CHAPTER II

OVERVIEW OF WASTE AND PLASTIC RECYCLING

2.1 Waste

2.1.1 Municipal Waste

Municipal refuse is composed of a vast array of products which have lost their usefulness and have been discarded. These wastes include home wastes, commercial wastes and city wastes. While home and commercial wastes are usually placed in a receptable for periodic removal by a collection agency to a landfill or incinerator, city wastes usually collect elsewhere and require special handling and disposal.

Home wastes include such diverse products as glass bottles, cans, plastic toys, cellophane, paper, cardboard, nails, small appliances, tools, light bulbs, clothes, rubber products, wood, and food items. If these products are not separated into classes such as metal, glass, paper, etc., in the home, this waste becomes very heterogeneous.

Commercial wastes are generated by retail business and institutions such as hospitals, banks, and schools. Although these wastes are also heterogeneous, they contain high percentages of office waste and packaging materials. City wastes include automobile bodies, large appliances, tires, dead animals, demolition waste, street sweepings, crankcase oil, and sewage sludge. A sample of municipal refuse is given in Table 2.1 (6)

Organic wastes, sewage sludges, animal wastes, crop wastes, and food wastes and high - nutrient mineral wastes must be returned to the soil, implying the displacement of synthetic soil nutrients. Metals must be returned to the industries that generate them.

Materials made of natural fibers, wood, paper, paper board, and some textiles, can be returned to their originating industries, implying the displacement of pulp wood, sheep's wool, cotton, and so forth. These and synthetic materials like synthetic textiles, plastics, and rubber can be converted directly to energy or into fuels, displacing fossil fuels.

Glass, ceramics, ashes, mine wastes, and similar minerals must move into construction materials, they must compete in an industry traditional in its structure and practices. An idealized view of total reclamation possibilities in domestic and commercial wastes are shown in Figure 2.1 (7).

2.1.2 Integrated Waste Management

Many communities throughout the United States are struggling with questions of how to safety and effectively manage their municipal solid waste. Most are discovering that there are no quick - fix solutions to the waste issue and that the only real solution is an integrated waste management approach that utilizes four basic strategies : (8)

- Source reduction
- Recycling
- Incineration
- landfill

Table 2.1 Typical municipal refuse

Paper	Glass, ceramics, ash
- corrugated paper boxes	Vegetation
- newspaper	- ripe tree leaves
- magazine paper	- flower garden plants
- brown paper	- lawn grass green
- mail	- evergreen
- food cartons paper	Metals
- tissue paper	Miscellaneous
- wax cartons	- wood
- plastic coated paper	- plastics
Moisture	- rag
Garbage	- leather goods
- vegetable food wastes	- rubber composition
- citrus rinds and seeds	- paint and oils
- meat scraps, cooked	- vacuum cleaner catch
- fried fats	- dirt

Currently about 80 percent of the municipal trash in the United States is disposed of in landfills, 10 percent is incinerated and10 percent is recycled. To conserve diminishing landfill space, many states now are developing plans with goals to increase significantly the quantities of recovered materials. For example, the U.S. Environmental Protection Agency has proposed a national recycling goal of 25 percent by 1992. In addition, the share of waste disposed of in waste - to - energy incinerators is projected to increase to 20 percent. Incineration reduces the volume of municipal solid waste

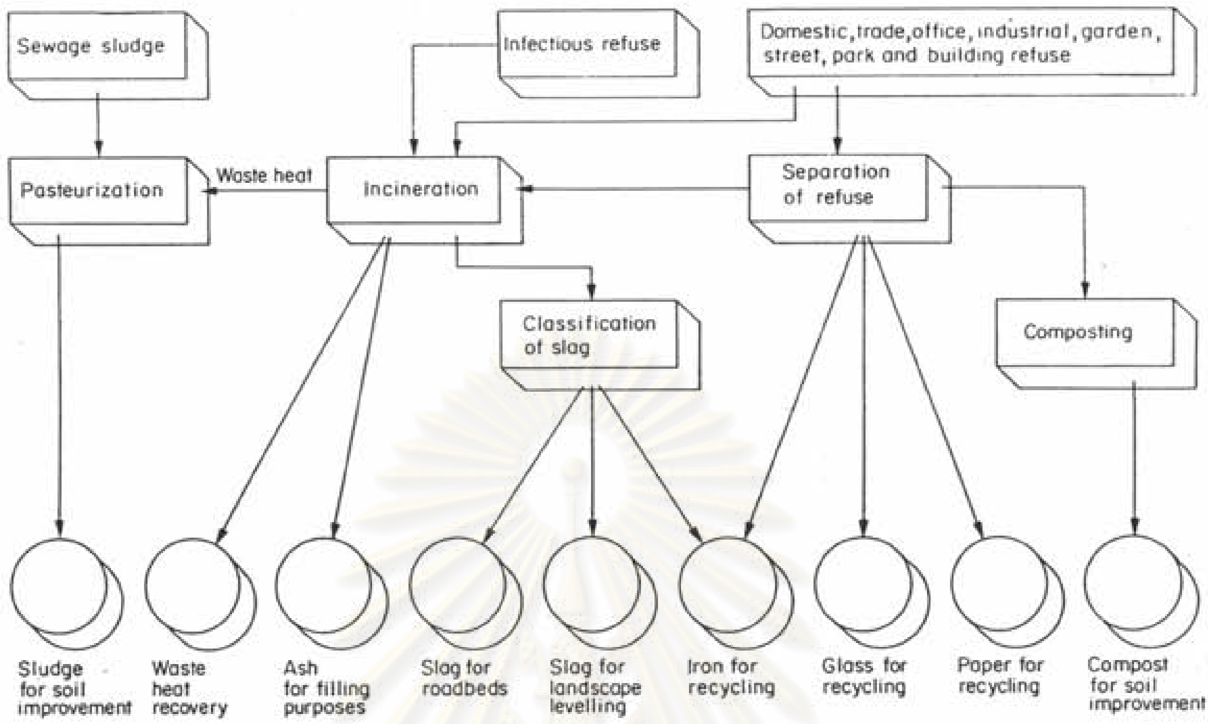

Figure 2.1 An idealized view of total reclamation possibilities in domestic and commercial wastes

by about 75 % ; the ash that remains goes to landfills. The energy contents of average composite municipal solid waste approximately 4500 BTUs/lb (9). Basic operation of a modern refuse incinerator are shown in Figure 2.2 (7). The issues of concern are that incineration creates hazardous air emissions, problems of ash disposal, global warming carbon dioxide gases, and a large expense for the tax payer. Advocates of recycling areconcerned that greater reliance on the incineration of municipal solid waste will detract from recycling initiatives, because the technologies of incineration and recycling compete for much of the same trash. Although both methods can considerably reduce the volume municipal solid waste, recycling does so at much lower expense and without emissions and ash.

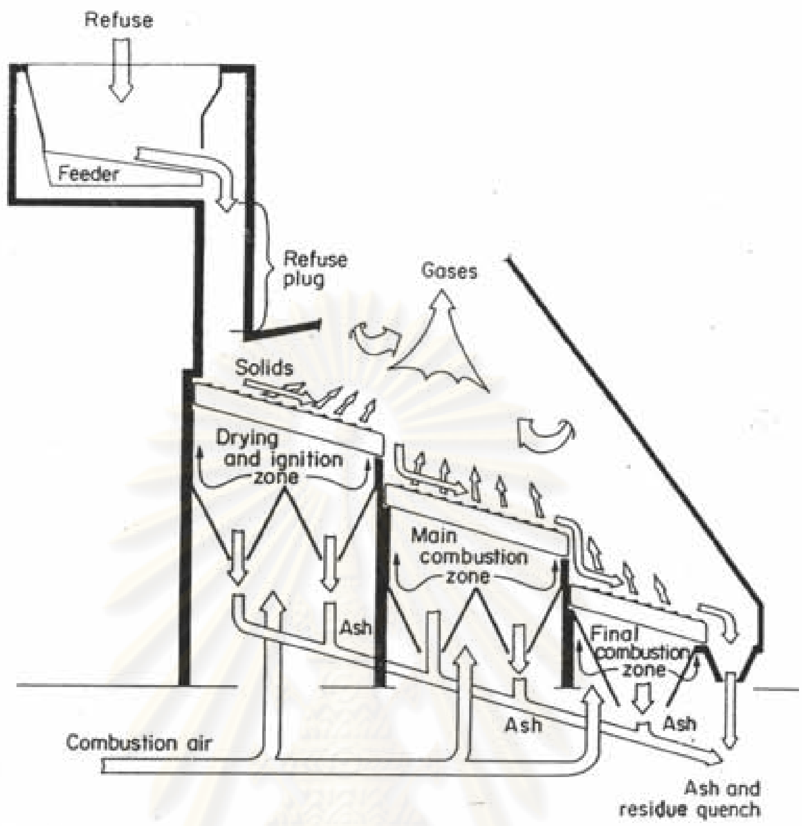

Figure 2.2 Basic operation of a modern refuse incinerator

A much greater percentage of municipal solid waste is incinerated in Europe and Japan than in the United States. In West Germany, 15 percent of municipal solid waste is recycled, 22 percent to 30 percent is incinerated in 42 plants (10 ,11), and the remainder is landfilled. A higher percentage of municipal solid waste is incinerated in Sweden and the Netherlands than in West Germany (10). In total, Western Europe currently incinerates 30 to 40 million tons of municipal solid waste per year, or approximately one third of the total generated. With little landfill space, Japan has the best record of recycling. Approximately 40 percent to 50 percent of municipal solid waste is recycled and 23 percent is incinerated.

In the United States, the composition of municipal solid waste is shown in Figure 2.3 (8). Paper products and yard waste represent 59 percent by weight, with plastics, metals, and glass each falling in the 7-9 percent range.

Packaging, which has been targeted by several states in their new waste reduction strategies, represents about 30 percent of the municipal solid waste by weight. The primary packaging materials are paper and paperboard, with a 48 percent share. Plastics make up only about 13 percent of the materials used in packaging, or approximately 7 million tons in 1987. About 24 percent of this total was used in making bottles. Plastics share of packaging and uses of plastics in packaging are shown in Figure 2.4 and 2.5 (8). Plastics most used for packaging are PE, 60 % ; PET, 10 % ; PVC, 5 % ; PP, 3 % ; and others, 22 % (12).

The polyethylene terephthalate soft drink bottle and the high density polyethylene milk, mineral water and fruit juice jugs are the primary beverage containers and represent more than 55 percent of the plastic bottles produced domestically in 1987 (milk, 30 percent; soft drink, 26 percent).

During 1987, about 150 million pounds of PET soft drink bottles and 70 million pounds of HDPE from soft drink bottle base cups and milk and other beverage containers were recycled in the United States. This is equivalent to 20 percent and 7 percent recycle rates, respectively, for these two types of materials.

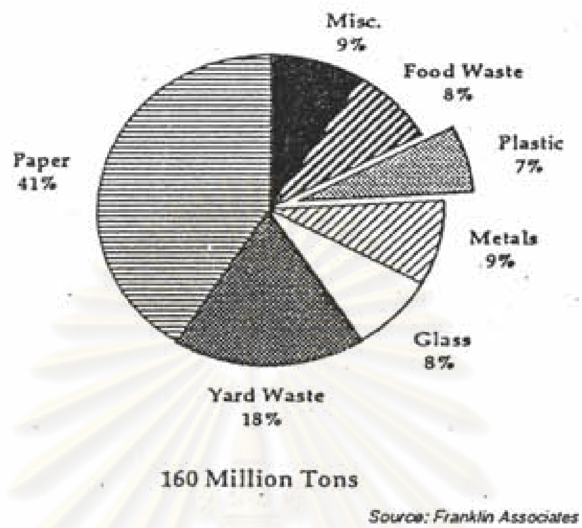

Figure 2.3 Municipal solid waste composition by material

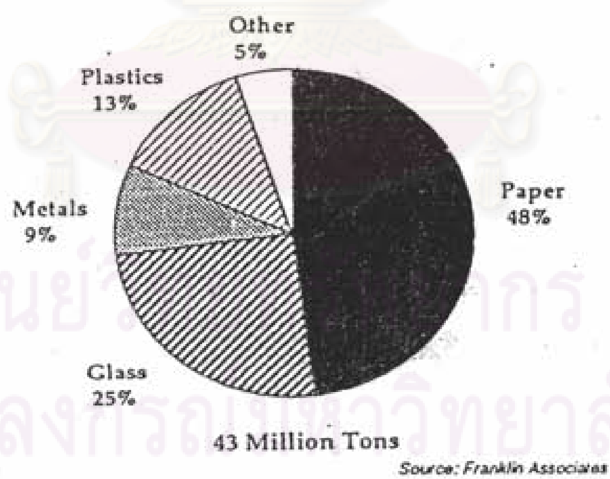

Figure 2.4 Plastics share of packaging

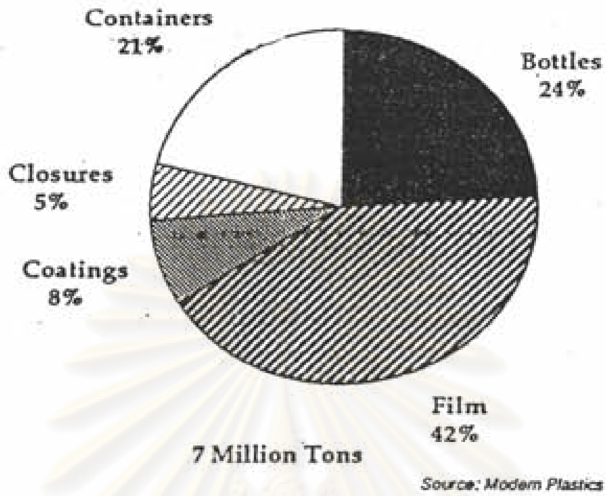

Figure 2.5 Uses of plastics in packaging - 1987

2.1.3 Separation of Waste

Plastics fraction can be removed from city garbage by separate collection or by any of a number of processes. The current center for Plastics Recycling Research (CPRR), in the USA position regarding the best way to maximize the volume of recyclables collected is to collect mixed recyclable materials from households on a regular basis. These multi - material recyclables include newspaper, glass, aluminium, tin cans, and plastic containers. Newspapers are bundled and set out at curbside, with the other mixed recyclables placed in a special recycling container set next to the newspapers. The recyclables are loaded into two separate bins on a truck, one for newspapers and one for the other recyclables, and are taken to a Materials Recovery Facility (MRF) for separation and preparations for distribution to reclaimers (13). The truck is shown in Figure 2.6 (8).

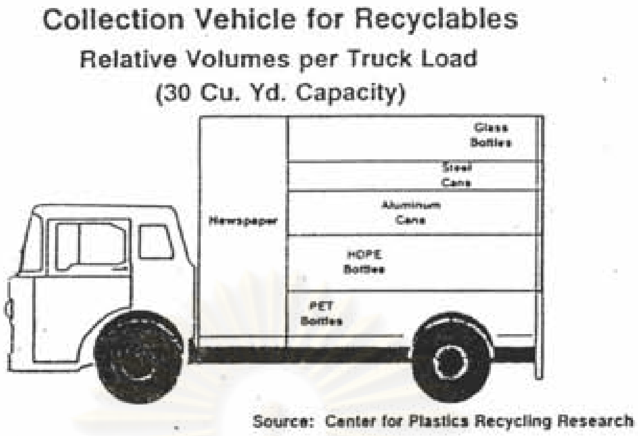

Figure 2.6 Collection vehicle for recyclables

The flow diagram of typical multi - material MRF is shown in Figure 2.7 (13). Newspapers from the collection vehicles are emptied onto a belt and taken directly to a baling machine and prepared for shipment. Mixed recyclables are then emptied onto a belt which leads them through a series of separation steps. First, tin plated steel cans (and other ferrous materials) are remove via a magnetic separation step. Second, aluminium (and other non - ferrous metals) are removed via an eddy - current separation step. Glass and plastic containers are then separated by density using a chain curtain on an inclined plane. Glass is separated into three color by hand; green, clear and brown. Plastics are hand separated into three categories ; un - pigmented HDPE and clear and green PET, to be sold directly to reclaimers, and the curbside tailing plastics, which now are landfilled.

