CHAPTER IV

RESULTS AND DISCUSSION

1. Sample Collection

Samples of virgin resin were collected as presented in Table 4.1. Samples of recycled resin were collected from ten recycled plants over a long period of time. Nine of these plants are located in Banbon district and the rest in Onnuch district. Details are presented in Table 4.2. Samples of ground waste plastics were also collected as shown in Table 4.3. Ground waste plastics are the feed for pelleting machines in the recycling plants.

Samples are either of polyethylene (mainly HDPE), polypropylene, or polystyrene.

Most local plastic recycling plants are similar; and in the recycling process, most plastic waste undergo the same path as shown in Figure 2.1. Therefore, the collected 38 samples are believed to provide good representative data.

2. Safety Limits

Table 4.4 shows the safety limits of contaminants set by the ISO/DP 8124/4.1.

Table 4.1 Virgin resin's code number,source, description and date of collection.

Item	Description	Plant No.	Date of collection
PE 35-001	Blow molding TPI, GM 2860	5	27-11-92
PE 110-001	Blow molding TPI, GM 2860	5	25-08-93
PE 15-001	Blow molding TPI, 2502H	5	27-11-92
PP 25-001	Blow molding TPI, 1102H	5	27-11-92
PS 111-001	Tape cassette TPI, offgrade	5	25-05-93
PS 111-002	Tape cassette TPI, offgrade	5	11-08-93

Table 4.2 Recycled plastic pellet's code number, source, description and date of collection.

Item	Description	Plant No.	Date of collection
polyethylene			
PE 14-001	drinking water bottles	4	29-07-92
PE 14-002	drinking water bottles	4	16-04-93
PE 14-003	drinking water bottles	4	11-05-93
PE 13-001	drinking water bottles	3	17-07-92
PE 13-002	drinking water bottles	3	08-12-95
PE 33-001	mixed bottles	3	17-07-92
PE 43-001	mixed bottles	3	17-07-92
PE 53-001	mixed bottles	3	17-07-92
PE 63-001	mixed bottles	3	17-07-92
PE 17-001	mixed bottles	7	29-04-93
PE 17-002	mixed bottles	7	22-12-95
PE 12-001	nonbottle	2	03-06-92
PE 22-001	nonbottle	2	22-12-95
PE 11-001	nonbottle	1	22-12-95
polystyrene			
PS 18-001	nonbottle	8	25-05-93
PS 16-001	nonbottle	6	22-12-95
PS 11-001	bottle	1	03-06-92
PS 11-002	bottle	1	22-12-95
PS 21-001	bottle and nonbottle	1	03-01-92

Table 4.2 continued.

Item	Description	Plant No.	Date of collection
polypropylene			
PP 16-001	nonbottle	6	23-08-93
PP 17-001	nonbottle	7	09-08-95
PP 17-002	nonbottle	7	09-08-95
PP 17-003	nonbottle	7	22-12-95
PP 13-001	nonbottle	3	17-07-92

Table 4.3. Ground waste plastic's code number, source, description and date of collection

Item	Description	Plant No.	Date of collection
polyethylene			
PE 17-101	mixed bottles	7	09-08-93
PE 17-102	mixed bottles	7	22-12-95
PE 11-101	mixed bottles	1	22-12-95
PE 13-101	drinking water bottles	3	17-07-92
PE 13-102	drinking water bottles	3	08-12-95
PE 22-101	drinking water bottles	2	22-12-95
polystyrene			
PS 18-001	bottles	8	25-05-93
PS 11-102	bottles	1	22-12-95
PS 16-101	bottles	6	22-12-95
polypropylene			
PP 16-101	nonbottles	6	23-08-93
PP 16-102	nonbottles	6	22-12-95
PP 17-101	nonbottles	7	09-08-93
PP 17-102	nonbottles	7	09-08-93
PP 17-103	nonbottles	7	22-12-95

Table 4.4. Safety limits of contaminants for packaging plastics

Type of plastics	contaminant (ppm)			
	lead	cadmium	mercury	styrene monomer
polyethylene	250	100	100	-
polypropylene	250	100	100	-
polystyrene	250	100	100	1000

3. Quantity of Contaminants

In this work, toxic contaminants : lead, cadmium, mercury, and styrene monomer were determined quantitatively. The result are as follows.

3.1. Quantity of Lead

The content of lead were measured quantitatively by the atomic absorption spectrophotometers. In this analytical technique as described in chapter III, the organic substance was completely eliminated as illustrated in Figure 4.1. The quantity of lead in virgin resins, recycled plastic pellets and ground waste plastics are revealed in Table 4.5, Table 4.6, and Table 4.7, respectively and graphically in Figure 4.1, Figure 4.2, and Figure 4.3 , respectively.

According to Table 4.5, there is no lead in the virgin resins. According to Table 4.6, eight out of twenty-six samples contains lead in exceed of 250 ppm limit. Those samples that exceed the limit came from original plastic product of baskets and basin.

Table 4.5 Quantity of lead in virgin resins.

Item	Description	Content of lead (ppm)
PE 35-001	Blow molding TPI, GM 2860	0.00
PE 110-001	Blow molding TPI, GM2860	0.00
PP 15-001	Blow molding TPI, 1102H	0.00
PP 25-001	Blow molding TPI, 1102H	0.00
PS 111-001	Tape cassette TPI, offgrade	0.00
PS 111-002	Tape cassette TPI, offgrade	0.00

Table 4.6 Quantity of lead in recycled plastic pellets.

Item	Form	Content of lead (ppm)	Color
PE 12-001	Fish containers	252.25	red
PE 22-001	Baskets and others	321.25	green
PE 14-001	Water bottle	1.25	white
PE 14-002	Water bottle	0.00	white
PE 14-003	Water bottle	0.00	white
PE 17-001	Basket and basin	609.50	red
PE 17-002	Basket and basin	236.75	black
PE 11-001	Beverage bottle	1.00	blue
PE 23-001	Container, basin	342.50	black
PE 33-001	Basin	609.75	black
PE 43-001	Powder bottle and others	0.25	blue
PE 53-001	Powder bottle and others	432.25	red
PE 63-001	Powder bottle and others	18.00	blue
PE 13-001	Water bottle	2.75	white
PE13-002	water bottle	0.00	white
PS 18-001	Beverage bottle	20.25	black
PS 11-001	Beverage bottle	0.00	purple
PS 11-002	Beverage cup	0.00	white
PS 16-001	Beverage bottle	26.50	black
PS 21-001	Beverage bottle	1.00	blue
PP 16-001	Basket and others	71.75	green
PP 16-002	Basket and others	152.25	black
PP 17-001	Basket and others	415.25	red
PP 17-002	Basket and others	84.75	black
PP 17-003	Basket and others	117.00	black
PP 13-001	Basket and others	154.25	black

Table 4.7 Quantity of lead in ground waste plastics.

Item	Plant No.	Content of lead (ppm)	Color
PE 13-101	3	6.00	white
PE 13-102	3	0.00	white
PE 11-101	1	1.50	white
PE 22-101	2	66.00	green
PE 17-101	7	84.75	red
PE 17-102	7	20.50	white
PS 11-102	1	0.00	white
PS 16-101	6	2.00	black and green
PS 18-101	8	1.25	black
PP 16-101	6	106.50	green
PP 16-102	6	87.00	red
PP 17-101	7	203.75	red
PP 17-102	7	217.50	black
PP 17-103	7	129.50	red

Table 4.7, shows that no ground waste plastics containing lead more than 250 ppm. The lead content may come from either some or all of the following sources:

a. air pollution[14]

b. colour additives[22]

c. municipal waste[23]

d. closure filling

e. residue lead in washing tank in the recycling plant.

