CHAPTER IV

RESULT AND DISCUSSION

4.1 Plants Search

In the beginning of this work, the Industrial Work Department , Industries Ministry and the Association of Thai Plastic Industrial were contacted to obtain lists of factories. The lists contain mostly plastic fabricators, only a few of plastic waste processing plants are found. Some of these plastic waste processing plants were later found to be no longer in operation.

Most plastic waste processing plants are small and are not registered officially. Knowledge of their existence is limited to only a few people involved in the plastic waste business. Therefore, strong effort was needed to find out these plants and their locations. Most plasic waste dealers did not reveal where they sold their goods. However, the areas in which these plants located were studied and searching was carried out. All plants found are located in lanes.

The plant and market data obtained in this work, fullfill most of the original plan but not completely. This is due to: (a) plant owners revealed only some of their data, for example, the operating cost, and their customers were kept in secret. (b) In some cases, cooperation was not given by plant owners. (c) Most plant owners do not possess scientific background. Some learn their knownhow through experience. So they do not understand the importance of research.

By observation and interview, all the recycle resin plants are small and similar. The data obtained in this work, though from few plants, are believed to be typical data representing the plastic recycling industry.

4.2 Waste Collection

Plastic recycling plants aquire their raw material , plastic waste, from plastic waste dealers who in turn purchase plastic waste from small dealers and street collectors.

4.2.1 Sources of Plastic Waste

4.2.1.1 Municipal Disposal Sites

There are three municipal disposal sites ; namely, Nong-Khaem, On-Nooch, and Ram-Intra as described in chapter II.

4.2.1.2 Street Collectors

Street collectors collect plastic waste from residential area, offices, cafeteria, etc.

4.2.1.3 Plastic Fabricating Plants

Normally, there are middle men purchase plastic waste and scrap which are generated by plastic fabricating plants, and sell them to plastic recycling factories.

4.2.2 Types of Plastic Waste

There are various types of plastic waste; namely, high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), acrylonitrile - butadiene - styrene (ABS), poly(ethylene terephthalate) (PET), and poly (vinyl chloride) (PVC).

Table 4.1 (36) shows the types of polymer or resin of which common plastic goods are made. The local plastic recycling plants deal only HDPE, LDPE, PP, PS, ABS, and PVC. PVC recycling activity is very limited due to harmful vapor generated during PVC processing. No local recycling plants are known to recycling PET due to difficulty in reprocessing.

Table 4.1 Plastic Goods

Polymer	Goods
HDPE	bottles for medicine, foodstuff and shampoo
	petrol tanks, chemical tanks
	plastic pipes and joints
	insulation for electrical wire and cables
	household gas and water pipes
	shopping bags
	hot foodstuff bags
	rope, net, mesh
	basket
	bowl
	packaging for cosmetic
	brush
	mat
	shoes
	drinking water bottles
	button
	batteries
LDPE	plastic bags for frozen food
	kitchenwares
	plastic bags for industrial use
	multi-purpose bags, hot and cold foodstuff bags

Table 4.1 continued

Polymer	Goods
LDPE	plastic flowers
	plastic sheets for basin lining
	toothpaste tube
	toys
	brush
PP	toys
	carpet fabric
	clothing bags
	kitchen ware
	fertilizer bags
	drinking straws
	wire insulation and cables
	batteries
	furniture
	shoes
	basin
	bottles
	fishing net
	car bumper
	PVC pipes, hoses, and joints
	vegetable oil bottles
	chemical pipes for industrial use

Table 4.1 continued

Polymer	Goods
PVC	insulation for electrical wire
	plastic sheet for basin lining
	artificial leather
	floor rubber sheet
	household rubber sheet, tent
	shoes
	car bumper
	wallpaper
	pool-pondlines
	tape connectors
PS	tape cassette
	toys
	tray
	batteries
	cups
	handlecups
	plates
	clamshell
	packaging material
	plastic food utensils
	clear plastic food containers

Table 4.1 continued

Polymer	Goods
ABS	furniture
	tray
	packaging for cosmetic
	automobile
	batteries
	camper tops
	toys
	pipe and joints
	television frame
	telephone
PET	washbasin
	drinking water bottles
	dual-ovenable foodtrays
	electrical wire and cables
	textiles
	plates
	cups

4.2.3 Percentage of Each Plastic Type in Waste

Table 4.2 shows the composition of plastic waste from On-Nooch and Nong-Khaem areas. The data shows that the composition of plastic waste in these two areas are rather similar.

Table 4.2 The composition of plastic waste from On-Nooch and Nong-Khaem.

Type of Plastic	Percent of waste at On-Nooch		Percent of waste at Nong-Khaem	
	Dealer No.1*	Dealer No.2*	Dealer No.1**	Dealer No.2**
PE				
Bottle			40	
- Color	15	15	-	30
- Colorless	35	35	-	20
Nonbottle	15	15	15	14
PP	15	30	15	16
PVC	-	5	20	20
PS	10	-	-	-

* Date of sample collection : 17-07-92

** Date of sample collection : 15-01-93

4.2.4 Price of Plastic Waste

At waste disposal site, plastic waste cost about two baht/kg. Street collectors purchase from household at 1-2 baht/kg. Post-consumer drinking water bottle are sold for 4-5 baht/kg.

4.3 Processing of Plastic Waste

From various plant visiting, the local plastic recycling process consist of several stages as shown in Figure 4.1.

4.3.1 Separation

Plastic waste is first, sorted to separate various generic types, namely, PE, PP, PS, and PVC. PE waste is further separated into bottle and non - bottle : PE of blow molding and injection grades.Then each single generic plastic waste is separated with respect to its color for example colorless, red, and blue.

Separation is accomplished by sight inspection of experience operators.

4.3.2 Grinding

After separation plastic waste is ground to smaller size of 0.5 - 2.5 cm. Appearance of ground plastic waste depends onthe original waste. For waste bottles, the ground plastic appears as flake of sheet. The grinding machines are small simple equipment of about 5 horse power and of local

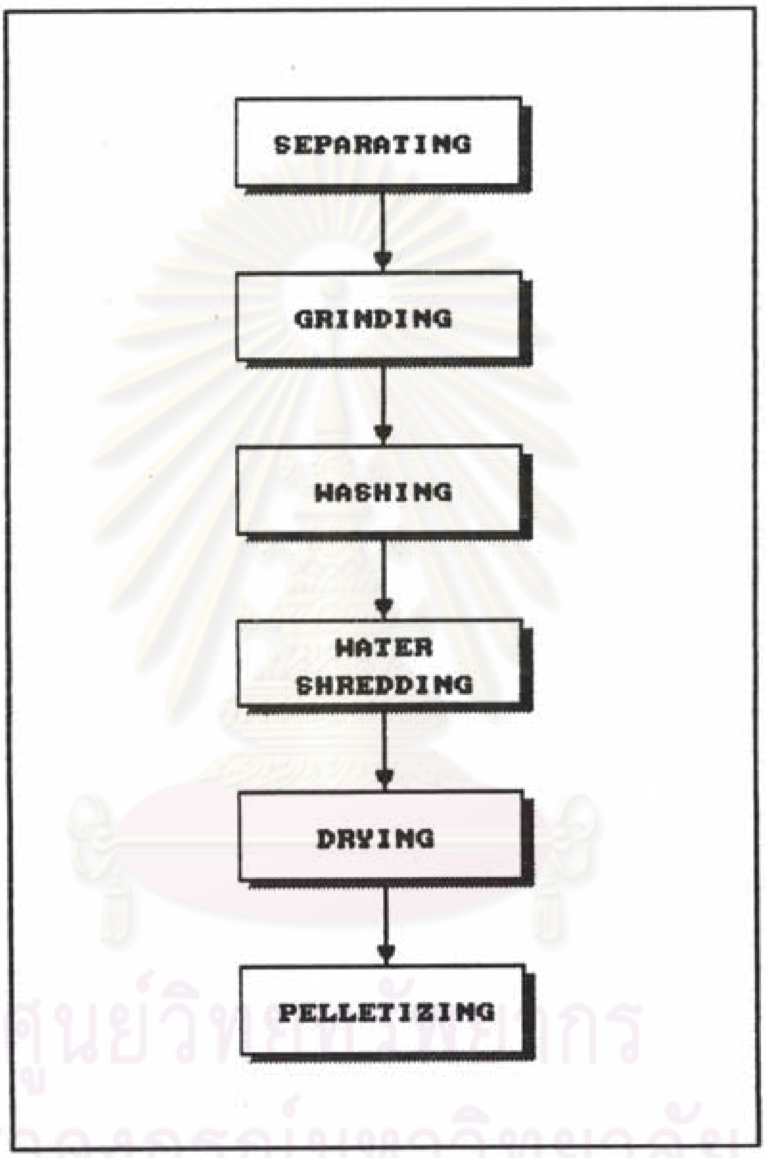

Figure 4.1 Processing of plastic waste

made.

4.3.3 Washing

Ground plastic is washed in a stirred tank with detergent and/or NaOH, then the ground plastic is transferred to a pond where it is leached. The pond is divided into two or three sections. The ground plastic is moved along the pond from the first section to the second section and then finally the third section.

4.3.4 Drying

The cleaned ground plastic from the pond is transfered into water shredding unit, to remove adhere water by centrifugal force. Then the ground plastic is dried in a dryer in which drying is accomplished by method of heat conduction, i.e., contact with hot surface. Heat is generated from either electricity or cooking gas. Dryers are of local made.

4.3.5 Pelletizing

The dried ground plastic is transferred into the hopper of a pelletizing machine. Usually pigment of the desired color is also added. The thread of plastic from the extruder is water-cooled before it goes to a cutting machine. A typical pelletizing machine is of 25 horse power and is made locally.

4.4 Structure of Plastic Recycling Industry

The local plastic recycling industry is labour intensive. Recycling plants are of small scale. These plants have been operating for years. The equipment are old and of local made. Investment is relatively low. Usually, a recycling plant does not cover the entire recycling process. A plant may have only grinding operation, while another plants have only pelletizing operation. Thus there are many parties involve in plastic recycling industry. The structure of local plastics recycling industry is shown in Figure 4.2

Street Collectors

Street collectors go from house to house to buy plastic waste and to sell them to waste dealers.

Waste Sorters

Waste sorters are municipal garbage collecting crew and those people live near the municipal waste disposal sites. They sort sellable plastic waste and sell them to waste dealers.

Waste Dealers

Waste dealers purchase waste from various plastic waste collectors which include street collectors and waste sorters. Some plastic waste are from far away provinces.

Waste dealers classified plastic waste with respect to generic types and sell them to grinders. The labour cost for classifing plastic waste is 0.2 baht/kg. Some waste dealers also operate grinding machines.

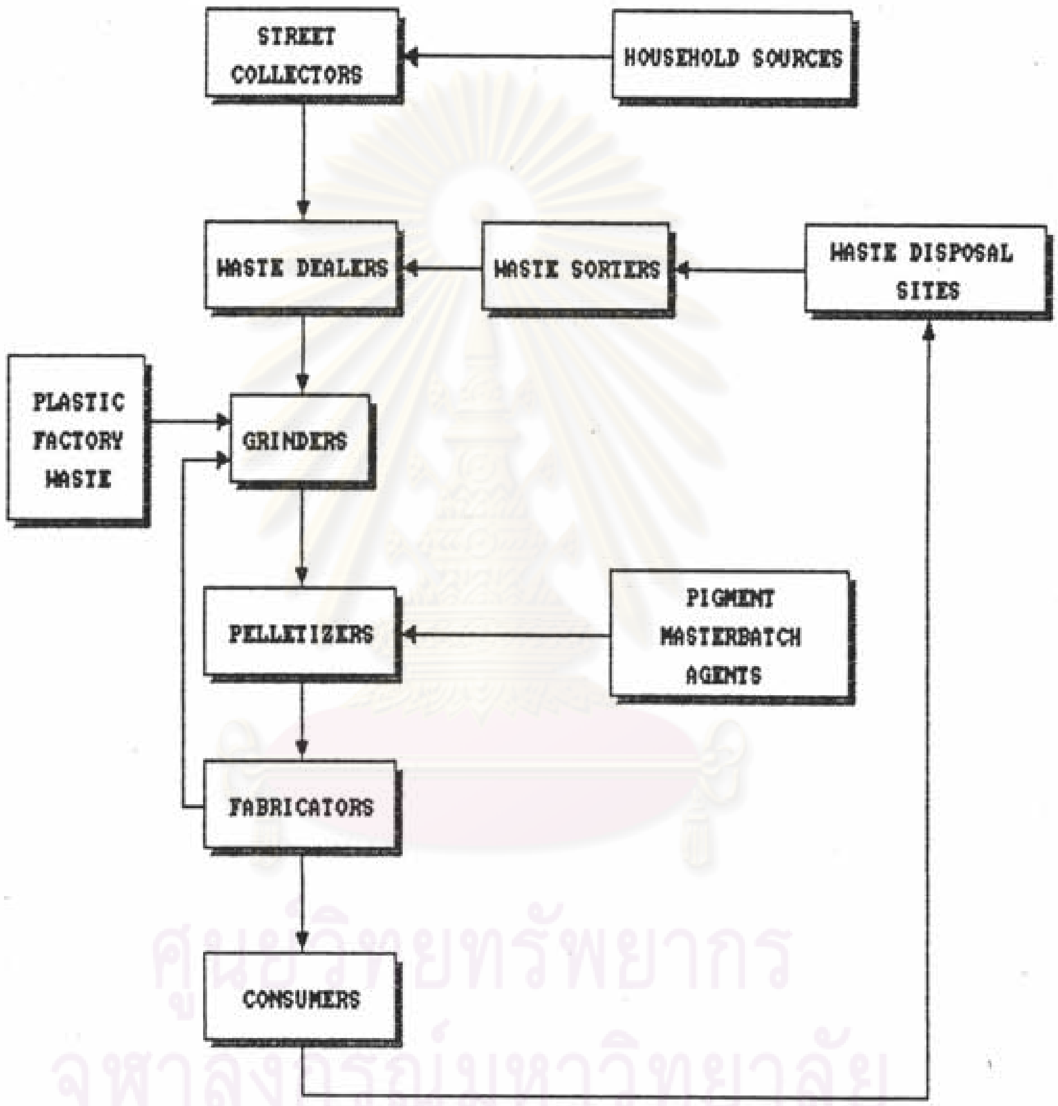

Figure 4.2 Structure of local plastic recycling industry

Grinders

Grinders obtain plastic waste from waste dealers and/or plastic fabricating plants. Plastic waste from fabricating plants may pass through middle man before it reaches the grinders. Upon receiving plastic waste, the grinders will involve five operations, namely, separation, grinding, washing, water shredding , and drying.