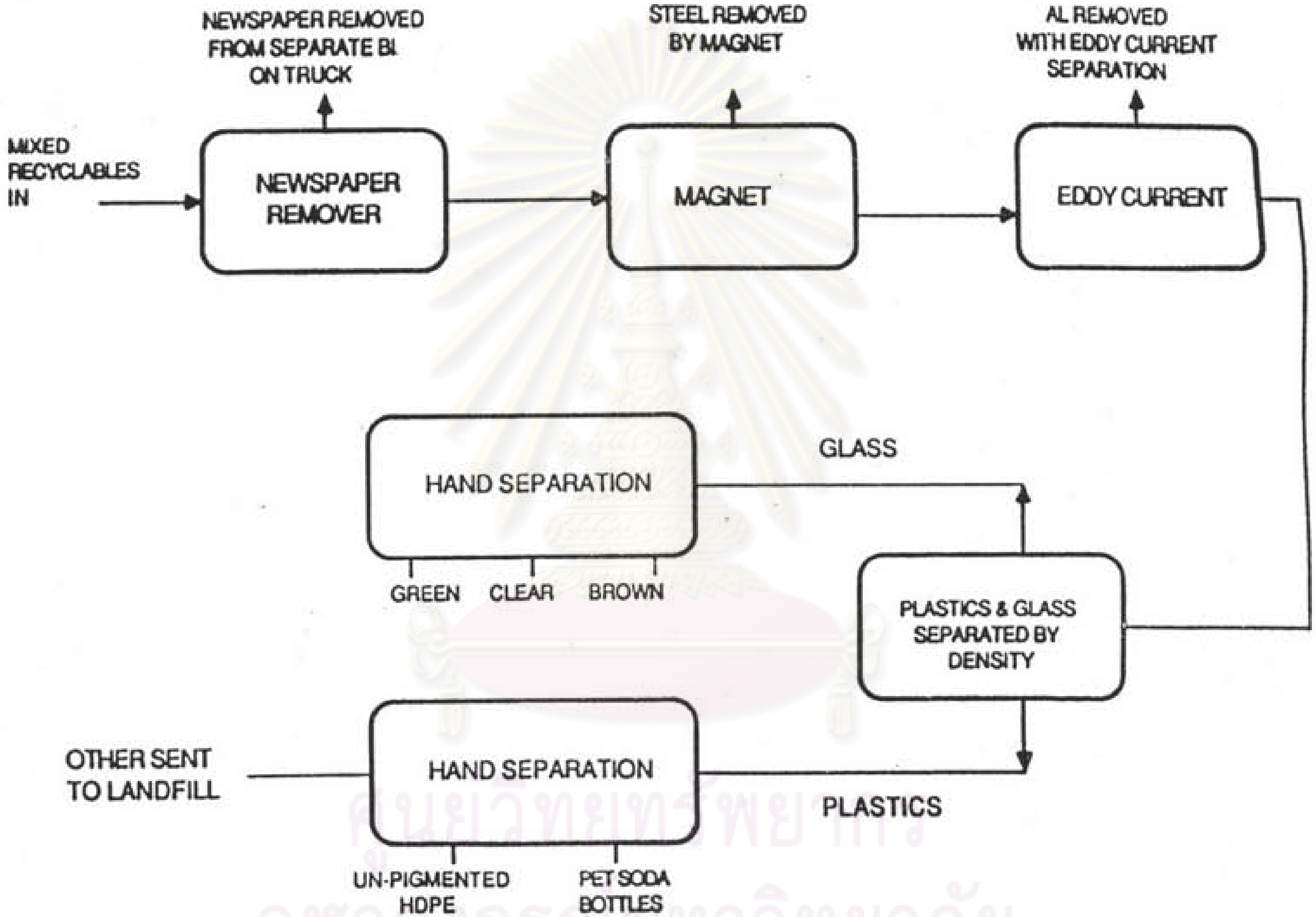

Figure 2.7 Flow diagram of typical multi - material Material Recovery Facility

2.2 Local Waste

2.2.1 Solid Waste Generation and Disposal Rates

Estimates of the amount of solid waste generated in the Bangkok Metropolitan area are very difficult to arrive at because of the amount of scavenging and recycling that occurs between the points of waste generation and the disposal sites. Little reliable information is available regarding the quantity of material removed from the waste stream by source separation and recycling at homes and commercial establishments.

Source separated materials, particularly from residences and small commercial establishments, are generally sold to street scavengers who operate from door to door on tricycle carts. These street scavengers sell the collected materials to local recycling shops.

Figure 2.8 (14) is a graphic illustration of the average daily waste tonnage disposed of per month since 1984. As shown in this Figure, waste quantities nearly doubled between the beginning of FY 1984 (October 1983) and August 1987 from an average of 2500 to 4700 metric tons per day. The graph also shows that there is a variation in the tonnages delivered to the sites during the course of a given year.

2.2.2 Solid Waste Characteristics

Several studies have examined the characteristics of solid waste in Bangkok. These studies reported analyses of samples from the mixture of wastes that arrives at the disposal sites. Additionally, JICA reported analyses from various sources of waste generation. The existing data base from these

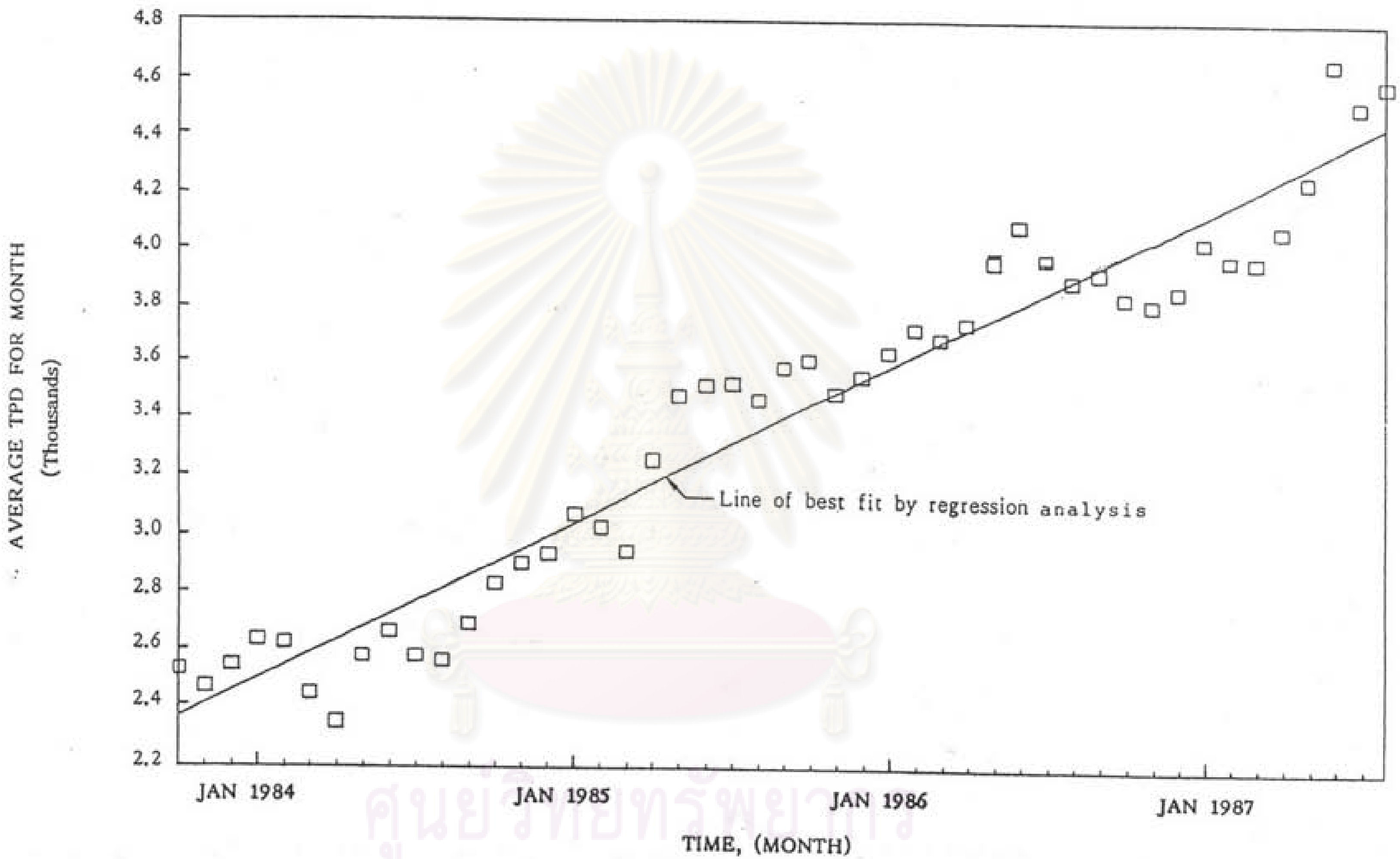

Figure 2.8 Average daily solid waste quantities delivered to disposal sites

studies (summarized in Tables 2.2 and 2.3 (14).) has been useful in determining technological issues for ultimate disposal of the entire mixed solid waste stream.

The overall composition of Bangkok's solid waste as determined in previous studies compares well with compositions determined for urban areas found in middle-income developing countries, as shown on Table 2.4 (15). Thailand is officially defined by the World Bank as a middle-income developing country according to economic data, such as Gross National Product.

Table 2.5 (14) shows Bangkok total population, the projected level of service and the service population for each of the 24 districts through the year 2007. As shown in this Table, the total service population is expected to increase from approximately 4,729,000 in 1987 to about 7,522,000 in 2007.

As shown in Table 2.5, it is expected that the level of service provided in the six city core districts will remain at 100 percent through the planning period. Therefore, an increase in the level of service is not a factor in projecting the future waste quantities to be delivered to the disposal sites from these districts.

In the four urban districts the population is projected to increase by about 354,000 people by the year 2007. An estimated 90 percent of the population in this area currently receives waste collection services, and it is anticipated that service will be extended to 97 percent of the population in the next 20 years. The growth in population, combined with an improvement in the level of service, is expected to result in an increase in the service population of about 422,000 people.

In the nine semi-urban districts, a population increase of approximately 2,159,000 is expected by the year 2007. It isestimated that about 85 percent of the existing population in this area is currently served and that 89 percent of the total population will be served by the end of the planning period. The service population is expected to increase by about 2,051,000 people by the year 2007.

Only 26.5 percent of the population in the five semi-rural districts currently receive waste collection services. The projected increase in population in this area is not large and the population density is expected to remain relatively low. Therefore, waste collection services are expected to increase only modestly to about 41 percent of the total population by the year 2007. This will result in an increase on the service population of approximately 180,000.

Figure 2.9 (14) is a graphical representation of the waste projections. As shown in this Figure, the average daily tonnage of wastes arriving at the disposal sites is projected to increase to approximately three times the current tonnage and reach a level of from 12,870 to 14,760 T/D by the year 2007. The median of the high and low projections is shown in Table 2.6.

Table 2.7 (14) shows the projected breakdown of the waste stream by physical components for the year 2007.

Each district manages its own fleet of assigned vehicles within the district. They are dispatched as early as possible in the morning to commercial areas and later to residential areas. Each vehicle is assigned a collection area which is small enough so that it can be covered by the truck and crew. The driver and crew often set their own pattern within the area rather than follow a predetermined route. Frequently, it is necessary to double back

Table 2.2 Solid waste characteristics from previous studies physical compostion, as reported by JICA 1982

Component	Source of Generation				(Unit: Percent on dry weight basis)				Incoming Solid Waste	
	Household	Market	Large Store	Hotel	Office	Textile Factory	Automobile Factory	Sawmill	Percent on dry weight basis	Percent on wet weight basis
1. Paper	24.7	9.8	59.0	45.1	63.6	5.7	42.0	0.0	18.0	18.3
2. Textile	4.7	1.1	1.4	3.5	1.5	81.7	6.5	0.2	4.4	3.6
3. Garbage	25.0	41.7	7.3	11.5	4.9	0.9	1.6	0.0	16.5	29.9
4. Grass and Wood	7.6	29.7	2.6	5.1	3.5	1.6	4.2	86.5	19.6	23.2
5. Plastics	11.2	4.7	19.8	9.8	10.1	5.2	18.2	1.4	10.3	7.5
6. Synthetic Glue	-	-	-	-	-	-	-	11.6	-	-
7. Rubber and Leather	1.2	0.4	0.6	0.9	0.7	0.5	5.5	0.0	2.7	1.4
8. Ferrous Metal	5.0	1.2	2.0	5.7	4.1	3.0	10.1	0.2	4.5	2.0
9. Non-Ferrous Metal	0.3	0.1	0.2	0.7	0.2	0.0	0.2	0.0	0.3	0.1
10 Glass	5.5	0.9	1.7	7.1	4.2	0.0	0.4	0.0	5.5	2.4
11. Bones, Stones and Ceramics	8.6	8.3	1.6	3.6	2.0	0.3	0.3	0.1	10.3	5.6
12. Dry Cells	0.48	0.0	0.8	0.4	0.2	0.0	-	-	0.4	0.2
13. Sand Paper	-	-	-	-	-	-	5.4	-	-	
14. Miscellaneous	5.9	2.1	3.0	6.6	5.0	1.1	5.6	0.0	7.5	5.8

Table 2.3 Solid waste characteristics at On-Nooch disposal site as sampled and analysed by ONEB[1]

ANALYTICAL PARAMETER	JAN.86	FEB.86	MAR.86	APR.86	MAY 86	JUN.86	JUL.86	AUG.86	SEP.86	OCT.86	NOV.86	DEC.86	AVERAGE	STD	MIN	MAX
I. Waste Components, % wet weight																
1. Combustible																
1.1 Paper	23.09	12.68	22.90	24.20	21.72	21.04	28.61	21.69	20.95	9.71	14.28	17.29	19.85	5.14	9.71	28.61
1.2 Garbage	19.06	32.06	12.72	21.15	18.61	23.73	17.55	20.50	15.86	20.50	19.76	22.68	20.35	4.53	12.72	32.06
1.3 Textile	14.43	6.29	4.44	20.72	5.70	3.29	3.04	7.17	3.83	3.30	7.00	12.67	7.66	5.26	3.04	20.72
1.4 Wood	3.30	6.26	13.55	4.27	8.76	5.88	8.40	15.18	14.57	20.61	15.67	8.56	10.42	5.15	3.30	20.61
1.5 Plastic	18.09	8.47	21.55	12.44	9.20	18.46	15.68	15.02	17.58	20.56	13.91	16.97	15.66	3.93	8.47	21.55
1.6 Rubber and Leather	0.00	0.00	0.00	0.00	7.61	0.00	0.22	0.00	0.00	3.34	0.00	0.00	0.93	2.21	0.00	7.61
Sub-total	77.97	65.76	75.16	82.78	71.60	72.40	73.50	79.56	72.79	78.02	70.62	78.17	74.86	4.46	65.76	82.78
2. Non-Combustible																
2.1 Ferrous Metal																
2.2 Non-ferrous Metal																
2.3 Glass																
2.4 Stone and Ceramics																
Sub-total	8.02	20.02	8.79	2.30	4.50	6.62	4.22	4.04	8.13	12.21	9.87	5.36	7.84	4.56	2.30	20.02
3. Miscellaneous																
3.1 Size > 5 mm.																
3.2 Size < 5 mm.																
Sub-total	14.00	14.23	16.04	14.91	23.90	20.97	22.28	16.39	19.09	9.76	19.52	16.49	17.30	3.83	9.76	23.90
Total	99.99	100.01	99.99	99.99	100.00	99.99	100.00	99.99	100.01	99.99	100.01	100.02				
II. Combustion Characteristics																
1. Moisture Content, % wet weight	56.49	58.78	56.07	56.27	59.96	53.84	58.49	57.05	54.54	54.67	55.18	54.00	56.28	1.90	53.84	59.96
2. Ash Content, % wet weight	12.07	15.08	13.04	10.90	11.21	13.05	13.51	10.57	13.64	13.59	15.16	11.71	12.79	1.46	10.57	15.16
3. Combustible Content, % wet weight	31.44	26.14	30.89	32.83	28.83	33.11	28.00	32.38	31.82	31.75	29.67	34.30	30.93	2.26	26.14	34.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.01	100.01	100.01				
4. Gross Calorific Value (Kcal/kg, dry basis)	3691.96	2856.93	3798.26	3604.61	3793.70	3770.32	3784.11	3765.12	3841.61	3429.75	3551.64	3699.58	3632.30	260.56	2856.93	3841.61
5. Combustible Content of Miscellaneous,% Against Miscellaneous																

