

Factors influencing the chemical characteristics of landfill leachates*

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Abstract

The stabilisation of municipal refuse in sanitary landfills gives rise to leachates which are often highly polluted. This paper defines the stabilisation process and discusses the naturally occurring decomposition phases of the refuse mass. Each phase has a characteristic leachate composition, and analytical monitoring reflects the end products of the chemical, physical and microbiological decomposition processes at work. Chemical leachate data from the Coastal Park landfill site near Cape Town are cited to illustrate the various attenuation mechanisms associated with landfills.

Introduction

Comparative studies in several countries on the various possible means of eliminating solid urban waste (landfilling, incineration, composting, etc.) have shown landfilling to be the cheapest. This has resulted in a world-wide trend towards controlled landfilling as the preferred means of disposing both solid urban refuse as well as a large proportion of solid industrial waste (Lema *et al.*, 1988). Unfortunately, many landfills have not been properly designed, operated or maintained and have impacted adversely on the environment. Many landfills are in fact co-disposal sites with hazardous components superimposed on the normal conversion and stabilisation processes (Pohland and Gould, 1986). Relatively little attention has been paid to the collection and treatment of landfill leachates, today recognised as one of the gravest problems associated with the operation of refuse tips (Lema *et al.*, 1988). In contrast, Ham (1988) has advocated the concept of designing a landfill as a bio-reactor in order to promote controlled microbiological decomposition, reduce leachate strength, promote gas formation and utilisation and to promote stabilisation of landfill surfaces, thus favouring productive final uses and reducing the long-term care requirements.

This paper describes the nature of the refuse stabilisation processes in a sanitary landfill and the attenuation mechanisms determining the chemical characteristics of the resulting leachate. Leachate data obtained from the Coastal Park landfill site are cited for illustrative purposes.

Definition and description of refuse stabilisation in a sanitary landfill

Municipal refuse is a complex conglomerate of organic and inorganic materials possessing undesirable characteristics necessitating further processing to render them environmentally acceptable. Such treatment is generally termed stabilisation. Refuse and sewage sludge stabilisation (Ross, 1989) remains a major cost factor in waste management and continues to elude exhaustive definition. The currently favoured definition of sewage sludge stabilisation (Vesilind *et al.*, 1986) has been adapted to define refuse stabilisation.

Stated in positive terms, refuse stabilisation may be defined as "a process or series of processes producing an end product of such characteristics that its ultimate use will be acceptable in terms of both environmental impact and public health."

Such a holistic characterisation of refuse management is illustrated in Fig. 1. Raw refuse is at one end of the continuum, the environment at the other. Stabilisation represents the connecting link between raw refuse and its eventual disposal into the environment. The stabilisation process selected must effect a transformation of the raw material into a final product which will not cause unacceptable environmental damage when disposed of (Vesilind *et al.*, 1986).

In a controlled, compressed and airtight refuse dump the organic material is decomposed by the combined and co-ordinated metabolic activity of several major trophic groups of bacteria possessing different carbon-catabolising functions (Gujer and Zehnder, 1983). Studies by Pohland *et al.* (1983) have led to a convenient description of the decomposition phases of refuse undergoing stabilisation in a landfill and the associated indicator parameters. These are illustrated in Fig. 2 for selected leachate and gas characteristics. In a typical landfill setting, overlapping of the phases may impede detection and correct interpretation of the progression of events. In reality, no landfill has a single "age", but rather a family of different ages, associated with different sections within the landfill complex and their progression toward ultimate stabilisation.

Various basic factors affect the level of biological activity in the decomposition of refuse: biological factors such as bacteria, food, nutrients, presence of toxic materials, and environmental factors such as moisture, temperature, pH and degree of anaerobic conditions (absence of oxygen). Anaerobic digestion results in stabilisation of some 40 to 60 per cent of the organic matter present. A degradation scheme for the organic fraction (COD) in a landfill has been elaborated by Gujer and Zehnder (1983).

The amount of biogas being produced by a landfill site depends on the type of organic matter dumped and on the biological breakdown conditions. One metric ton of municipal waste will produce between 50 and 400 m³ biogas over a period of years or decades (Ham, 1988).

Only rainfall falling on a landfill is normally significant in leachate formation. Biodegradation of organic material is generally stimulated when the tip has a water content of 50 to 70 per cent (field capacity) - a figure unlikely to be attained in dry areas or during dry periods. Recycling leachates remedies this situation by increasing biological activity and thus reducing pollutant concentration while increasing the mineralisation of wastes (Pohland, 1980; Tittlebaum, 1982).

