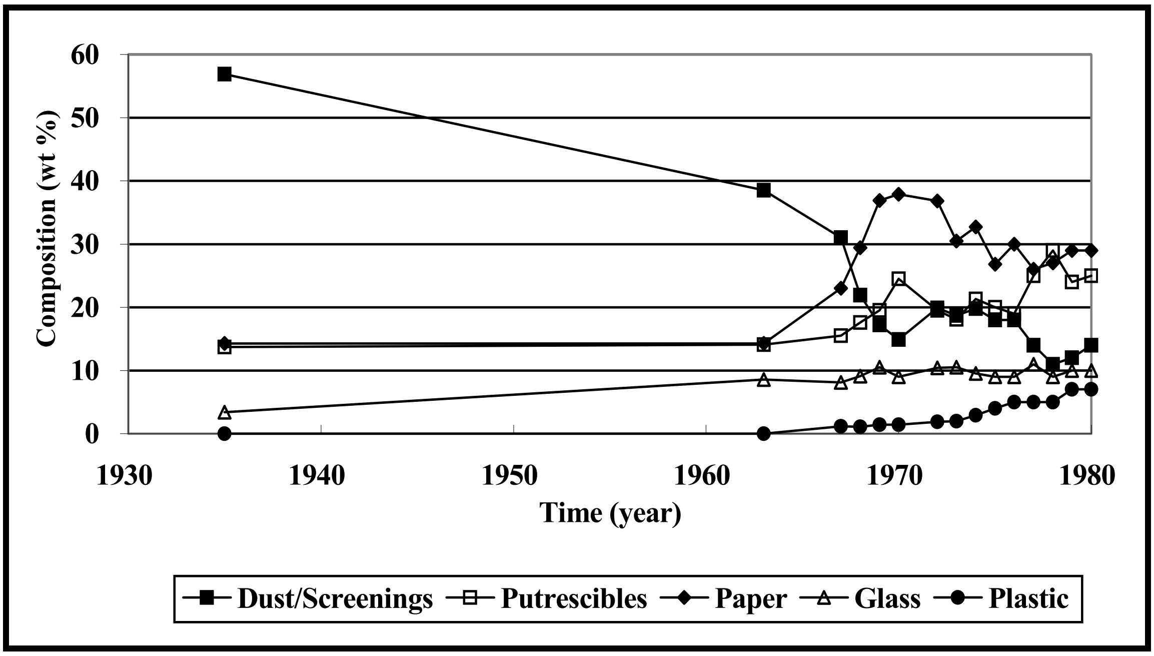
CHAPTER III. WASTE QUANTITIES AND CHARACTERISTICS

A. Introduction

The range of the numerical values presented in Chapter I (Table I-1) illustrates the wide variation that can be expected to exist between countries with respect to the quantity and composition of waste generated. On the other hand, careful scrutiny of the data indicates that despite the variation, three general trends do exist. The first trend is in quantities. It suggests that increases in per capita waste generation parallel increases in degree of economic development. The second trend concerns the concentration of paper in the waste stream. According to the data, the development of a country is closely accompanied by an increase in the concentration of paper in the waste. The third, and perhaps the most important, trend concerns biological solid waste and relates to the quantity of putrescible matter and ash. According to the data in Table I-1, the amounts of putrescible materials and ash in MSW generally decrease as the development of a country advances.

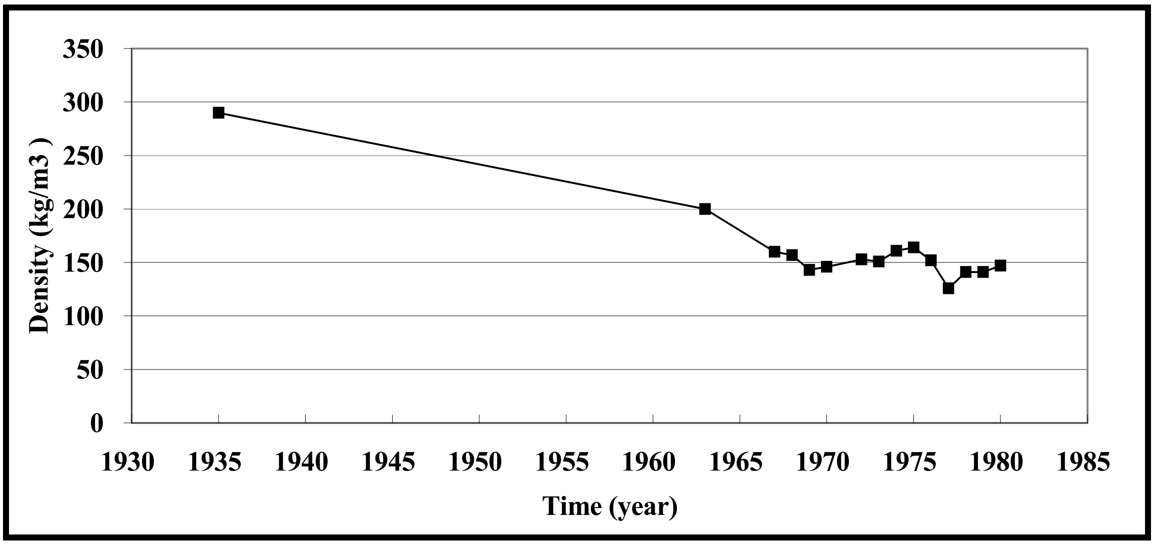
The variation and trends in quantity, composition, and other characteristics of urban waste are not confined to the national level. Indeed, they persist even at the community level. The persistence is due to the fact that the characteristics of the waste stream are affected by an array of factors. Ranking high among these factors are degree of industrialisation, extent and nature of socioeconomic development, and the climate.

Both short-term (e.g., seasonal) and long-term (e.g., 5-year periods) variations in characteristics occur in the case of solid waste; thus, the need for measurements. Two examples of long-term and significant changes in the composition and bulk density of the waste stream of the United Kingdom (UK) are illustrated in Figures III-1 and III-2, respectively. The historical trends shown for the UK are similar to those of many economically developing countries, except shifted forward in time by 40 to 60 years.



