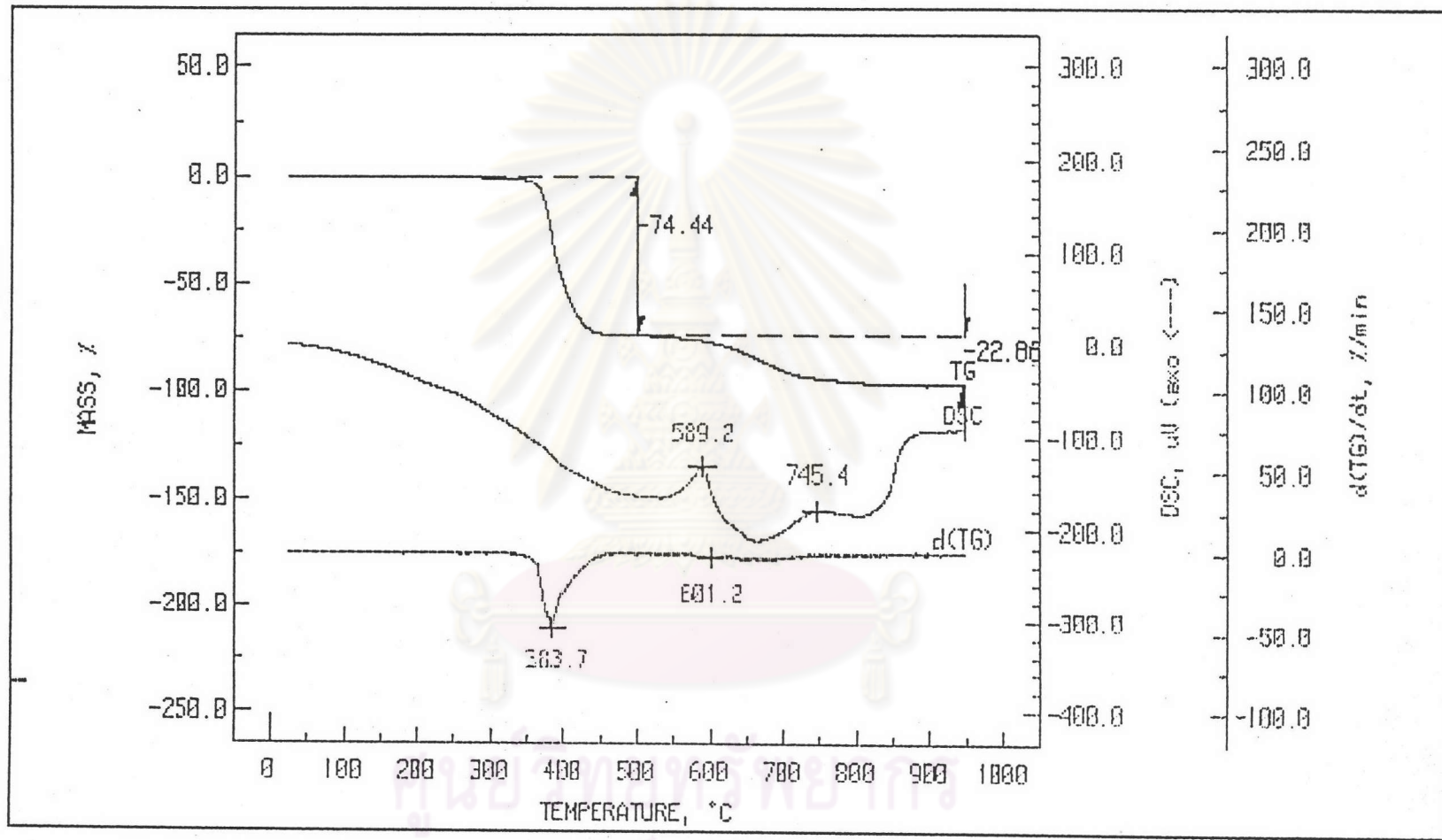


Figure B.25 TGA, DTG and DSC curves for ABS containing BTBPE/ZHS

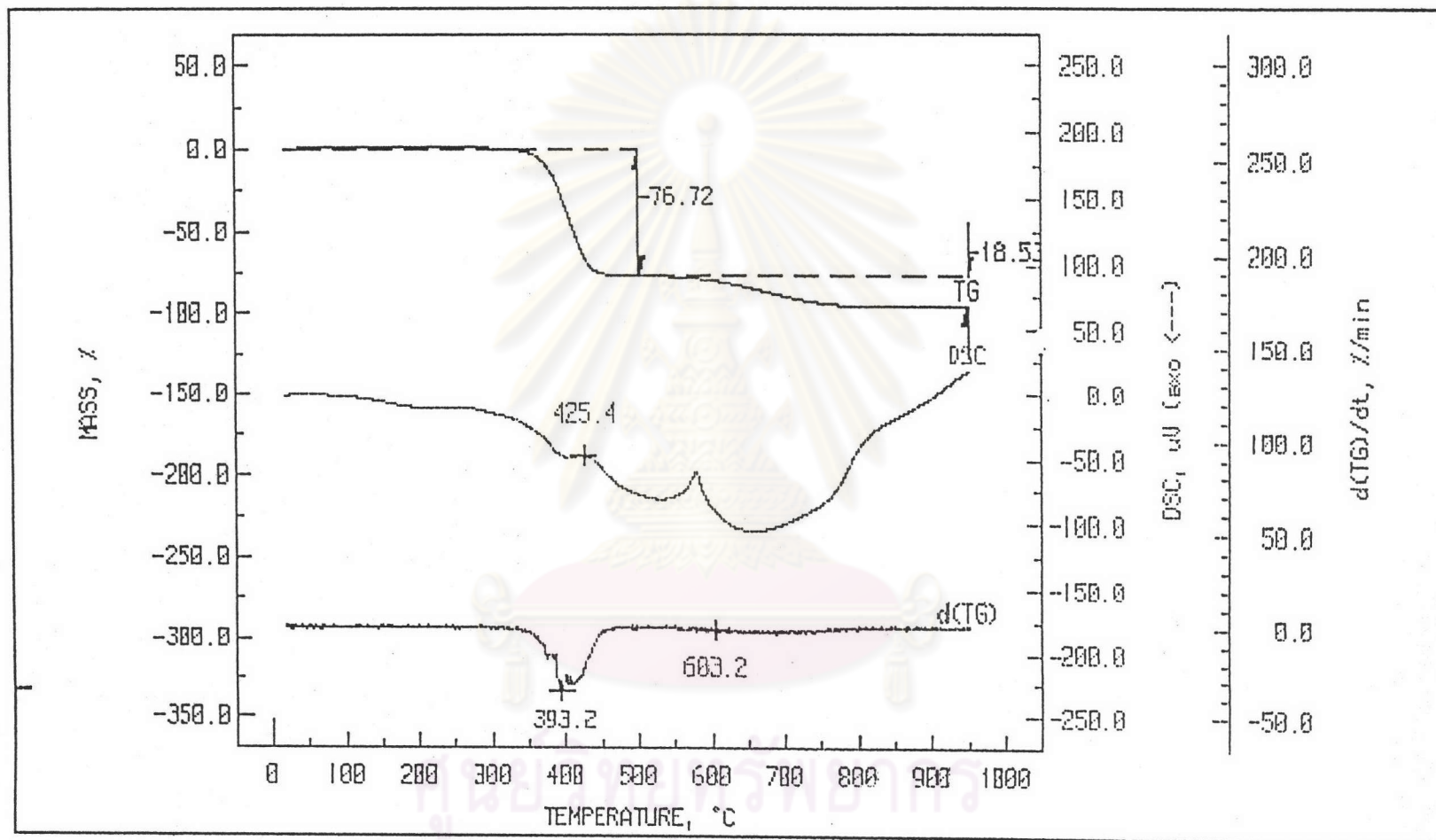


Figure B.26 TGA, DTG and DSC curves for ABS containing BTBPE/ZS