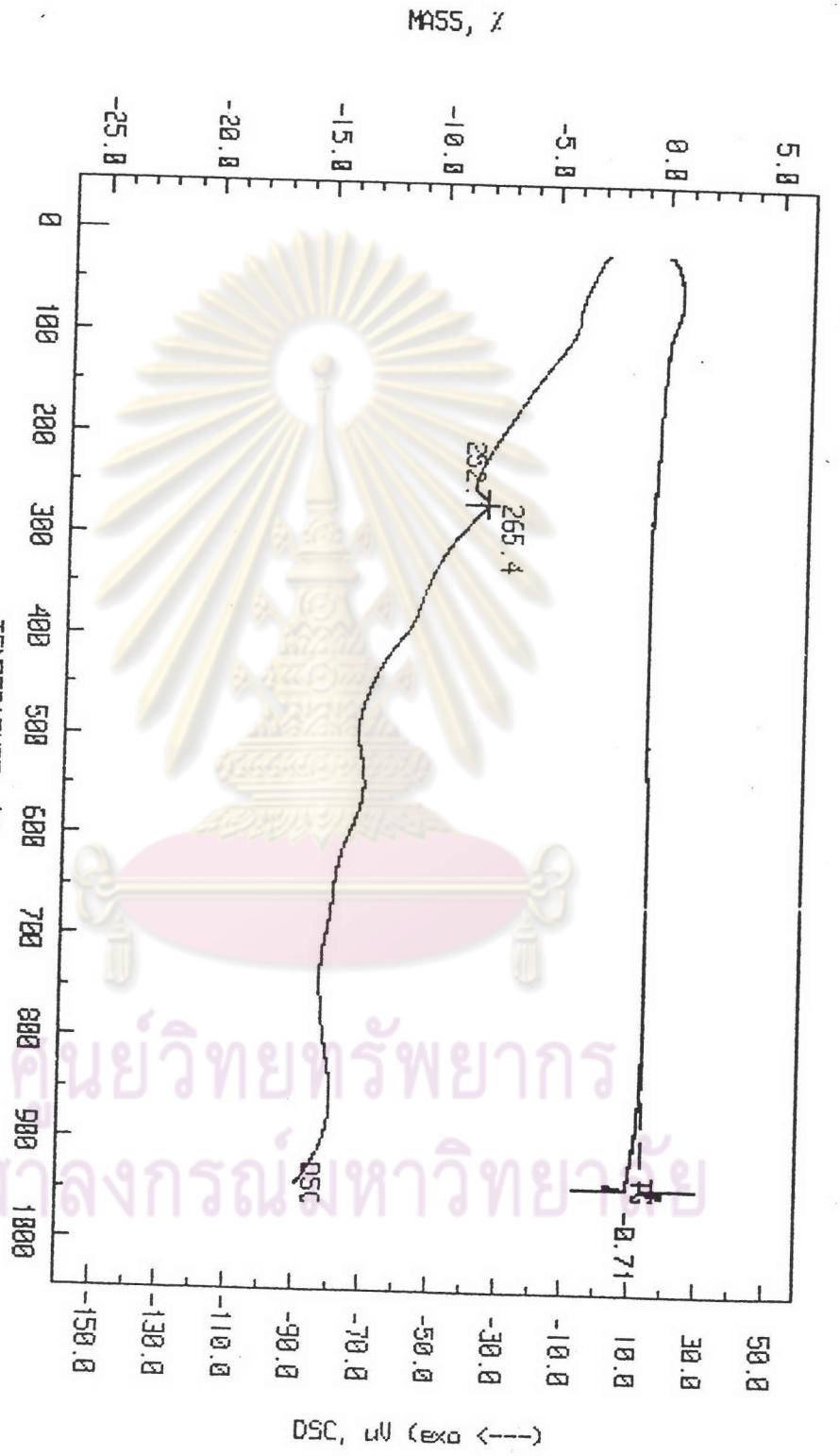

Figure 4.1 TGA chromatogram of PS 18-001 for lead analysis.

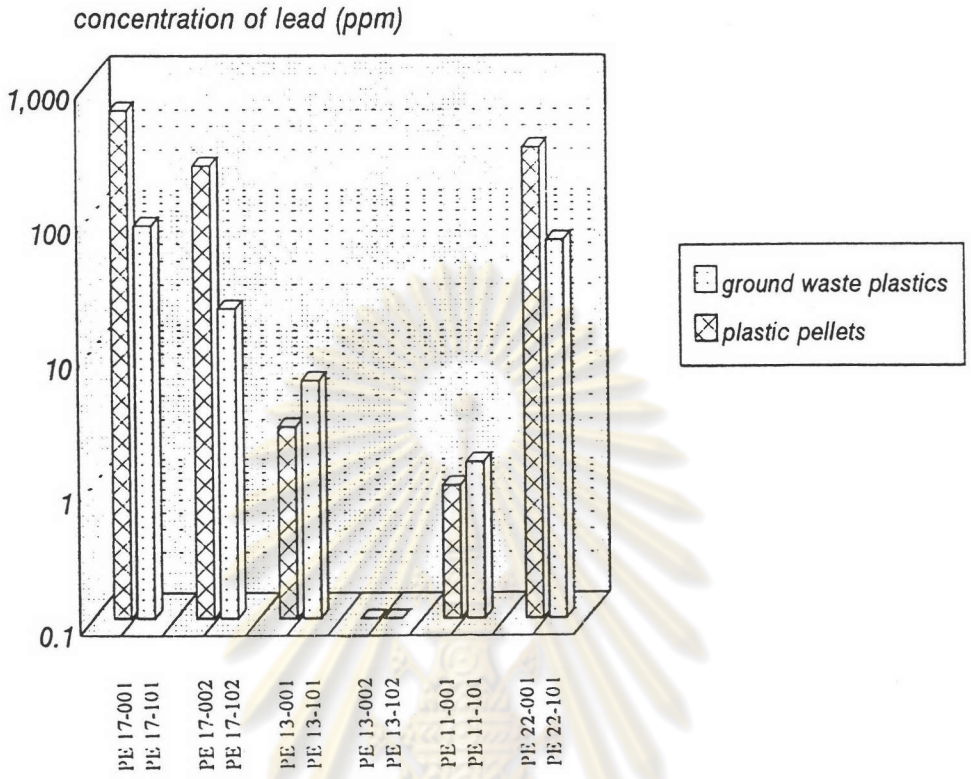

Figure 4.2 Comparision of amount of lead between recycled polyethylenes and ground waste polyethylenes.

Figure 4.2, Figure 4.3, Figure 4.4 compare contaminants in various pairs of feed (ground waste plastics) and product (recycled pellets or resin) of pelleting machines. Referring to Figure 4.1, for sample pairs of PE 13-001 and PE 13-101 and PE 11-001 and PE 11-101 , lead content decreased as plastic passed through the pelleting machine. This may be caused by vaporization of feed. These two pairs of samples are colourless, that is : no colour additive was added. Other pairs of samples, there is an increase in lead content as plastics passed through the pelleting machine. This increase in lead is due to addition of colour additive. Sample PE 11-001 is red, PE 17-002 is black and PE 22-001 is green.