Source: Reference 14.

Figure III-1. Historical changes in MSW composition in the United Kingdom



Source: Reference 14.

Figure III-2. Historical changes in MSW bulk density in the United Kingdom

Despite the obvious fact that a thorough understanding of the characteristics of the waste is requisite to making rational decisions in solid waste management, it remains a prevalent practice to pay little heed to conducting a comprehensive and accurate survey of quantity and composition. Instead, reliance is had on some inaccurate method, especially the traffic count. Although traffic counts, if coupled with estimates of volume, may give an indication of the quantities being disposed; strictly speaking, they serve to ascertain solely that which is implied by the term -- namely, the number of vehicles entering the disposal site.

Rigorous, scientifically performed studies of waste quantities and characteristics are required to proper design, operate, and monitor solid waste management systems.

This chapter is concerned primarily with describing important waste characterisation parameters, and methods of determining them, so that designers can have a firm foundation to plan and implement waste management systems. The parameters and methods of determination are described in the following sections.

B. Quantities and composition

Quantity and composition surveys have an essential role in determining the dimensions of the key elements in solid waste management. A list of such elements would certainly include method and type of storage, type and frequency of collection, crew size, method of disposal, and degree of resource recovery. The utility of the surveys extends not only to the evaluation of present conditions, but also to the prediction of future trends. Consequently, frequent and ongoing surveys are the mainstays of a successful solid waste management program.

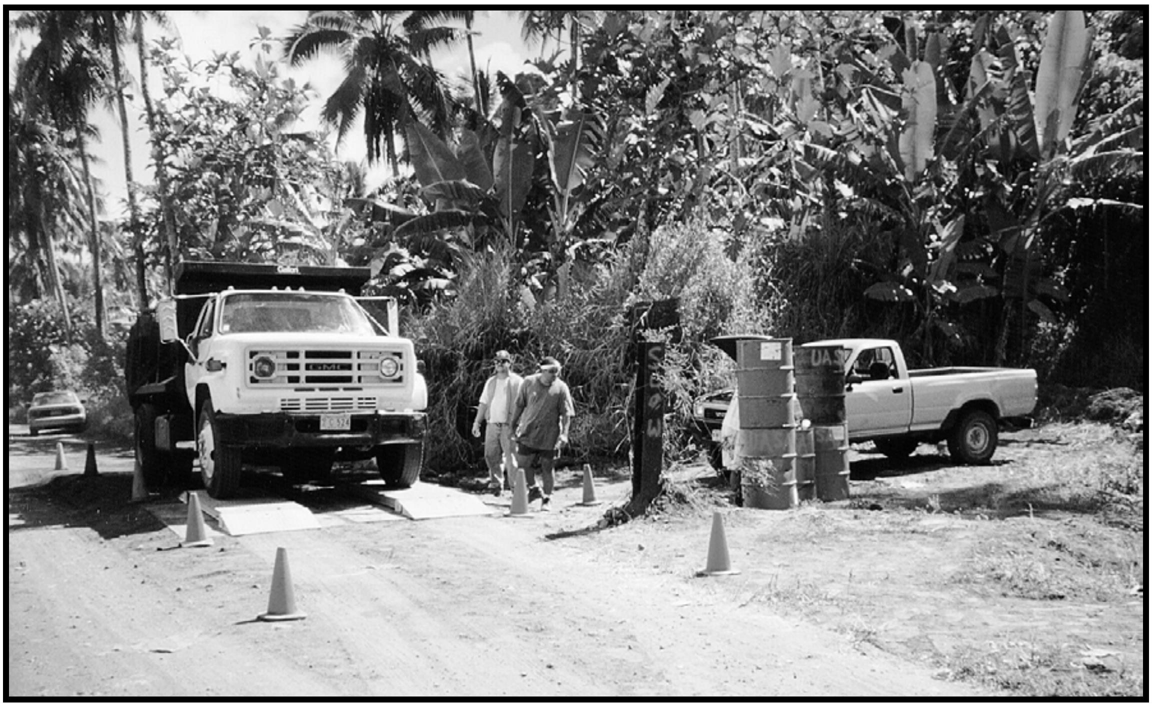
Surveys either of quantity or of composition must take into consideration scavenging and illegal dumping.

B1. PROCEDURES

B1.1. Quantities

Several methods are available for determining the quantity of wastes that require disposal. The accuracy of the results depends upon the method followed.

Perhaps the only means of arriving at an accurate estimate of the quantity of wastes is one that involves weighing each vehicle and its load of wastes as it enters the disposal site. The approach involves the use of a weighing scale sufficiently large to accommodate vehicles of all sizes that come to the site. Several types of scales can be used. For example, the scales may be permanently installed, or a portable version may be used. The authors have not encountered difficulties in the use of portable scales. The portable scales are equipped with load cells that can be powered by either direct or alternating current. Of course, tare weight (weight of the empty vehicle) also must be determined. An example of a collection vehicle being weighed using a set of portable scales is shown in Figure III-3. A sample data sheet for a weight survey is presented in Figure III-4.



Courtesy: CalRecovery, Inc.

Figure III-3. Collection vehicle being weighed on a set of portable scales

To account for changes due to seasonal or other temporal factors, the weight survey should be conducted for a minimum two-week period, at either two or four intervals distributed throughout the year.

If circumstances make it unfeasible to weigh every loaded refuse vehicle, then recourse can be had to a procedure that entails the weighing of a few randomly selected incoming vehicles. To arrive at the total input, the sample weights are multiplied by the number of loads per day. Although results obtained by such a modified weight survey may be less accurate than those obtained by weighing each vehicle, they are better than those obtained without recourse to any actual weighings.

The third and final method to be described herein is the least accurate of the three in terms of results obtained. It involves the collection of the following data: 1) average density of waste, 2) number of loads collected per day, and 3) average volume per load. The latter quantity is obtained by measuring the vehicle body. The total daily weight is the product of all three, i.e., density, volume, and number of loads per day. For example, if the density is 300 kg/m^3, the average vehicle volume is 4 m^3, and the total number of loads per day is 100, then the total daily input to the disposal site is 120 Mg.