The grinders then sell the clean dry plastic to pelletizers. Some grinders also operate pelletizing machines themselves.

Pelletizing

Some pelletizers also own fabrication plants in which their own recycling pellets are consumed. The pelletizing plants and fabricating plants are not on the same compound.

4.5 Estimation of Quantity of Plastic Waste

4.5.1 Plastic Waste from Plastic Factories

Data obtained from plant visit are summerized and presented on Table 4.3. The plants are of various sizes ranging from 0.5 tons/day to 5,000 tons/year. However, most plants are relatively small with 2 or 3 extruders. Normally, one extruder of 25 horse power produces about two tons of products per day.

Percentage of in plant recycling vary from 0 to 30 while percentage of waste vary from 0 to 10. When percentage of in plant recycling is high, the percentage of waste is low. Waste usually consists of burned plastic and dirty plastic mostly contaminated with printing color.

Table 4.3 Characteristic of some local plastic plant

Plant No	Product	Capacity	Temperature (°C)	% In Plant	% Waste Recycle
1	Bowls, Basins, Baskets ,etc.	2-3 T/D	240-250	-	2-3
2	Bottles for Milk, Cosmetic, Lube oil, and Chemicals	3500 T/Y	-	30	negli-gible
3	Lube oil		180	20	5
4	Bottles for Drinking water, Lube oil, Caps, Fertilizer containers, Articles made to order	7 Blow molding machine	-	-	2
5	Bottles for Medicine, Articles made to order	15-20 T/M	175-250	9	1
6	Bottles for Lube oil, Cosmetic, medicine, and Chemicals	1200 T/Y	160-200	5	10
7	Bottles for Cosmetic, Medicine, and Agricultural Chemicals	90 HP	-	-	30
8	Pipe fitting, Articles made to order	>25 HP	-	10-15	< 1
9	Beverage bottles	3.5 T/D	245	0	0.2
10	Drinking water bottles	50 HP	170	10	1
11	Dringing water bottles	0.5 T/D	190	-	1

Waste mainly is caused by carelessness. It is felt that percentage of waste can be reduced. Therefore, a basis of one percent waste is used for estimating the quantity of waste from factories.

Annual consumption of HDPE and PP are 180,000 tons each (37). Consequently, it is estimated that plastic plants generate 1,800 tons of HDPE waste and 1,800 tons of PP annually.

4.5.2 Plastic Waste from BMA Collection Truck Crews and Open Dump Scavengers

Data obtained from waste dealers near the municipal dump sites are as follow :

- 3,500 tons/year at Nong - Khaem.
- 3,000 tons/year at On-Nooch.

Therefore, the total plastic waste is 6,500 tons/year near this two dump sites.

According to Table 4.2, about 30 % of plastic waste is of HDPE bottle, and another 15 % , PP. Therefore, the waste contains 3,250 tons/year HDPE bottles and 975 tons/year PP. Total PE and PP in the plastic waste is 4,225 tons/year.

4.5.3 Plastic Waste from Street Collectors

Table 4.4 shows percentage of various plastic waste belong to bulk plastic waste dealers and grinders. The percentage of HDPE bottle is about 60. The demand for bottle grade HDPE is 65,000 tons in 1992 (38) .

Accounting 1 % waste during fabricating, the total HDPE bottle is 64,350 tons/year. Assuming all this HDPE bottle were collected by the street collectors and truck crews and open dump scavengers. HDPE bottles collected by street collectors is 64,350 - 3,250 = 61,100 tons.

By Table 4.4, total plastic waste of HDPE and PP collected by street collectors is 71,300 tons of which 10,200 tons being PP.

The quantities of HDPE and PP waste is concluded in Figure 4.3 and Table 4.5

4.5.4 Quantity of Colorless Bottles in Plastic Waste

By Table 4.2, quantities of colorless bottle collected by truck crews and open dump scavengers is 2,275 tons/year.

By Table 4.4, quantities of colorless bottle collected by street collectors is 25,500 tons/year.

4.5.5 Plastic Waste at Municipal Waste Disposal Sites

Plastic waste at municipal waste disposal site is of no value, i.e., not sellable. These plastic waste consists mainly ofbags, and other items made of either PET or thermoset. Bags have a very high value in surface area to weight ratio, and gather too much dirt to be recycled economically. PET and thermoset are not recycled by local recycling plants.

From Table 2.2, the percentage of plastic in municipal waste is 7.5 in 1982, which lies in the range of 2 to 10 % for industrialized countries (Table 2.4). Therefore, the present percentage of plastic in municipal waste is assumed to be 7.5. With a waste generation rate of 6,000

Table 4.4 Percentage of various plastic waste from waste dealers and grinders

Type of plastic	Percent of waste at On-Nooch	Percent of waste at Nong-Khaem
PE		
Bottle		
- Color	50	25
- Colorless	20	25
Nonbottle	-	10
PP	15	10
PVC	-	10
PS	-	10

Table 4.5 Quantities of HDPE and PP waste from plastic fabricating plants, municipal waste sites, and street collectors (Tons per year)

Type of plastic	Plastic fabricating plants	Municipal waste sites	Street collectors	Total
HDPE	1,800	3,250	61,100	66,150
PP	1,800	975	10,200	13,950
Total	3,600	5,200	71,300	80,100

tons per day, the plastic waste at the disposal site weight 450 tons per day or 164,250 tons per year.

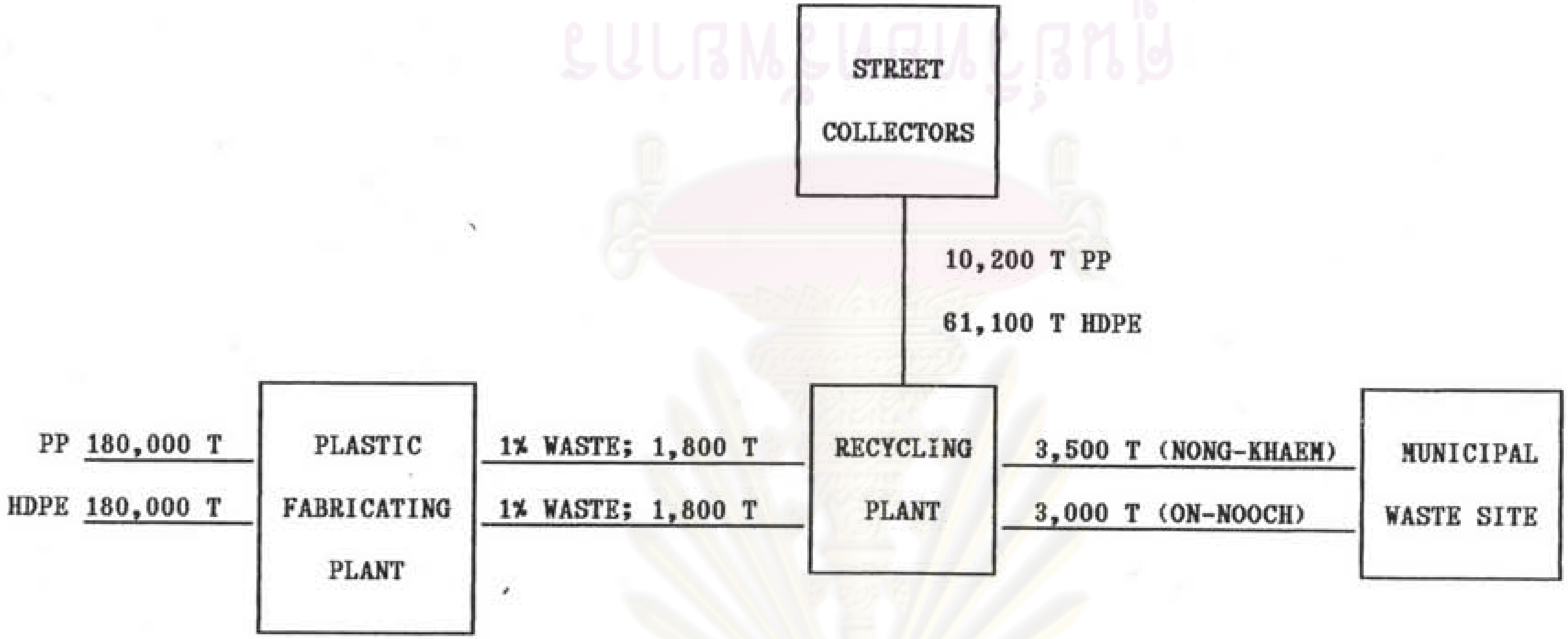

Figure 4.3 Diagram of quantities of HDPE and PP waste

4.6 Quality of Waste Sorting

Plastic waste comprises various types of plastics ; mainly PE,PP, PS, and PVC. Therefore, waste sorting is required in the plastic recycling process. Good quality of sorting is desirable. If sorting is done well, recycling resin should contain only single type of plastic.

In this work, samples of recycling pellets were subjected to Differential Scanning Calorimetry (DSC) experiment in order to identify the type of plastics. In addition, the experiment can reveal if only homopolymer or polymer mixture exist in the recycling pellets. Thus, the quality of waste sorting can be determined. The sorting is poor, if recycling pellets contain mixture of various types of polymers. However, in some cases, no effort is spent to separate different types of plastics. More over, there are cases in which different types of plastics are mixed to increase the quality ; for example, HDPE and LDPE are mixed.

Table 4.6 shows the list of virgin resin of various types and grades provided by TPI. Their thermograms generated by DSC are shown in Figures 4.4-4.12. These thermograms were used later as reference for identifying the types of recycling pellets. The thermograms show that the melting temperature (Tm) of HDPE lies within 126.68 ^{o}C to 130.10 ^{o}C (see Figure 4.4 - 4.8); that of LDPE lies within 104.11 ^{o}C to 107.46 ^{o}C (see Figure 4.9- 4.10) and that of PP lies within 161.68 ^{o}C to 162.39 ^{o}C (see Figure 4.11-4.12). The thermogram in Figure 4.11 is that of the homopolymer while the thermogram in Figure 4.12 is that of the copolymer of PP and PE. Here, there are two peaks, the large one at 162.39 ^{o}C is that of PP and the small one at 125.56 ^{o}C indicating the present of PE.

DSC experiment were then conducted for recycling pellets from four recycling plants listed in Table 4.7. This table also shows the types of plastic waste from which the pellets were made of. The thermograms of these recycling pellets are presented in Figures 4.13-4.25. Tables 4.8 and 4.9 present a summary of the results.