1 The Office of the National Environmental Board (ONEB) collected

Table 2.4 Patterns of municipal refuse quantities and characteristics for low, middle and upper income countries

	Low-Income Countries[a]	Middle-Income Countries[b]	Industrialized Countries[c]
Waste generatiion (kg/cap/day)	0.4-0.6	0.5-0.9	0.7-1.8
Waste densities (wet weight basis- kg/cubicmeter)	250-500	170-330	100-200
Moisture content (% wet weight at point of generation)	40-80	40-60	20-40
Composition (% by wet weight)			
Paper	1-10	15-40	15-50
Glass, Ceramics	1-10	1-10	4-12
Metals	1-5	1-5	3-13
Plastics	1-5	2-6	2-10
Leather, Rubber	1-5	-	-
Wood, Bones, Straw	1-5	-	-
Textiles	1-5	2-10	2-10
Veggetable	40-85	20-65	20-50
Misc.inerts	1-40	1-30	1-20
Particle Size, % greater than 50 mm	5-35	-	10-85

a Includes countries which had an annual per capica income of less than US$400 in 1983.

b Includes countries which had an annual per capita income of more than US$400 and less than US$6,850 in 1983.

c Countries with industrial market economies had annual per capita incomes from US$4,780 to US$16,290 in 1983.

d This may be reduced in areas with household or commercial garbage grinders which discharge to sewers.

Table 2.5 Projected of collection service and service population, by district

DISTRICT	EXISTING CONDITIONS(1987) TOTAL POP.	% SERVED	POPULATION SERVED	PROJECTED CONDITIONS(1992) TOTAL POP.	% SERVED	POPULATION SERVED	PROJECTED CONDITIONS(1997) TOTAL POP.	% SERVED	POPULATION SERVED	PROJECTED CONDITIONS(2002) TOTAL POP.	% SERVED	POPULATION SERVED	PROJECTED CONDITIONS(2007) TOTAL POP.	% SERVED	POPULATION SERVED
City Core Districts	852,195	100	852,195	891,740	100	891,740	930,266	100	930,266	959,999	100	959,999	990,932	100	990,932
1 Phra Nakhon	111,847	100	111,847	112,174	100	112,174	113,998	100	113,998	114,286	100	114,286	114,575	100	114,575
2 Pom Prab Sattru Phai	88,297	100	88,297	90,386	100	90,386	93,673	100	93,673	95,654	100	95,654	97,678	100	97,678
3 Pathum Wan	144,404	100	144,404	151,272	100	151,272	160,844	100	160,844	168,053	100	168,053	175,585	100	175,585
4 Samphanthawong	51,287	100	51,287	52,330	100	52,330	54,015	100	54,015	54,869	100	54,869	55,737	100	55,737
5 Bang Rak	92,535	100	92,535	101,592	100	101,592	108,815	100	108,815	115,577	100	115,577	122,759	100	122,759
8 Phaya Thai	363,825	100	363,825	383,987	100	383,987	398,922	100	398,922	411,560	100	411,560	424,599	100	424,599
Urban Districts	1,105,113	90	992,203	1,193,103	91	1,088,923	1,278,149	94	1,195,311	1,364,947	95	1,300,666	1,459,041	97	1,414,656
7 Dusit	575,484	100	575,484	639,185	100	639,185	704,033	100	704,033	772,312	100	772,312	847,140	100	847,140
16 Thon Buri	277,074	73	202,221	291,098	75	218,323	302,541	80	242,033	313,213	85	266,231	324,261	90	291,835
17 Khlong San	144,496	81	117,245	148,204	85	125,973	150,962	90	135,866	153,043	92	140,799	155,152	94	145,843
19 Bangkok Yai	108,059	90	97,253	114,616	92	105,447	120,552	94	113,319	126,379	96	121,324	132,188	98	129,838
													0		
Semi-Urban Districts	3,299,513	85	2,791,366	3,827,547	86	3,287,873	4,331,799	87	3,764,736	4,861,021	88	4,268,313	5,458,293	89	4,842,559
6 Tan Nawa	427,975	95	406,576	489,911	96	470,314	549,207	97	532,731	613,365	98	601,097	685,017	99	678,166
9 Huai Khwang	264,328	80	210,544	307,969	82	252,534	351,464	84	295,229	399,678	85	339,726	454,506	86	390,876
10 Phra Khanong	647,050	88	570,190	736,688	90	663,020	823,328	90	740,995	909,655	90	818,690	1,005,034	90	904,531
11 Bang Khen	568,423	67	378,695	671,930	70	470,351	769,857	74	569,694	867,504	78	676,653	977,537	82	801,580
12 Bang Kapi	430,265	100	430,265	533,543	100	533,543	625,312	100	625,312	728,984	100	728,984	849,843	100	849,843
18 Bangkok Noi	299,429	100	299,429	322,248	100	322,248	345,126	100	345,126	366,776	100	366,776	389,783	100	389,783
20 Bang Khun Thian	275,180	50	137,590	325,962	51	166,241	380,632	52	197,929	439,329	53	232,844	507,078	54	273,822
21 Phasi Charoen	234,296	100	234,296	264,740	100	264,740	292,513	100	292,513	321,144	100	321,144	352,578	100	352,578
22 Rat Burana	152,566	81	123,781	174,456	83	144,882	194,360	85	165,206	214,586	85	182,398	236,917	85	201,379
Semi-Rural Districts	352,922	26	93,501	414,113	31	126,464	484,998	36	174,208	566,245	40	227,354	662,102	41	273,352
13 Nong Chok	58,477	11	6,452	62,472	15	9,371	66,966	20	13,393	72,047	20	14,409	77,513	20	15,503
14 Min Buri	76,224	28	21,438	87,646	30	26,294	100,747	32	32,239	115,623	32	36,999	132,695	34	45,116
15 Lat Krabang	60,816	33	19,829	69,988	35	24,496	80,563	38	30,614	92,927	40	37,171	107,188	42	45,019
23 Taling Chan	93,737	26	24,559	112,990	30	33,897	135,993	35	47,597	163,073	40	65,229	195,547	40	78,219
24 Nong Khaem	63,668	33	21,222	81,016	40	32,406	100,729	50	50,364	122,575	60	73,545	149,160	60	89,496
OVERALL	5,609,742	84	4,729,265	6,326,503	85	5,395,006	7,025,213	86	6,064,522	7,752,212	87	6,756,332	8,570,368	88	7,521,499

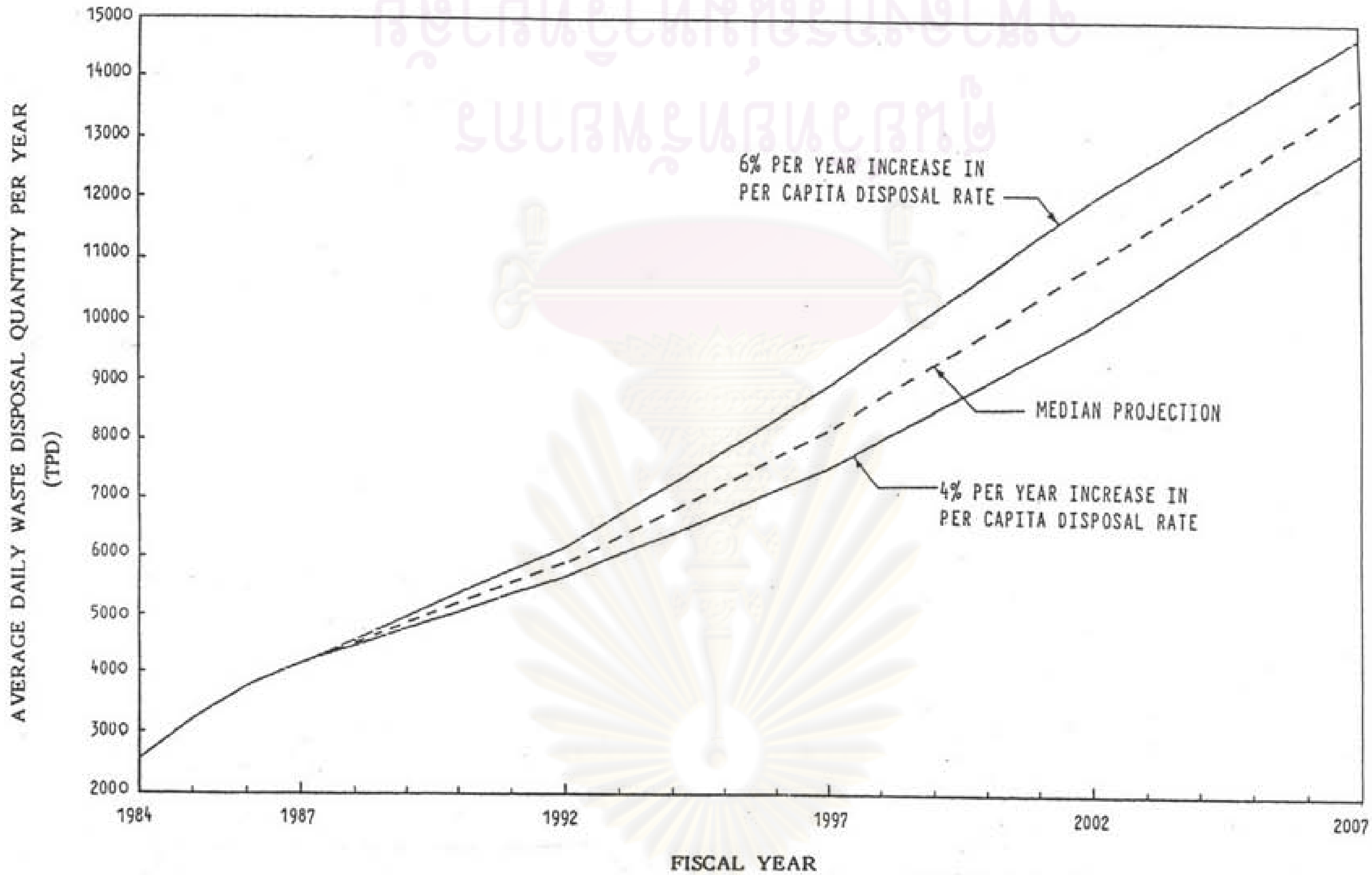

Figure 2.9 Waste quantity projection

Table 2.6 Median projections of solid waste quantities

Year	AverageT/D
1987	4,148
1988	4,502
1989	4,854
1990	5,206
1991	5,558
1992	5,910
1993	6,376
1994	6,842
1995	7,308
1996	7,774
1997	8,240
1998	8,792
1999	9,344
2000	9,896
2001	10,448
2002	11,000
2003	11,564
2004	12,128
2005	12,692
2006	13,256
2007	13,820

Table 2.7 Projected physical composition of waste stream

I. Waste Component	Range in percent wet weight	
	1987 Sampling	Projected year 2007
1. Combustible		
1.1 Paper	10-20	12-22
1.2 Garbage	25-40	20-35
1.3 Textile	6-8	6-9
1.4 Wood and Grass	10-16	8-15
1.5 Plastic	10-15	12-18
1.6 Rubber & Leather	1-3	1-3
2. Non Combustible		
2.1 Ferrous Metals	1.5-2.0	1.7-2.2
2.2 Non-Ferrous Metals	0.1-0.3	0.2-0.3
2.3 Glass1-3	2-4	
2.4 Stone and Ceramics	4-6	3-5
3. Millcellaneous	4-7	4-6
II. Combustion Characteristics		
1. Moisture Contents	55-60	52-56
2. Ash Content	10-15	12-20
3. Combustible Content	25-30	27-32

within the area for wastes carried out late for pickup. In some cases, a final pass through the area is made before the end of the collection day.

Since crews actively try to recover recyclable materials, the trucks also carry baskets for those materials. Sorting and separating recoverable materials occurs as the truck is being filled and thus lengthens the time for loading waste. In setting priorities within the assigned areas, there is a tendency to first service locations likely to contain larger amounts of recyclable material. As shown in Figure 2.10 (14), trucks from some districts go to one, two or all three sites, depending on distance or travel time. At the entrances to the disposal site, collection trucks mill about the drop off points of the recycling businesses. There, baskets of recovered materials are removed from the trucks and sold.

2.2.3 Treatment and Disposal

The Department of Public Cleaning's Garbage Disposal Division currently operates disposal sites at three locations ; Nong-Khaem , On-Nooch, and Ram-Intra - as shown in Figure 2.10. The distribution of the waste stream among these sites during the period March to July, 1987 is shown in Table 2.8 (14).

All three disposal sites contain open dumping areas, composting facilities and small incinerators to burn materials rejected by the compost processing equipment. Over 90 percent of the solid waste delivered to the three sites is disposed of by open dumping.