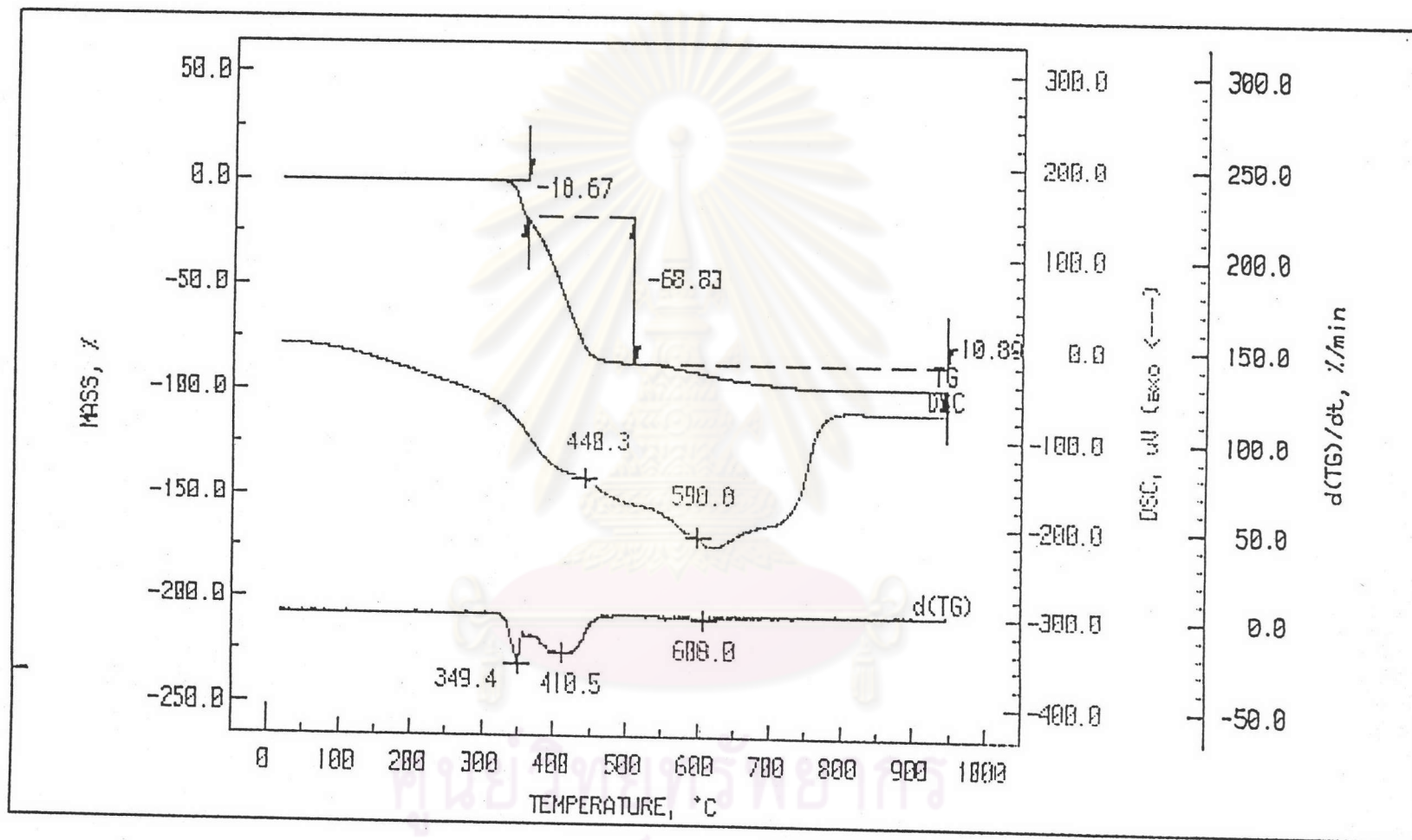


Figure B.27 TGA, DTG and DSC curves for ABS containing BTBPE/Sb₂O₃

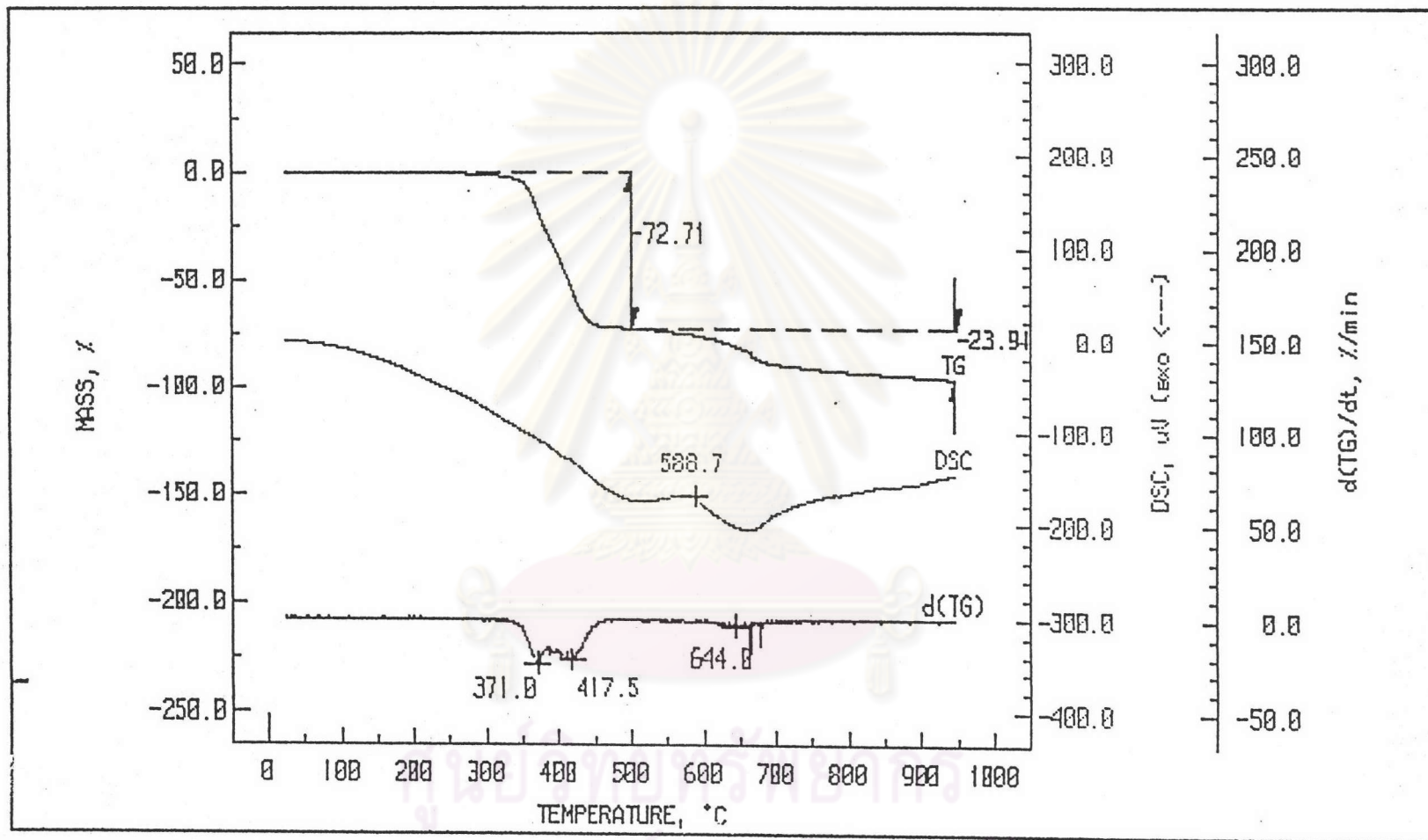