Table 4.6 Virgin resins in DSC tests

Sample No.	Polymer	Application	Grade	Thermogram appears in Figure
PE15-001	HDPE	Blow molding	TPI, G2855	4.4
PE25-001		Blow molding	TPI, GG2745	4.5
PE35-001		Blow molding	TPI, GM2860	4.6
PE45-001		Film extrusion	TPI, A3355	4.7
PE55-001		Injection - molding	TPI, V1160	4.8
LDPE15-001	LDPE	Film extrusion	TPI, JJ4324	4.9
LDPE25-001		Injection-molding	TPI, ST1018	4.10
PP15-001	PP	Autoparts (Copo)	TPI, 2502H	4.12
PP25-001		Sheet for file (Homo)	TPI, 1102H	4.11

Table 4.7 Recycled plastic pellets in DSC tests

Sample No.	Polymer (expected)	Plant No.	Form of Waste	Date of Production	Thermogram appears in Figure
PE12-001	HDPE	2	Fish containers	03-06-92	4.13
PE22-001	HDPE	2	Orange baskets and others	03-06-92	4.14
PE13-001	HDPE	3	Water bottle	17-07-92	4.15
PE23-001	HDPE	3	Container, Basin	17-07-92	4.16
PE33-001	HDPE	3	Basin	17-07-92	4.17
PE43-001	HDPE	3	Powder bottle and others	17-07-92	4.18
PE53-001	HDPE	3	Powder bottle and others	17-07-92	4.19
PE63-001	HDPE	3	Powder bottle and others	17-07-92	4.20
PE73-001	HDPE	3	Powder bottle and others	17-07-92	4.21
PE14-001	HDPE	4	Water bottle	29-07-92	4.22
PP13-001	PP	3	Basket and others	17-07-92	4.23
PS11-001	PS	1	Beverage bottle	03-06-92	4.24 (a),(b)
PS21-001	PS	1	Beverage bottle	03-06-92	4.25 (a),(b)

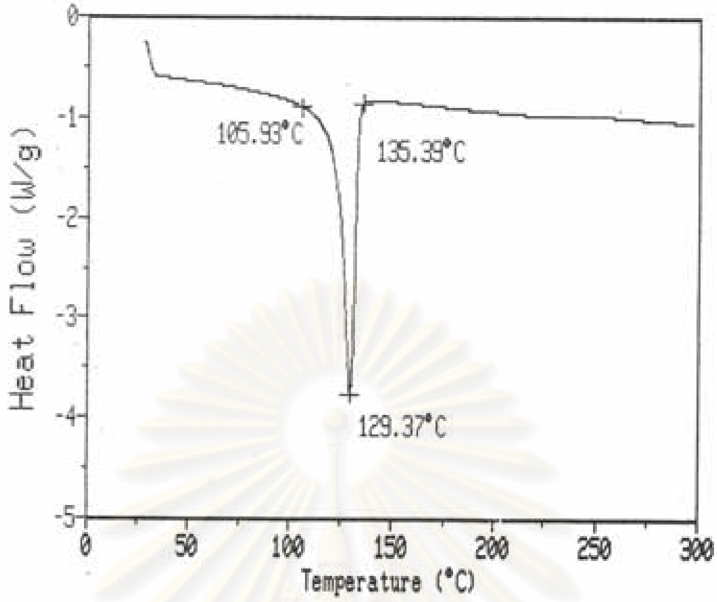

Figure 4.4 Thermogram of virgin HDPE (PE15-001)

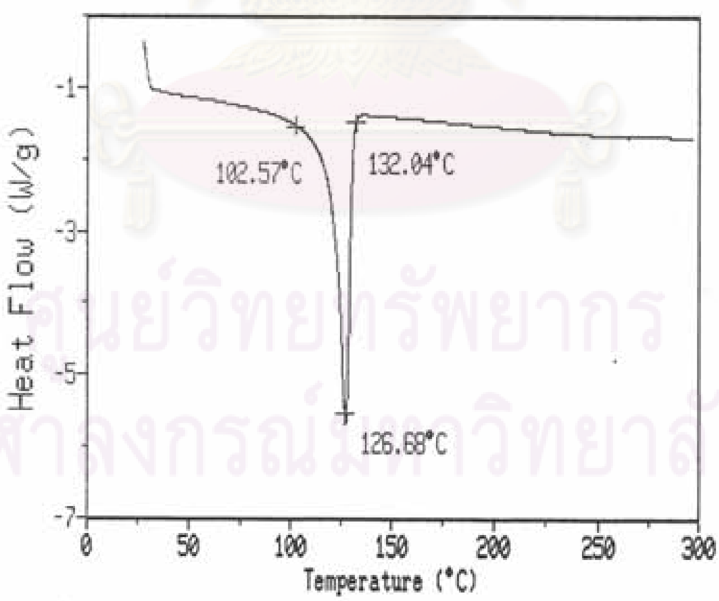

Figure 4.5 Thermogram of virgin HDPE (PE25-001)

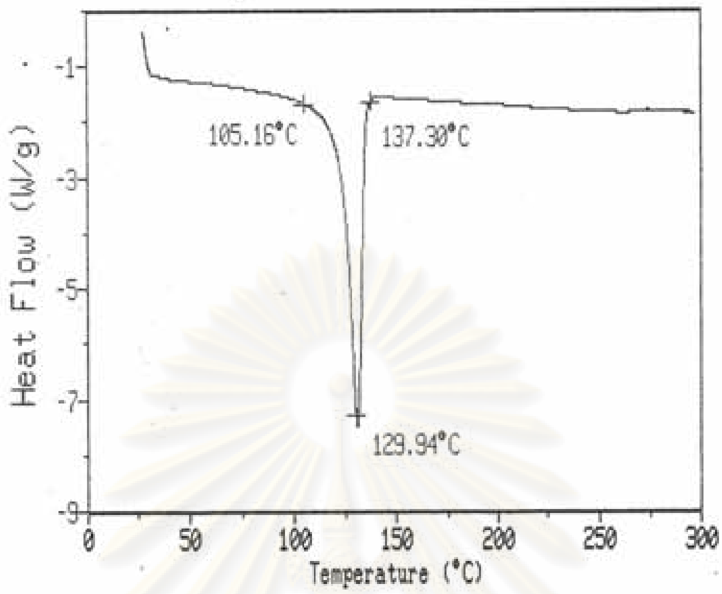

Figure 4.6 Thermogram of virgin HDPE (PE35-001)

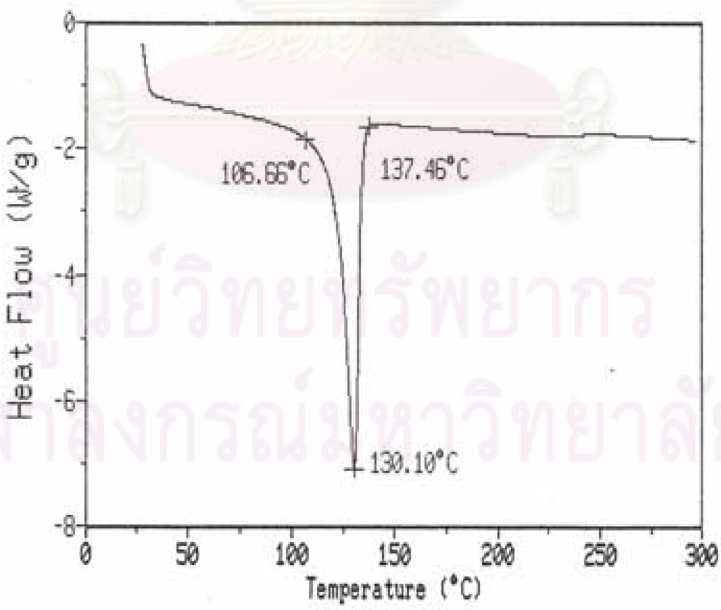

Figure 4.7 Thermogram of virgin HDPE (PE45-001)

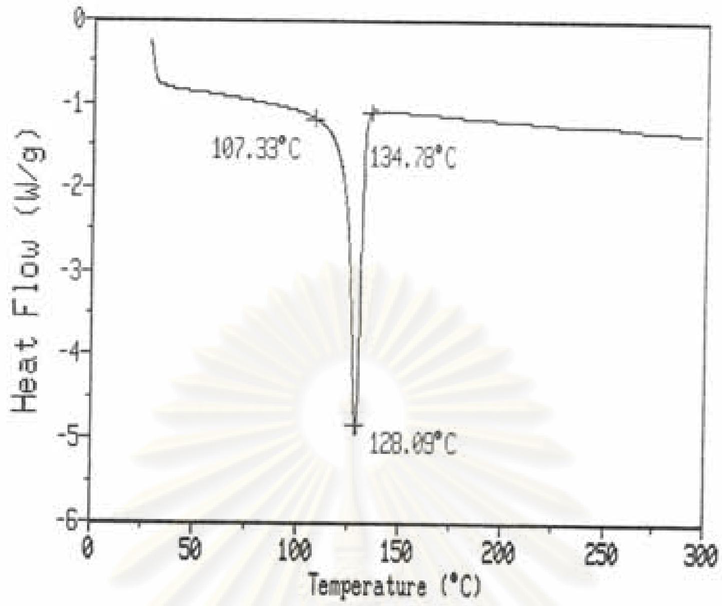

Figure 4.8 Thermogram of virgin HDPE (PE55-001)

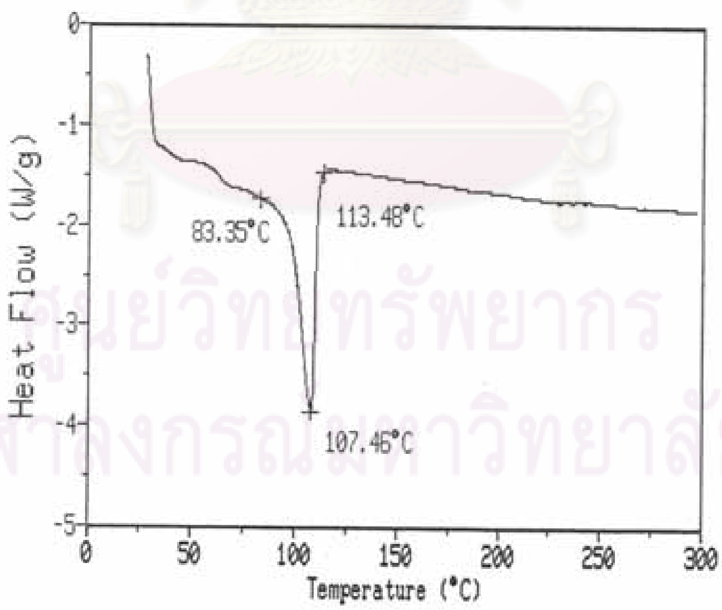

Figure 4.9 Thermogram of virgin LDPE (LDPE15-001)

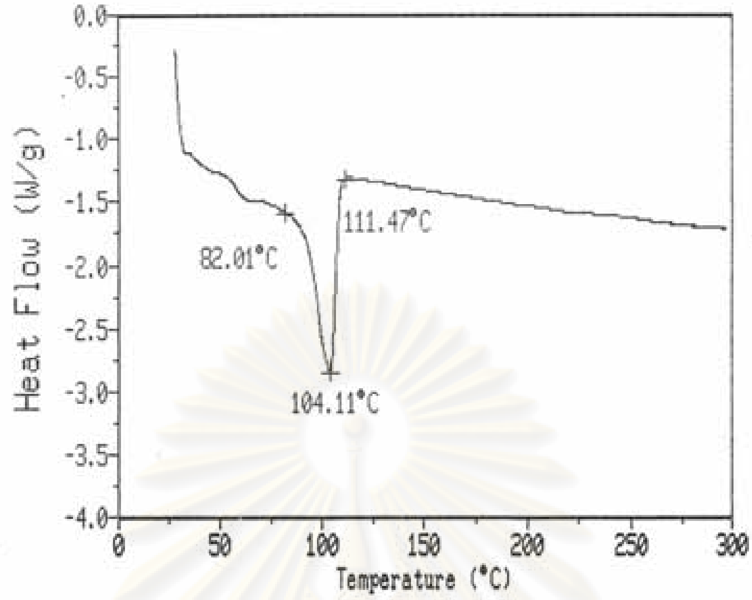

Figure 4.10 Thermogram of virgin LDPE (LDPE25-001)

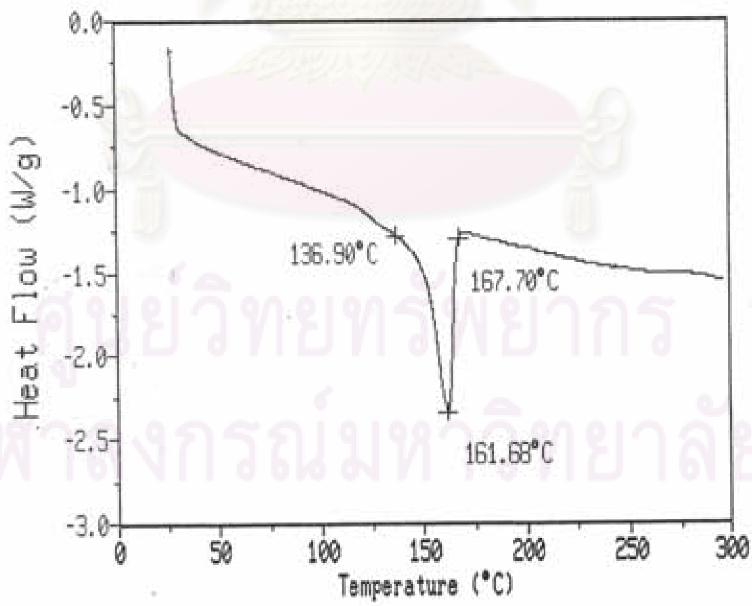

Figure 4.11 Thermogram of virgin PP (PP25-001)

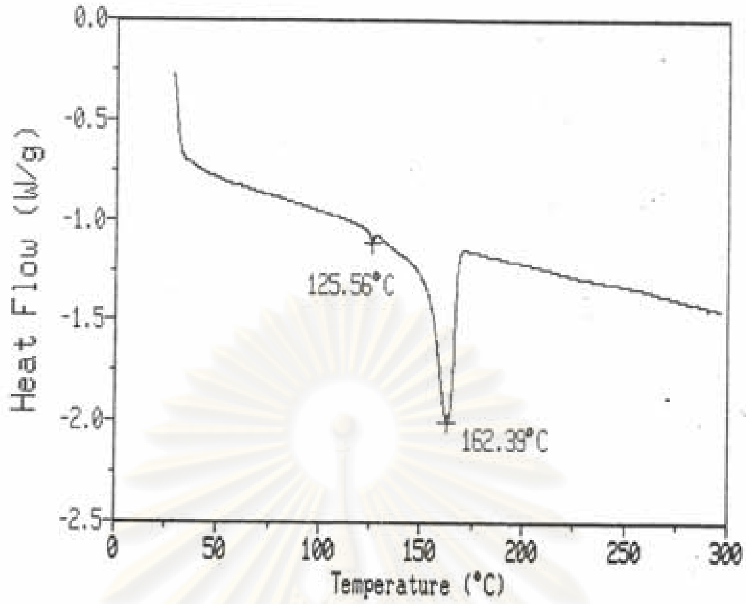

Figure 4.12 Thermogram of virgin PP (PP15-001)