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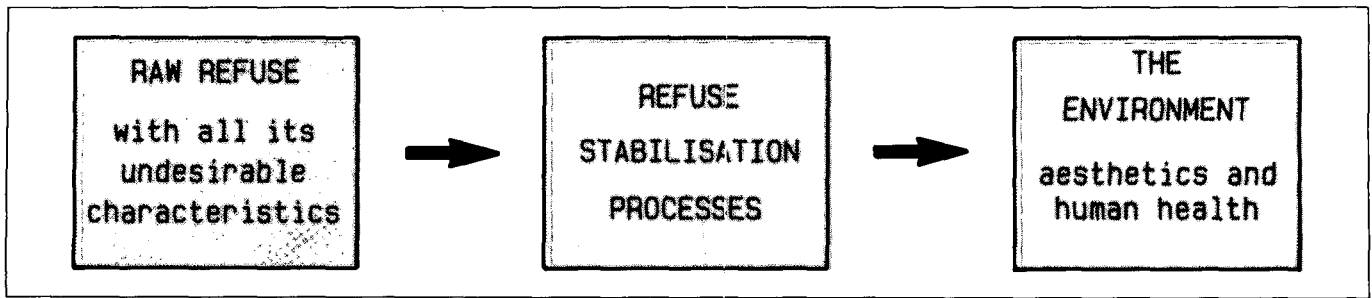