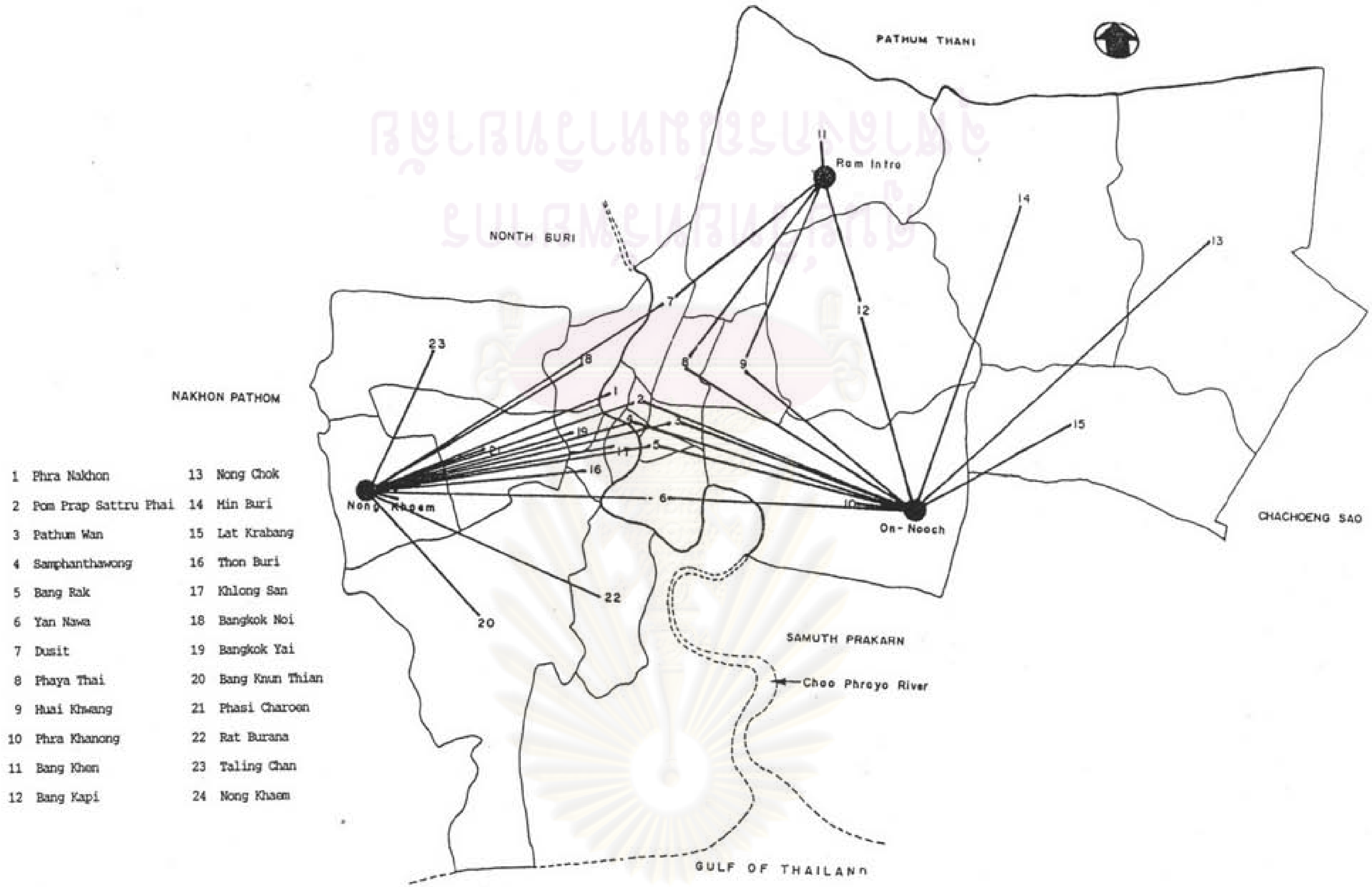

Figure 2.10 Disposal sites at three locations ; Nong-Kheam, On-Nooch, and Ram-Intra

Four primary composting plants were constructed at the three disposal sites in the late 1970's. Two plants, each rated at 320 T/D input capacity, were constructed at On-Nooch; one rated at 320 T/D at Ram-Intra; and one rated at 160 T/D at Nong-Khaem. All four plants were built by the John Thompson Company and include waste shredding and classification steps followed by primary fermentation in a five storey high, tipping floor type fermentation barn. An incinerator was constructed as part of each plant to burn the reject stream from the waste classification equipment.

Table 2.8 Distribution of waste stream to disposal sites

Month	March 1987 to July 1987 Amount of Waste Delivered (TPD)			
	Nong-Khaem	On-Nooch	Ram-Intra	Total
March	1503	1454	1012	3669
April	1573	1522	988	4083
May	1683	1570	1005	4258
June	1821	1635	1209	4665
July	1768	1434	1313	4515
Avg.overperiod	1670	1523	1105	4298
%ofTotal	38.8	35.5	25.7	100

Nong-Khaem Disposal Site

The Nong- Khaem disposal site is located in Nong-Khaem District in the westerly portion of Bangkok. This site has been in use since 1972 and encompasses approximately 370 rai (59.2 hectares). During the period March to July, 1987, an average of 1,670 T/D of waste was disposed of at this site. All of it was placed in the open dump.

The facilities located at Nong-Khaem include administration and maintenance buildings, truck scale and scale house, truck washing yard, compost plants and an open dumping area. In addition, the Fertilizer Enterprise operates compost screening and packaging facilities in a number of large buildings on the southerly side of the site.

A Flow chart of the compost facilities at Nong-Khaem is shown in Figure 2.11 (14)

On-Nooch Disposal Site

The On-Nooch disposal site is located in Phra Khanong District in the south central portion of the city. This site encompasses an area of approximately 581 rai (93.0 hectares) and has been in operation since 1964. The quantity of solid waste received at this site averaged 1,523 T/D between March and July, 1987. Nearly all of this waste was disposed of by open dumping.

The facilities located at On-Nooch include administration and maintenance buildings, two separate truck scales and scale houses, truck washing facilities, two primary composting plants with incinerators for compost rejects and a large open dumping area. In addition, night soil treatment and disposal facilities are located on the south side of the site and a compost screening building is located in the south east part of the site.

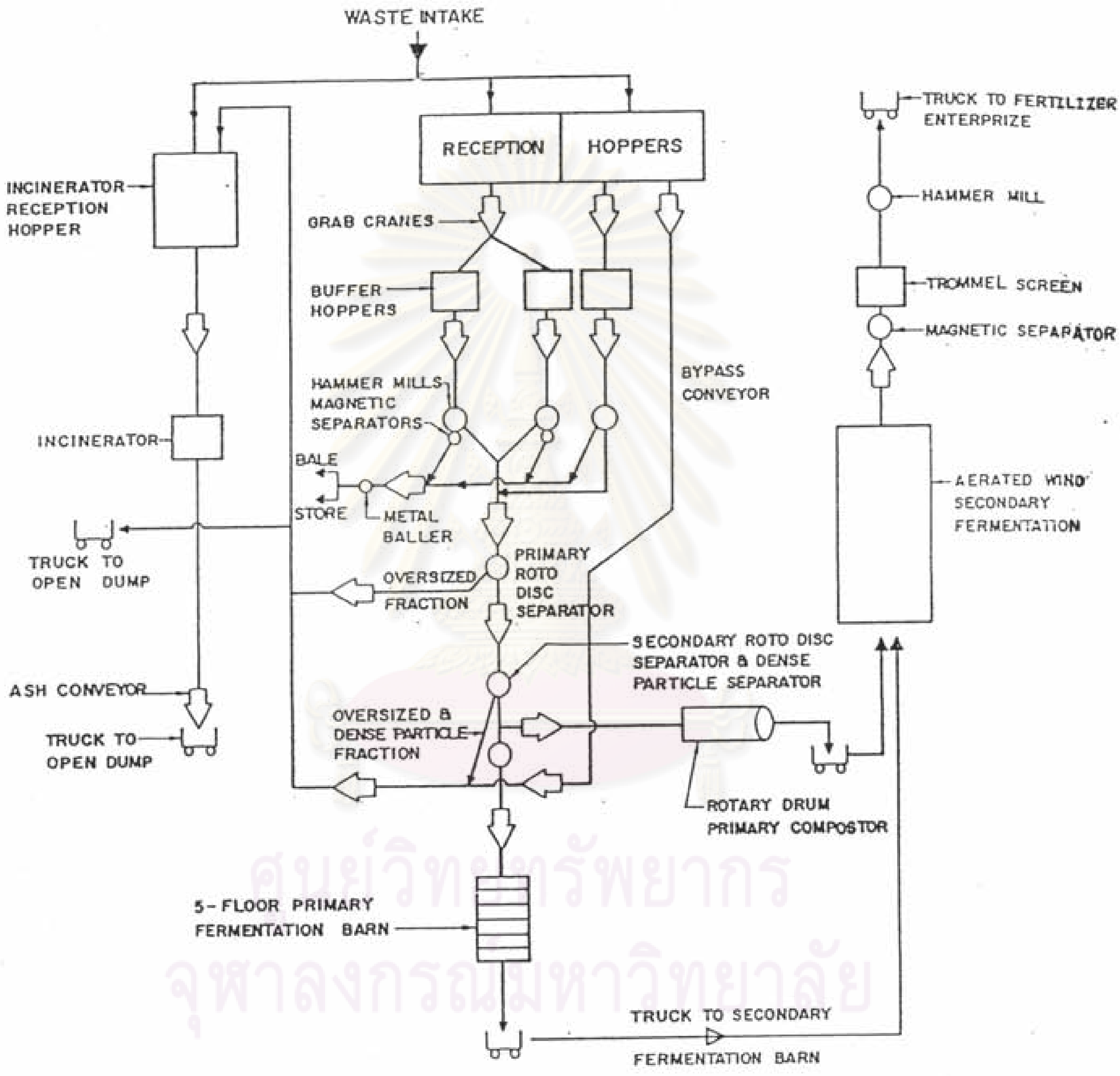

Figure 2.11 Nong-Khaem compost plant

The composting facilities at On-Nooch consist of two John Thompson type primary fermentation plants with an input capacity of 320 T/D each. Both plants were constructed to a common design between 1972 and 1978 and were started up by the Bangkok Metropolitan Administration (BMA) in 1978. The flow diagram for the plants is shown in Figure 2.12. (14)

Ram-Intra Disposal Site

The Ram-Intra disposal site is located in Bang-Khen district in the northern part of Bangkok. This site was placed in operation in 1972 and encompasses an area of approximately 89 rai (14.25 hectares) of which 59 rai are owned by BMA and 30 rai are used under an agreement with an adjacent land owner.

The compost plant at Ram Intra is similar to those at On-Nooch and was designed for an input of 320 wet metric tons in eight hours at the receiving pit, 160-200 T/D at the fermentation barn and 120 to 160 T/D at the incinerator. No compost screening facilities were ever constructed at the site, and the primary compost produced by the plant has always been placed in the open dump or given away without screening.

2.3 Management of Plastic Waste

Although plastic constitute only a minute fraction of today's municipal solid waste, their amount is expected to rise rapidly in the future and they do present a troublesome disposal problem. Plastics can be recycled into useful products.

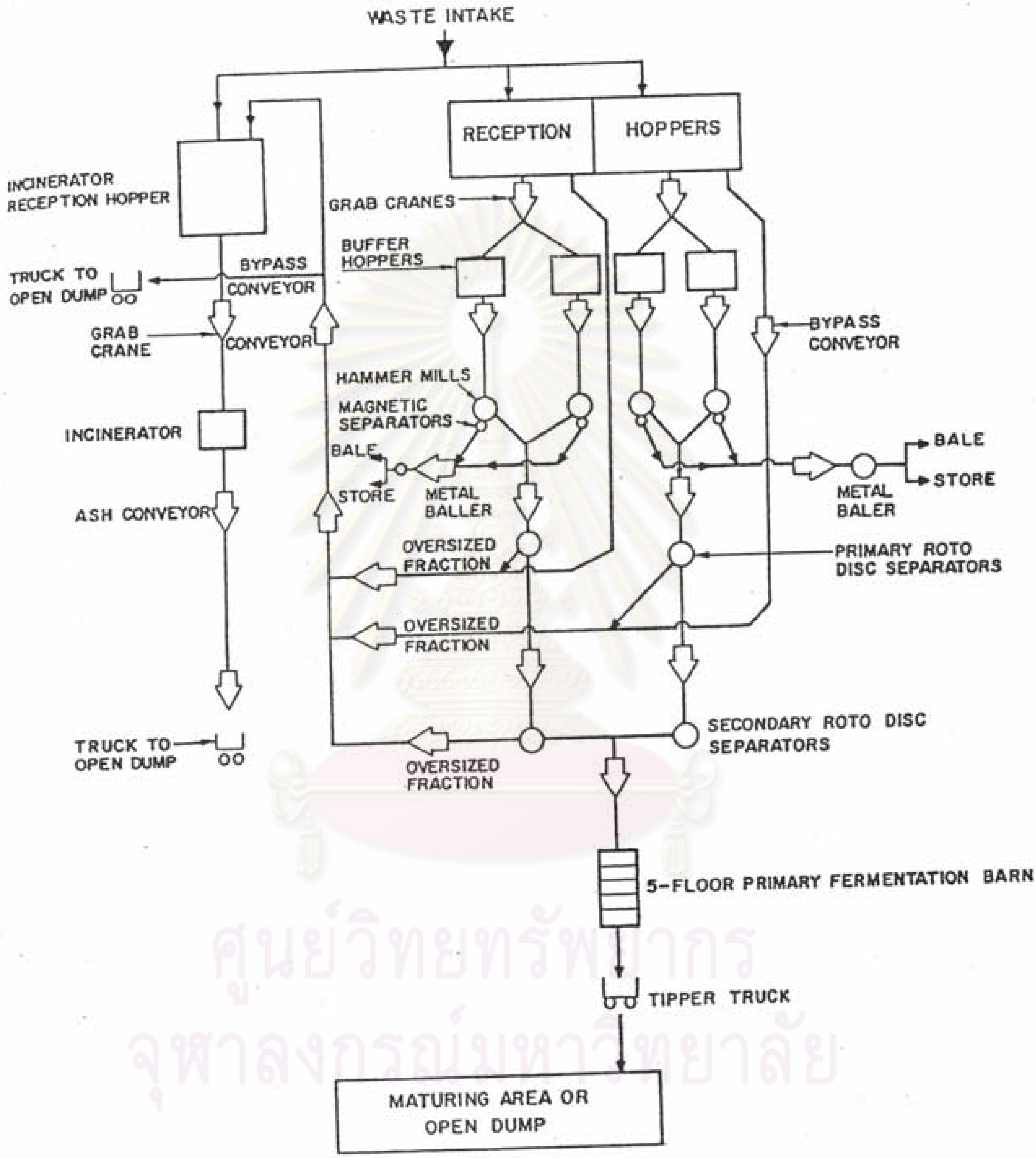

Figure 2.12 On-Nooch and Ram-Intra compost plants

2.3.1 Type of Plastic Waste

Waste plastics consist of plastics resin or product that must be reprocessed or disposed of.

Industrial Plastics Waste is a plastic waste generated by various industrial sectors, nonconsumer plastic, which includes waste from molders, converters, packers, resin manufacturers, and so on. Normally this plastic waste is easy to identify, comes from a single source, can be processed on traditional molding equipment and may be commingled. Some cleaning may be required.

Post - Consumer Plastic Waste is any plastic that has been used by the consumer and discarded. It applies to an individual plastic or to a mixture of plastic. It could be one type of plastic, such as HDPE milk jugs ; two types of plastic, such as PET beverage bottles with HDPE base cups ; or a mixture of a large variety of plastics.

Commingled Plastic Waste may be a mixture of two plastics or a variety of plastics. PET and PE, the focus of most post-consumer plastic waste collection programs, are said to be commingled. "Commingled" also is used to describe post- consumer plastic waste that includes a mixture of all types of resins that are in multilayered, printed, laminated, plated, pigmented, painted, or modified forms.

Contaminated Plastic Waste may have nonplastic material enclosed, such as paper foil, wood chips, floor sweepings, lunch bags, product residue, aluminium closures, wire reclaim, fiber waste, magnetic strips, and plating.

Nuisance Plastics are waste plastics that cannot be reprocessed under the existing technoeconomic conditions.

Scrap Plastics are waste plastics that are capable of being reprocessed into commercially acceptable plastic products.

2.3.2 Plastic Cycle

The flow of plastics products as well as plastics waste is shownin Figure 2.13 (16). The resin manufacturer supplies the fabricator and compounder with raw materials. Scrap plastics from the resin manufacturer are sold to the reprocessor for reprocessing, or to the fabricator as second - grade resins.

The fabricator sells his product to the converter, packager, assembler, or consumer. Scrap plastics are recycled within the fabricator's plant or sold to a reprocessor. Raw materials can come from the resin supplier or compounder (virgin material), reprocessor (reprocessed scrap) , or converter (scrap plastics).

The compounder buys resins from the resin manufacturer, compounds them with additives, and resells them to the fabricator. The scrap plastics can be reprocessed in the compounder's own plant or sold to the reprocessor.