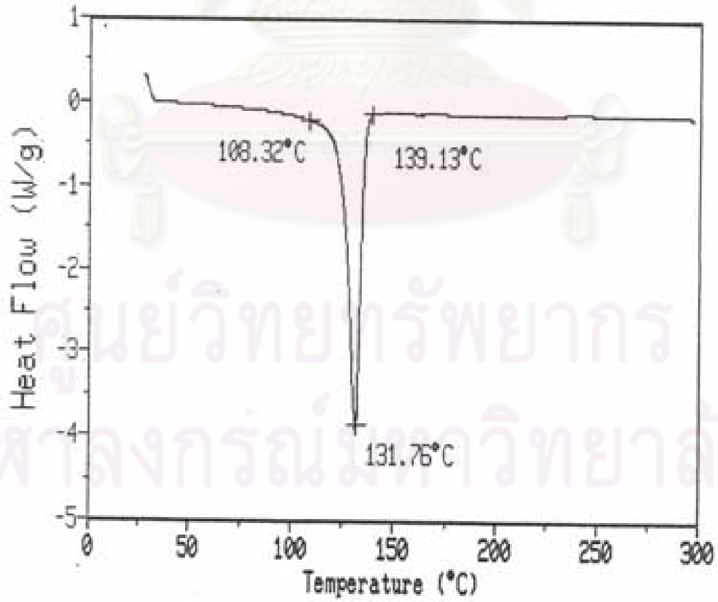

Figure 4.13 Thermogram of recycled HDPE (PE12-001)

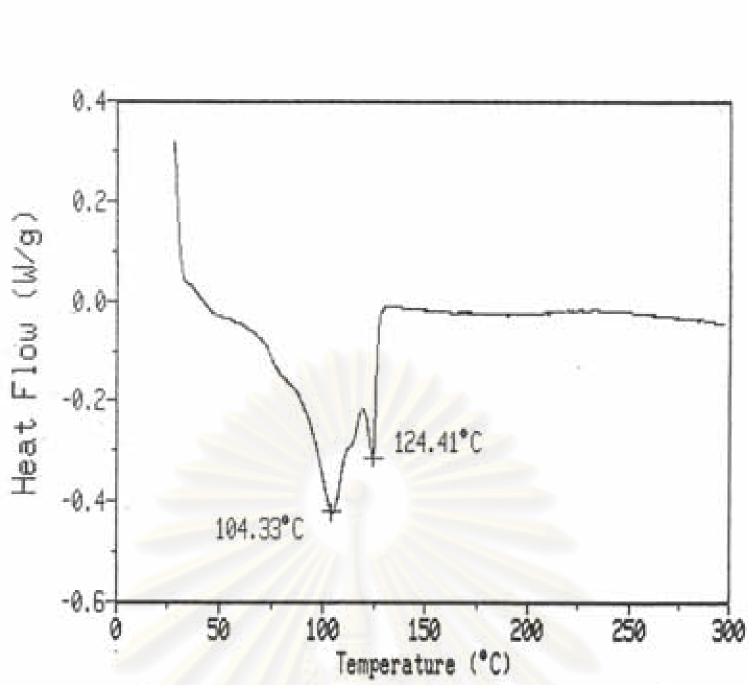

Figure 4.14 Thermogram of recycled HDPE (PE22-001)

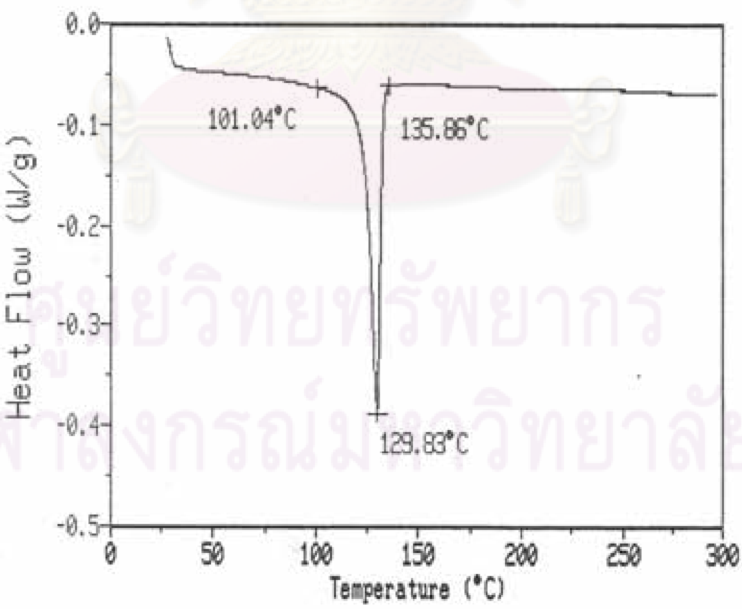

Figure 4.15 Thermogram of recycled HDPE (PE13-001)

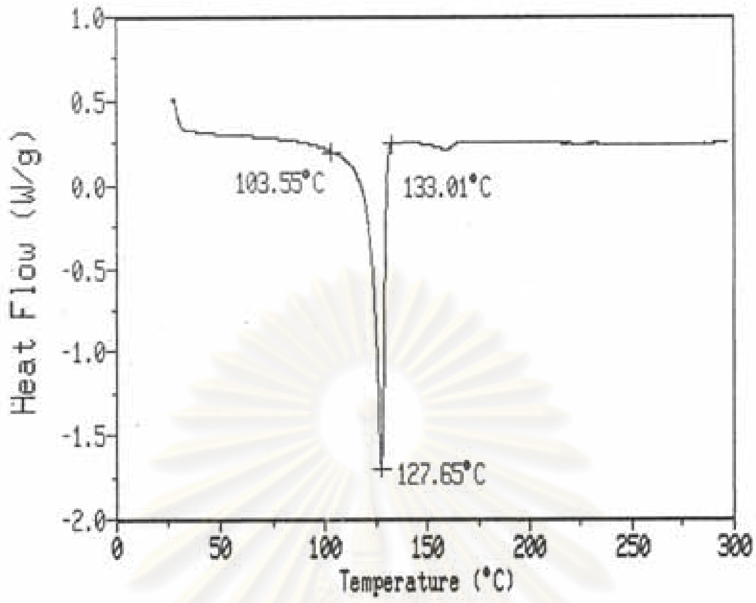

Figure 4.16 Thermogram of recycled HDPE (PE23-001)

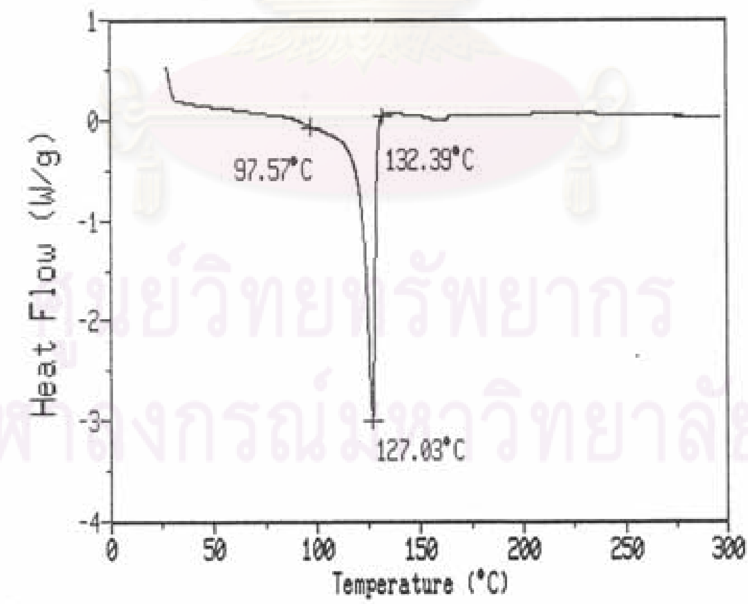

Figure 4.17 Thermogram of recycled HDPE (PE33-001)

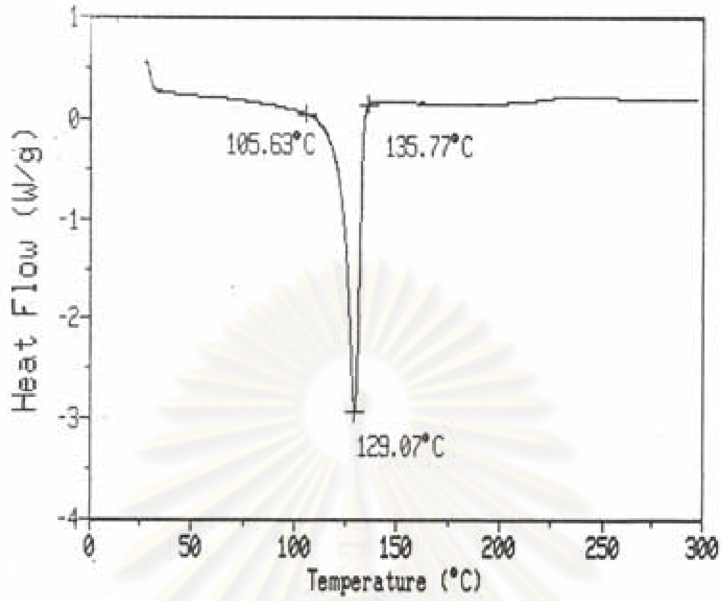

Figure 4.18 Thermogram of recycled HDPE (PE43-001)

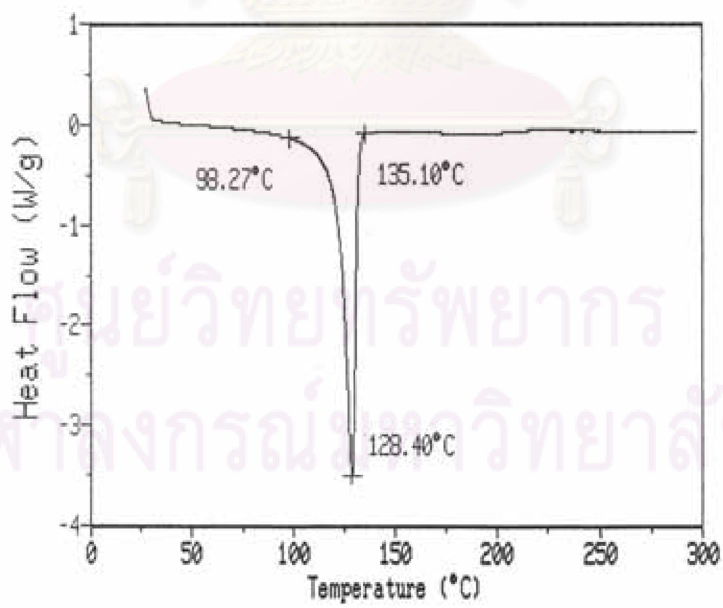

Figure 4.19 Thermogram of recycled HDPE (PE53-001)

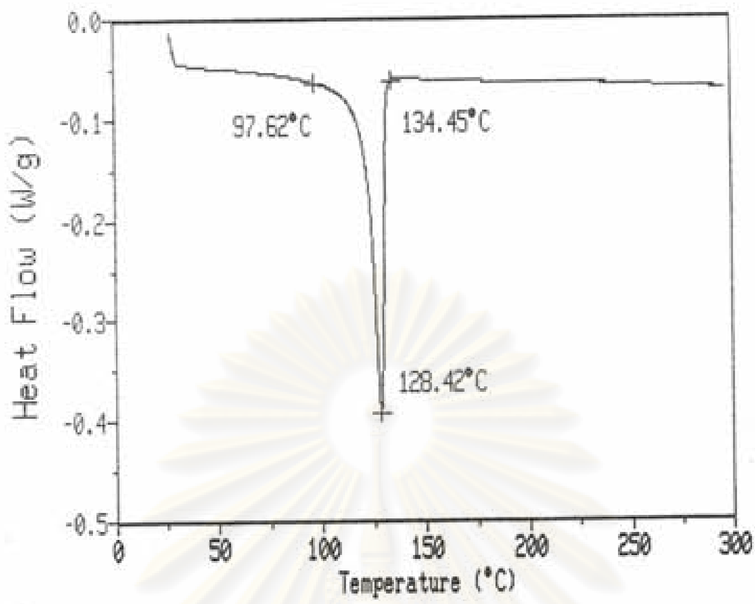

Figure 4.20 Thermogram of recycled HDPE (PE63-001)