Figure 1
Holistic characterisation of refuse management

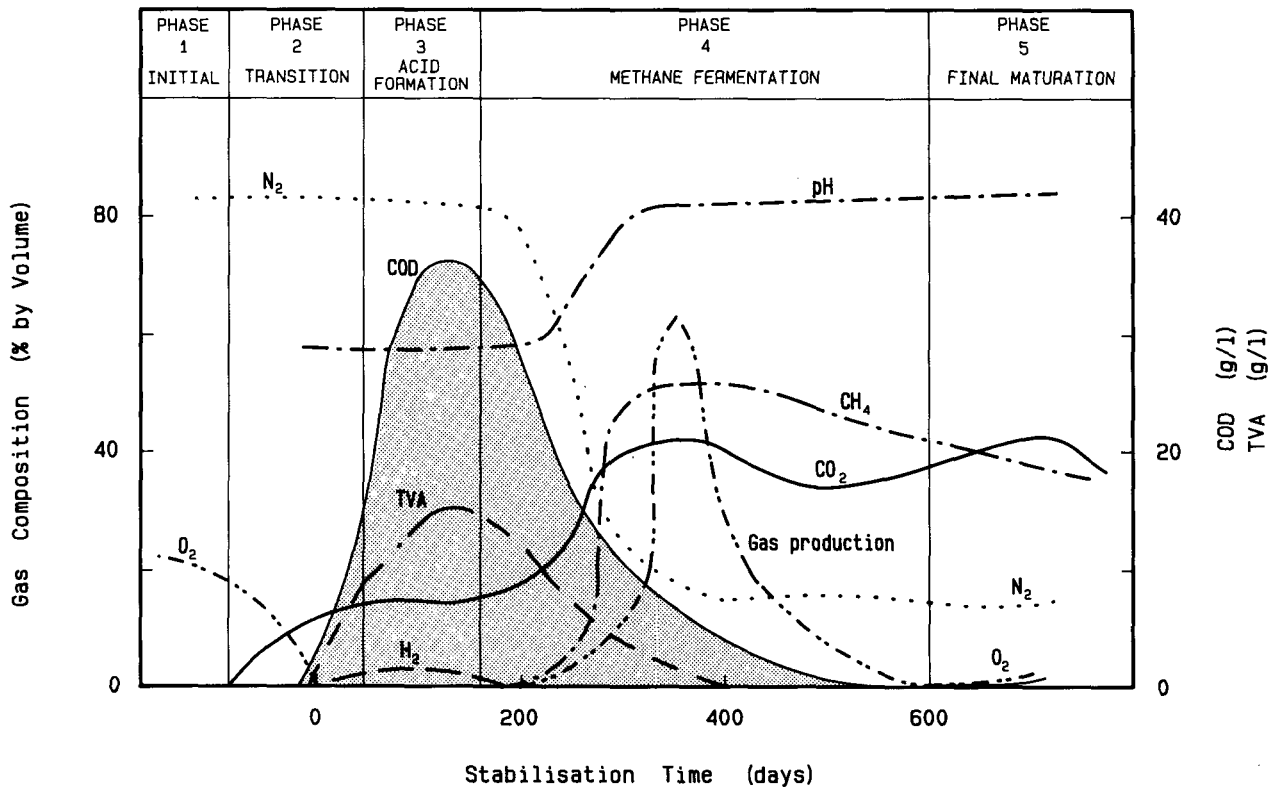


Figure 2
Changes in the selected indicator parameters during the phases of landfill stabilisation (from Pohland et al., 1983)

Attenuation mechanisms in landfill stabilisation processes

Decomposition of refuse is a complex process with probably all of the different chemical, physical and microbiological decomposition processes occurring simultaneously at any given time (Ham, 1988). Certain reactions are inhibited by the formation of specific compounds, resulting in competition for substrate by the various bacteria present. Biological decomposition in a landfill controls the physical and chemical processes via its effect on such variables as pH and redox potential. Examples of major attenuation mechanisms in landfill stabilisation are listed in Table 1.

TABLE 1
MAJOR ATTENUATION MECHANISMS IN LANDFILL STABILISATION

Chemical	Physical	Biological
Neutralisation	Ion exchange	Hydrolysis
Precipitation	Adsorption	Catabolism
Oxidation	Absorption	Fermentation
Reduction	Filtration	Nitrification
Complexation	Evaporation	Denitrification
Ionisation	Extraction	Sulphate reduction
Acid-base reactions	Encapsulation	Mineralisation

TABLE 2
ANALYSES OF LEACHATES OF CELL NO. 1 FROM COASTAL PARK LANDFILL SITE, CAPE TOWN, AS A
FUNCTION OF THE STABILISATION TIME

Parameters		Stabilisation time (months)				
		5 (86-08-07)	12 (87-03-11)	21 (87-12-21)	29 (88-08-23)	42 (89-09-12)
Total solids @ 105°C	mg/l	-	-	-	16 860	10 133
Total dissolved solids @ 105°C	mg/l	33 750	39 450	31 980	16 480	10 133
Total volatile solids @ 600°C	mg/l	-	-	-	8 700	2 708
Chemical oxygen demand (O)	mg/l	38 100	56 373	49 000	19 300	2 000
Ammonia nitrogen (N)	mg/l	197	1 483	1 340	1 140	1 340
Organic nitrogen (N)	mg/l	47	263	250	150	110
Nitrate and nitrite (N)	mg/l	16	6	1	46	30
Total phosphates (P)	mg/l	13	2	75	2	9
pH		5,9	6,3	6,2	7,5	7,8
Conductivity @ 25°C	mS/m	1 902	2 620	2 580	1 827	1 251
Chloride (Cl)	mg/l	3 660	3 600	2 400	2 400	2 400
Sulphate (SO ₄)	mg/l	98	886	460	119	37
Alkalinity (CaCO ₃)	mg/l	7 969	7 500	6 750	6 150	8 500
Sodium (Na)	mg/l	1 690	1 941	1 490	1 345	1 413
Potassium (K)	mg/l	1 780	2 077	1 627	1 591	1 800
Calcium (Ca)	mg/l	-	-	-	471	112
Magnesium (Mg)	mg/l	-	-	-	262	274
Copper (Cu)	µg/l	142	103	94	<25	42
Chromium (Cr)	µg/l	<25	364	160	<25	101
Zinc (Zn)	µg/l	13 790	4 616	490	529	319
Cadmium (Cd)	µn/l	80	61	30	12	13
Nickel (Ni)	µg/l	730	824	595	217	249
Lead (Pb)	µg/l	1 500	393	890	<50	106
Lithium (Li)	µg/l	-	-	-	255	231
Volatile acids (as acetic)	mg/l	-	11 580	3 740	940	<1
Volatile acids (total)	mg/l	-	22 500	-	3 825	<1

Pohland and Gould (1986) present an example of the interaction between the various controlling mechanisms in respect of landfill assimilation capacity for heavy metals. This involves a combination of: mobilisation by leaching, particularly under acid conditions; metal precipitation by sulphide, carbonate or hydroxide; enhanced immobilisation via reducing conditions coupled with an opportunity for filtration and sorption during leachate recycling; and mobilisation or remobilisation via complexation with humic-like substances.