The converter purchases a semifinished plastic product (e.g., plastic film) and converts it into the finished product (e.g., a plastic package). The plastic scrap generated by the converter goes to the reprocessor or fabricator. The packager, assembler, and distributor purchase finished products from the fabricator or converter, assemble and package them, and sell them to the consumer, though not necessarily directly. This segment generates nuisance

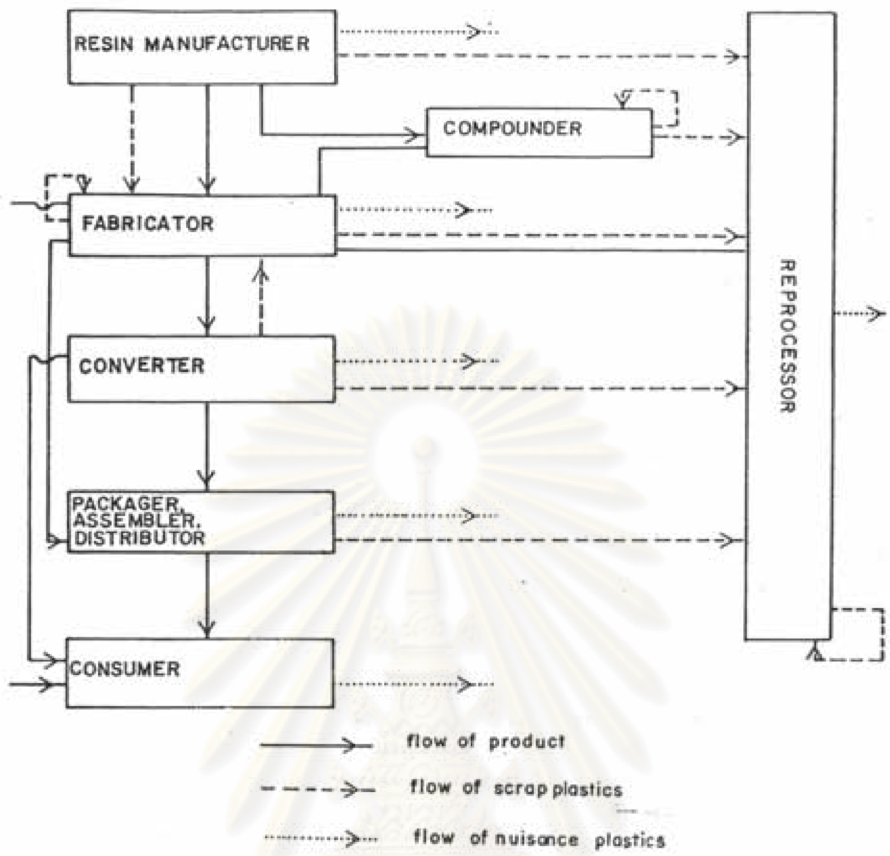

Figure 2.13 Flow of plastics products and plastics waste

plastics, but virtually no scrap plastics.

The reprocessor purchases scrap plastic from various industrial sectors, reprocesses them, and sells them, to the fabricator. Small amounts of scrap plastics generated by the reprocessor are recycled in plant.

The consumer, at the end of the plastics cycle, generates only nuisance plastics, which eventually end up together with nuisance plastics generated by the industrial sector in landfill or an incinerator.

2.4 Waste Separation Processes

2.4.1 Separation of Components of Municipal Refuse

Municipal refuse can be treated as a potential source of raw materials. Not only do the individual constituents have some economic value, but the municipal refuse, if it must be disposed of without the recovery of value, actually has negative value. The scarcity of raw materials and the concern about environmentally safe disposal of refuse have added a new dimension to the question of recycling solid wastes. Although plastics constitute only a small portion of municipal refuse, the actual quantity is enormous. In order to recycle the components of municipal refuse, they must first be separated ; numerous commercial and experimental processes are available for this purpose. Most of existing separation plants consist of two main stages : preparation of the feed (size reduction), and separation.

Size Reduction

Size reduction of municipal solid refuse is the mechanical separation of the material into smaller pieces. It is accomplished mainly by the mechanical forces of tension, compression, and shear applied by crushers, shears, shredders, chippers, rasp mills, drum pulverizers, disk mills, pulpers, and hammermills.

Separation Method

The method used to separate the indiv707069696969nts of solid waste are based on differences in their physical properties. The following properties are widely used as a basis for separation processes :

1. Particle Size

Since such properties as ductility, strength, and impact resistance vary from one material to another, the components of municipal refuse will vary greatly in particle size following the reduction stage. If a given component has a particle size considerably larger or smaller than the others, it can be separated from the rest of the refuse on that basis.

2. Density

There are a variety of separation methods utilizing density differences.

3. Electromagnetism

Ferrous metals are recovered from refuse using magnetic separators. The principle is widely used because of its simplicity.

4. Color

The difference in appearance of various components of solid waste has been a criterion for many years in hand sorting. Automated separation methods based on color differences are not available. They are ideally suited for the segregation of materials such as glass and for the further separation mixed waste glass into color categories.

The preceding fundamental material properties are the basis of the following separation methods :

1. Manual Separation

Manual separation is the oldest technique still used in less affluent societies. It is of little importance in modern separation plants. The method is sometimes used at the incoming feed belt to scavenge easily separable items. Hand separation of paper, cardboard, glass containers, and so on, is best practiced at the source.

2. Gravity Separation

Widely used types of equipment for gravity separation are vibrating tables, ballistic separators, inclined conveyors for removal of stones and other heavy particles, and fluidized bed separators.

3. Air Classification

Three parameters are utilized in air classification :size, specific gravity, and shape. Generally zigzag or similar - shaped columns are used. Air enters at the bottom of the column and the material to be separated in the middle. A series of columns with different geometries or flow rates will produce several grades of materials. Usually the light fractions at the top are collected in cyclone separators while the air and dust are returned to the column. Instead of a vertical column separator, a vortex classifier may be used in which a radially inward flowing air vortex replaces the upward flow. Other types of air classifiers utilize horizontal air flow, rectangular chamber with zigzag baffles, a rotary cylinder and a current of air, and vertical vanes. The choice of a specific system depends on the type of feed and the desired degree of separation. Air classification is the most widely used technique for the separation of solid wastes. The various arrangements for air classifiers are shown in Figure 2.14 (17).

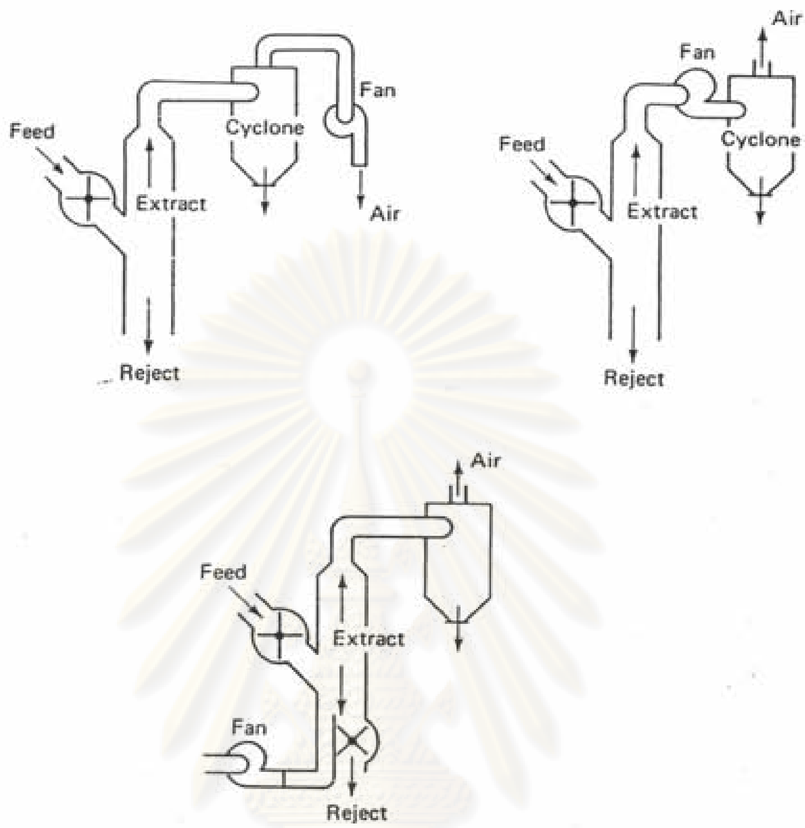

Figure 2.14 Three basic arrangements for air classification

4. **Magnetic Separation**

This method is used in virtually all systems for the removal of ferrous metals. Separation is acheived by mechanisms such as magnetic pulleys, dry and wet drum separators, and cross - belt saparators.

5. **Electrostatic Separation**

Electrostatic separation is somewhat similar to magnetic separation. It relies on the ability of some materials, such as plastics or paper, to acquire and hold an electrostatic charge. The particles are attracted to a charged roll or belt, or are deflected in an electrostatic field.

6. **Color Separation**

Optical separation has found an application in the sorting of glass according to color. It may find a similar application in the separation of different colored plastics.

Processes for separating components of solid wastes may be classified as wet or dry. Dry processes are generally simpler, require lower energy input, and have fewer potential environmental problems. Wet processes are usually capable of producing much cleaner and more uniform products. Dry and wet separation techniques may be used as parts of the same process. The Black - Clawson and Flakt systems, descriptions of which follow, illustrate the principles of the wet and dry processes, respectively.

Black - Clawson Hydrasposal/Fibreclaim Process

Figure 2.15 (18) shows a flowsheet of the Black -Clawson materials recovery system. Raw waste from trucks is conveyed to a Hydropulper, where it is converted into a 3 to 4 % slurry in water. The slurry, containing paper, food waste, plastics, glass, and small metal pieces, is extracted from the bottom of the pulper through small openings. Larger objects are ejected through an opening near the bottom and removed from the system by a continuous bucket elevator. The discharge from the bucket elevator is washed in a rotary drum washer, and the ferrous metals are removed by magnetic separation. The slurry from the pulper is pumped through a liquid cyclone to remove inorganic materials. The reject residue contains about 80 % glass and some aluminium. The next step is to reduce to discrete fibers any paper that has not disintegrated thus far, and to screen out such materials as plastics, wood, and leather. This is accomplished on a so -called VR Classifier,

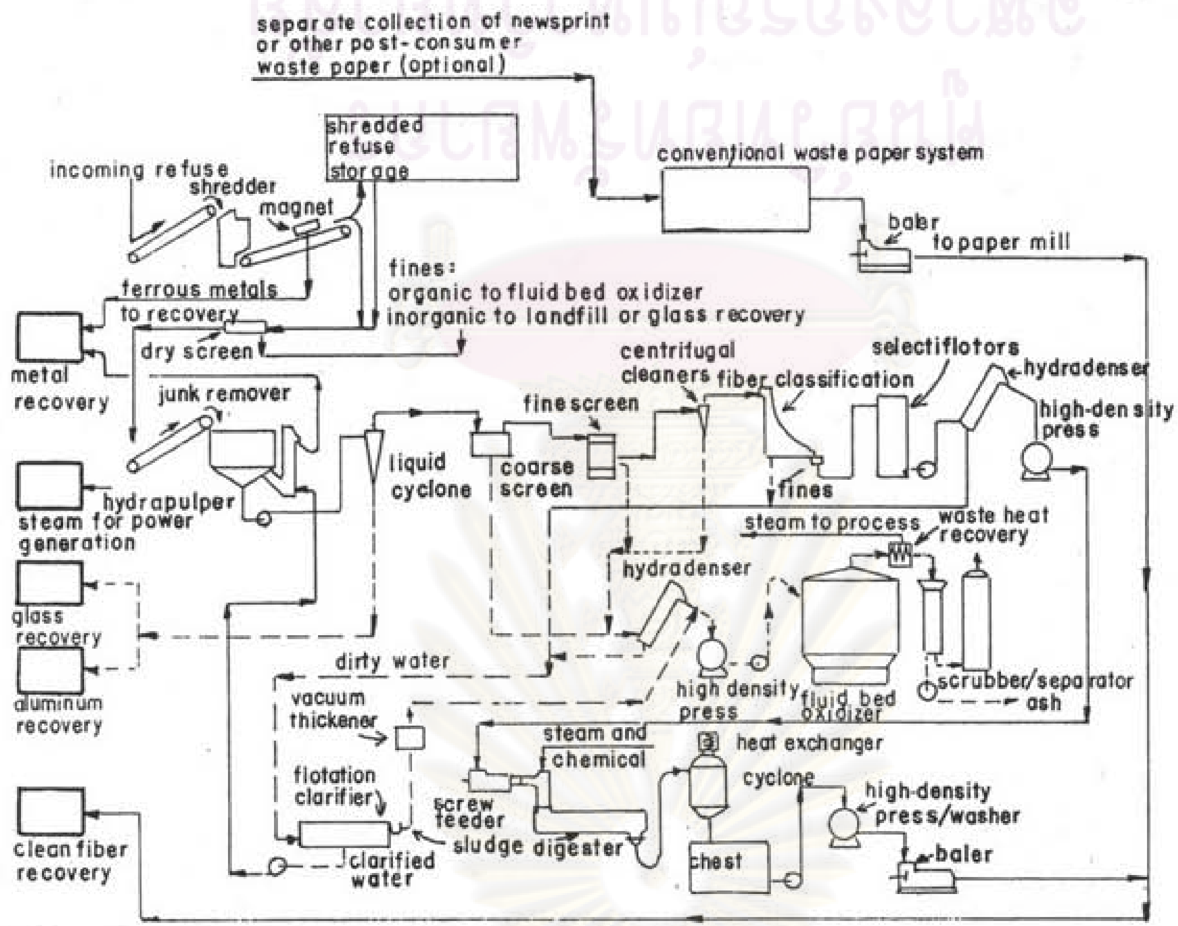

Figure 2.15 Flowsheet for Black-Clawson hydrasposal/fibreclaim System

a heavy screen plate with 1/8 - in. diameter perforations, and a high - speed rotor operating against it. The pulsating action of the rotor prevents the screenfrom plugging. Objects larger than 1/16 -in. are removed in a second stage of screening, while small slivers and fine dirt are removed in a second stage of centrifugal cleaning.

After leaving the centrifugal cleaner the slurry is pumped over an inclined screen with horizonral slots. About 85 % of the water goes through the slots, carrying with it very short fibers, debris, clay, and food particles. The recovered fibers are dewatered in two stages. The equipment for the first stage is an inclined thickener consisting of a perforated cylinder set at a 60^{o} angle within which rotates a screw. The screw conveys the pulp through the perforated cylinder and discharges 10 % pulp into a cone press where it is dewatered to approximately 40 % solids. The main product from the Black - Clawson process is pulp of papermaking quality. The drawbacks of the system are high power demand and the necessity for extensive wastewater treatment.