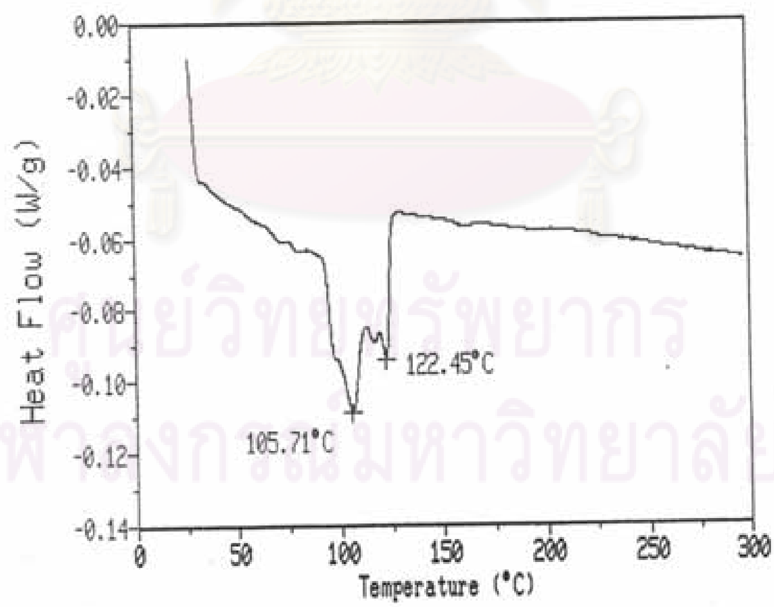

Figure 4.21 Thermogram of recycled HDPE (PE73-001)

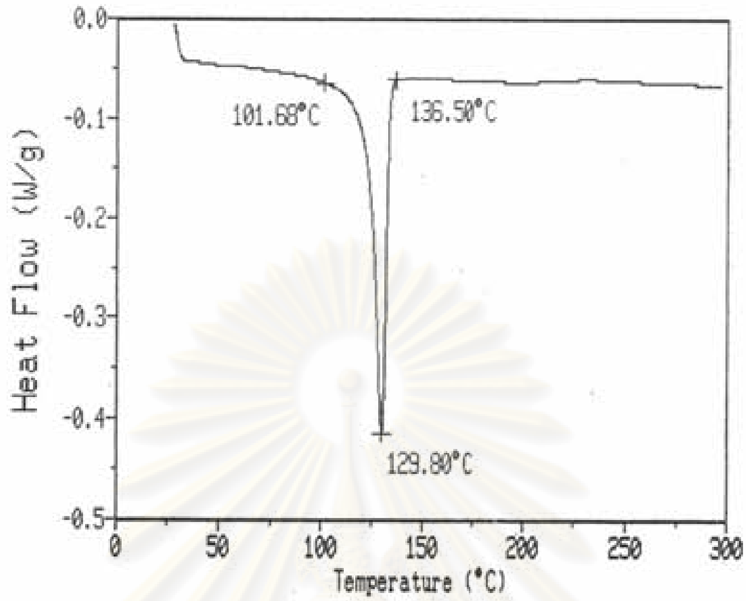

Figure 4.22 Thermogram of recycled HDPE (PE14-001)

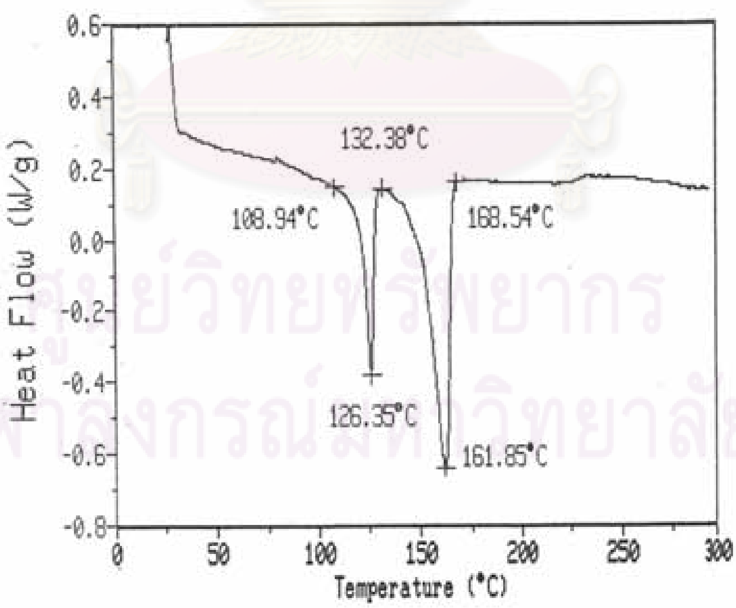

Figure 4.23 Thermogram of recycled PP (PP13-001)

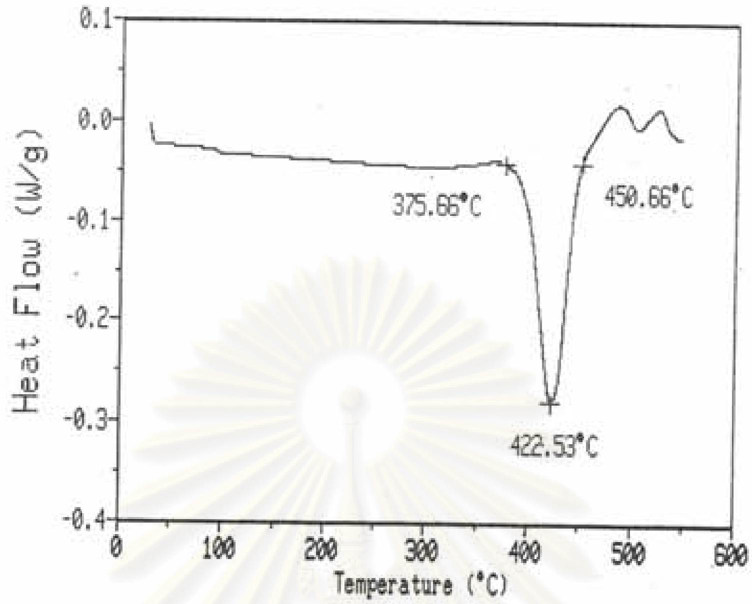

Figure 4.24 (a) Thermogram of recycled PS (PS11-001)

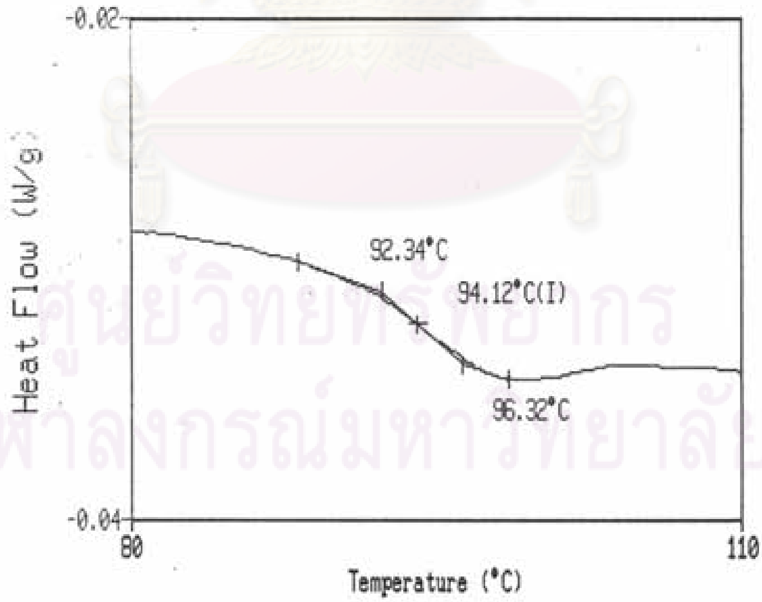

Figure 4.24 (b) Thermogram (Tg) of recycled PS (PS11-001)

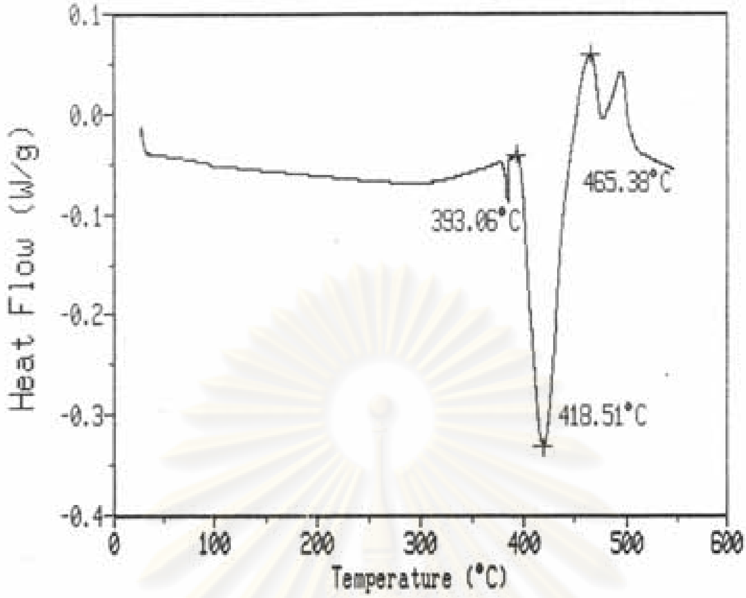

Figure 4.25 (a) Thermogram of recycled PS (PS21-001)

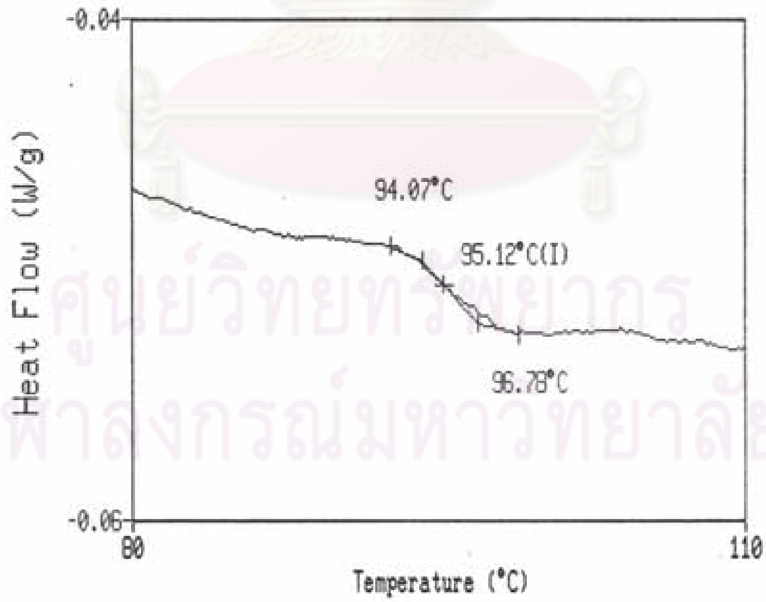

Figure 4.25 (b) Thermogram (Tg) of recycled PS (PS21-001)

Table 4.8 Summary of DSC results of virgin resin

Sample No.	Result Melting point, Tm, ^oC
PE15-001	129.37
PE25-001	126.68
PE35-001	129.94
PE45-001	130.10
PE55-001	128.09
LDPE15-001	107.46
LDPE25-001	104.11
PP15-001	125.56, 162.39
PP25-001	161.68

The thermograms of these recycling pellets expected to be HDPE are in Figures 4.13-4.22. All the thermograms show single peak except those in Figures 4.14 and 4.21. Those of single peak have Tm of HDPE and thus these pellets were confirmed to be of HDPE. In figure 4.14, the thermogram shows two peaks, one corresponding to that of LDPE, and the other, that of HDPE. Thus, these recycling pellets are a mixture of LDPE and HDPE. According to the plant No.3 operator, the plastic waste used are mixture of drinking - water bottles which are of HDPE and saline bottles which are of LDPE. In Figure 4.21, the thermogram also shows two peaks; one corresponding to that of LDPE and the other, that of HDPE. In this case, the plastic waste were delivered directly from fabricating plants.

Table 4.9 Summary of DSC run results of recycled plastic pellets

Sample No.	Plant No.	Form of Waste	Result Melting point, Tm, °C
PE12-001	2	Fish containers	131.76
PE22-001	2	Orange baskets and others	104.33, 124.41
PE13-001	3	Water bottle	129.83
PE23-001	3	Container, Basin	127.65
PE33-001	3	Basin	127.03
PE43-001	3	Powder bottle and others	129.07
PE53-001	3	Powder bottle and others	128.40
PE63-001	3	Powder bottle and others	128.42
PE73-001	3	Powder bottle and others	105.71, 122.45
PE14-001	4	Water bottle	129.80
PP13-001	3	Basket and others	126.35, 161.85
PS11-001	1	Beverage bottle	Tg = 94.12
PS21-001	1	Beverage bottle	Tg = 95.12

In Figure 4.23, the thermogram with two peaks reveals that the recycling pellets contain both HDPE and PP. In this case, the recycling pellets were made from broken baskets and basins. The recycling plant operator made no attempt to separate HDPE and PP. The thermograms in Figure 4.24 and 4.25 are those of PS. Figure 4.24 belongs to the recycling pellets made of Beverage bottles, while Figure 4.25 belongs to the recycling pellets made of Beverage bottles and broken tape casette cases.

Base on the DSC experiment together with our interview and observation, conclusion may be drawn that with the experience and skill of the sorting operators, sorting or quality of recycling pellets is reliable.

4.7 Mechanical Properties

4.7.1 Mechanical Properties of Virgin Resin

Result of the experimental determination of tensile and impact strength of virgin resin are presented in Table 4.10. Data for each test specimen can be found in Appendix F . The tensile stresses for each grade of PE are different, ranging from 21.59 to 27.56. The difference in impact strength are much more striking. Similar observation can be applied to PP.

This value of mechanical properties of virgin resin will serve as a reference for those of recycling resins.