Chemical characteristic of landfill leachates - Examples

The Cleansing Branch of the Cape Town Municipality is currently engaged in research on the practical application of toxic material co-disposal with municipal refuse at the Coastal Park solid waste landfill site near Cape Town. Provision has been made for routine leachate quality and quantity monitoring, by placing high density polyethylene geomembranes beneath the five-metre refuse layer. Cell No. 1 (14 m x 14 m), lacking a sand layer, serves as a control, and was commissioned in March 1986. Analyses of the leachates of Cell No. 1 from the Coastal Park landfill site during the period 1986-1989 are presented in Table 2 (Stow, 1989). The data show a wide variation in values for the different sampling dates, corresponding to various phases of the stabilisation process.

The following conclusions may be drawn regarding the significance of the main chemical parameters:

Total dissolved solids

The TDS value indicates that the leachate was initially markedly saline due to high concentrations of both organic and inorganic components. The TDS was reduced from a peak value of 33 750 mg/l to 10 130 mg/l after 42 months due to fermentation of organic compounds and non-solubility of inorganics at neutral pH values.

The ratio of TDS to electrical conductivity did not remain constant over the 42 months of stabilisation but decreased from an initial value of 17,7 to 8,1. This was due to the decreasing concentration of dissolved organics, some non-conducting. For natural waters, the ratio of TDS to conductivity (mS/m) is normally 6.

COD

The COD concentration provides a good approximation of organics in the leachate. Figure 3 illustrates the COD concentration of the leachate at Coastal Park during the first three years after commissioning the landfill Cell No. 1. The COD reached a peak value of 56 g/l after 1 year, thereafter decreasing and ultimately falling to 2 g/l by the third year. These figures accord with those reported by Pohland *et al.* (1983) and Lema *et al.* (1988). During the same period, the concentration of the inorganic ions such as chloride, sodium and potassium in the leachate remained fairly constant (Table 2). This illustrates that the organic matter in the leachate was reduced by biological mechanisms and not merely by a dilution effect.