Flakt Waste Recovery System

The experimental plant designed and built by AM Svenska Flaktfabriken is a good example of a dry separation system. Figure 2.16 (19) is a schematic of the process. The feedstock is prepared by a combination of shredder (which breaks the plastic bags in which the refuse is packed, thus exposing the material) and a rotating trommel screen (which separates out excessively large items). From the trommel the material is moved by rotary feeder into a zigzag type air classifier. Closed - circuit air circulation is employed and only a small portion of the circulation air is filtered and discharged. The fan motor provides heat, which helps to dry the material being

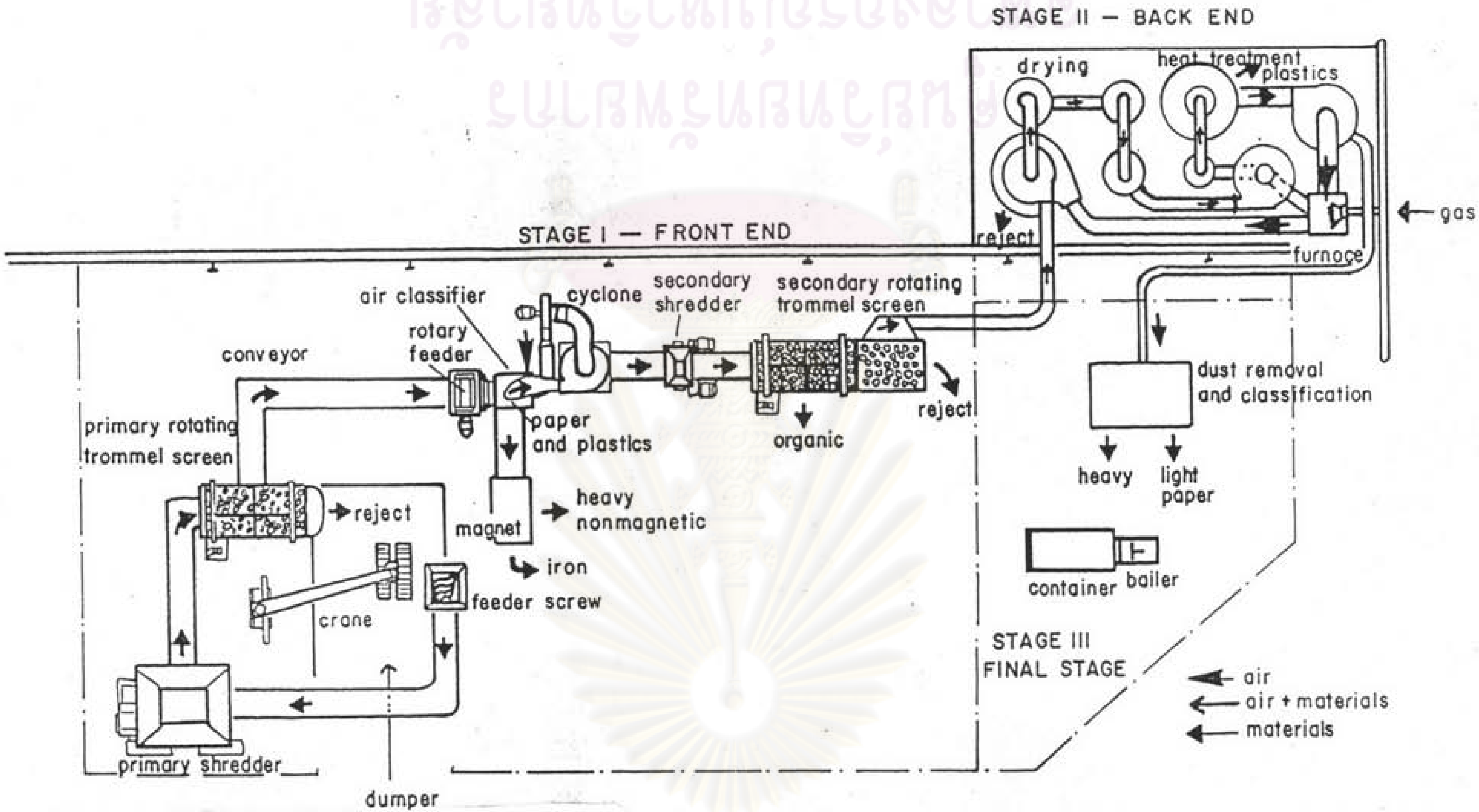

Figure 2.16 Flakt dry separation system

separated. The light fraction is discharged through the cyclone (Figure 2.17 (19)) onto the rotary feeder and into the secondary shredder. The purpose of the secondary shredder is to liberate the entrained impurities and to achieve a more uniform particle size. The light fraction consists of moist paper, some plastic film, and textiles. The fine impurities, consisting of wood waste, sand, dust,and so on, are separated by the second rotating trommel screen. The pneumatically conveyed material from stage one is a mixture of moist paper partially contaminated by organic matter. Some plastic film and textile remain.

The purpose of stage two is to carry out further purifications of the paper product and render it biologically stable . This purification is achieved by drying with hot air (Figure 2.18 (19)). The dryer is divided into two stages :

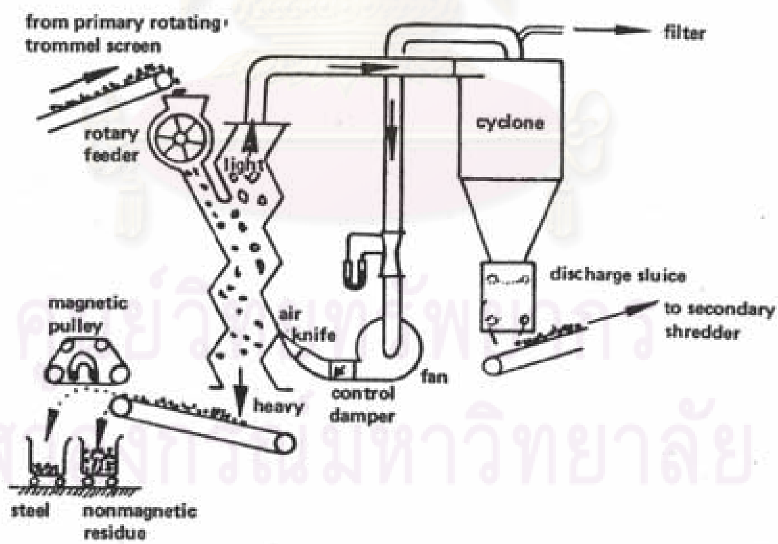

Figure 2.17 Arrangement of vertical air classifier

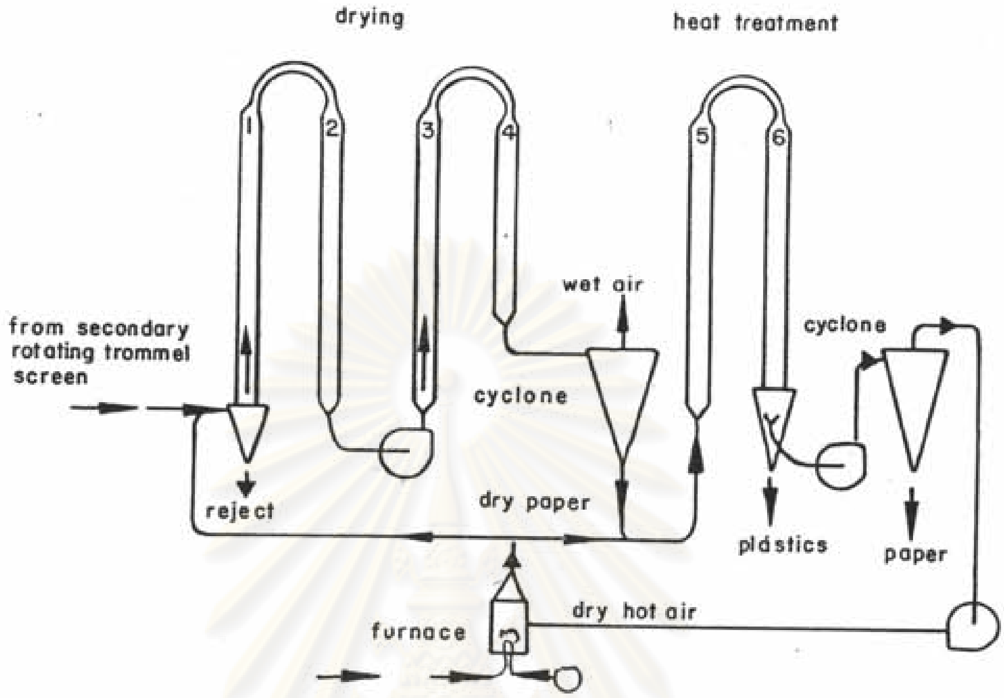

Figure 2.18 Paper dryer

in the first the material is dried and the humid air discharged ; in the second the material is heat - treated with recycled dry air. The dryer incorporates two separators. In the first heavy material with entrained paper is separated out : The reject consists mainly of textiles. The heat treatment of the second stage is used to destroy bacteria in the paper ; plastic is considered an impurity. Although most of the plastic material is separated out by pretreatment in stage one, a certain amount is entrained with the paper. Under the action of heat, the flakes of plastic contract to small balls which can be separated out aerodynamically. This separation is achieved in the last heating tower, which is equipped with a special separator.

2.4.2 Separation Processes Specific to Plastics

Separation of Paper/Plastics Mixtures

Mixtures of plastics and paper are a common product of municipal waste dry separation plants. To increase the value of the product, the mixture has to be separated into its components. The main problem in separation derives from the aerodynamic similarity of plastic film and paper. Three main principles have been suggested as the basis of separation methods : (1) the application of heat, (2) wet pulping, and (3) electrodynamic separation.

(1) Process Involving the Application of Heat.

Figure 2.19 (20) illustrates the "hot cylinder" method. The separation device consists of an electrically heated,chrome - plated cylinder enclosed within a hollow rotating tube fitted with vanes to ensure a tumbling action about the heated cylinder. The drum and the heated cylinder rotate in opposite directions. A doctor blade is in contact with the heated cylinder at the bottom. There is a trough connected to the bottom of the blade. Material is fed into the drum through a sheet metal tube inserted at the entrance. Plastic materials coming into contact with the hot cylinder melt and are removed by the doctor blade. Removal of over 90 % of plastics from the paper can be achieved. The plastic stream is relatively paperfree: 1 % or less of paper contaminants can be achieved.

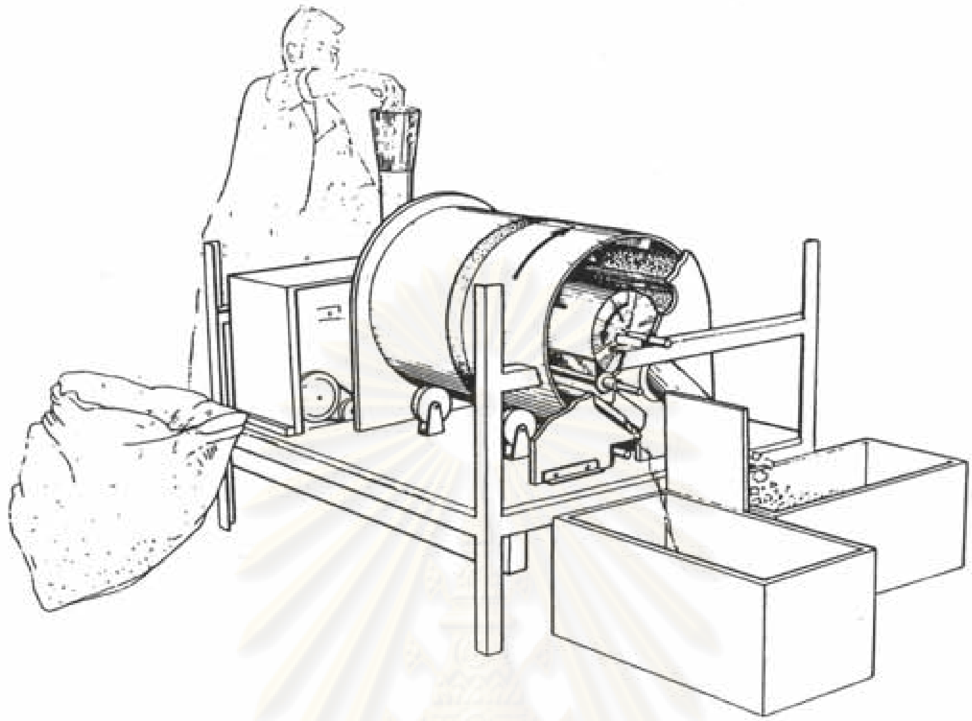

Figure 2.19 Hot "cylinder" separation method

(2) Wet Separation Process.

A wet separation process patented by Black - Clawson Fibreclaim, Inc. (21), is applicable to the recovery of plastics from the light fraction obtained from the dry separation plant. It can also form a basis for a complete wet separation process. A conveyor delivers waste material to a shredder. The output from the shredder is transferred to an air classifier. The light fraction from the air classifier comprises approximately 60 % paper, 20 % plastics, and the balance rags and vegetation residue. The light fraction is transported to a pulper equipped with rotor and extraction plate having relatively small perforations. Pulped paper is capable of passing through the openings. Plastic particles retained in the tub are discharged from time to time through a separate outlet provided with a shutoff valve. The plastic - rich fraction is transferred to a dewatering device and then to an air classifier.

(3) Electrodynamic Separation

Figure 2.20 (23) is the schematic for the electrodynamic separator. The mixture of plastics and paper is fed into the separator by a vibratory feeder. The material falls onto the rotating ground drum and is carried into the corona formed between the wire beamed electrode and the drum. The paper is drawn toward the electrode while the plastics adhere to the drum. As the drum rotates, the plastics are brushed free at the bottom. Good separation of the 1- to 3 -in. shredded material was obtained at voltages ranging from 35 to 5 kV at a spacing of about 6 in.

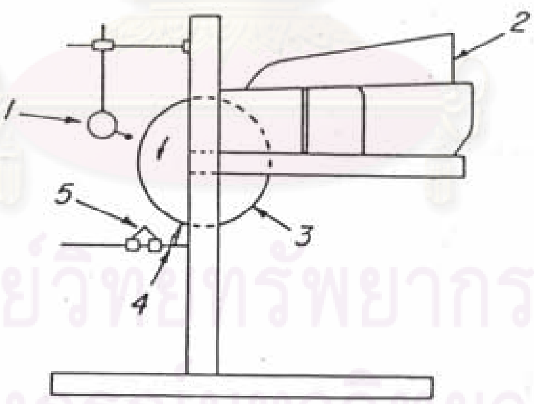

Figure 2.20 Schematic diagram of electrodynamic separator :

(1) combination 4-in. aluminum electrode with wire electrode;

(2) vibratory feeder; (3) grounded rotating drum; (4) brush;

(5) adjustable stream splitter

Separation of Plastics from Plastic - Coated Fabric

A large amount of waste PVC - coated fabric is available, mainly from companies involved in its manufacture or conversion. All processes developed for the separation of PVC from fabrics involve solvent extraction of the polymer. (24, 25)

Figure 2.21 (24) is a flow diagram of a process developed by Fiber Process, Inc. Materials arriving at the plant are cut into sizes suitable for hand sorting of the various colors. The sorted material is dried and loaded into a jacketed vessel, which is then sealed and an inert gas introduced. The vessel is filled with a solvent such as tetrahydrofuran (THF), and the agitated mixture is heated to a temperature slightly below the boiling point of the solvent. The resin dissolves in the solvent, and the solution is transferred to the storage tank. A total of three washes is needed for completes extraction. Solvent trapped in the fibers is driven off by heated nitrogen. The dry fibers are then baled and wrapped for shipment. The polymer solution may be filtered to removed pigments, fillers, or other contaminants, and then fed into a preconcentrator, usually a vertical - film evaporator. The output contains 30 to 40 % solids. The final drying takes place under vacuum in a spray dryer. The dryer yields a colorless, granular PVC resin, or compound of the original formulation. Solvent is condensed and returned to the process.

Separation of Polymer from Polymer-Coated Wood Fiber

Polymer coatings now constitute an obstacle to paper recycling efforts. They also constitute a potential source of recycled plastic which could be reused in the same. Two separating techniques are described : the wet pulping and solvent extraction processes.