Table 4.10 Mean tensile stress and mean impact strength of virgin plastic pellets

Item	Description	Mean tensile stress, MPa	Mean impact strength, J/m
PE15-001	Blow molding TPI, G2855	25.99	97.11
PE25-001	Blow molding TPI, GG2745	21.59	291.70
PE35-001	Blow molding TPI, GM2860	26.45	177.20
PE19-001	Blow molding TPE, H6430B	27.56	387.93
PE110-001	Blow molding TPI, GM2860	26.54	152.55
PP15-001	Blow molding TPI, 2502H	21.79	303.25
PP25-001	Blow molding TPI, 1102H	32.19	28.00
PS15-001	Tape Cassette TPI, 101H	32.94	30.36
PS25-001	Tape Cassette TPI, offgrade	35.63	36.49

4.7.2 Mechanical Properties of Recycled Resin

Result of the experimental determination of tensile and impact strength of recycled resin are presented in Table 4.11. Data for each test specimen can be found in Appendix F.

Value of the tensile stress of recycled resin lies from 23.99 to 25.55 for those PE resin made from drinking water bottle, 22.24 to 23.37 for PE resin made from mixed bottle, 21.37 to 25.38 for PE resin made from non - bottle articles. Resin PE73-001 and PE22-001 have relatively low value of tensile stress of 9.50 and 11.08, respectively. As shown in Figure 4.14 and 4.21, there are polymers of HDPE and LDPE blend.

Value of the impact strength for PE resin made from drinking water bottles lies from 98.31 to 175.20. Those of PE resin made from mixed bottle lies from 36.55 to 75.98 and those of PE resin made from non - bottle articles lie from 47.70 to 47.80.

In local market, bottles are made mainly from resin PE15-001 and PE19-001. PE25-001 is also used to make bottle, but in less quantity.

Base on the tensile stress data, the recycled resin made from drinking water bottles is the best in quality among the recycled resin. Its tensile stress in average is about 7.5 % lower than that of the virgin resin, and 10.42 % lower in the worse case.

The tensile stress of recycled resin made from mixed bottles and non-bottle are 14.82 % and 12.70 % lower than that of recycling resin made from drinking water bottle, respectively.

Table 4.11 Mean tensile stress and mean impact strength of recycled plastic pellets

Item	Description (source of material)	Plant No.	Date of sample collection	Mean tensile stress,MPa	Mean impact strength,J/m
PE	**Bottle**				
PE13-001	- mostly	3	17-07-92	24.62	113.98
PE13-002	drinking	3	18-03-92	23.99	175.20
PE14-001	water	4	29-07-92	25.55	98.31
PE14-002	bottle	4	16-04-93	24.05	106.24
PE14-003		4	11-05-93	24.08	124.00
PE43-001	- mixed	3	17-07-92	23.37	69.53
PE53-001	bottles	3	17-07-92	22.73	75.98
PE63-001		3	17-07-92	23.11	73.20
PE73-001		3	17-07-92	9.50	nobreak
PE17-001		7	29-04-93	22.24	55.70
PE17-002		7	09-08-93	17.49	36.55
PE23-001	**Nonbottle**	3	17-07-92	21.37	47.80
PE12-001		2	03-06-92	25.38	47.70
PE22-001		2	03-06-92	11.08	nobreak

Table 4.11 continued

Item	Description (source of material)	Plant No.	Date of sample collection	Mean tensile stress, MPa	Mean impact strength, J/m
PP					
PP13-001	**Nonbottle**	3	17-07-92	23.17	19.57
PP16-001		6	29-04-93	22.35	11.64
PP16-002		7	09-08-93	29.47	53.27
PP17-001		7	09-08-93	25.17	48.03
PP17-002		7	09-08-93	20.06	45.51
PS					
PS11-001	**Bottle**	1	03-06-92	30.43	31.74
PS21-001	**Bottle and nonbottle**	1	03-06-92	32.07	14.60
PS18-001	**Nonbottle**	8	25-05-93	27.97	25.61
PS18-002		8	11-08-93	22.39	32.85

The impact strength of the recycled resin made from drinking water bottles lies either below that of PE15-001 or between those of PE15-001 and PE19-001. This indicates that the recycled resin contains either single grade or mixed grade.

Value of the tensile stress and impact strength for recycled PP resin made from nonbottle articles lie from 20.06 to 29.47 and 11.64 to 53.27, respectively. The variation of these values are compared to results of virgin PP resin. Virgin PP resin in this experiment have two grades ; homopolymer and copolymer with tensile stress of 32.19 and 21.79, respectively as shown in Table 4.10. According to Table 4.11, the tensile stress of recycled PP resin is in the range of 20.06-29.47 which is above that of copolymer, but below that of homopolymer. Therefore, the recycled PP resin is either mainly of homolymer or a mixture of homopolymer with lesser amount of copolymer.

Value of the tensile stress for recycled PS resin made from bottles, and nonbottle articles lie from 22.39 to 32.07. Its tensile stress in average is about 20.59 % lower than of the virgin resin, 34.70 % lower in the worse case. Value of impact strength lie from 14.60 to 32.85. Its value is lower than that of virgin resin by 1.73 to 56.33 % .

Different dates for collecting samples from recycling factories effect the tensile stress and impact strength of nonbottle PE, mixed bottle PE, nonbottle PP, bottle PS, bottle and nonbottle PS. Their properties are uncertain because of the variation in composition of raw material. The properties of each collection for recycled PE resin made from drinking water bottles is similar because most of their raw material have only one composition.

4.8 Minimum Value of Mechanical Properties of Recycled Resin

From visiting the municipal waste dump site, it is evident that no sellable plastic waste are left overnight. As soon as dump trucks arrive at the dump sites, sellable plastic waste are sorted out. Consequently, degradation of plastic is assumed to be due to processing only. Degradation due to environment is negligible.

4.8.1 Development of Model

Processed polymer lowers their mechanical properties due to thermal degradation. In plant recycling, polymer is reprocessed thus rendering low mechanical properties. It is expected that repeating recycling will further decrease mechanical properties.

Recycled resin may compose polymer of various numbers of repeating recycles.The bulk of the recycled resin is that of recycled once, with those of the second, the third, and the fourth, ...times in decreasing quantity. Evaluation of properties of these recycled resin may be calculated by the model developed as follows :

Let P_o = Original properties of polymer. Example of property : Tensile stress, Impact strength.

$P_1, P_2, P_3, ...$ = Properties of processed polymer of the first, the second, the third, ... times of processing.

m = Mass.

p = $P_{i+1} / P_i \quad i = 0, 1, 2, ...$

r = Fraction of waste that is recycled.

Assumption : p is constants of the property of the first-time-processed, P_1 is pP_o, the property of the second-time-processed polymer, P_2 is $pP_1 = p^2P_o$, the property of the third-time-processed polymer, P_3 is $pP_2 = p^3P_o$, and the property of n-times-processed polymer, P_n is $pP_{n-1} = p^nP_o$.

Assumption : m kg of virgin resin is used; so the mass of the first , the second, the third,... and n times of processed polymer is m, rm, $r^2m, ..., r^{n-1}m$ kg , respectively.

The properties of recycled compose these various resin; so the mean property of mixture, $P_{mixture}$, is as follow :

$$P_{mixture} = \text{Mean Property of Mixture}$$

$$= \frac{mP_1 + (rm)P_2 + (r^2m)P_3 + \ldots + (r^{n-1}m)P_n}{m + rm + r^2m + \ldots + (r^{n-1}m)}$$

$$= \frac{mpP_o + (rm)p^2P_o + (r^2m)p^3P_o + \ldots + (r^{n-1}m)p^nP_o}{m + rm + r^2m + \ldots + (r^{n-1}m)}$$

$$= P_o \left[\frac{p + rp^2 + r^2p^3 + \ldots + r^{n-1}p^n}{1 + r + r^2 + \ldots + r^{n-1}} \right]$$

$$= P_o \left[\frac{p\,(1 + rp + r^2p^2 + \ldots + r^{n-1}p^{n-1})}{1 + r + r^2 + \ldots + r^{n-1}} \right]$$

$$= P_o \left[\frac{p\,[1 + \sum_{i=1}^{n-1} (rp)^i]}{1 + \sum_{i=1}^{n-1} r^i} \right]$$

Table 4.12 and Figure 4.26 to 4.28 demonstrate the simulated properties of recycled resin generated by the model for various value of p and r.

This model development is based on the same concept of those in (16)

Table 4.12 Simulated values of recycled plastic pellets property

p	r	$P_{mixture}/P_0$				
		n=1	n=2	n=3	n=4	n=5
0.9	0.1	0.900	0.892	0.890	0.890	0.890
	0.2	0.900	0.885	0.880	0.879	0.878
	0.3	0.900	0.879	0.870	0.865	0.864
	0.4	0.900	0.874	0.859	0.851	0.847
	0.5	0.900	0.870	0.850	0.837	0.829
0.8	0.1	0.800	0.785	0.783	0.783	0.783
	0.2	0.800	0.773	0.765	0.763	0.762
	0.3	0.800	0.763	0.747	0.740	0.738
	0.4	0.800	0.754	0.729	0.717	0.711
	0.5	0.800	0.747	0.713	0.693	0.681
0.7	0.1	0.700	0.681	0.678	0.677	0.677
	0.2	0.700	0.665	0.655	0.652	0.651
	0.3	0.700	0.652	0.632	0.624	0.622
	0.4	0.700	0.640	0.610	0.595	0.588
	0.5	0.700	0.630	0.589	0.566	0.553