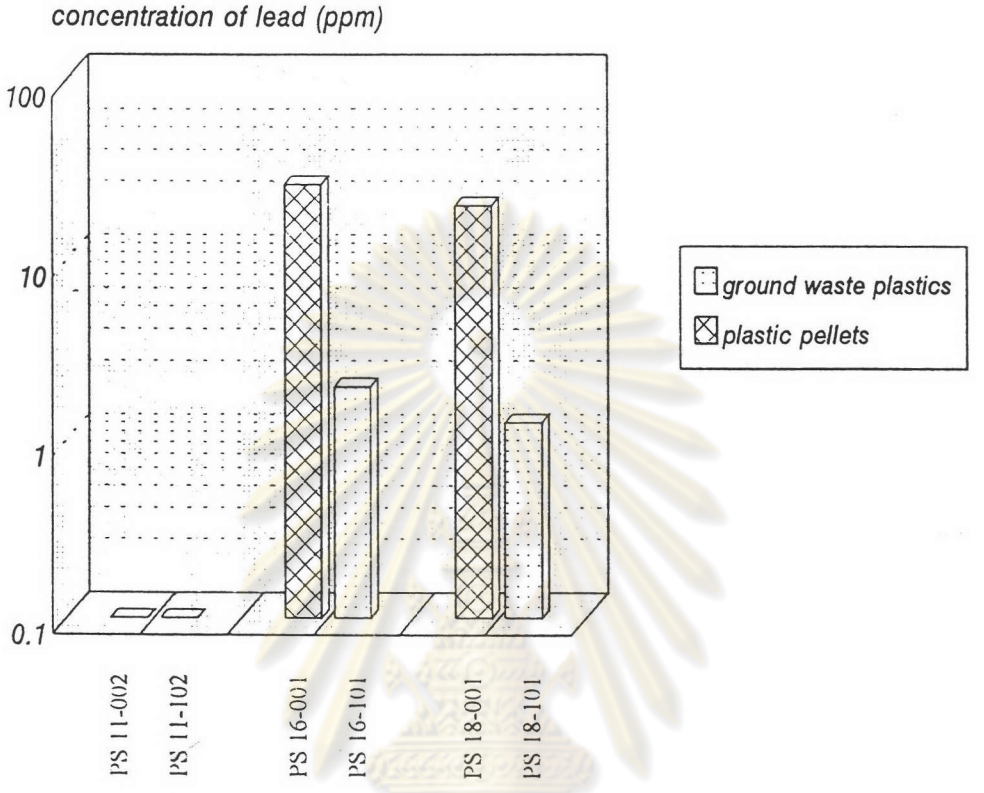

Figure 4.3 Comparision of amount of lead between recycled polystyrenes and ground waste polystyrenes.

For Figure 4.3, it shows no lead in polystyrene pair (PS 11-002 and PS 11-102), this is because of no addition of colour additive and the original plastic product as beverage bottle which is colourless. The other sample pairs are PS 18-001 and PS 18-101 and PS 16-001 and PS 16-101, whose lead content increased because the colour additive was added during recycling process. The colour for PS 18-001 and PS 16-001 is black.

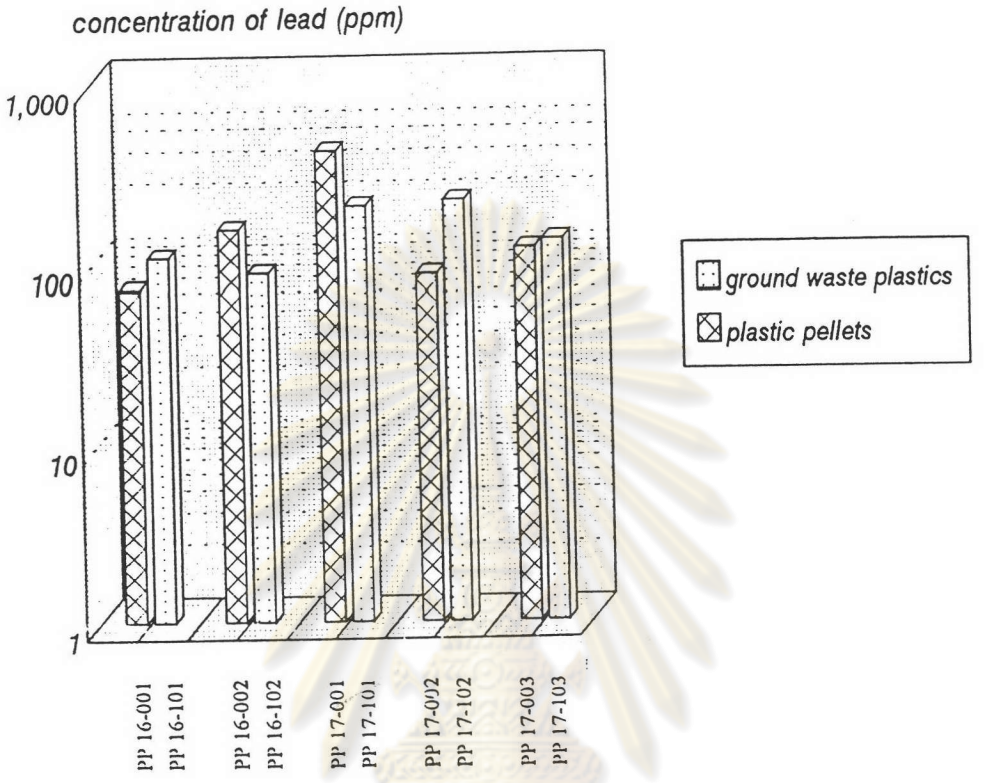

Figure 4.4 Comparision of amount of lead between recycled polypropylenes and ground waste polypropylenes.

Figure 4.4, shows the lead content in the pairs of samples : PP 17-001 and PP 17-101 and PP 16-002 and PP 16-102. Lead content was increased during secondary production due to addition of color. Their color are red and black, respectively. While the lead content of sample pairs of PP 16-001 and PP 16-101, PP 17-003 and PP 17-103, and PP 17-002 and PP 17-102decreased. This phenomena is probably due to lead volatility.

3.2. Quantity of Cadmium

Cadmium was analyzed quantitatively by atomic absorption spectrophotometer. In this analytical technique as described in chapter III, the organic substance was completely eliminated as illustrated in Figure 4.5. The content of cadmium in virgin resins were presented in Table 4.8, recycled pellets were in Table 4.9 and ground waste plastics were in Table 4.10 and graphically in Figure 4.6, Figure 4.7, and Figure 4.8, respectively.

Table 4.8 Quantity of cadmium in virgin resins.

Item	Content of cadmium (ppm)
PE 35-001	0.00
PE 110-001	0.00
PE 15-001	0.00
PE 15-001	0.00
PP 25-001	0.00
PS 111-001	0.00
PS 111-002	0.00

Table 4.8 shows that there is no cadmium in virgin resins. Referring to Table 4.9, two out of twenty-six samples contains cadmium more than 100 ppm limit. The two sample are PE 12-001 and PE 17-001. They came from original plastic product of baskets and basins.

Table 4.9 Quantity of cadmium in recycled plastic pellets.