At times, the degree of the accuracy required may be beyond that attainable with any one of the three preceding methods. Instances in which such a high degree of accuracy would be a necessity are the determination of the extent of storage needs, the required capacity of a transfer station, or the potential for resource recovery. The deficiency as far as the three cited instances are concerned arises from the fact that the methods are based only on those wastes that are brought to a recognised disposal site. They do not take into account the wastes disposed elsewhere.

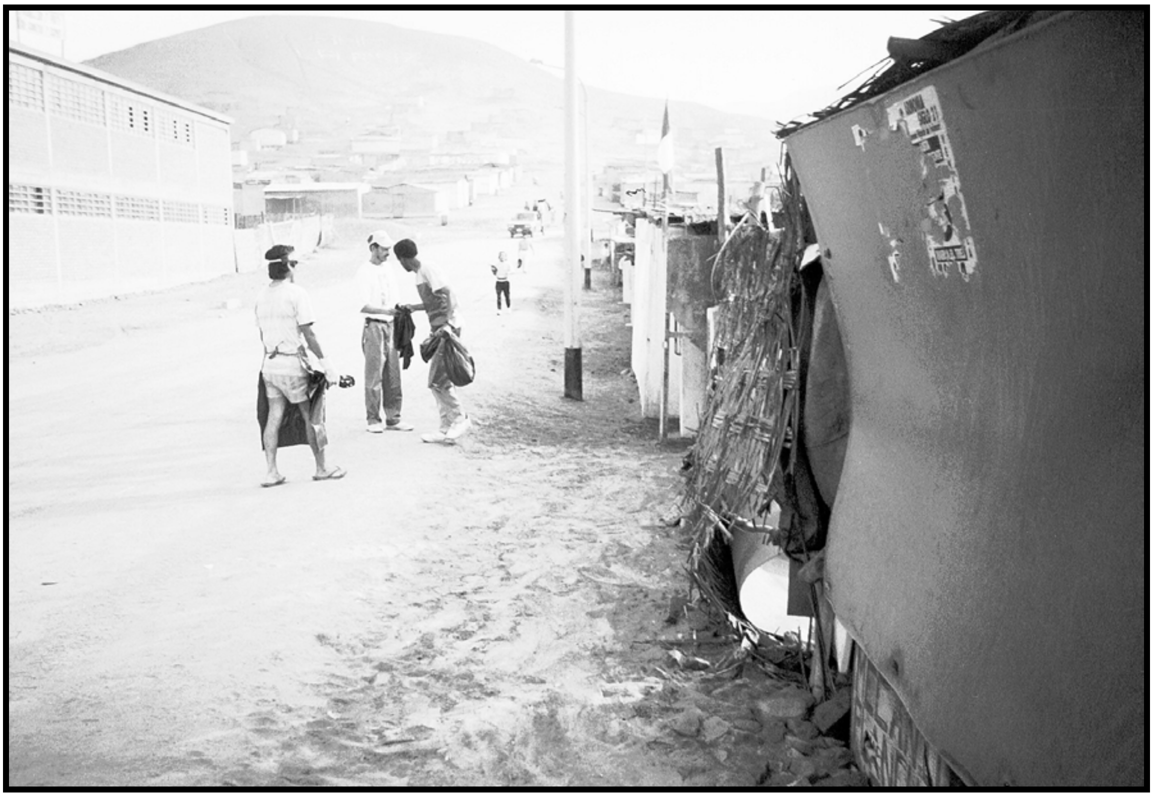
Generator			**Weight/Volume**				**Self-Haul Wastes**							
							Self-Haul Vehicles					**Waste Categories**		
Residential	**Commercial**	**Industrial**	**Gross Weight (kg)**	**Tare Weight (kg)**	**Capacity of Vehicle (m^3)**	**Volume of Waste (%)**	**Pickup Truck**	**Other Truck**	**Automobile**	**Handcart**	**Other**	**Yard Waste**	**C&D[a]**	**Other[b]**
Recorded by: _______________									Date: _________________					

[a] C&D = Construction and demolition debris.
[b] "Other" - describe.

Figure III-4. Sample data sheet for a weight survey

A means of determining the real total generation, i.e., wastes brought to the disposal site plus wastes destined for disposal elsewhere, is to multiply the per capita rate of generation (e.g., kg/cap/day) by the number of individuals in the generation area (e.g., community, nation). A difficulty with this approach is that any attempt to reach a truly representative number for the per capita generation rate would be beset with many difficulties. Obviously, it would be physically and economically unfeasible to measure each individual's output even in a small, highly organised community. Consequently, resort must be had to sampling at the generation source.

Rather than attempt to carry on such a sampling program on a large scale, in terms of practicality and economic feasibility, it is better to set up a modest program in which special sampling areas are selected and defined. In setting up areas, care should be taken that all socioeconomic groups are represented. Each participating household in the sampling area is provided with a container of some sort, perhaps a plastic bag, in which the day's output of wastes is placed, as shown in Figure III-5. Each day, the containers are collected and tagged by the agency making the study and are transported to a central point to be weighed, and the weights and other information (e.g., number of individuals in the household, social status) are recorded. Ideally, the containers should be collected daily and the participant be supplied with a new (i.e., empty) container only when the filled one is collected, as shown in Figures III-6, III-7, and III-8. Samples should be collected for at least a 10-day period.



Courtesy: Alternativa

Figure III-5. Distribution of plastic bags for waste characterisation program

Courtesy: Alternativa

Figure III-6. Collection of bags

Courtesy: Alternativa

Figure III-7. Determination of total weights

Courtesy: CalRecovery, Inc.

Figure III-8. Bags used to determine quantity of waste generated

To ensure full cooperation, the sampling program and the rationale behind it should be fully explained to the participants. An individual best qualified for such a task would be a local social worker.