Figure B.28 TGA, DTG and DSC curves for ABS containing BTBPE/ZHS/CPE

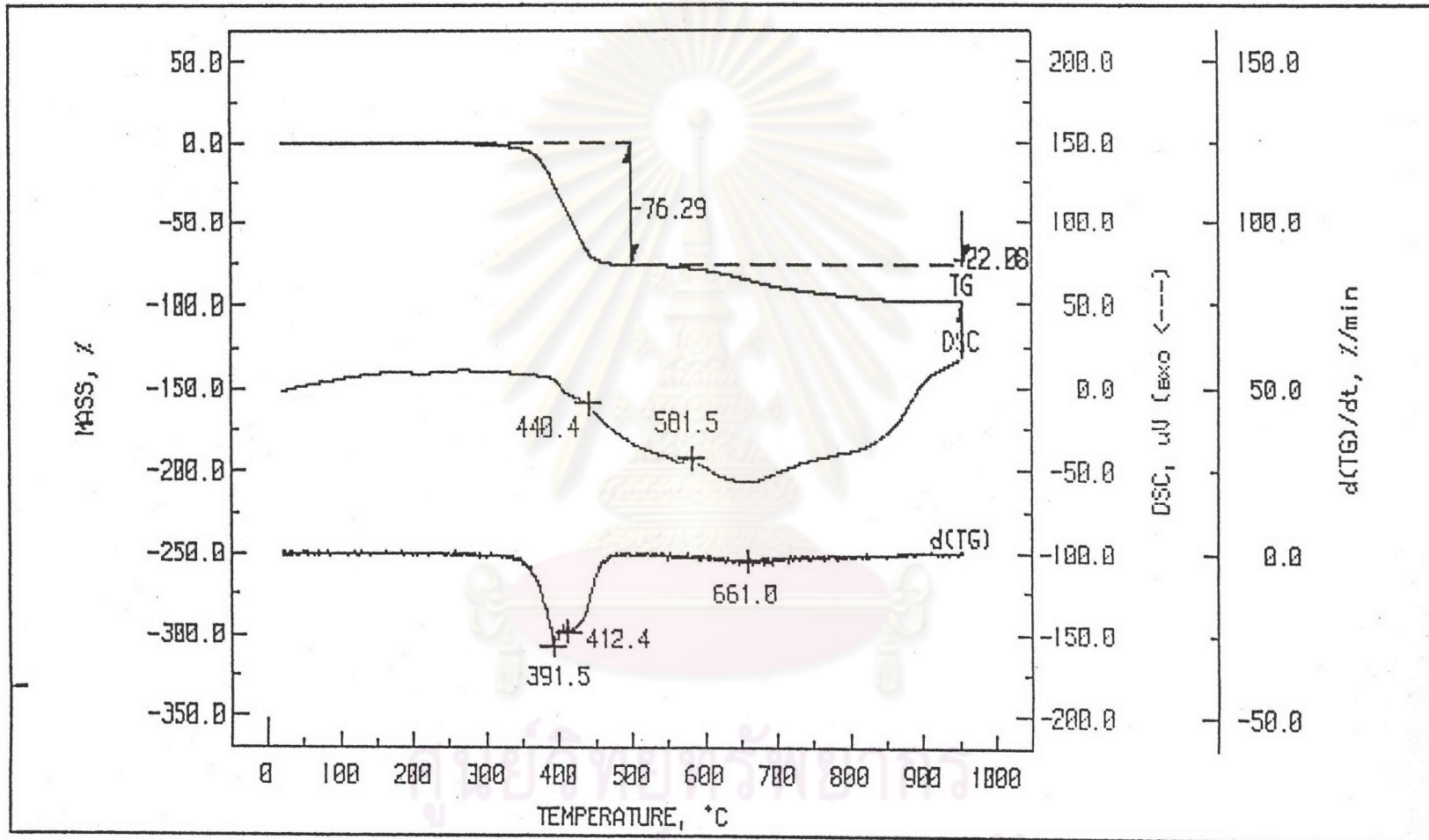


Figure B.29 TGA, DTG and DSC curves for ABS containing BTBPE/ZS/CPE