Item	Plan No.	Content of cadmium (ppm)
PE 12-001	2	665.00
PE 22-001	2	104.00
PE 14-001	4	0.00
PE 14-002	4	0.00
PE 14-003	4	0.00
PE 17-001	7	193.00
PE 17-002	7	31.00
PE 11-001	1	0.00
PE 23-001	3	18.00
PE 33-001	3	92.00
PE 43-001	3	11.00
PE 53-001	3	0.00
PE 63-001	3	0.00
PE 13-001	3	0.00
PE13-002	3	0.00
PS 18-001	8	26.00
PS 11-001	1	8.00
PS 11-002	1	0.00
PS 16-001	6	47.00
PS 21-001	1	0.00
PP 16-001	6	66.00
PP 16-002	6	39.00
PP 17-001	7	61.00
PP 17-002	7	57.00
PP 17-003	7	22.00
PP 13-001	3	70.00

Table 4.10 Quantity of cadmium in ground waste pellets.

Item	content of cadmium (ppm)
PE 13-101	0.00
PE 13-102	0.00
PE 11-101	0.00
PE 22-101	29.00
PE 17-101	1.00
PE 17-102	11.00
PS 11-102	0.00
PS 16-101	49.00
PS 18-101	2.00
PP 16-101	77.00
PP 16-102	75.00
PP 17-101	102.00
PP 17-102	157.00
PP 17-103	112.00

Table 4.10, ground waste plastics as PP 17-101, PP 17-102, and PP 17-103 contain cadmium content exceed limited value. Cadmium might come from the following sources:

a. municipal waste (Ni-Cd battery, rubber and so on.[24]

b. pigment which had cadmium as component.[25]

c. closure filling such as lubricant[24]

d. washing water of the process of cleaning might contain residued cadmium from the former plastic washing in the tank.

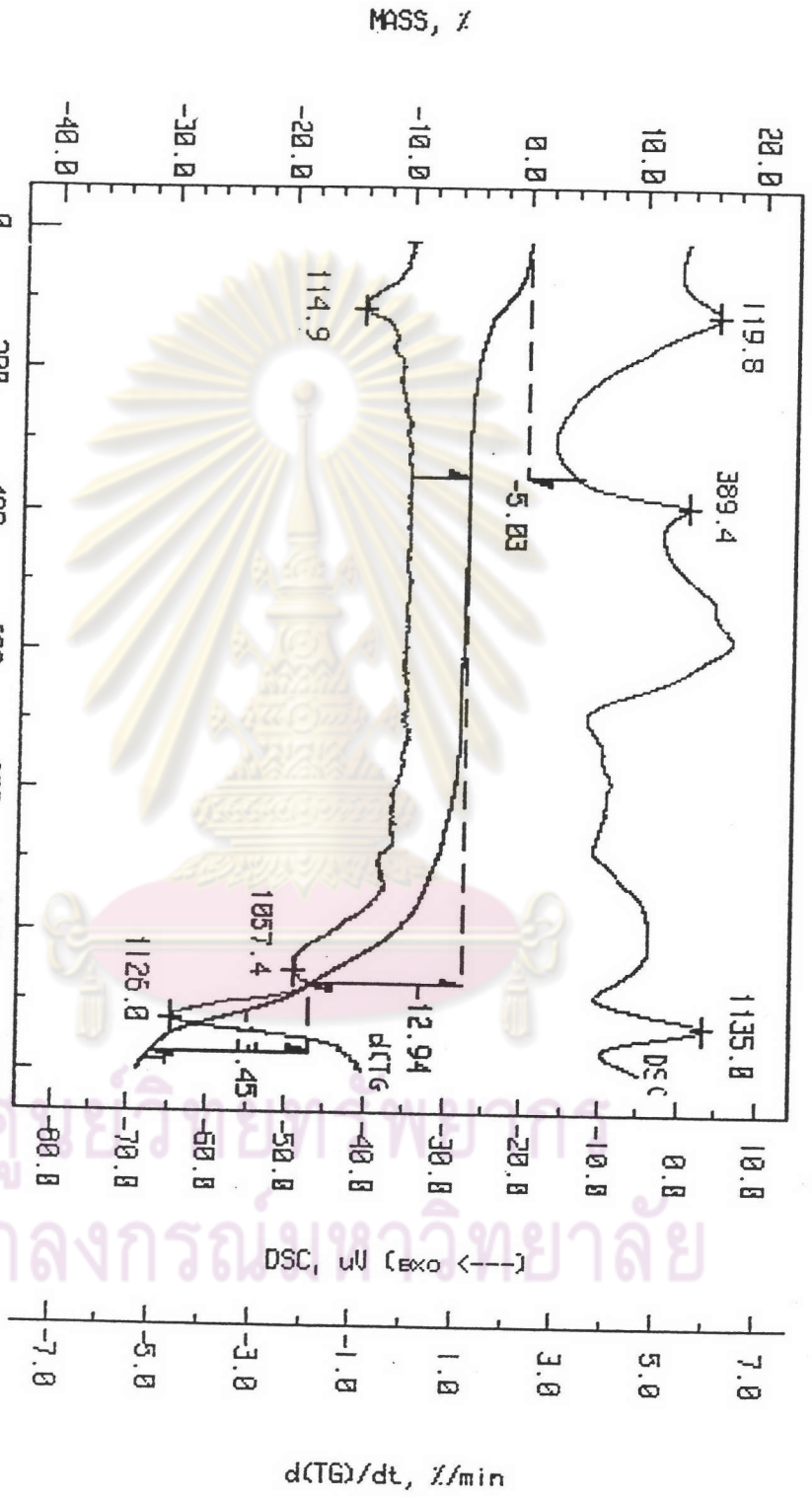

Figure 4.5 TGA chromatogram of PS 18-001 for cadmium analysis.

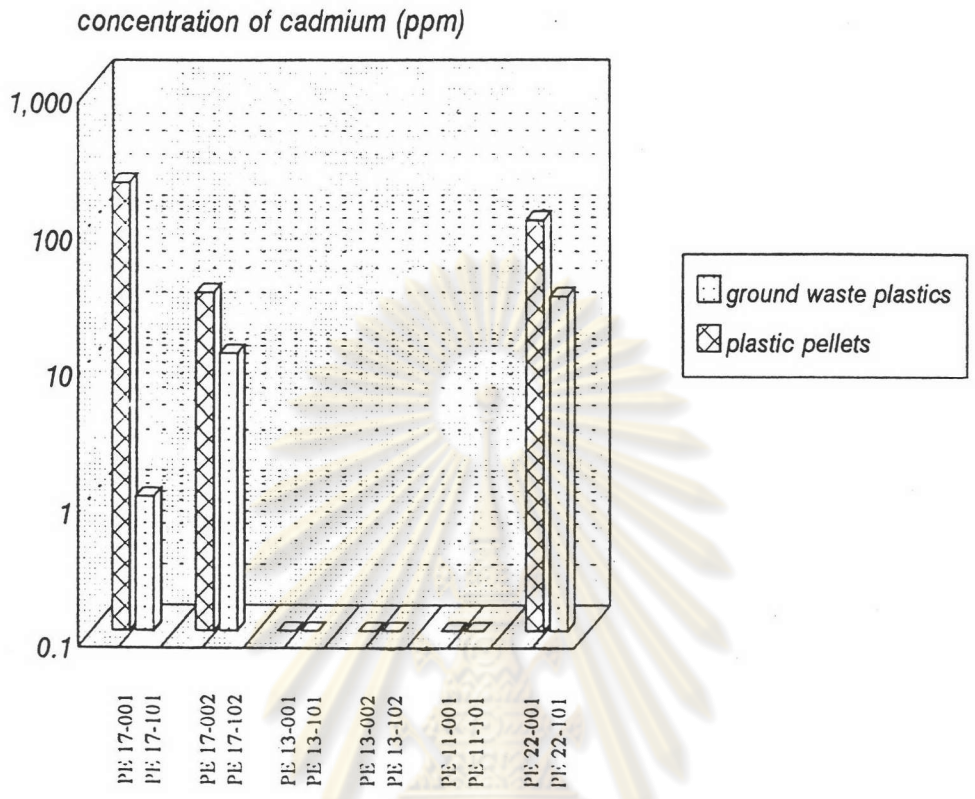

Figure 4.6 Comparision of cadmium content between recycled polyethylenes and ground waste polyethylenes.