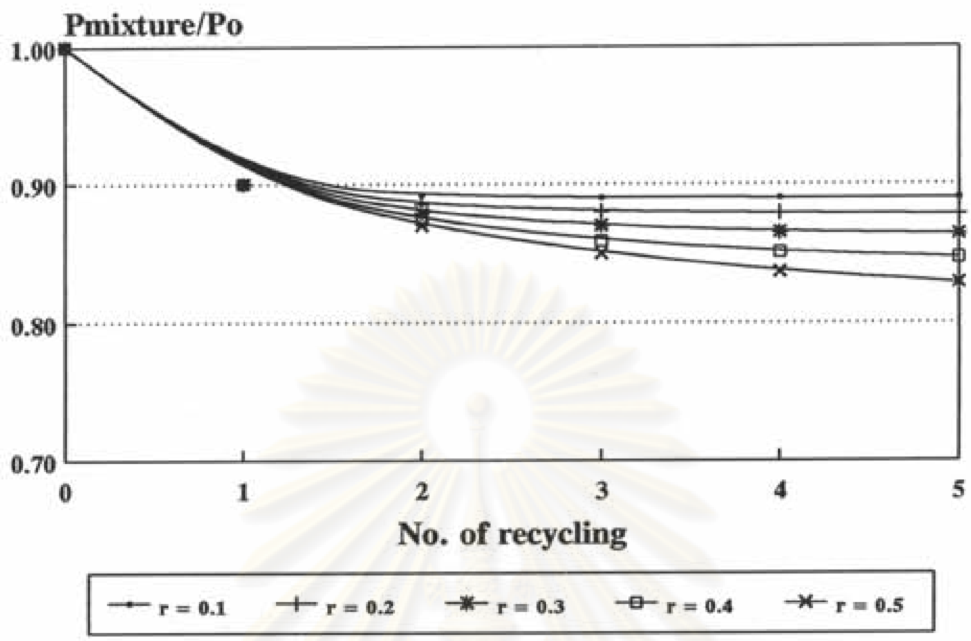

Figure 4.26 Property generated by the model for p = 0.9

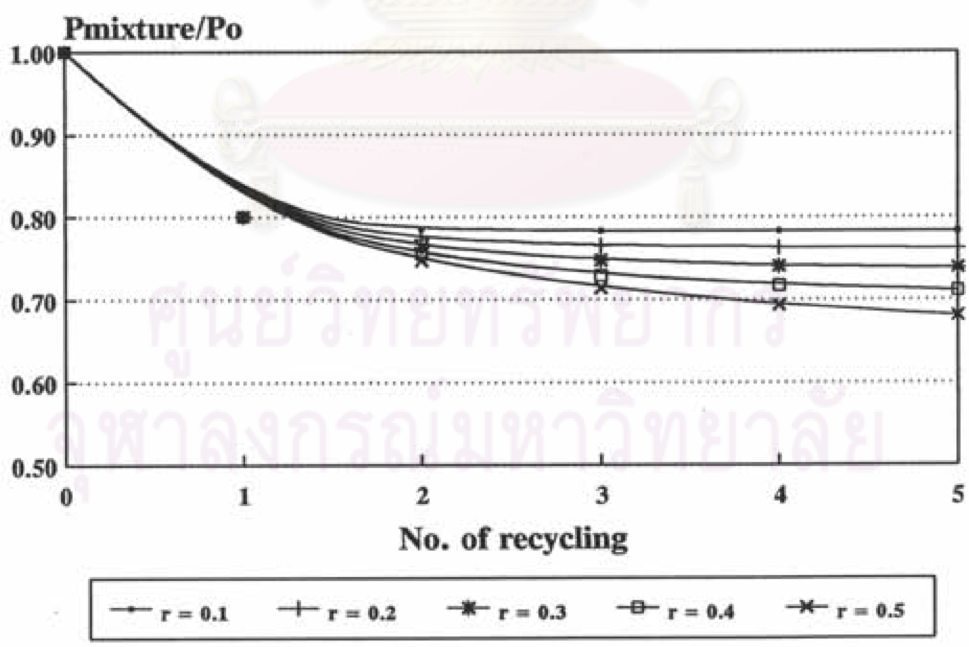

Figure 4.27 Property generated by the model for p = 0.8

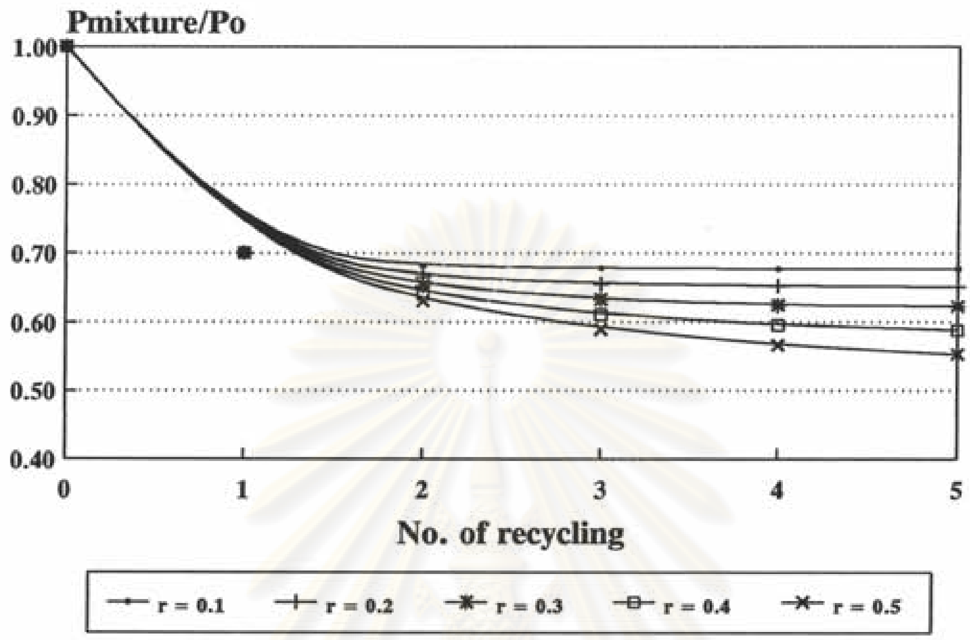

Figure 4.28 Property generated by the model for p = 0.7

4.8.2 <u>Determination of Parameter Values</u>

4.8.2.1 <u>p - Value in the Process of Making Drinking Water Bottle</u>

The result of the experiment is presented in Tables 4.13 and 4.14 for the tensile stress and impact strength, respectively. A pair of feed and product in plant No. 9, 10 are (PE19-001, PE19-101) and (PE110-001, PE110-101), respectively.

Table 4.13 Tensile stress of a pair of feed and product in a drinking water bottle plant (Feed being virgin resin) (details in Appendix F)

Plant no.	Tensile stress of feed, MPa	Tensile stress of product, MPa	p
9	27.56	26.77	0.97
10	26.54	25.64	0.97
average			0.97

Table 4.14 Impact strength of a pair of feed and product in a drinking water bottle plant (Feed being virgin resin) (details in Appendix F)

Plant no.	Impact strength of feed, J/m	Impact strength of product, J/m	p
9	387.93	208.19	0.54
10	152.55	78.50	0.51
average			0.53

4.8.2.2 p - Value in the Process of Making Recycled Plastic Pellets from Drinking Water Bottles

The result of the experiment is presented in Tables 4.15 and 4.16 for tensile stress and impact strength, respectively. A pair of feed and product in plant No.3,4,4 are (PE13-102, PE13002), (PE14-102, PE14002),and (PE14-103, PE14003), respectively. PE13002, PE14002, and PE14003 are recycled plastic pellets.

Table 4.15 Tensile stress of a pair of feed and product in a repellet plant (Feed being ground post - consumer drinking water bottle HDPE) (details in Appendix F)

Plant no.	Tensile stress of feed, MPa	Tensile stress of product, MPa	p
3	23.70	24.14	1.02
4	23.19	24.97	1.08
4	23.97	23.98	1.00
average			0.97

Table 4.16 Impact strength of a pair of feed and product in a repellet plant (Feed being ground post -consumer drinking water bottle HDPE) (details in Appendix F)

Plant no.	Impact strength of feed, J/m	Impact strength of product, J/m	p
4	108.26	96.54	0.89
4	91.95	96.63	1.05
average			0.97

4.8.2.3 p - Value for Combine Process

One cycle of recycling process is a combine process of drinking water bottle process and recycled pellet process. The p - value of a combine process is then the product of p - values of both processes.

Therefore, in one cycle of recycled process, p - value for tensile stress is 0.97 x 1.00 = 0.97 and p - value for impact strength is 0.53 x 0.97 = 0.51.

4.8.2.4 p - Value in the Process of Making Recycled Plastic Pellets from Mixed Bottles

The result of the experiment is presented inTables 4.17 and 4.18 for tensile stress and impact strength, respectively. A pair of feed and product in plant No. 7 are (PE17-101, PE17-001) and (PE17-102, PE17-002), respectively.

Table 4.17 Tensile stress of a pair of feed and product in arepellet plant (Feed being mixture of ground post-consumer bottle PE) (details in Appendix F)

Plant no.	Tensile stress of feed, MPa	Tensile stress of product, MPa	p
7	22.34	22.24	0.99
7	23.27	17.49	0.75
average			0.87

Table 4.18 Impact strength of a pair of feed and product in a repellet plant (Feed being mixture of ground post-consumer bottle PE) (details in Appendix F)

Plant no.	Impact strength of feed, J/m	Impact strength of product, J/m	p
7	82.14	55.70	0.68
7	182.14	36.55	0.20
average			0.44

4.8.2.5 p - Value in the Process of Making Recycled Plastic Pellet PP

The result of the experiment is presented in Tables 4.19 and 4.20 for tensile stress and impact strength, respectively. A pair of feed and product in plant No. 6,7 are (PP16-101, PP16-001), (PP16-102, PP16-002), (PP17-101, PP17-001), and (PP17-102, PP17-002), respectively.

Table 4.19 Tensile stress of a pair of feed and product in a repellet plant (Feed being mixture of ground PP) (details in Appendix F)

Plant no.	Tensile stress of feed, MPa	Tensile stress of product, MPa	p
6	30.43	22.35	0.73
6	29.12	29.47	1.01
7	19.79	25.17	1.27
7	16.06	20.06	1.25
average			1.07

Table 4.20 Impact strength of a pair of feed and product in a repellet plant (Feed being mixture of ground PP) (details in Appendix F)

Plant no.	Impact strength of feed, J/m	Impact strength of product, J/m	p
6	21.06	11.64	0.55
6	46.78	53.27	1.14
7	41.42	48.03	1.16
7	39.74	45.51	1.15
average			1.00

4.8.2.6 p - Value in the Process of Making Recycled Plastic Pellet PS

The result of the experiment is presented in Tables 4.21 and 4.22 for tensile stress and impact strength,respectively. A pair of feed and product in plant No. 8 are (PS18-101,PS18-001), and (PS18-102, PS18-002), respectively.

Table 4.21 Tensile stress of a pair of feed and product in a repellet plant (Feed being mixture of ground PS) (details in Appendix F)

Plant no.	Tensile stress of feed, MPa	Tensile stress of product, MPa	p
8	27.36	27.97	1.02
8	22.67	22.39	0.99
average			1.01

Table 4.22 Impact strength of a pair of feed and product in a repellet plant (Feed being mixture of ground PS) (details in Appendix F)

Plant no.	Impact strength of feed, J/m	Impact strength of product, J/m	p
8	26.78	25.61	0.96
8	34.28	32.85	0.96
Average			0.96

4.8.3 Prediction of Minimum Properties

In addition to p-value in 4.8.2, which were determined experimentally, p-value by rough statistics which is based on properties in Tables 4.10 and 4.11 are presented in Table 4.23.

Table 4.23 p-value for P_1/P_o

Resins	Tensile stress, MPa			Impact strength, J/m		
	Virgin pellets	Recycled pellets	p	Virgin pellets	Recycled pellets	p
PE	25.63	23.12*	0.90	221.30	92.87*	0.42
PP	26.99	24.04	0.89	-**	-	-
PS	34.29	28.22	0.82	33.43	26.20	0.78

* Blow molding grade only

** A good average value cannot be obtained based on Table 4.10

4.8.3.1 Recycled Pellets from Drinking Water Bottles

According to Table 4.13 and 4.15, tensile stress of PE product decreases slightly and remains essentially unchanged during repelleting process. Table 4.14 shows that impact strength of product in a drinking water bottle plant is lower by half; but decreases only little during repelleting process as shown in Table 4.16.

p-value for tensile stress and impact strength for one cycle of drinking water bottle process and recycled pellet process from 4.8.2.3 are 0.97, and 0.51 respectively. From these p-values, properties of recycled pellets can be generated by the derived model for various r. Their $P_{mixture}/P_o$ and curves are shown in Tables 4.23 and 4.24 and Figures 4.29 and 4.30.

The curves in Figures 4.29 and 4.30 show that their properties will be decreased by the number of recycling process and have a constant value at number of recycling = 5. Therefore, the worst expected tensile stress and impact strength are 94.6 % and 35.3 %, respectively of the original properties.

4.8.3.2 Recycled Pellets from Mixed PE

According to Tables 4.17 and 4.18, p-value are lower than that of recycled pellets made from drinking bottles (4.8.3.1), and further more, p-value of two different samples are quite different. This may caused by: a) No mixing of feed. Feed may consist of various grades of HDPE and LDPE. Consequently, product composition may not be the same as feed composition. b) Pigment is usually added in the case of recycled pellets from mixed bottles which already contain pigment. c) Processing temperature may be set higher ;

Table 4.24 $P_{mixture}/P_o$ of tensile stress for recycled pellets from drinking water bottles

r	$P_{mixture} / P_o$				
	n=1	n=2	n=3	n=4	n=5
0.1	0.970	0.967	0.967	0.967	0.967
0.2	0.970	0.965	0.963	0.963	0.963
0.3	0.970	0.963	0.960	0.959	0.958
0.4	0.970	0.962	0.957	0.954	0.952
0.5	0.970	0.960	0.953	0.949	0.946

Table 4.25 $P_{mixture}/P_o$ of impact strength for recycled pellets from drinking water bottles

r	$P_{mixture} / P_o$				
	n=1	n=2	n=3	n=4	n=5
0.1	0.510	0.487	0.484	0.484	0.484
0.2	0.510	0.468	0.458	0.455	0.454
0.3	0.510	0.452	0.432	0.425	0.422
0.4	0.510	0.439	0.407	0.394	0.388
0.5	0.510	0.427	0.385	0.364	0.353

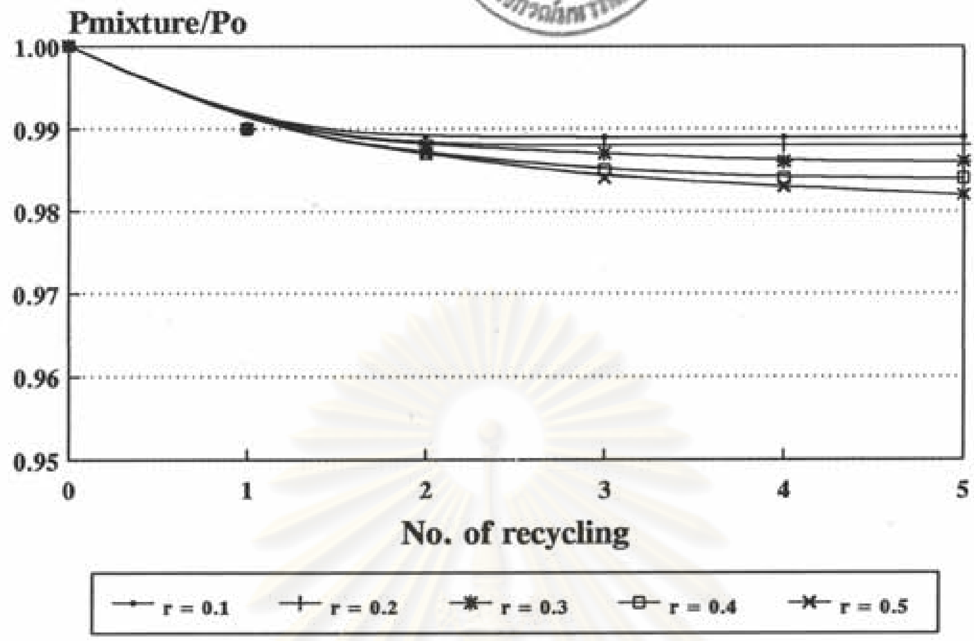

Figure 4.29 Tensile stress for drinking water bottle and recycled pellets process generated by the model for p = 0.97

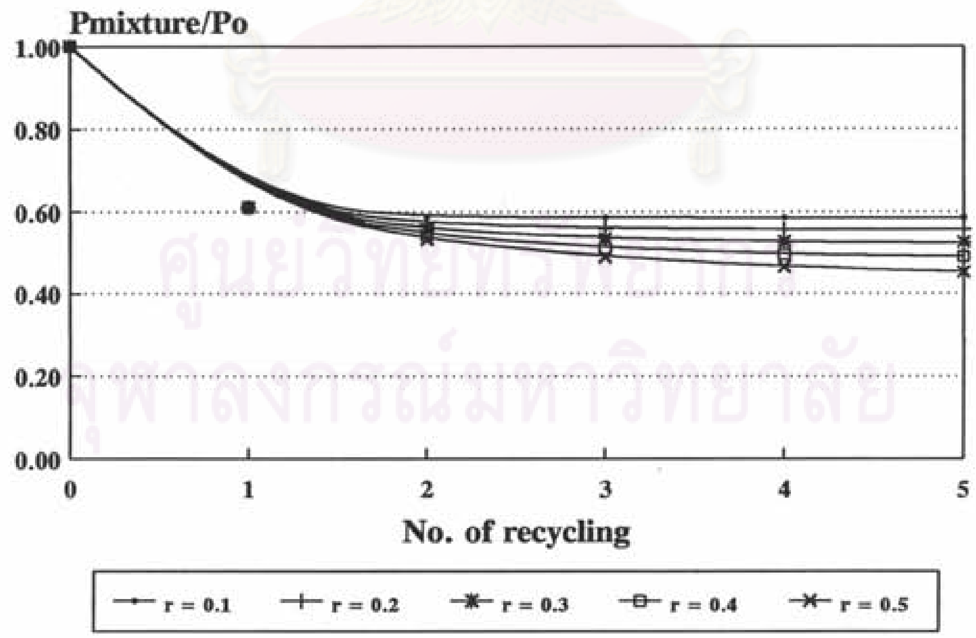

Figure 4.30 Impact strength for drinking water bottle and recycled pellets process generated by the model for p = 0.51

thus cause more degradation.