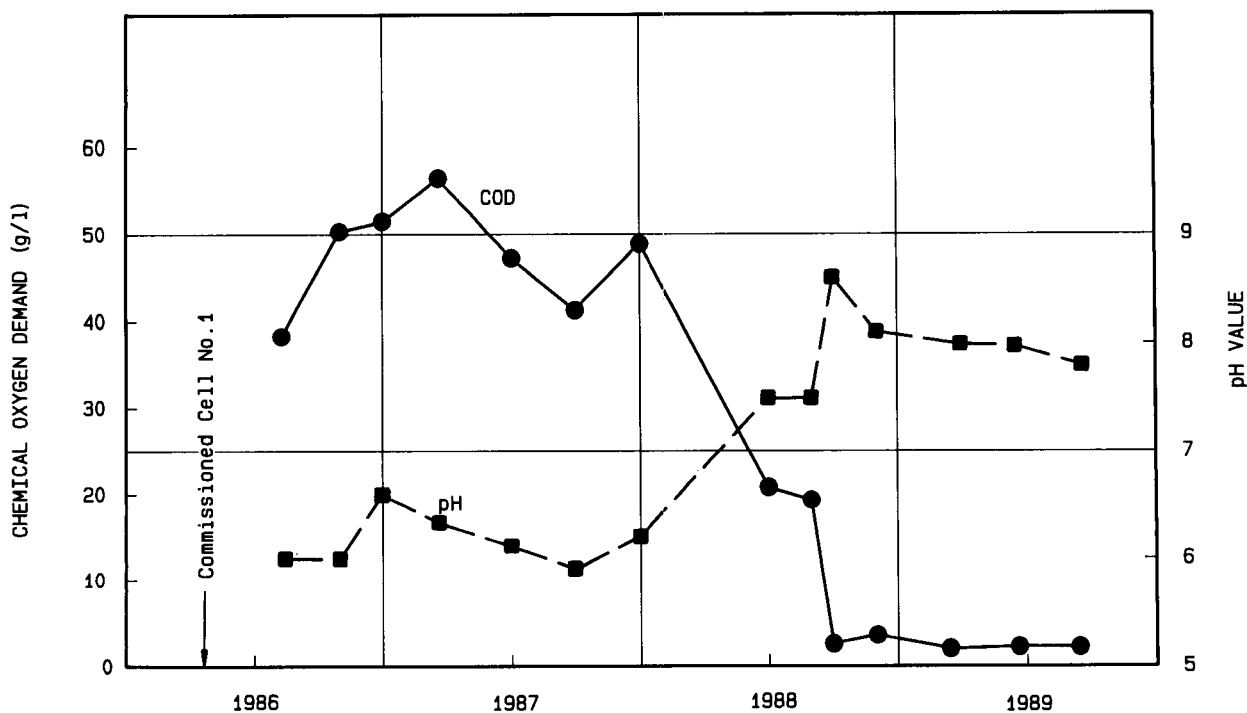


Figure 3
Chemical characteristics of the leachate of Cell no. 1 at the Coastal Park Landfill Site, Cape Town

Volatile fatty acids, mainly as acetic acid, contributed some 50 per cent of the COD load after 12 months' stabilisation time. This is typical of a "young" landfill site. Leachates from more "mature" landfills generally have a higher percentage COD content of refractory materials. Chian and De Walle (1977) report other organic fractions in leachates as consisting of proteins, carbohydrates and hydroxylated aromatics.

Britz *et al.* (1989) conducted laboratory-scale anaerobic treatability studies on Coastal Park leachate and reported a 90 per cent COD concentration reduction at space load rates of 15 kg COD.m⁻³.d⁻¹ at 35°C.

Ammonia

The ammonia-N concentration was still fairly high (1 340 mg/l) after 42 months' stabilisation, indicating continuing decomposition of organic nitrogen in the refuse mass. Ammonium ion concentration plays an important role in determining the bicarbonate alkalinity or buffering capacity of the anaerobic system.

Nitrate

The presence of the oxidised forms of nitrogen in the leachate indicates that nitrification of ammonia has taken place. The relatively low nitrate and nitrite concentration (30 mg/l) in comparison with ammonia (1 340 mg/l) indicates constrained oxygen (air) availability to the nitrifying bacteria and persistence of negative-redox anaerobic conditions even after 42 months' stabilisation.

Phosphorus

Total phosphate concentration in the leachate was generally low (in the 2 to 75 mg/l range) in comparison with the COD and Kjeldahl nitrogen values, possibly reflecting nutrient imbalances during certain phases of the stabilisation process. The requisite

COD:N:P ratio in aqueous anaerobic systems is of the order of 500:5:1. The ratio for anaerobic solid state fermentation is unknown.

pH value

Figure 3 shows leachate pH variation as a function of stabilisation time. During the acid formation phase, pH was below 6, thereafter increasing and ultimately attaining a value in excess of 7,5 (methane fermentation phase) at 30 months after commissioning of Cell No. 1.

Sulphate

The sulphate concentration in the leachate was reduced from a high initial value of 886 mg/l to as little as 37 mg/l after 42 months' stabilisation time. This indicates the presence of sulphate-reducing bacteria which convert sulphate to hydrogen sulphide gas which in turn plays an important role of detoxification by precipitating heavy metals.

Alkalinity-volatile acid relationship

Increasing volatile acid levels are neutralised by the bicarbonate alkalinity and give rise instead to "volatile acid-salts" alkalinity. Under these conditions, bicarbonate alkalinity can be approximated by the following formula (McCarty, 1964):

$$BA = TA - (0,85)(0,833) VA$$

where: BA = bicarbonate alkalinity (mg/l CaCO₃)
 TA = total alkalinity (mg/l CaCO₃)
 VA = volatile acids (mg/l CH₃COOH)
 0,85 = only 85% of volatile acid-alkalinity is measured by titration of total alkalinity to pH 4.

0,833 = convert volatile acid units to equivalent alkalinity units.

An increase in volatile acids over the available cation alkalinity component results in the formation of free volatile acids with partial destruction of buffering potential, accompanied by a drop in pH and decreased gas production (Ross and Louw, 1987).

Table 2 shows a deficit of 8 250 mg/l CaCO₃ bicarbonate alkalinity at 12 months' stabilisation and consequent depression of pH to 6,3. After 29 months, leachate pH had been restored to 7,5 due to an excess bicarbonate alkalinity of 3 472 mg/l CaCO₃.