In Figure 4.6 , for polyethylene pairs of PE 17-001 and PE 17-101 , PE 17-002 and PE 17-102 and PE 22-001 and PE 22-101, cadmium content increased when plastics passed through the pelleting machine. This increase in cadmium is due to addition of colour additive. Sample PE 17-001 is red, PE 17-002 is black, and PE 22-001 is green. The other of polyethylene pairs are colourless so no colour is added.

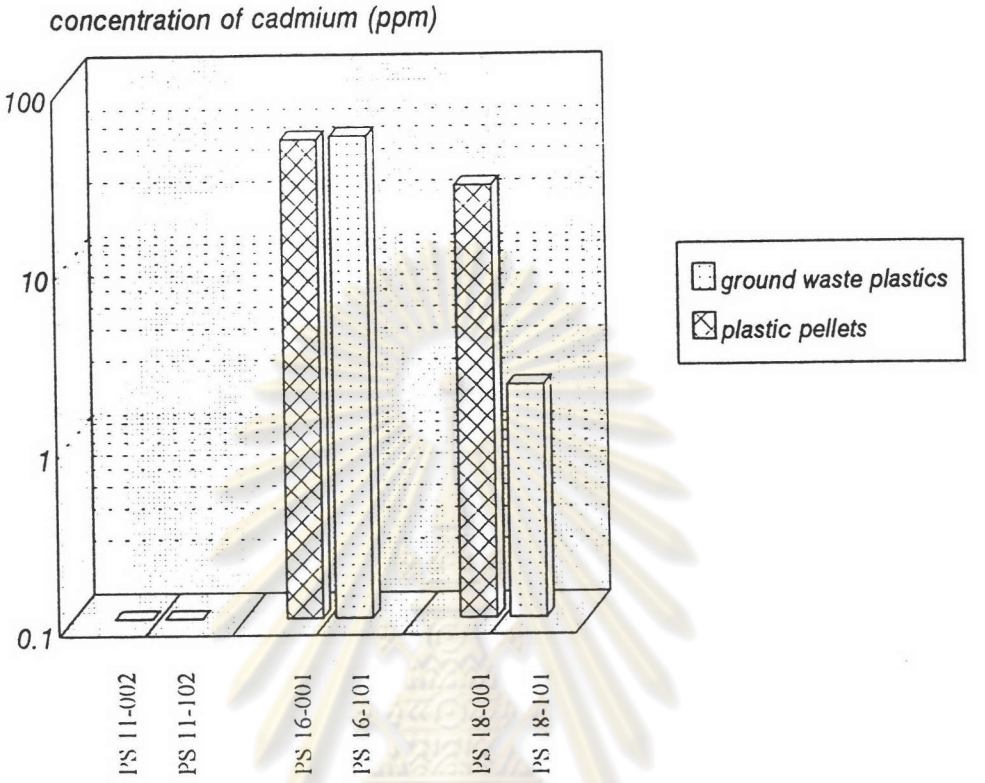

Figure 4.7 Comparision of cadmium content between recycled polystyrenes and ground waste polystyrenes.

In Figure 4.7, for sample pair of PS 18-001 and PS 18-101, cadmium content is increased, because of addition of colour in plastic during pelleting. For the other sample pair of PS 16-001 and PS 16-101, cadmium content decreased. This event shows that during pelleting, colour was added. The last sample pair of PS 11-002 and PS 11-102 is colourless due to no addition of colour in plastics.

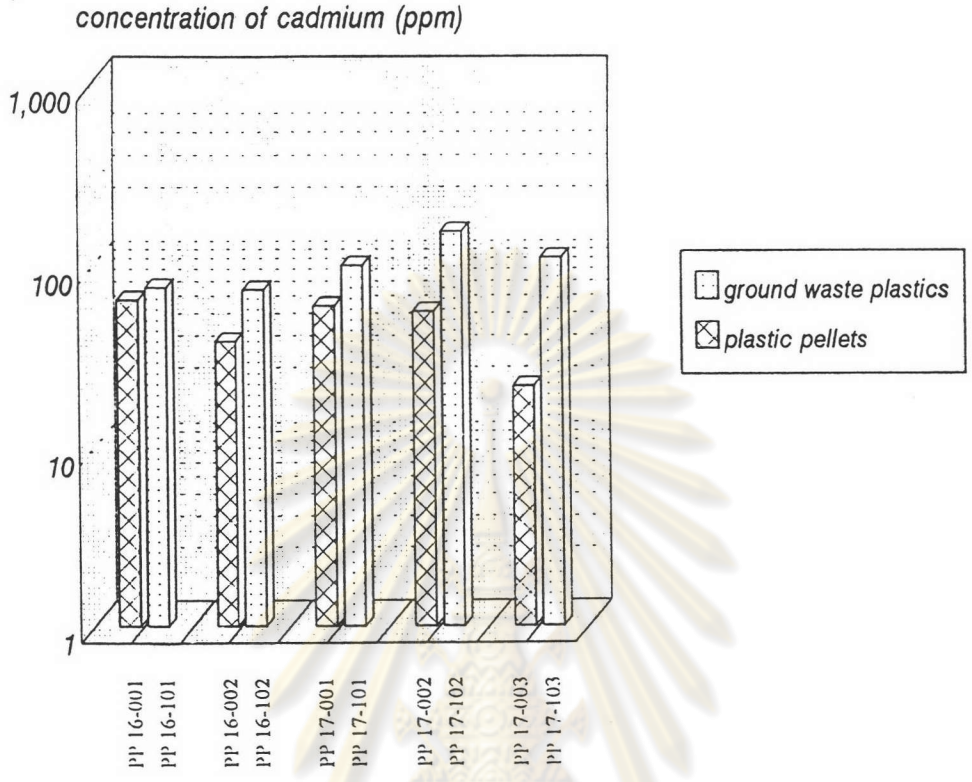

Figure 4.8 Comparision of cadmium content between recycled polypropylenes and ground waste polypropylenes

In Figure 4.8, for all polypropylene pairs, cadmium content decreased as plastics passed through the pelleting machine. This may be caused by vaporization of cadmium.

3.3. Quantity of Mercury

Mercury was measured quantitatively by cold vapour technique atomic absorption spectrophotometer. This technique incorporates hydride system. The quantity of mercury in virgin polymers, recycled plastics, ground waste plastics are presented in Table 4.11, Table 4.12, and Table 4.13, respectively. Comparison of recycled pellets and ground waste plastics is shown in Figure 4.9, Figure 4.10, and Figure 4.11, respectively.

According to Table 4.11, there is no mercury in virgin resins

Table 4.11 Quantity of mercury in virgin resins.

Item	Content of mercury (ppb)
PE 35-001	0.00
PE 110-001	0.00
PP 15-001	0.00
PP 25-001	0.00
PS 111-001	0.00
PS 111-002	0.00

Table 4.12 Quantity mercury in recycled plastic pellets.