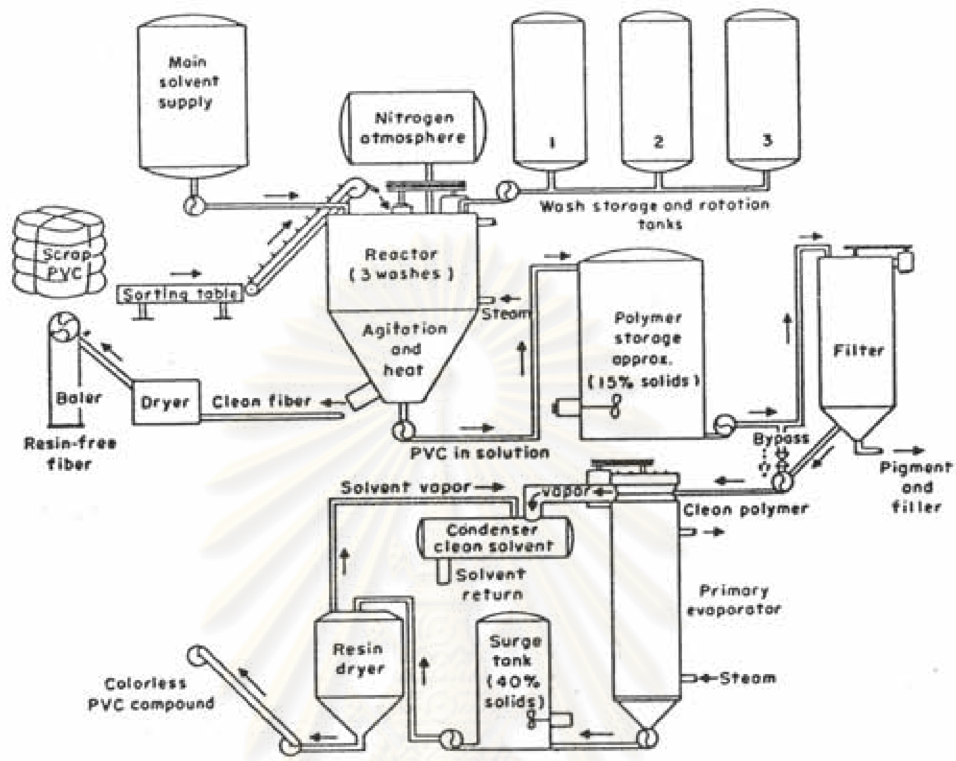

Figure 2.21 Fiber process, Inc. PVC recovery system

1. Wet Pulping Process

Felton (26) describes various wet pulping paper recovery processes. In all these processes the paper is pulped forming an aqueous suspension, while the coating remains in the form of large sheets or particles. Screening can be used to separate pulp from plastic. The pulp is usually relatively clean, but the plastic portion tends to contain some paper fibers.

2. Solvent Extraction

The schematic of a solvent recovery system is given in Figure 2.22 (27). The process is designed to treat material such as coated kraft wrapping and packaging papers, plastic - coated food board, oil - saturated

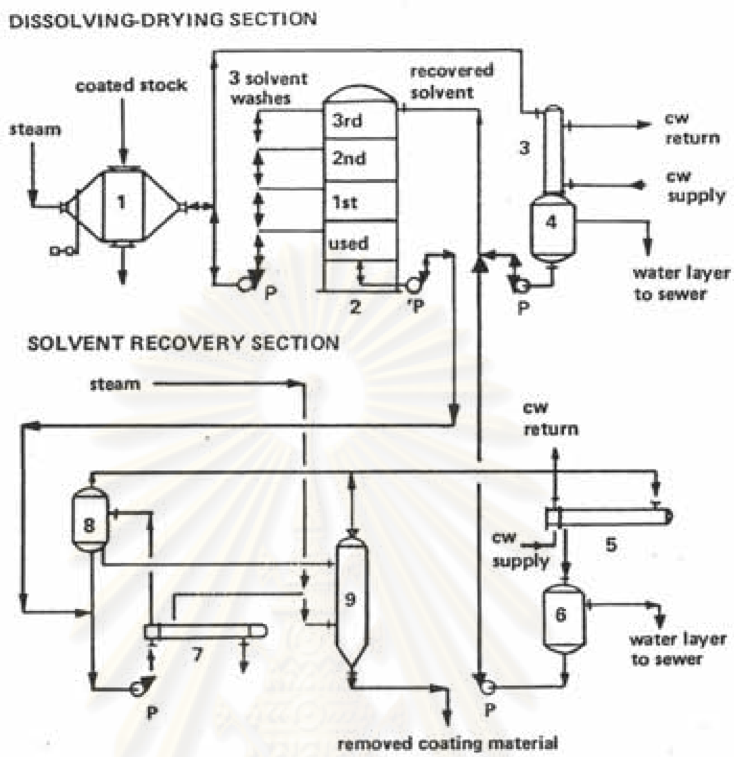

Figure 2.22 Riverside recovery process: (1) dissolver-dryer; (2) solvent storage tank ; (3,5,7) condenser; (4,6) decanter; (8) flash evaporator; (9) pump

kraft, waxed cup stocks, and asphalt - laminated corrugated containers. The separation is achieved by multiple washing of the wastepaper stock with hot solvent (perchloroethylene) and steam stripping the residual solvent from the fiber after the final wash. The process is comprised of the following steps :

- air - dry waste material is charged into the dissolver - dryer.
- solvent extraction is carried out.
- residual solvent is removed from the clean material by steam evaporation.
- steam - dry material is ready for pulping.

- steam is condensed and the solvent decanted.
- solvent is distilled, recovered and reused ; the coating, adhesive, or impregnating polymer is recovered for possible reuse.

2.4.3 Separation of Mixtures of Plastics

Both industrial and post-consumer plastics wastes often occur as mixtures of generic groups of plastics. The following separation techniques have been investigated : (1) float/sink methods, (2) processes utilizing differences in surface tension, and (3) solvent extraction. These processes have the potential for separating simple two- or three - component mixtures of industrial plastic wastes, but their usefulness in the separation of a complex post-consumer plastic waste mixture is questionable. Thus far, none of these approaches has been implemented on an industrial scale.

1. Float/Sink Separation

The three main plastic components of municipal solid waste - polyolefins, PVC, and PS have slightly different densities: polyolefins are 0.90 to 0.96, PVC 1.22 to 1.38, and PS 1.05 to 1.06 g/m^3. These density differences can be used to separate a mixture of plastics into generic groups using a sink/float separator. The flowsheet of such a process, proposed by the U.S. Bureau of Mines, is given in Figure 2.23 (28). The separation is achieved using four liquid media : water (ρ=1 g/m^3), two water alcohol mixtures (ρ= 0.93 and 0.91 g/m^3), and an aqueous salt solution (ρ = 1.20 g/m^3).

Figure 2.24 shows the schematic of an experimental hydraulic hydraulic separator using only water as a separating medium : it is a combination of float/sink and elutriation separation. A mixture of chopped

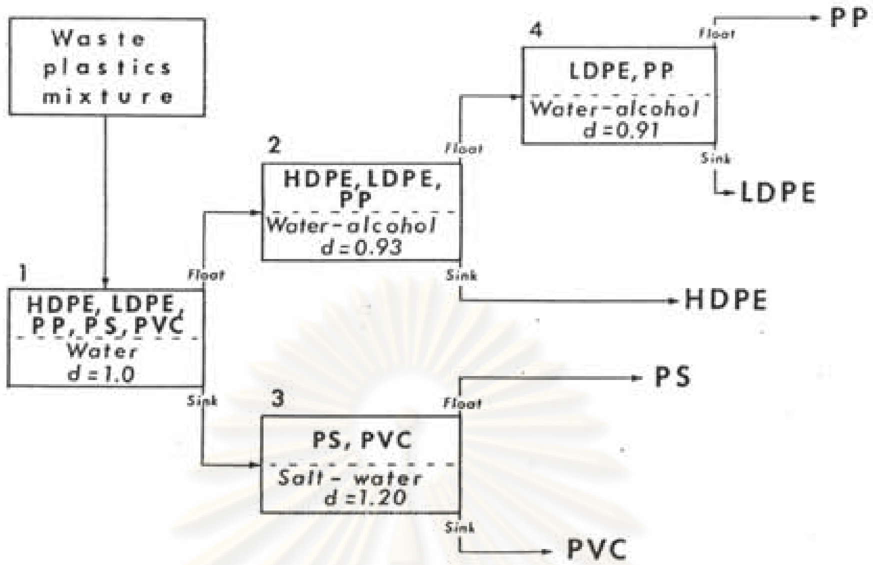

Figure 2.23 A method for isolating the five thermoplastics commonly found in packaging wastes by sink-float separations in four liquids with different densities

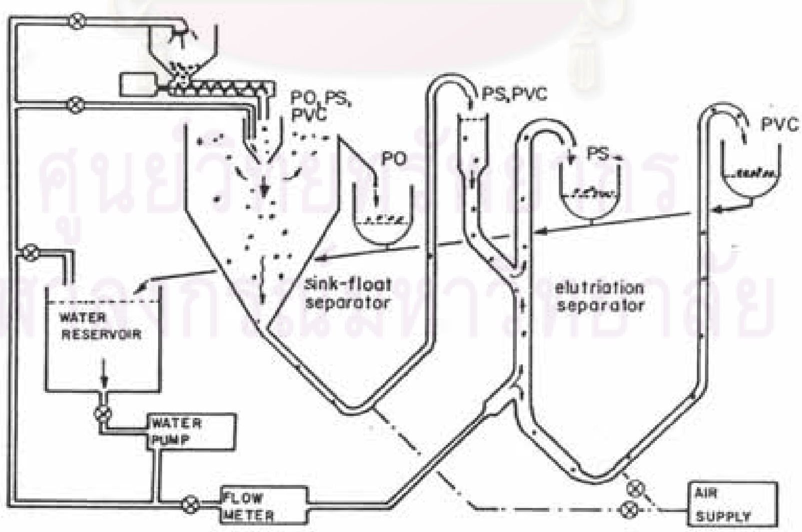

Figure 2.24 Hydraulic separator

plastics is fed into the sink/float separator where the polyolefins are floated off and the other components sink. The heavy fraction is transported to the elutriation column where the PS is carried with the water current and the PVC sinks. The segregated fractions are caught on screens while the water is recycled to the main reservoir. To test the separator, a plastics - rich fraction from Black - Clawson process was upgraded from 14 % plastic to an almost all plastics mixture. Table 2.9 gives the sink/float analysis of this mixture. Polyolefin (PO) and PS fractions are relatively uncontaminated compared to the PVC fraction. Most of the thermosets and composites remain with the heavy PVC fraction.(29)

Table 2.9 Analysis of fractions obtained from the Hydraulic separation of upgraded plastic concentrate from the Black-Clawson process

Fraction	(wt%)	wt% by density, g/cm^3			
		<1.0	1.0-1.2	1.2-1.5	>1.5
PO	48	97	3	-	-
PS	33	0.59	54.5	-	
PVC	19	-	28	40	32

2. Separation Using Selective Wetting Characteristics

Although plastics are generally hydrophobic, their wetting characteristics can be selectively adjusted by the addition of surfactants. Figure 2.25 shows a typical set of contact angle curves. The contact angle decreases as the concentration of wetting agent increases. The effects of wetting agents are quite different on different plastics. The effect on PP is slight, but wetting increases on PE, PS, and PVC (in that order). Because of the lower density of plastics, considerably larger particles can be floated. A flotation cell for plastics must satisfy the following conditions : (1) air bubbles of the most suitable size for the flotation of plastics must be uniformly generated; (2) agitation is necessary to avoid sedimentation of large particles ; (3) there should be no turbulent water flow in the separation zone ; and (4) the water surface must be smooth and stable. (30)

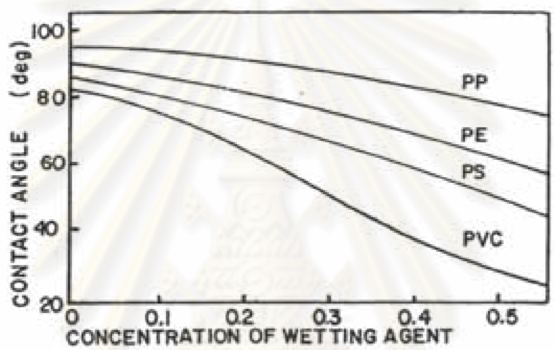

Figure 2.25 An example of the relationship between concentration of wetting agent and contact angle

3. Solvent Separation

High-molecular-weight polymers are rarely soluble in one another. When two chemically different polymers are mixed they usually form separate phases. Even when a common solvent is used to dissolve each of the plastics, such solutions are not miscible. If a mixture of plastics is dissolved in a solvent, the several phases will contain solutions of almost pure components. Sperber and Rosin (31) studied the separation of a mixture of polyolefins (PO), PS, and PVC in various solvents. They found that a mixture of cyclohexanone and xylene makes an efficient solvent system. Table 2.10 shows the results of their experiments, which indicate that the major thermoplastics in

Table 2.10 Experimental results of solvent separation

Run	Wt % LDPE	Wt % HDPE	Wt % PP	Wt % PS	Wt % PVC	Total polymer (%)	% Cyclo-hexanone	Temp. (°C)	% PO in PO layer	% PS in PS layer	% PVC in PVC layer
1	45	21		17	17	17	15	125	98.8	96.9	98.4
2	45	21		17	17	10	15	115	99.5	98.6	98.9
3	36.3	16.5	13.2	17	17	10	15	125	80.8; 17.3[a]	97.1	97.9
4	45	21		17	17	10	10	125	98.5	96.8	97.4
5	45	21		12	22	10	15	125	97.8	97.7	98.8
6	66			17	17	10	15	125	99.0	97.5	98.3
7		66		17	17	10	20	120	98.9	98.8	98.3
8	41.6	19.4	19.5	19.5	10	10	115	99.1	99.1	99.1	98.8
9	45	21		17	17	12.5	15	125	99.5	98.9	99.1
10	45	21		17	17	12.5	20	115	99.3	99.2	99.5
11		66		17	17	12.5	20	125	99.2	98.5	98.7
12	41.6	19.4		19.5		19.5	12.5	15	115	99.5	99.3
13	45	21		17	17	15	15	125	99.9	99.5	99.6

Table 2.10 Continued

Run	Wt % LDPE	Wt % HDPE	Wt % PP	Wt % PS	Wt % PVC	Total polymer (%)	% Cyclo-hexanone	Temp. (°C)	% PO in PO layer	% PS in PS layer	% PVC in PVC layer
14	45	21		17	17	15	15	115	99.6	99.6	99.3
15	36.3	16.5	13.2	17	17	15	15	125	77.1; 22.4[a]	99.1	99.0
16	45	21		17	17	15	30	125	99.3	99.2	99.8
17	66			17	17	15	15	125	99.8	99.4	99.2
18	45	21		17	17	15	20	115	∿100	99.8	99.3
19	41.6	19.4		19.5	19.5	15	20	115	99.5	99.6	99.9
20	45	21		22	12	15	20	125	99.2	99.2	99.4
21	48.4	22.6		14.5	14.5	15	20	115	99.8	99.7	99.5

[a]First number = %PE, second number = %PP.
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a waste mix can be successfully separated. The effectiveness of the process is influenced by the following factors : composition of the solvents, temperature, type of waste feed, and the solvent/feed ratio.

2.5 Plastic Recycling

Plastic recycling is often broken down into four basic methods which are being used throughout the world today to varying extents.

1. **Primary Recycling** : The use of uniform, uncontaminated plastic waste to manufacture plastic products (primary restricted to plant - generated scrap).

2. **Secondary Recycling** : Utilization of plastic waste unsuitable for direct reprocessing with standard plastic processing equipment. Feedstock includes post-consumer plastics waste, mixed industrial plastics waste, discrete industrial plastics waste.

3. **Tertiary Recycling** : Pyrolysis of municipal refuse. This process is capable of producing simple chemical compounds out of mixtures of waste materials otherwise incinerated or placed in landfills.

4. **Quarternary Recycling** : The reduction of combustible waste, which may or may not be accompanied by the generation of energy, to inert residue by controlled high - temperature combustion.

Primary Recycling

If refuse is not possible, then primary recycling is preferred. As a general rule, scrap plastic must be used in an end application that can tolerate lower performance specifications than the product yielding the scrap. However, there are a few instances where the scrap can be recycled back into the same product. Much of the recycling that occurs in fabricator's facilities is primary recycling. A flowsheet of an in - plant primary recycling process is shown in Figure 2.26 (16). Converting equipment converts feed material consisting of virgin and recycled plastics into a product. Some waste is also produced, most of which is recycled ; a certain proportion of the waste may have to be discarded. After one cycle the product stream consists of the material that has undergone one and the material that has undergone two processing cycles.