By reconciling the numbers obtained from a weight survey at the disposal site with those based on per capita generation as determined through sampling, it is possible to arrive at an estimate of total waste generation that is sufficiently accurate to meet most needs, whether they be for facility and equipment design or for waste management planning. Table III-1 presents estimated quantities of waste collected (expressed in kg/cap/day) in various cities.

B1.2. Composition

A full knowledge of the composition of the wastes is an essential element in: 1) the selection of the type of storage and transport most appropriate to a given situation, 2) the determination of the potential for resource recovery, 3) the choice of a suitable method of disposal, and 4) the determination of the environmental impact exerted by the wastes if they are improperly managed.

A reasonably realistic estimate of the composition of a community's waste output requires an analytical period of two weeks' duration, repeated two to four times per year. During the two weeks, samples are taken from the collection vehicles at the disposal site. All types of municipal wastes should be sampled, i.e., residential, commercial (offices and markets), and light industrial. The ratio of the number of samples of each type of waste to the total number of samples should be the same as that of the quantities of each type to the total quantity disposed. For example, if the output of residential waste is ten times greater than the combined commercial and light industrial wastes, then the number of samples of residential wastes should be ten times that of the other two combined.

Table III-1. Estimated quantity of waste collected in various cities and countries

Location	Estimated Quantity (kg/cap/day)[a]
India	0.3 to 0.55
Bolivia	0.3 to 0.6
Guatemala City, Guatemala	0.3 to 0.6
Lima, Peru	0.3 to 0.8
Philippines	0.4
Asunción, Paraguay	0.46
Malaysia	0.5
Uruguay	0.5 to 0.9
Tegucigalpa, Honduras	0.52
Rio de Janeiro, Brazil	0.54
Jakarta, Indonesia	0.6
Buenos Aires, Argentina	0.6 to 1.0
Mexico DF, Mexico	0.68
San Salvador, El Salvador	0.68
San José, Costa Rica	0.73
Papua, New Guinea	0.8
Santiago, Chile	0.9 to 1.2
Caracas, Venezuela	0.91
Fiji	0.91
Japan	0.91
Singapore	1.0
Vienna, Austria	1.18
Antigua	1.25
Guam	1.35
Paris, France	1.43
Hong Kong	1.68
Australia	1.87
Seoul, Korea	2.0
New Zealand	2.0

Sources: References 9-11, 15, 16.

[a] Ranges indicate data collected from different cities in the country or from different sectors in a city.

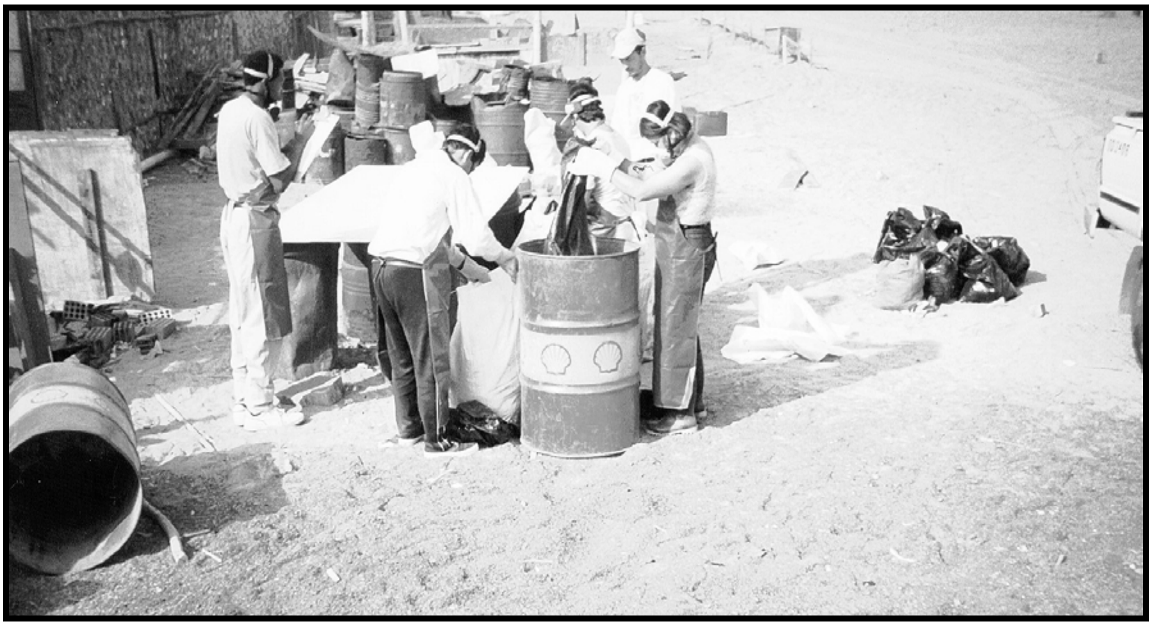
Regarding sample size, the minimum weight per sample should be on the order of 100 kg. If the sample size is too small, the possibility of obtaining a representative sample is lessened. On the other hand, accuracy is not improved sufficiently to warrant taking samples greater than 100 kg in size [1].

To reduce the magnitude of errors arising from moisture change and from decomposition, analysis of the samples should be begun within two to three hours after collection.

A sample data sheet developed for the conduct of compositional studies in the United States is shown in Figure III-9. Because the data sheet shown in the figure is very comprehensive, it may be modified as needed. Indeed, in some countries, it may not be necessary to sort the refuse into every category shown in the figure. For example, mixed paper, newspaper, and cardboard can be combined under the single category of paper. To carry out the analysis, the wastes in the samples are sorted according to the categories listed in the selected data sheet. In the sorting process, each type of waste is placed in its appropriate container (see Figure III-10). At the completion of the sorting, each container and its contents are weighed (gross weight). Gross and tare (empty container) weights should be recorded. The difference between the two weights is the net weight of the individual components.