Item	content of mercury (ppb)
PE 12-001	0.00
PE 22-001	250.00
PE 14-001	0.00
PE 14-002	0.00
PE 14-003	0.00
PE 17-001	1003.80
PE 17-002	0.00
PE 11-001	0.00
PE 23-001	792.00
PE 33-001	822.00
PE 43-001	148.20
PE 53-001	1516.00
PE 63-001	1290.00
PE 13-001	19.60
PE13-002	0.00
PS 18-001	34.00
PS 11-001	358.00
PS 11-002	0.00
PS 16-001	876.00
PS 21-001	312.00
PP 16-001	509.20
PP 16-002	952.00
PP 17-001	456.80
PP 17-002	417.00
PP 17-003	602.00
PP 13-001	126.00

Table 4.13 Quantity of mercury in ground waste plastics.

Item	Content of mercury (ppb)
PE 13-101	34.00
PE 13-102	0.00
PE 11-101	0.00
PE 22-101	620.00
PE 17-101	36.00
PE 17-102	0.00
PS 11-102	506.00
PS 16-101	1198.00
PS 18-101	48.00
PP 16-101	34.00
PP 16-102	1280.00
PP 17-101	585.40
PP 17-102	202.00
PP 17-103	1026.00

Referring to Table 4.12 and Table 4.13, in all of recycled plastics and ground waste plastics, mercury content does not exceed limiting value of 100 ppm. Mercury can contaminate plastic by way of:

a. addition of colour[25]

b.municipal refuse consisting of battery, broken thermometer, amalgram, and so on.[24]

c. closure filling such as cosmetics, insectiside, etc.[26]

d. residue mercury in washing tank in the recycling plant

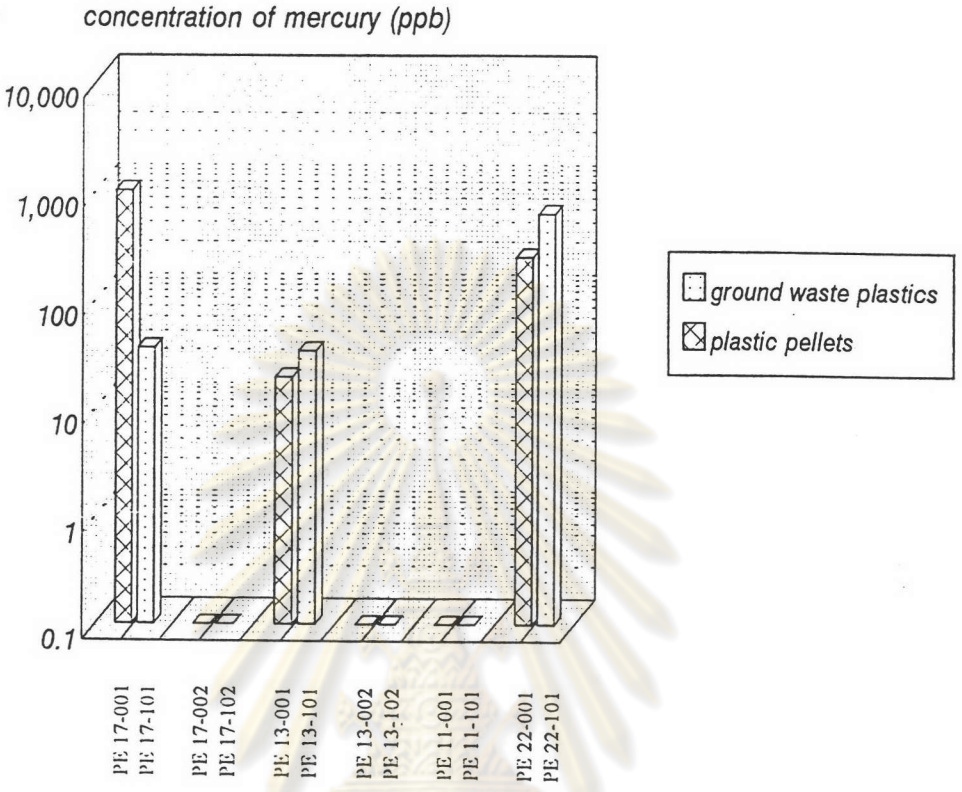

Figure 4.9 Comparision of mercury content betweeen recycled polyethylenes and ground waste polyethylenes.

Figure 4.9, Figure 4.10, Figure 4.11 compare contaminants in various ground waste plastics and recycled pellets from pelleting machines.

In Figure 4.9, for sample pairs of PE 13-001 and PE 13-101 and PE 22-001 and PE 22-101, amount of mercury decreased as plastic passed through the pelleting machine. This may be caused by vaporization of mercury. Mercury in the sample pair of PE 17-001 and PE 17-101 increased due to the colour additive was added. The colour of PE 17-001 is red.

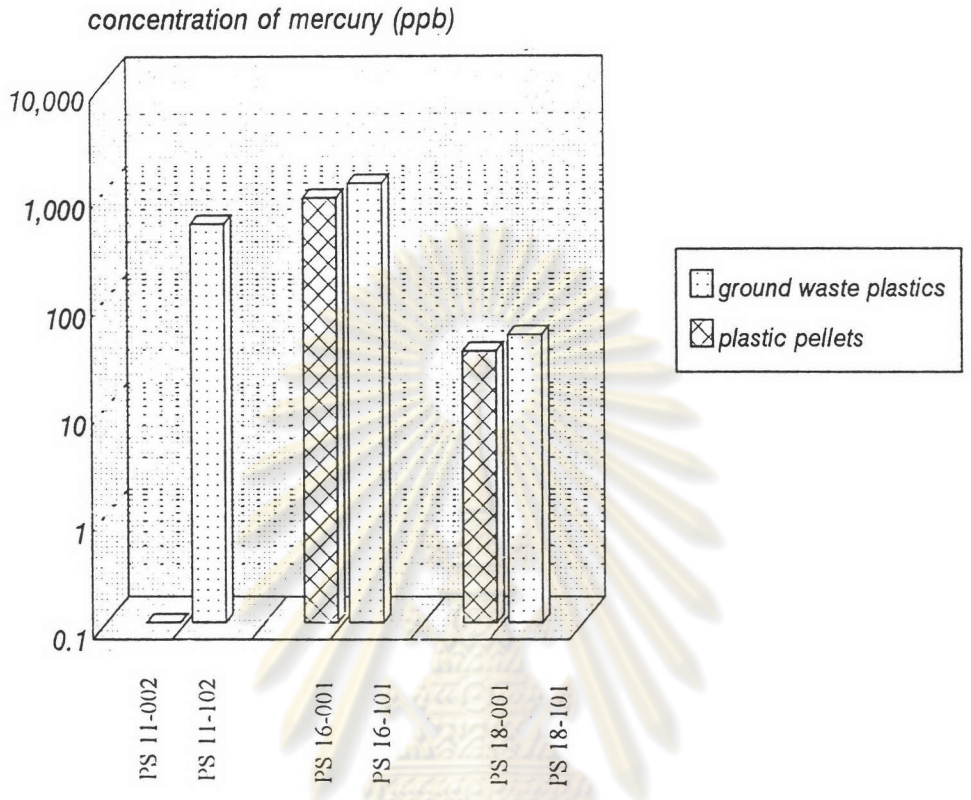

Figure 4.10 Comparision of mercury content between recycled polystyrenes and ground waste polystyrenes.

Figure 4.10 shows that, in all polystyrene pairs of PS 18-001 and PS 18-101, PS 11-002 and PS 11-102, and PS 16-001 and PS 16-101, mercury content decreased when those plastics passed through the pelleting machine. This may be caused by vaporization of mercury.