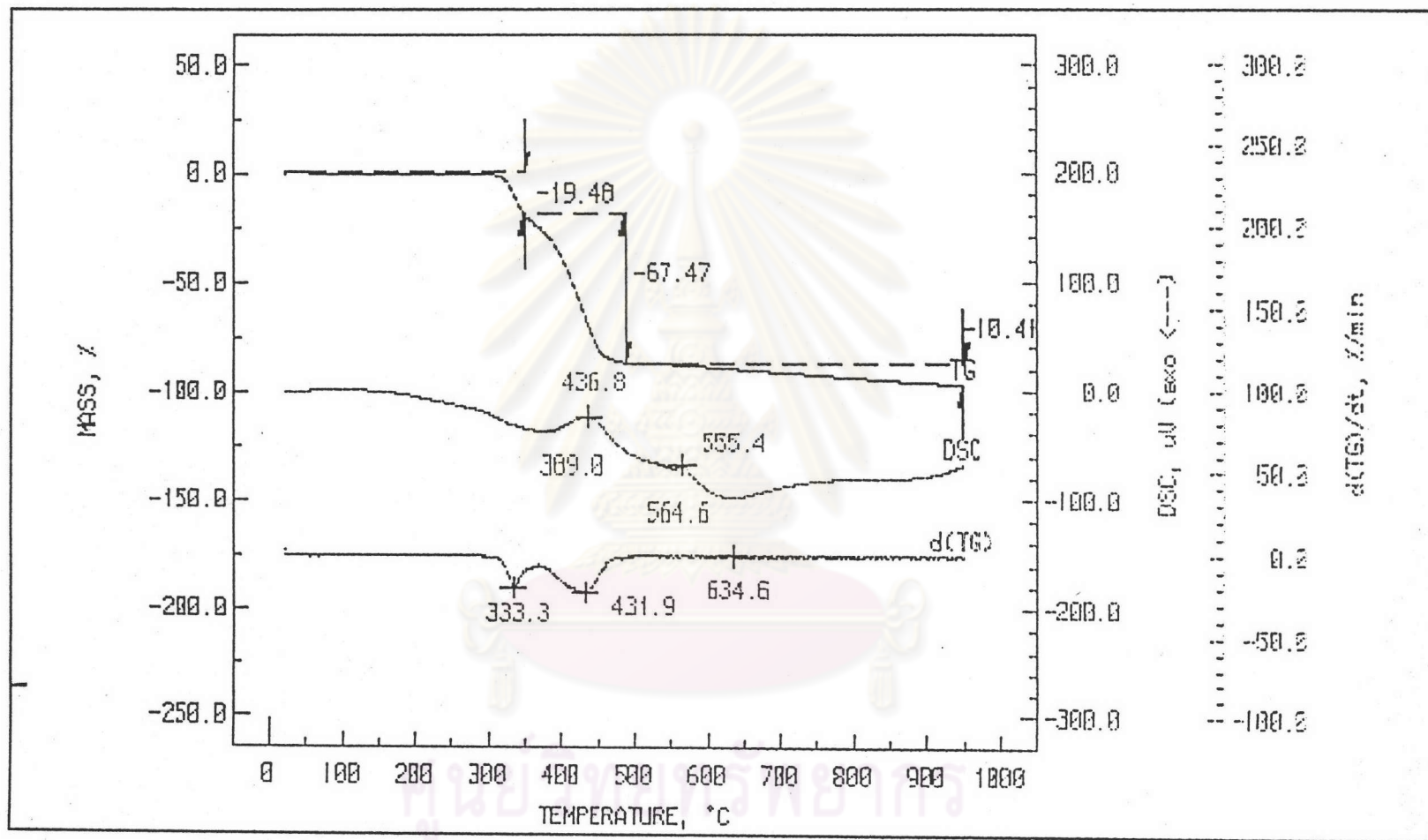


Figure B.30 TGA, DTG and DSC curves for ABS containing BTBPE/Sb₂O₃/CPE

VITA

Miss Areeya Ariyaphattanakul was born on June 22, 1971 in Chumporn. She received her Bachelor of Science Degree in Chemistry from the Department of Chemistry, Faculty of Science, Srinakharinwirot University in 1993. She began her master's degree studies in the multidisciplinary program of Petrochemistry and Polymer, Graduate School, Chulalongkorn University, in 1994 and completed the program in 1997.



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