Sample #		**Start Weight**	**Date**	**Recorded by**	
CATEGORY	**Gross Weight**	**Container Type/Tare**	**CATEGORY**	**Gross Weight**	**Container Type/Tare**
Paper			**Other Organic**		
(a) Corrugated/Paper Bags			(a) Food		
(1) Uncoated Corrugated			(b) Yard/Landscape		
(2) Coated Corrugated			(1) Leaves/Grass		
(3) Brown Paper Bags			(2) Prunings/Trimmings		
(b) Newspaper			(3) Branches/Stumps		
(c) Office Paper			(c) Ag. Crop Residues		
(1) White Ledger			(d) Manures		
(2) Coloured Ledger			(e) Wood		
(3) Computer Paper			(f) Textiles		
(4) Other Office Paper			(g) Tires		
(d) Mixed Paper			(h) Remainder/Composite		
(1) Magazines/Catalogues			**Other Inorganic**		
(2) Phone Books/Directories			(a) Inerts		
(3) Other Mixed Paper			(1) Rock		
(e) Remainder/Composite			(2) Concrete		
Glass			(3) Brick		
(a) Clear Bottles/Containers			(4) Soil & Fines		
(b) Coloured Bottles/Containers			(5) Asphalt		
(1) Green Bottles/Containers			(6) Gypsum Board		
(2) Brown Bottles/Containers			(b) Remainder/Composite		
(c) Flat Glass			**HHW & Special Waste**		
(d) Remainder/Composite			(a) Household Hazardous		
Metal			(1) Paint		
(a) Ferrous Metals			(2) Automotive Fluids		
(1) Tin/Steel Cans			(3) Batteries		
(2) Other Ferrous			(4) Remainder/Composite		
(b) Non-Ferrous Metals			(b) Special Waste		
(1) Aluminium Cans			(1) Ash		
(2) Other Non-Ferrous			(2) Biosolids		
(c) White Goods			(3) Industrial Sludge		
(d) Remainder/Composite			(4) Treated Medical Waste		
Plastic			(5) Bulky Items		
(a) HDPE			(6) Remainder/Composite		
(1) Natural HDPE			**Mixed Residue**		
(2) Coloured HDPE			**Comments:**		
(b) PET					
(c) Film Plastic					
(d) Other Plastic					
(1) PVC					
(2) PP					
(3) PS					
(e) Remainder/Composite			(continue on reverse side if needed)		

Figure III-9. Sample waste composition data sheet



Courtesy: Alternativa

Figure III-10. Waste composition analysis in a peri-urban area

C. Other characteristics

In addition to analysing for composition, it is recommended that the sampling program include provisions for determining moisture content, bulk density, and particle size distribution. The measurement of these three properties is especially recommended if no prior scientific waste characterisation study has been performed locally. These particular characteristics have a substantial influence on determining: 1) wastes that will be difficult to manage, 2) proper and best methods for storing, collecting, processing, and disposing of the wastes and 3) marketability of potentially recoverable materials. In addition to the moisture content, particle size, and bulk density, a knowledge of several other properties of solid waste are also required for properly planning, designing, and operation waste management programs. Among such other properties are chemical/thermal and mechanical analyses.

Moisture Content

The moisture content is determined as follows: The sample is weighed as received ("wet weight"). It is then allowed to stand until it is air-dry, i.e., its moisture content is in equilibrium with that of the ambient air. The percent moisture content is then obtained through the following formula:

$$\text{Moisture Content (\%)} = \frac{W_W - W_D}{W_W} \times 100$$

where:

- W_W = wet weight of sample, and
- W_D = dry weight of sample.

C1. BULK density

The bulk density can be measured by filling a container of known volume with wastes and then weighing the loaded container, as shown in Figure III-11. (The container should be constantly shaken during filling.) The bulk density is calculated by dividing the net weight of the refuse (weight of loaded container minus weight of empty container) by its volume. The result is expressed as kg/m^3. Bulk densities obtained in various countries are presented in Table III-2. In addition, bulk densities of various types of wastes are given in Table III-3. For comparison purposes, the densities of virgin materials are presented in Table III-4.

Courtesy: CalRecovery, Inc.

Figure III-11. Determination of bulk density

C2. SIZE distribution

Size distribution may be determined with the use of a set of manually manipulated screens. The screens should have square openings, particularly those with large openings, and the sizes of the openings included in the set should be 100, 50, and 25 cm. The screens, particularly those with large openings, can be easily made with lumber and wire, as shown in Figures III-12 and III-13. The sample size should range from 150 to 300 kg.

Table III-2. Bulk densities of residential wastes for various countries

Country	Density (kg/m^3)
United Kingdom	150
United States	100
Egypt	330
Nigeria	250
Singapore	175
Tunisia	175
Bangladesh	600
Burma	400
India	400 to 600
Indonesia	400
Mexico	300 to 500
Nepal	600
Pakistan	500
Paraguay	390
South Korea	200 to 450
Sri Lanka	400
Thailand	250
Tanzania	330

Sources: References 3, 4, 6.