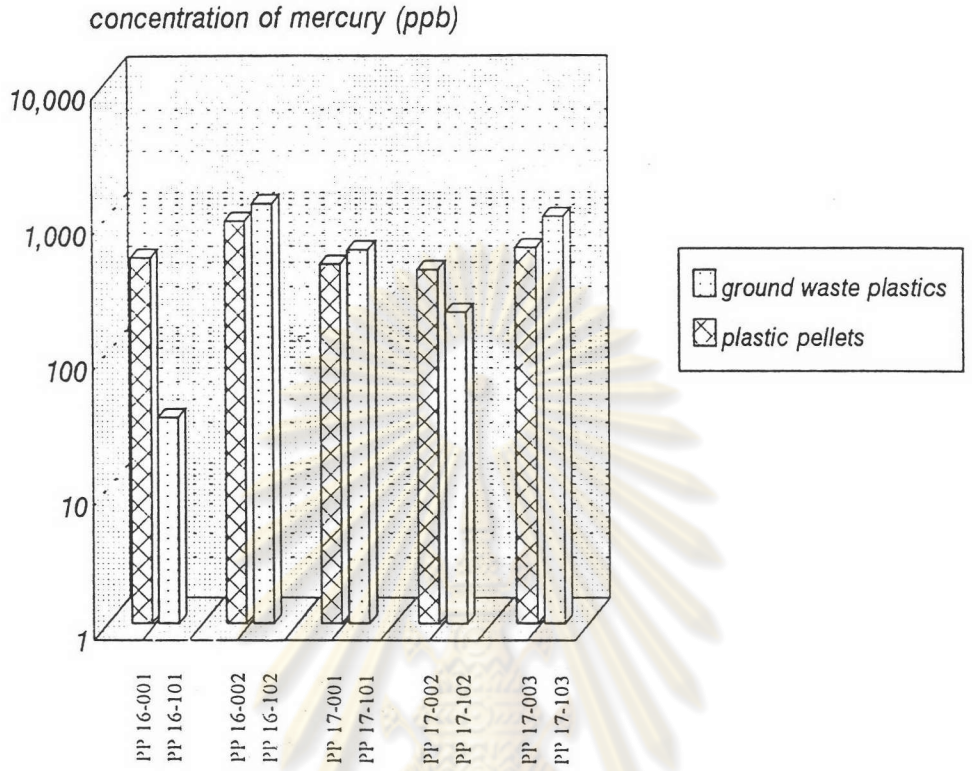

Figure 4.11 Comparision of mercury content between recycled polypropylenes and ground waste polypropylenes.

For Figure 4.11 reveal that, in sample pairs of PP 16-001 and PP 16-101 and PP 17-002 and PP 17-102, mercury content increased due to addition of colour. In the other three sample pairs, mercury content increased as they passed through the pelleting machine. This may be caused by vaporization of mercury.

3.4. Quantity of Styrene Monomer

Styrene monomer may come from either depolymerization of polystyrene or unreacted styrene from polystyrene plant. Styrene monomer which appeared can be harmful to consumers who use that plastic products. So it is essential to determine styrene monomer content by gas chromatography. Limited value of styrene monomer in packaging plastics (polyethylene, polypropylene, and polystyrene) equal 1000 ppm(mg/kg). GC chromatrogram of virgin polystyrene are shown in Figure 4.12 and Figure 4.13 and presented styrene monomer content in plastics is presented in Table 4.14.

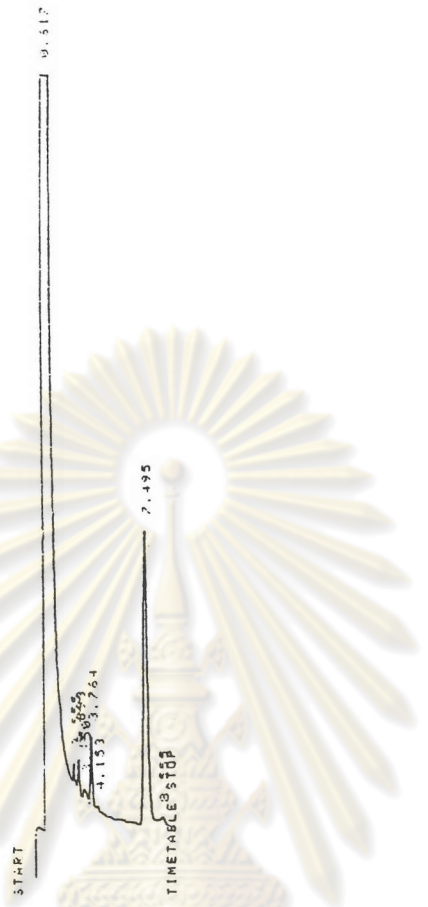

Figure 4.12 GC chromatogram of virgin polystyrene (PS 111-001).

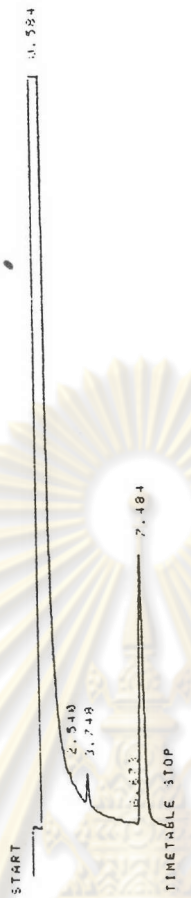

Figure 4.13 GC chromatogram of virgin polystyrene (PS 111-002).

Figure 4.12 and Figure 4.13 show peak area of styrene monomer (about 3.75) and other volatiles in virgin polystyrenes.

Table 4.14. Content of styrene monomer in polystyrene

Item	Plant No.	content of styrene monomer (ppm)
PS 111-001	5	1093.76
PS 111-002	5	921.90

According to Table 4.14, PS 111-002 had less styrene monomer content than limited value. The other polystyrene styrene monomer content exceed the limited value. The styrene monomer content may be obtained from the followings :[27]

a. unreacted styrene monomers.

b. polystyrene can degrade during fabrication.

GC chromatrograms of recycled plastics are shown in Figure 4.14, Figure 4.15, Figure 4.16, Figure 4.17 and Figure 4.18, respectively, and styrene monomer content is presented in Table 4.15.

Figure 4.14 GC chromatogram of recycled polystyrene (PS 18-001).

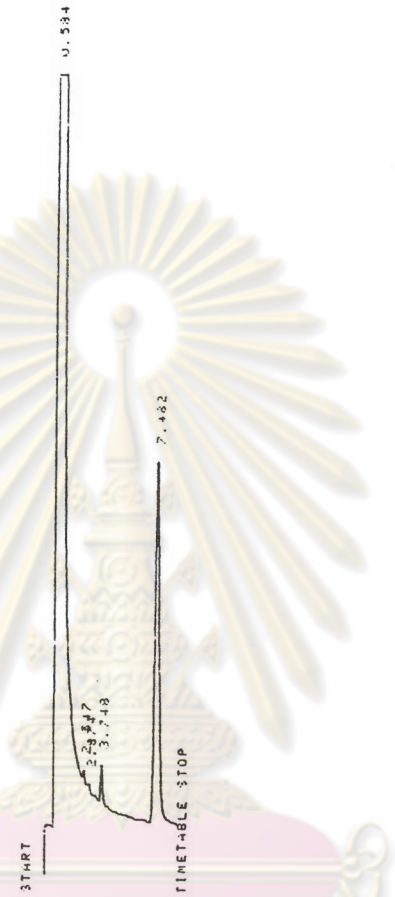

Figure 4.15 GC chromatogram of recycled polystyrene (PS 11-001).