Cation/anion balance

A balance of this nature reflects the accuracy of the analyses and the extent to which the main inorganic constituents in the leachate have been identified and analysed. For example, the analyses in Table 2 after 29 months' stabilisation recorded the following for Cell No. 1:

Total dissolved solids	= 16 480 mg/l
Total volatile solids	= 8 700 mg/l
Total cations (K, Na, Ca, Mg, NH ₄)	= 225 meq/l
Total anions (SO ₄ , Cl, Alk., NO _x -N, P)	= 196 meq/l
Cation/anion balance	= 14,6%.

Metals

High concentrations of toxic metals (e.g. zinc concentration of 13,8 mg/l after 5 months' stabilisation in Table 2) may inhibit the biological activity of the refuse mass. Metal concentration was generally low at the Coastal Park landfill site. This may be attributable to precipitation as insoluble sulphides or complexation with humic-like substances reducing the overall toxic effect.

General discussion

- The chemical quality of leachates between different landfill sites may vary considerably and is a function of many variables such as: nature of the refuse dumped and whether shredded and compacted; age of the landfill site; environmental factors e.g. moisture, temperature, pH, etc. Owing to these variables, the age of the landfill will not necessarily reflect the degree of stabilisation of the refuse mass.
- Chemical monitoring of the leachate reflects the intermediate or end-products of the various decomposition processes taking place and the degree of completion of the overall stabilisation process.
- Each phase of the stabilisation process has a characteristic leachate composition. Overlapping of phases may impede detection and correct interpretation of the progression of events.
- The chemical characteristics of the leachate from the Coastal Park landfill site are very similar to those reported by other workers for "young" landfill sites (Lema *et al.*, 1988).
- Useful indices of the degree of decomposition are leachate parameters such as COD, alkalinity - volatile fatty acid - pH relationships, degree of mineralisation, conversion of organic nitrogen and phosphorus to inorganic forms, and rate of gas production. Salient data should be plotted on graphs, more readily revealing trends than columns of figures. Rate of parameter variation over time is more important than absolute values for predicting the progress of the stabilisation process.
- Landfill leachates constitute a serious pollution hazard during certain phases of the stabilisation process. Their stench, high organic matter and volume make treatment imperative.
- The advantages of integrating sewage treatment and refuse treatment by siting the two plants adjacent to each other are illustrated in Fig. 4. Local authorities should regard the landfill

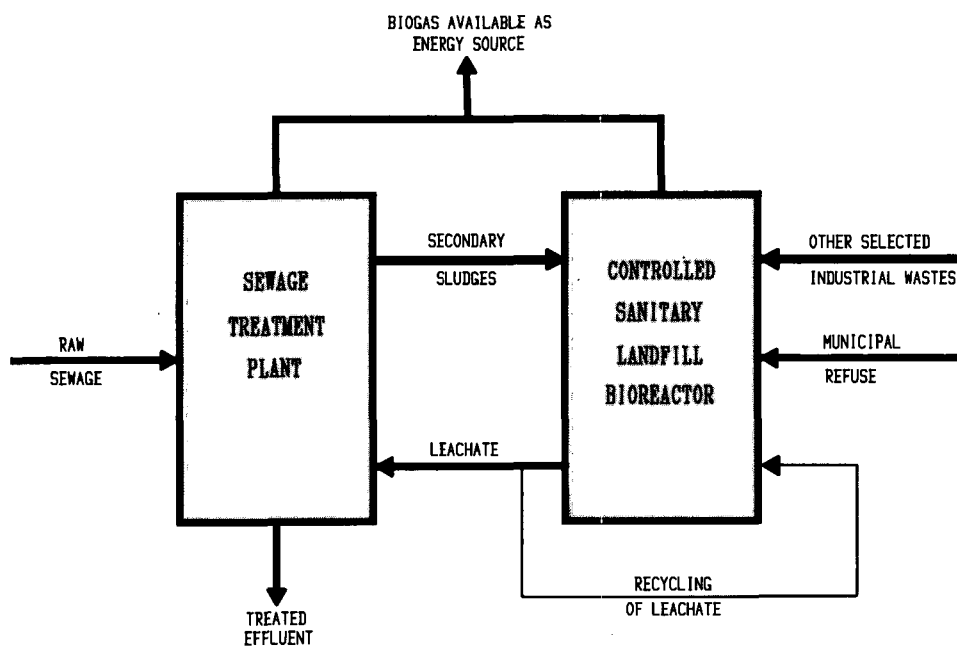


Figure 4
Integrated management of municipal wastes

site as an integral part of a comprehensive waste management strategy, with a single department responsible for such matters (Ross, 1990).

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