Table III-3. Typical bulk densities of mixed MSW and various components of MSW

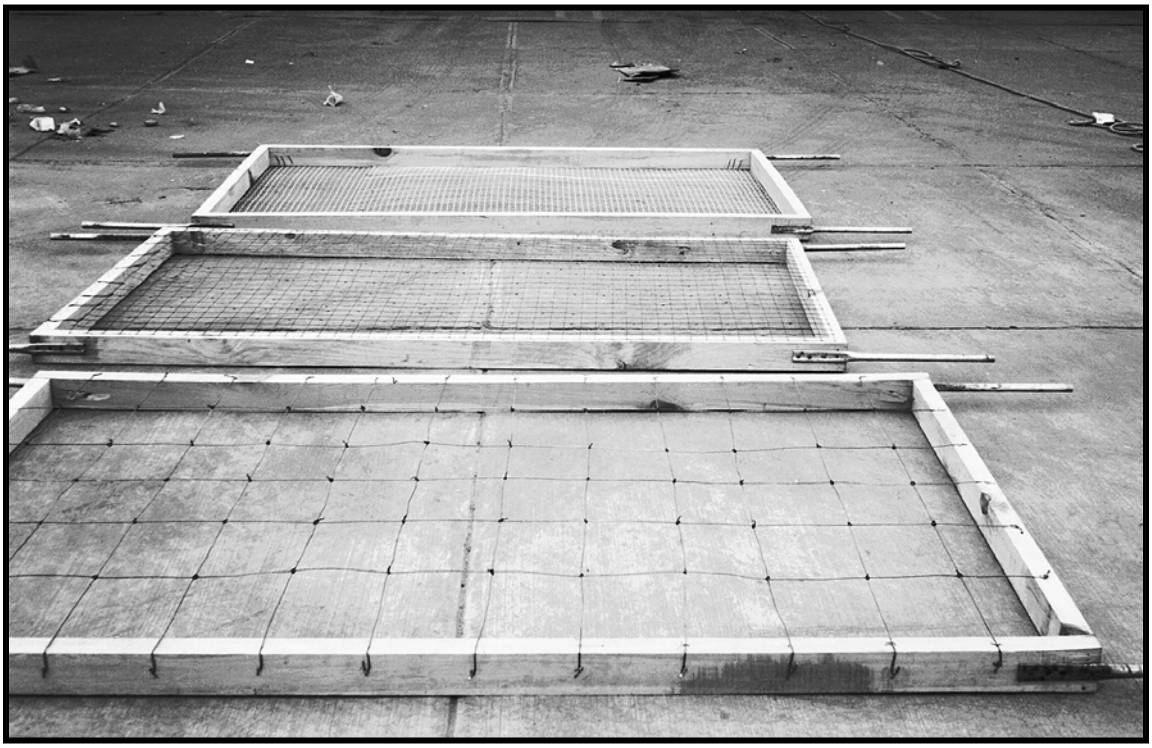
Component	Density (kg/m^3)
MIXED SOLID WASTE	
Mixed MSW	
Loose	90 to 178
After dumping from compactor truck	207 to 237
In compactor truck	297 to 416
In landfill	475 to 772
Shredded	119 to 237
Baled	475 to 712
Mechanically-Recovered Fractions (Loose)	
dRDF	481 to 641
Aluminium scrap	224 to 257
Ferrous scrap	369 to 417
Crushed glass	1,042 to 1,363
Powdered RDF (Eco-Fuel)	417 to 449
RECOVERED MATERIALS	
Loose	
Corrugated	16 to 32
Aluminium cans	32 to 48
Plastic containers	32 to 48
Miscellaneous paper	48 to 64
Garden waste	64 to 80
Newspaper	80 to 112
Rubber	209 to 258
Glass bottles	193 to 305
Food waste	353 to 401
Tin cans	64 to 80
Densified	
Baled aluminium cans	193 to 289
Cubed ferrous cans	1,042 to 1,491
Baled corrugated	353 to 513
Baled newspaper	369 to 529
Baled high grades	321 to 465
Baled PET	209 to 305
Baled HDPE	273 to 385

Source: Reference 8.

Table III-4. Bulk densities of virgin materials

Component	Density (kg/m^3)
Wood	593
Cardboard	689
Paper	705 to 1,154
Glass	2,501
Aluminium	2,693
Steel	7,855
Polypropylene	898
Polyethylene	946
Polystyrene	1,042
ABS	1,026
Acrylic	1,186
Polyvinylchloride (PVC)	1,250

Source: Reference 8.



Courtesy: CalRecovery, Inc.

Figure III-12. Screens specifically made to determine size distribution of waste

Courtesy: CalRecovery, Inc.

Figure III-13. Testing of the screens by crew members

Representative waste from the sample is placed on the largest of the screens (100 cm). The screen is shaken until particles of refuse no longer pass through the openings. Material remaining on the screen (oversize) is collected and weighed. The material that has passed through the screen (undersize) is placed on the screen with the 50-cm openings, which is shaken as in the preceding step. The process is repeated until all three screens have been used. The fractions that are sized are weighed, and the weight values are used to plot a size distribution curve. Typically, the size distribution is plotted as cumulative percent passing versus screen size. A sample data sheet is shown in Figure III-14. Sample size distribution curves for some waste components generated in the United States are shown in Figure III-15, and those for wastes generated in Mexico City in Figure III-16.

C3. CHEMICAL/thermal properties

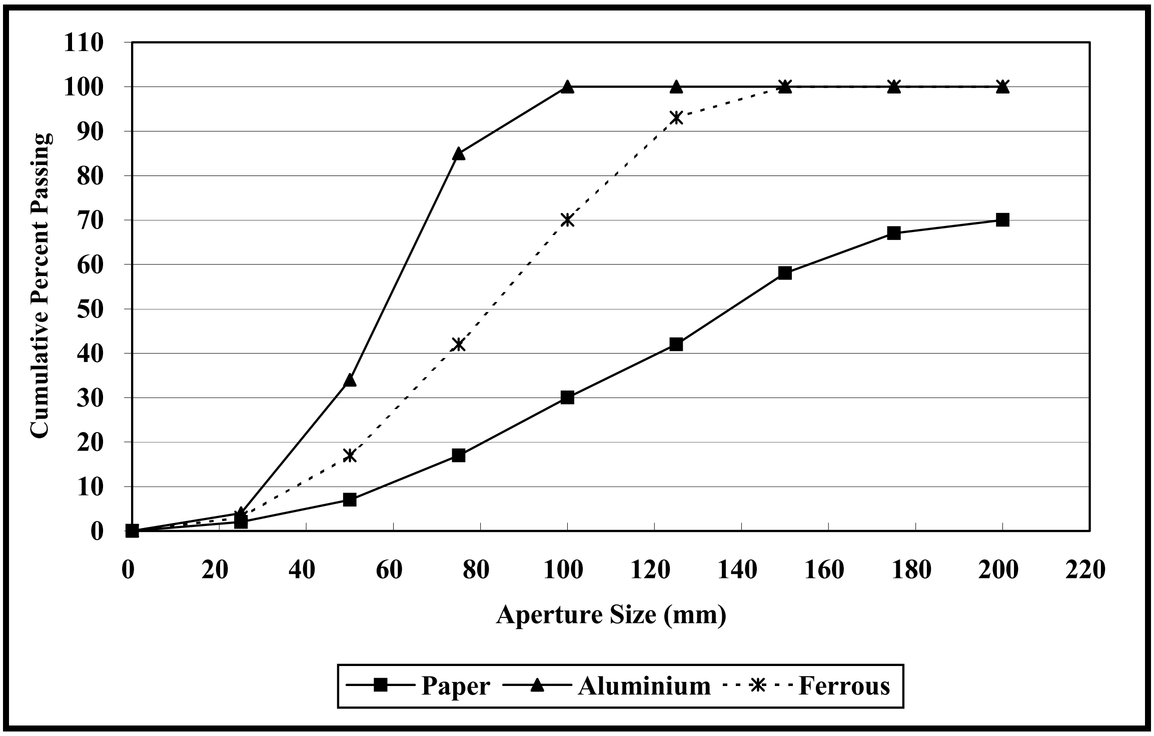
Determination of chemical/thermal properties of solid wastes or its components would be necessary in order to ascertain the most appropriate type of treatment. These analyses must be conducted by a reliable laboratory. The authors generally rely on either governmental laboratories or universities to perform the work. Typical analyses include moisture and ash contents; calorific value; and the concentrations of carbon, nitrogen, hydrogen, oxygen, and some heavy metals if there are reasons to suspect that they may be present. The results of analyses conducted in various countries are presented in Table III-5. Additional properties of MSW and its components can be found in Reference 13.