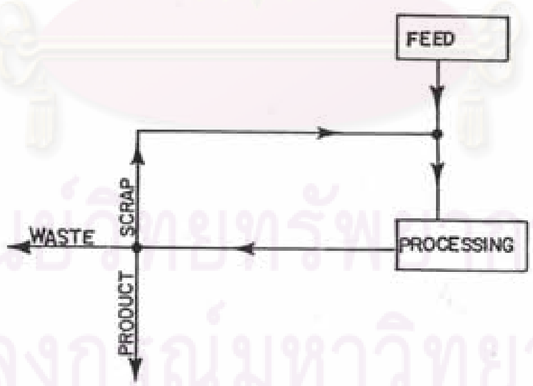

Figure 2.26 Diagram of recycling process

A major requirement for primary recycling is a very clean stream of scrap, thus if the fabricator is careful, he can recycle much of his own scrap.

One intriguing possibility for the primary recycling of consumer scrap is the possibility that the individual plastic milk cartons used in schools or other institutions, if collected, could be granulated, washed, and reprocessed into new polyethylene milk containers. Under these controlled environmental conditions, severe contamination of the plastic containers is very unlikely.

Secondary Recycling

Secondary recycling utilizes plastics waste unsuitable for direct reprocessing using standard plastic processing equipment. There are four main reasons for its slow development: (1) waste plastics tend to be highly contaminated with nonplastic substances (metal, sand) posing a danger to the processing equipment; (2) various plastics present in the waste mixture used as feedstock might be mutually incompatible, resulting in a product having poor mechanical properties ; (3) a feedstock with a consistent and reproducible composition is not always available ; and (4) in order to be economically viable, the product must be mass produced.

Plastic wastes of various origins can be considered potential feedstock for secondary recycling processes. From the processing viewpoint these wastes can be classified four ways.

1. Post-consumer Plastics Waste Recovered from Municipal Refuse.

This consists of a relatively consistent mixture of generic groups of plastics with a large nonplastic component. The majority of work on the utilization of plastics from municipal solid refuse has employed simulated plastics mixtures (mixtures of virgin resins having the same composition as plastics in the refuse) or actual plastics waste handpicked from refuse. It is rarely mentioned that this approach is only of theoretical value, as most techniques used to separate plastics from refuse result in a plastic fraction the composition of which is considerably different from that of the plastics in the refuse. Most dry separation methods, for example, result in a plastic fraction containing mainly films, and thus considerably richer in polyethylene and with much better properties than the total plastic portion of the refuse.

2. Post-consumer Plastics Waste Obtained from Returnable Packages.

Among these are milk jars and soft drink bottles. This material consists usually of only one type of plastic and contains only small amounts of nonplastic contaminants.

3. Mixed Industrial Plastics Waste.

This feedstock is usually obtained by collecting plastic waste from a number of industrial sources. Various plastics are present in the mixture, and the amount of nonplastic materials is small. The composition can vary with time.

4. Industrial Plastics Waste Consisting of a Single Type of Plastic.

Usually plastic waste is too contaminated with nonplastic materials or too degraded to be used in primary recycling.

Japan is probably the leader in secondary recycling technology, followed closely by the countries of Western Europe. Various technical approaches to secondary recycling are possible, including :

1. Reprocessing using slightly modified standard plastics processsing equipment. This has the advantage of a ready availability of equipment but the disadvantages of frequent production problems and poor product properties.

2. Reprocessing using specialized processing equipment. The advantages are fast production rates and a product with reasonable mechanical properties ; while a common disadvantage is high capital cost.

3. Chemical modification of mixed plastics waste. The advantage is a product with good mechanical properties ; the disadvantage is that material costs are increased without solving the processing problems.

4. Use of plastic waste in combination with virgin plastic (i.e. as a core in sandwich structure) . This has the advantage that good products can be manufactured at low material cost, and the disadvantage that only certain types of relatively uncontaminated plastic waste can be used.

5. Use of plastic waste filler in other plastic or nonplastic materials. This has an advantage in that waste material isused to extend a more expensive material and a disadvantage in that the applications and types of potential products are limited.

6. Use of plastic waste as a matrix in combination with low- cost filler. The advantage is that plastic waste acts only as a binder, the mechanical properties being contributed mainly by the filler. There is a disadvantage in that the applications and types of potential produts are limited.

Out of the six approaches just listed, only number 2 , reprocessing using specialized equipment, 4 , the use of plastics waste as a core in sandwich structures, and 5, the use of pulverized wastes as fillers in plastics, have been commercialized.

A demonstration plastics recycling plant capable of processing about 10 tons of plastics waste per week was set up in Japan by Japan Steel Works Limited (32). Figure 2.27 shows a schematic of that process.

Tertiary Recycling

Chemical from plastic waste ; by pyrolysis. Pyrolysis is defined as the physical and chemical decomposition of organic materials caused by heating in an oxygen - free or oxygen - deficient atmosphere. The pyrolysis process is capable of producing simple chemical compounds out of mixtures of waste materials which would otherwise have to be incinerated or disposed of by landfilling. The products of pyrolysis can be employed as commercially useful chemicals or as fuel.

The following advantages are claimed for pyrolysis.

1. Most municipal solid waste can be converted into an economically viable form.

2. The volume of waste can be reduced by 90 % or more.

3. The pyrolysis process is contained and thus does not cause air pollution.

4. Because the process is nonpolluting and requires little space, pyrolysis plants can be located in cities, resulting in lower transportation costs.

5. The process is a net energy producer.

6. The energy produced is in a convenient form, i.e., gas oil, and char.

7. The process can be set up so that any valuable chemicals can be recovered.

8. Since little oxidation takes place during the process, metallic components can be recovered after the waste has been pyrolyzed.

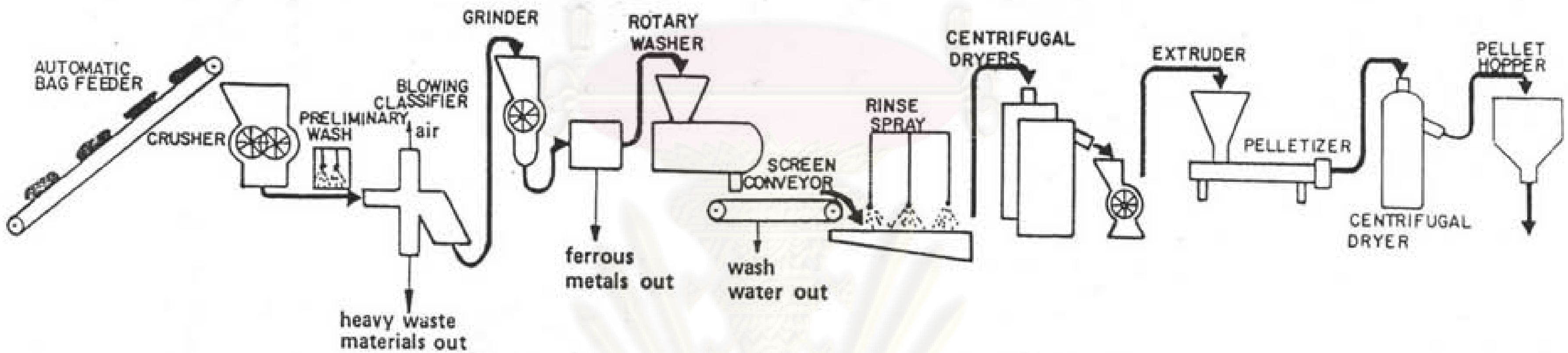

Figure 2.27 Schematic of Japan Steel Works' Nikko Waste plastic reclamation line

The main commercially useful product recovered in the pyrolysis of municipal solid waste is fuel gas with rather low BTU content, while the pyrolysis products of plastics can be use either as fuel or as feedstock for the chemical industry. Polymer decompose into smaller molecules, or monomers depending on their structure and the condition of the reaction. Polymers that decompose to monomers are shown in Figure 2.28 (33). During the pyrolysis process, the following reactions take place : (1) depolymerization, producing monomers ; (2) chain fragmentation, producing low - molecular - weight materials ; (3) production of unsaturated compounds ; cross - linking of the polymer, and char formation.

A Pyrolysis system consisting of an extruder, pyrolysis tube, heat exchanger, and product recovery equipment. Union Carbide's apparatus for the continuous pyrolysis of plastics is shown in Figure 2.29 (34). Table 2.11 shows some of the plastics pyrolysis systems.

Quarternary Recycling

Incineration of refuse may be defined as the reduction of combustible wastes to inert residue by controlled high - temperature combustion. The main reason for incineration is reduction in the volume of waste. Incineration is capable of reducing the weight of refuse by 80 % and the volume by over 90%.The ash that remains goes to landfills. Because of their high energy contents, plastics are particularly suited to waste - to energy plants. Polyethylene, polypropylene, and polystyrene have energy contents of 19,900, 19,850, and 17,800 BTUs/lb, respectively (9). In comparison, the energy contents of wyoming coal, newspaper, wood, and average composit municipal solid waste are 9600, approximately 8000, 6700, and 4500 BTUs/lb,

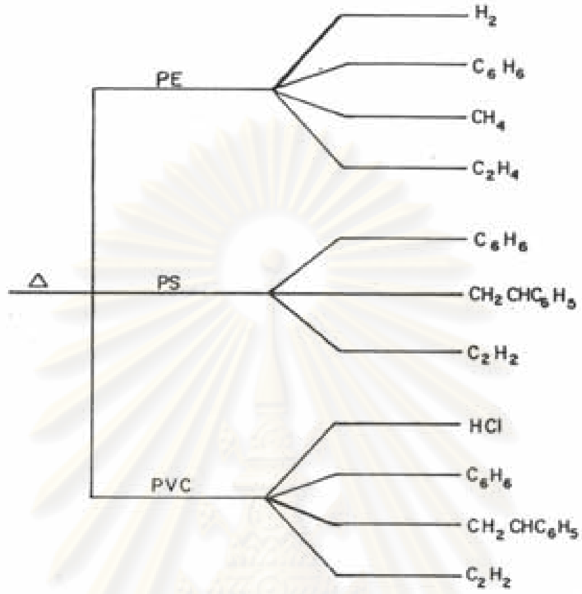

Figure 2.28 Major products of thermal decomposition of PE, PS, and PVC

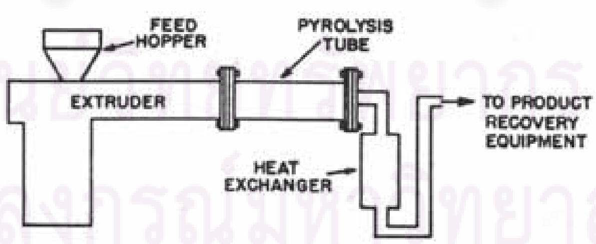

Figure 2.29 Union Carbide's apparatus for the continuous pyrolysis of plastics

respectively. Waste plastics can be a valuable source of energy. Although the standard incinerators are capable of handling municipal refuse containing plastics, they cannot usually handle pure plastics waste. The following problems are associated with the incineration of plastics.

Toxic gases : When PVC is burnt, HCl gas is generated, and urethane generate HCN.

Soot : Imperfect burning of plastics will produce soot.Plastics require 3 to 10 times more combustion air than the average municipal refuse. If they are burned in conventional incinerators, there will be a shortage of oxygen.

Disposal of ash : Lead and Cadmium salts are used as PVC stabilizers. They will remain as ashes containing lead and cadmium, causing disposal problems.

Disposal of water : HCl is produced by incineration of PVC. HCl is absorbed in water or by chemicals. Acidified water cannot be disposed of without proper treatment.

Incinerator damage caused by excessive heat : The temperatures generated during the combustion of plastics are much higher than those generated during the combustion of municipal refuse. The high temperature could cause damage incinerators.

Incinerator damage due to an insufficient oxygen supply : Most of the conventional incinerators are not capable of supplying an adequate amount of air for complete combustion of plastics. During the incomplete combustion, soot is produced which will stick to the pipe walls of the heat exchanging unit, affecting the performance.

Corrosive damage : Combustion products such as HCl, NH_3, SO_2, SO_3, NO_x, and RCOOH are corrosive and will cause damage to the components of the incinerator. If the waste contains water, it will accelerate the

Table 2.11 Some plastics pyrolysis system

Process developer	Reactor type and heating method	Reaction temperature (°C)	Plant capacity (tons/day)	Feedstock	Products
Union Carbide	Extruder, followed by annular pyrol. tube, electrically heated	420-600	0.035-0.07	PE, PP, PS, PVC, PETP, PA, mixes	Waxes
Japan Steel Works	Extruder				
Japan Gasoline Co.	Tubular reactor, externally heated			Dissolved or suspended in recycle-oil	Heavy oil
Prof. Tsutsumi	Tubular reactor, superheated steam as a heat carrier	500-650	1	Ps-foam	
Sanyo Electric Co.	Tubular reactor with a screw for carbon removal, dielectric heating reactor	260 (PVC) followed by 500-550	0.3 (pilot) 3 (Gifu) 5 (Kusatsu)	Foam PS, mixed plast. (select. collect.)	Monomer Fuel oil HCI
Mitsui Shipbuilding & Engineering Co.	Stirred tank reactor, polymer bath	420-455	24-30	Low-MW polymers (PE, APP)	Fuel oil
Mitsui Petrochemical Industries Co. (Chiba Works)					
Mitsubishi Heavy Ind. (Mihara Works)	Tank reactor with circulation pump and reflux cooling	400-500	0.7/2.4	Polyolefins	Naphtha kerosene fuel
University of Hamburg	Fluidized bed	640-840	0.08-0.24	PE, PS, PVC type rubber	Hydro-carbons
	Molten salt bath	600-800	Laboratory scale		Hydro-carbons

corrosive action of the gases.

Example of incinerator suitable for plastics waste is shown in Figure 2.30 (35). Itis suitable for the batch incineration of plastics. Waste plastics are fed through the feed doors and deposited on the fire grate. The gas ignited on the furnace floor is mixed with primary air. The gases produced during the combustion contain particulate matter as well as incompletely oxidized compounds. Final oxidation take place in the secondary burning chamber, where the auxiliary burner may be employed if the temperature is low.

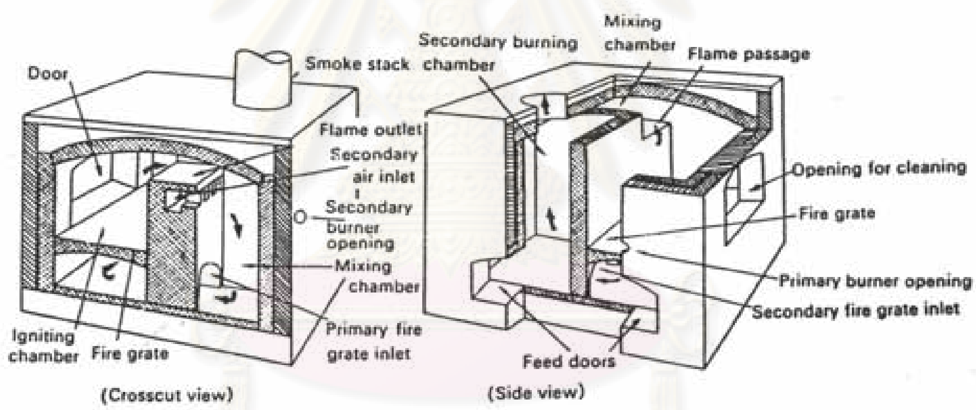

Figure 2.30 Floor-burning multistage-type incinerator