Minimum values of properties of recycled pellets from mixed PE may be obtained from p- values in Table 4.23 which are 0.90 and 0.42 and can be calculated to be 82.9 % and 27.4 % of the original properties for tensile stress and impact strength, respectively.

4.8.3.3 Recycled Pellets from Mixed PS

According to Tables 4.21 and 4.22, degradation of PS during repelleting process is very slightly. Degradation of PS virgin pellet may be estimated from Table 4.23, and its p-values are 0.82 and 0.78 for tensile stress and impact strength, respectively. Minimum property values can be calculated to be 70.9 % and 65.4 % of the original properties for tensile stress and impact strength, respectively.

4.8.3.4 Recycled Pellets from Mixed PP

p-values of recycled pellets from mixed PP are presented in Table 4.19 and 4.20. Error in the p-values may caused by the same factors as in 4.8.3.2 of recycled pellets from mixed PE. However, statistically, it is likely that degradation of PP during repelleting process is small as in the cased of PE and PS. Degradation of PP virgin pellet may be estimated from Table 4.23, and its p-values is 0.89 for tensile stress. Minimum property values can be calculated to be 81.3 % of the original properties for tensile stress.

4.9 Uses of Recycled Resin and Plastic Waste

4.9.1 Presented Use

4.9.1.1 Local

Nowaday, various plastic waste can be converted into new products by processing as described in 4.3. Recycled HDPE, PP are used to manufacture washbasins, pails, buckets, furniture, rope, bags, egg cartons, wood pallets, ring net, and cast net. Recycled PS is for manufacturing tape cassette. Recycled PVC is for manufacturing pipe fittings.

4.9.1.2 Abroad

In United states, Europe, and Asia has been recycling plastic waste is recycled to produce new parts. There are many products in production or under development such as (39):

- Walking shoes : Deja Shoes have uppers made from recycled polypropylene, soles of recycled rubber tires.
- Animal sculptures produced from Cylestone, a mixture of recycled plastic and recycled glass.
- Novaphalt: a construction material of asphalt mixed with LDPE for highway paving.
- Carpeting : beautiful carpeting in many colors made from recycled PET.
- Park benches and picnic tables : some made from commingled plastics, some from 100 percent HDPE.

-Containers, bins, trash cans, composters, shipping containers : some with percentages of recycled plastic, some 100 percent recycled.

- Parking stops of 30 to 40 percent post-consumer plastic.
- Plastic lumber products : mailbox posts, fence posts, decorative outdoor planters, and trash bins.
- Playground equipment.
- Various types of packaging : bags, bottles, EPS cushion packaging.
- Ice scrapers and snow brushes.
- Toys
- Nursery plant pots.
- Egg cartons of post-consumer PET.
- Nail dryers from recycled ABS refrigerator panels.
- Roofing panels.
- Marine pilings.
- Pallets.
- Watch bands.

The companies and firms that related to plastic cycle have worked together to improve recycled plastic waste into finish product. Examples of their research and development are as follows :

Plastic Bottle Institute (40) revealed that ketchup and syrup bottle made from polypropylene can be combined with HDPE from recycled milk jugs without affecting the production of new bottles made with the recycled HDPE material.

Poly - Anna Plastics Corp. (40) have injection mold pails and buckets made from 100 percent recycled plastic. They have even found a use for colored laundry detergent bottles before they are color sorted. All the colors are mixed together tocreatea special blend which is called " environmental green ". Its blend is used to mold recycling bins for curbside use.

Dow Chemical Canada Inc. and Resource Plastics Corp. (41) will work together to enhance making million of kilograms of recycled high density polyethylene made from recycled post-consumer container. Then, Resource Plastics worked in conjunction with Plax Inc. of Burlington to produce a motor oil container made from 100 percent post-consumer recycled plastic.

In China (42), the reclamation and pelletizing of mixed plastic wastes such as PE/PVC, PE/PP, and PE/PS has available technology on a large scale. The Xingguang Plastics Recycling Factory in Shanghai has introduced a reclamation line from Belgium, and pelletizing tests using waste mixtures of 90% PVC and 10% PE have good quality pellets. Various waste plastics can be processed into pipes, rods, sheet, washbasins, bathtubs, shoes, washboards, buckets, fruitpackaging boxes, and many kinds of farming tools. Beside, China has also made rapid advances in the manufacture of rubber products using a blend of rubber and plastic waste to make floor tiles and soles.

Dow Plastics and Quantum Chemicals (43) are now fine tuning new LLDPE materials for the production of trash bags, specially designed to be mixed with post-consumer resin. The Dow product is octene-based LLDPE material for mixing with 25 % recycled HDPE milk jugs and Quantum is butene-based LLDPE resin containing 15 % post-consumer resin.

Sonoco Products Co., Hartsville, S.C., (44) have produced Edgeboard, a protective industrial packaging product from recycled plastic and paper. Edgeboard comprises at least 50 % plastic by weight and provides moisture resistance and better surface protection. It is used in the argricultural, steel and aluminium , building materials, and rigid container markets to provide edge or surface protection during shipping and distribution.

Solvay Polymers, Inc., (45) has produced cases, crates, and pails from virgin high density polyethylene flake compounded with 25 % post-consumer recycled resin.

Du Pont Canada (46) has announced a program with Procter & Gamble Canada to recycle post consumer plastic waste into new bottles for P & G 's liquid laundry and cleaning products. Under the program, containers made of HDPE will be collected curbside and will be recycled by Plastic Recycling Alliance (PRA), a joint venture in North America between Du Pont and Waste Manager Inc.

The Technical Committee of SPI' s Plastic Bottle Institute (PBI) (47) studied recycled polypropylene containers used for ketchup, salad dressings, syrups and personal care, household and medical products. Test results demonstrate that PP can be effectively recycled as part of the post-consumer, high density polyethylene stream and reused in levels of up to 6 percent in the production of new HDPE containers.

The Dow Plastics Development Laboratory (48) in Tagerwilen, Switzerland has an automative panel manufactured from 30 percent recycled material. A core layer of recycled reinforced reaction injection molded (RRIM) material is sandwiched between two layers of glass reinforced material.

Vanguard Plastics, Inc., (49) is in the forefront of the grocery sack recycling effort that has captured the attention and participation of supermarkets and consumers throughout the country Van-guard works with them to provide large bins on site for consumers to return their plastic sacks. The sacks are shipped back to Vanguard, where they are processed and used to make more plastic sacks.

Plastipak Packaging, Inc.,(50) has manufactured 24-ounce salad dressing bottles for Kraft General Foods (KGF) that contain recycled plastic. This is the first time recycled plastics have been used in food containners other than soft drink bottles. Plastipak worked with three other companies: Kraft General Foods, of Glenview, IL; Clean Tech, Inc., of Dundee, MI and Hoechst Celanese Fibers and Film Group. The dressing bottles are made with PET resin that contains at least 25 % recycled PET.

Eastman Chemical Company (51), the world's largest manufacturer of polyester plastics for packaging, announced that it has received a no-objection letter from the United States Food and Drug Administration clearing the way for Eastman to manufacture production quantities of PET with recycled content for use in packaging applications that include beverage, food, and toiletries.

The National Association for Plastic Container Recovery (NAPCOR) (52) and Penn Racquet Sports have joined efforts to encourage the recycling of Penn tennis ball containers made of PET plastic. All Penn tennis ball containers are made with a minimum of 25 % recycled content. The company encourages tennis players to return their containers for recycling through local collection programs. PET plastic tennis ball containers can be used to make new soft drink and tennis containers, along with more than 50 other products, including fiberfill, industrial strapping and polyester carpet.

Five Penn plastic tennis ball containers produce enough fiberfill to fill a ski jacket.

The Pepsi-Cola Company (53) said that it has achieved an environmental breakthrough the use of recycled plastic in its soft drink bottles. Pepsi planed to introduce the first beverage containing recycled PET into the market place in 1991. The development marked the first time recycled plastic would be used in direct contact with food in packaging. Total recycled bottle content will be approximately 25 %.

The Coca-Cola company (53) and Hoechst Celanese Corporation said that they would introduce the first-ever plastic soft drink bottles made with a blend of recycled platics. They have been in contact with U.S. Food and Drug Administration which is reviewing the process.

PET plastic soft drink containers recycled in the U.S. (53) were used to make carpeting, fiberfill stuffing for jackets and comforters, lumber, piping, patio furniture and non-food bottles.

Retech, a unit of Dutch chemical group's recycling company Reko bv. (54) has received its PET waste mainly form the Benelux countries, West Germany and Austria Re-tech technology enables the company to obtain a very clean, crystal-clear regrind from PET waste. The larger part of this can be used as material for films, blister packs and bottles for the non-food sector. Demand for such products on the basis of recycled PET is also growing.

ARCO Chemical Company (55) has announced commercial availability of a grade DYLITE expandable polystyrene (EPS) resin that contains 25 % recycled material. It is expected to find widespread use in industrial and consumer packaging applications.

Lin Pac Plastics (56), the main supplier of expanded PS trays to Mc Donald's in Europe, has set up a recycling scheme in the U.K. Trays are separated from other materials at the store, and returned to Lin Pac's plant. The PS can be reused in such items as insulation board, coathangers, and loose-fill protective packaging. The cups are take to a plastic recycling company, Thermoplastics Compounders, Luton, England. The recycled material is slated for use in parts such as beer crates, car components, flooring, and other non-food application.

Reko, subs. DSM, Beek, Netherlands (57) has recycled Low Density Polyethylene (LDPE). The LDPE, sourced mainly from agricultural and horticultural film and houshold waste, will be converted into granules for production of refuse bags and sheet materials.

Himont USA., (58) one supplier of the polypropylene resins used to make battery cases. Almost 150 million pounds of battery case polypropylene are recycled in the U.S. each year. Approximately 40 % of this recovered PP was then used in the next generation of batteries.

Coors Brewery in Golden, Colo., (59) extrudes its own polypropylene slip sheets, used in place of wood pallets to hold beer cases, with up to 93 percent recycled material. The sheets can withstand about 2,000 lb without breaking or cracking, and are dimpled to provide cushioning from shocks.

Lever Brothers (60) has announced that it will commit to using at least 10 million pounds of recycled plastic annually in its household product bottles. Its agreement with Sonoco Graham Company, one of the largest producers of high density polyethylene bottles is expected to accelerate that company's efforts to develop nation wide plastic bottle recycling and to produce more of its bottles with recycled plastic. Lever is assured that virtually all of the bottles Sonoco produces for the company will soon contain recycled plastic at levels between 25 % and 35 %.

N.E.W. Plastics Corp., Luxemburg, WI, USA, (61) recycles clean HDPE post-consumer milk and water bottles and industrial scrap into conventionally extruded plastic "lumber" and sheeting.

Atlantic Poly Inc., (62) has manufactured polyethylene bags from 100 % recycled material.

"SafetyCade" (63) barricades are the first commercial product resulting from the plastics recycling development partnership between the Department of Transportation, The Illinois Department of Energy and Natural Resources, and Du Pont. SafetyCade is manufacture from about 100 recycled milk jugs, made from HDPE. The recycled HDPE is supplied by Du Pont after reclamation by the chicago facility of Plastic Recycling Alliance.

4.9.2 Recommend Use

Most of recycled pellets are used to make ordinary products in local markets such as washbasins, pails, buckets, baskets, etc. Since the impact strength of recycled pellets is much lower than of virgin resin, the above mentioned product will break after a short period of service. Thus, the broken products will end up as waste once more. This plastic waste cycle can not solve the waste problem.

To lessen the waste problem, it is recommended here that the recycled pellets be used in one of the following manners

1) recycled pellets should be used to make permanent products. For example fence posts, and pallets.

or 2) recycled pellets properties should be improved. For example making polymer blend and composite.