C4. MECHANICAL properties

Despite the fact that the proper design of processing plants as well as final disposal facilities should include a thorough understanding of the properties of refuse and its components, this requirement has, up until recently, been ignored. Perhaps this can be explained by the absence of reliable information readily available in the literature. This problem is particularly more pronounced in economically developing countries. Mechanical properties are especially important in the design of sanitary landfills and ancillary systems. This section presents the results of analyses carried out using raw (fresh) MSW, fractions of MSW, as well as landfilled MSW generated in industrialised countries in Western Europe. Due to the sharp differences in the composition and characteristics between these wastes and those from economically developing countries, it is recommended that the data presented in these sections be used simply as references and modified to suit the conditions of the particular location.

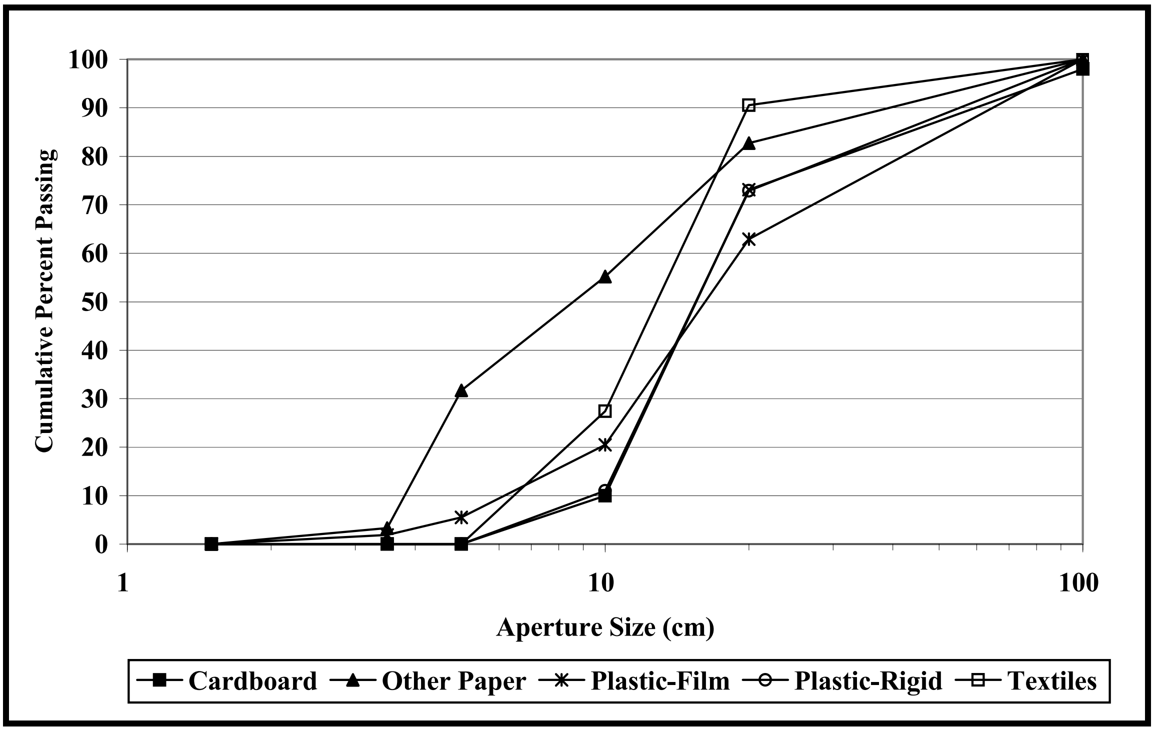
Date:			**Sample Wet Weight:**		
Location:			**Sample Dry Weight:**		
Sample No.:			**Moisture Content:**		
Type of Material:			**Type of Generator:**		
Screen Size	**Gross Weight Retained by Screen**	**Tare Weight**	**Net Weight Retained by Screen**	**% of Feed on Bottom Screen**	**Cumulative Wt % Passing Bottom Screen**
Total Sample Weight:					

Figure III-14. Sample data sheet for size distribution analysis



Source: Reference 2.

Figure III-15. Sample size distribution of raw MSW components in the United States



Source: Reference 5.