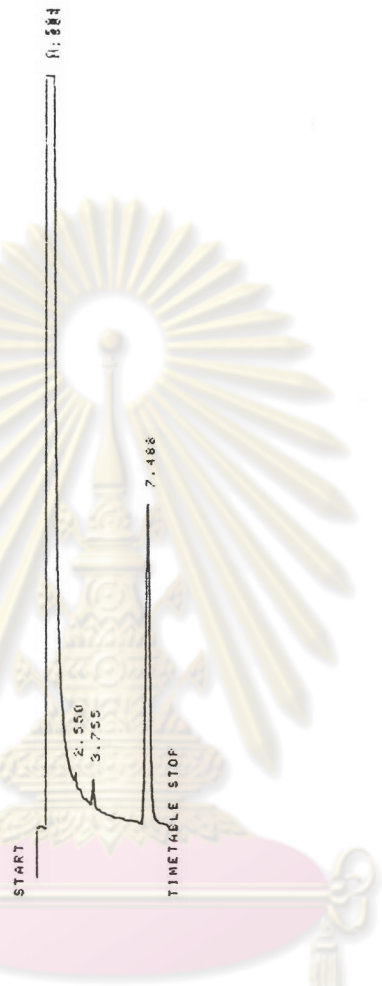

Figure 4.16 GC chromatogram of recycled polystyrene(PS 11-002).

Figure 4.17 GC chromatogram of recycled polystyrene (PS 16-001).

Figure 4.18 GC chromatogram of recycled polystyrene (PS 21-001).

Table 4.15 Styrene monomer content in recycled polystyrene pellets.

Item	Plant No.	Content of styrene monomer (ppm)
PS18-001	8	859.35
PS 11-001	1	487.65
PS 11-002	1	496.95
PS 16-001	6	537.45
PS21-001	1	931.20

All recycled polystyrenes contain less amount of styrene monomer than the limited value (1000 ppm). During production of this recycled polystyrene, due tohigh temperature (200°C) degradation of polystyrene occur resulting in , then styrene monomer as the product within recycled pellets. Furthermore, residued styrene monomers from processing is not complete.

GC chromatograms of a typical ground waste polystyrenes were shown in Figure 4.19, Figure 4.20, and Figure 4.21. Styrene monomer content is presented in Table 4.15.

Figure 4.19 GC chromatogram of ground waste polystyrene(PS 18-101).

Figure 4.20 GC chromatogram of ground waste polystyrene (PS 11-102).

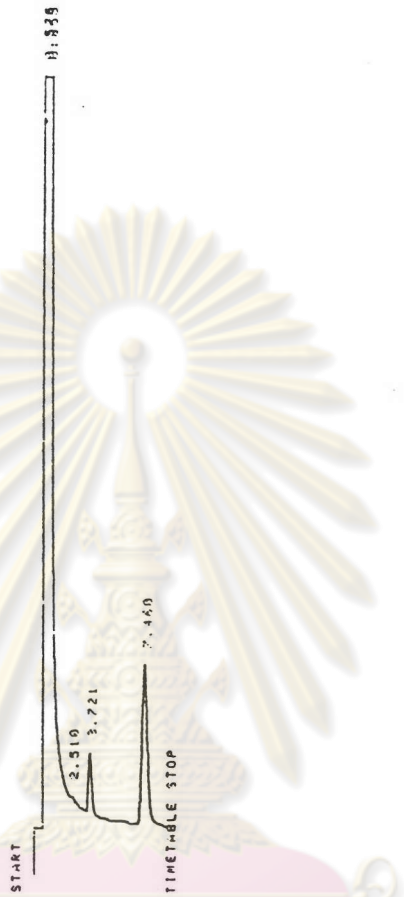

Figure 4.21 GC chromatogram of ground waste polystyrene (PS 16-101).

Table 4.16 Styrene monomer content in ground waste polystyrene.

Item	Plant No.	Content of styrene monemer (ppm)
PS 18-101	8	912.45
PS 11-102	1	424.95
PS 16-101	6	1840.65

According to Table 4.16, both PS 18-101 and PS 11-102 have less styrene monomer content than the limited value. The other has more styrene monomer content than limited value.

Styrene monomer content of recycled polystyrene pellets compared to that of ground waste polystyrene is shown in Figure 4.22.

Referring to Figure 4.22, for sample pairs of PS 18-001 and PS 18-101, amount of styrene monomer decreased as plastic passed through the pelleting machine. This may be caused by vaporization of styrene monomer. In the other pairs of sample (PS 11-002 and PS 11-102 and PS 16-001 and PS 16-101), there was an increase in styrene monomer content as plastic passed through the pelleting machine. This is because of the fact that polystyrene can degrade.

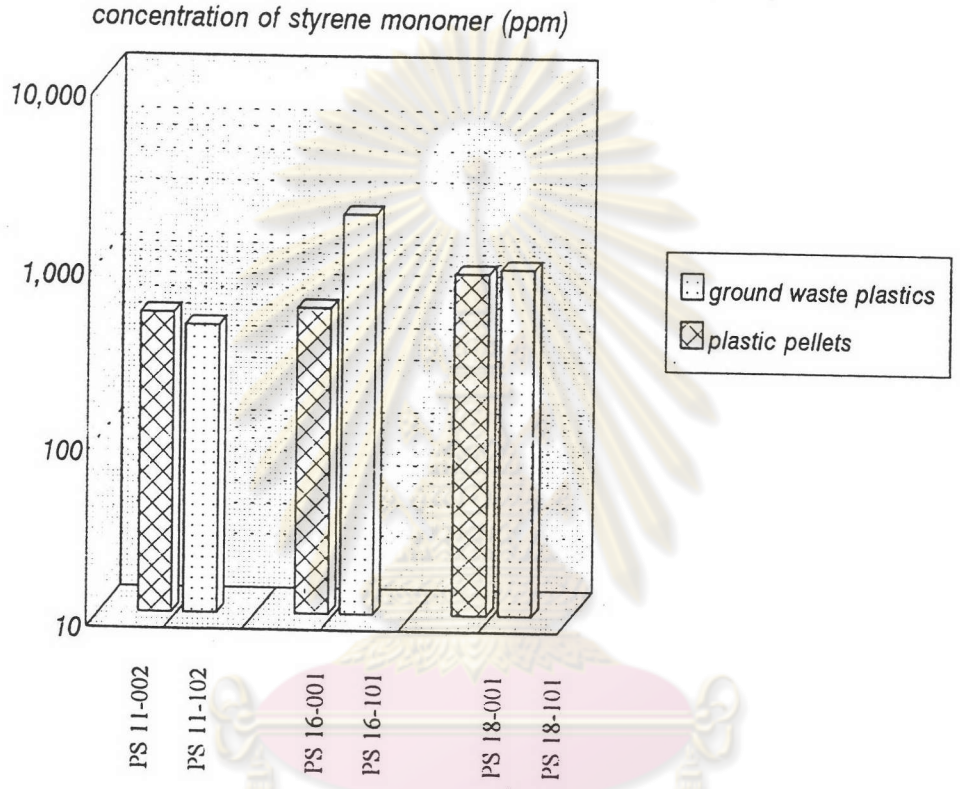

Figure 4.22 Comparision styrene monomer content between recycled polystyrene and ground waste polystyrene.