Figure III-16. Sample size distribution of MSW components in Mexico City

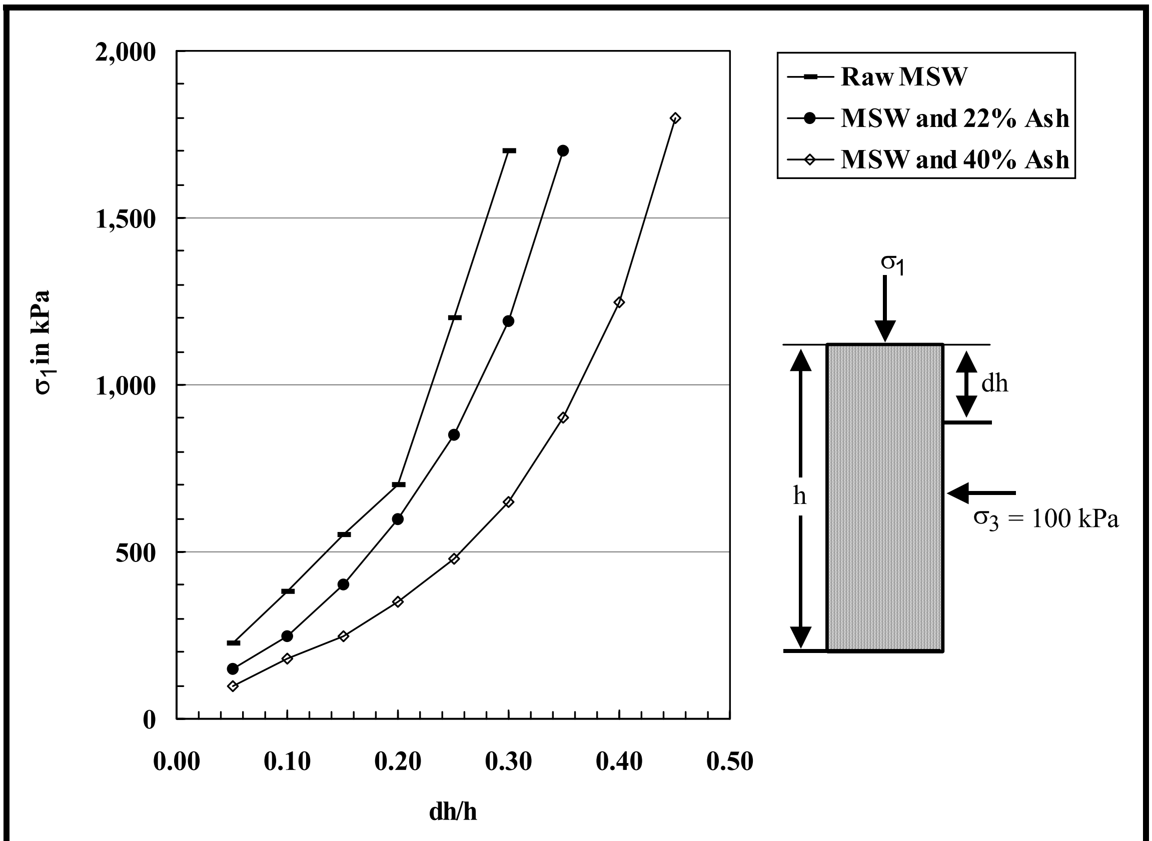
Table III-5. Physical and chemical characteristics of residential wastes from various countries

Location[a]	M.C. (%)	VS (%)	Ash (%)	C (%)	H (%)	N (%)	P (%)	Cl (%)	S (%)
Manila, Philippines	42.6	33.8	23.6	18.3	2.2	0.24			
Mexico City, Mexico	50	32.5	33	15	1.5	0.9			
Calcutta, India	42	32	26	18	N/A	0.55	0.55		
Seoul, Korea	44.2	17.7	38.1	8.9	1.2	0.47		0.22	0.04

Sources: References 4-7.
[a] Summer, medium-level residences.

C4.1. Stress-strain

The results of triaxial compression tests conducted on raw MSW and on mixtures of MSW and incinerator bottom ash are given in Figure III-17. As shown by the curves in the figure, ash has a considerable impact on the behaviour of refuse.



Source: Reference 10.

Figure III-17. Stress-strain curves for MSW samples

C4.2. Relationship between stress and dry density

The results of laboratory tests to ascertain the impact of normal stress on the dry density of different types of refuse are presented in Table III-6. The data in the table demonstrate that the samples of degraded refuse have substantially higher densities than the samples of fresh refuse.

C4.3. Absorptive and field capacities

Tests have been carried out using a large-scale compression cell to determine several hydrogeological and geotechnical properties of refuse. The results of these analyses are useful in the evaluation of leachate management systems. The tests to determine the absorptive and field capacity of the samples are presented in Tables III-7 and III-8, respectively.

Table III-6. Impact of normal stress on the dry density of refuse

Normal Stress (KN/m^2)	Dry Density (Mg/m^3)			
	Raw[a] Refuse	Residual[b] Refuse	Decomposed[c]	Mined[d]
100	0.54	0.58	0.89	
200	0.64	0.65	0.95	1.04
300	0.72	0.72	1.01	1.00
400				1.10

Source: Reference 11.
[a] As collected, without separation.
[b] Without "organic" components.
[c] Raw refuse after 1.5 yr of degradation in piles.
[d] Excavated from landfill after 5 yr.

Table III-7. Absorptive capacity of refuse

Material	Initial Moisture Content (% wet wt)	Initial Field Capacity (% dry wt)	Absorptive Capacity (L/Mg wet wt)
Raw refuse	34	112	393
Raw refuse	35	102[a]	332
Shredded refuse	28.8	141	718

Source: Reference 12.
[a] Field capacity at stress of 40 kPa.

Table III-8. Field capacity of refuse as a function of stress

Applied Stress (kPa)	Shredded Refuse		Unprocessed (Raw) Refuse[a]	
	Dry Density (Mg/m^3)	Field Capacity (% dry wt)	Dry Density (Mg/m^3)	Field Capacity (% dry wt)
Initial	0.25	141	0.33	N/D[b]
40	0.29	115	0.39	102
87	0.35	103	0.43	101
165	0.43	76	0.49	88
322	0.53	64	0.62	73
600	0.60	60	0.71	61

Source: Reference 12.
[a] Moisture content = 102% on a dry weight basis.
[b] N/D = Not determined.

D. References

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