CHARACTERIZATION OF LAND FILL LEACHATES AT A COMMUNITY - BASED WASTE DISPOSAL FACILITY

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ABSTRACT

An improved sanitary landfill was constructed for refuse disposal by a community in Adamawa state of Nigeria. Unlike the open dumps which allow leachate to soak into the ground or flow to surrounding areas, this community landfill has a leachate collection system that minimizes ground water pollution at the site. Recirculating the leachate through the landfill enhanced methane production. The landfill has an explosive gas extraction system which removes the methane for utilization as a fuel (Resource Recovery).

Results of the leachate charaterization revealed significant concentrations of colloidal fractions > 0.1 um, suggesting that treatment processes for the landfill leachates are likely to be affected by the associations between leachate pollutants and colloids. This project shows the potentials of community - based approach in developing environmentally sound solid waste disposal technique.

INTRODUCTION

Perhaps no other issue has so dominated the environmental scene recently in developing countries as that of solid waste management. And rightly so. Nearly three thousand tons of solid waste are generated in a state each day, and throughout the past decade open dump was found to cause environmental degradation. For too many years "out-of-sight" was truly "out-of-mind", and too few resources were devoted to addressing the sleeping giant of waste disposal.

Finally, however, public attention and resources are being focused upon this important arena, and substantial progress is being made. At both the state and local level, as well as in the private sector, significant accomplishments are showing us that there assuredly is a light at the end of this dark tunnel after all. This becomes especially apparent when reviewing the many accomplishments that have occurred recently. In fact, so many positive steps were taken over the past years so - by the state, by the private sector, and by a number of towns and cities.
Recycling has become the exciting byword of the day with a host of recycling activities cropping up at an incredibly fast pace in some developing countries. Also, new state-of-the-art landfills and trash-to-energy facilities are being developed. Further progress has been made in long-overdue planning, research, and community assistance programs (3, 7).

Many challenges of course still lie ahead. Developing countries particularly need to reduce the great volumes of the waste through greater source reduction efforts. This will require commitment from both the public and private sectors alike. Also, much more must be done in managing such spcify wastes as tires, used oil, and septage. Solid waste enforcement efforts as well as landfill operations which can often involve very high costs are other key areas that continue to pose dilemmas at the state and local levels.

During the International Drinking Water and Sanitation Decade 1980 - 1990, the main emphasis was placed on the improvement of water supply and safe disposal of human excreta. Solid Water Management (SWM) received comparatively little attention. Today, since urban SWM is considered to be one of the most immediate and serious environmental problems confronting urban Governments in developing countries (DCs), it should be given high priority. The major environmental consequences of the present situation are serious negative impacts on human health and on the quality of life. The hygienic situation with regard to basic sanitation and domestic waste collection is generally very poor, especially in peri-urban areas with low-income communities. The waste generated by the fast growing cities is incresingly beyond the collection capacity and financial limita-

tions of most municipal administrations. Usually, not even the operation costs of the collection services are covered by adequate fees, and the available funds from the central budget are insufficient to finance adequate levels of service to all segments of the population. In a situation where resources are scarce, priority is usually given mainly for political reasons, to middle and high income areas. In addition, many urban poor live in unplanned and unauthorized areas (often outside the municipal boundaries) and are, therefore, not eligible for municipal services. Inadequate service coverage of the population in low-income urban areas has been identified as one of the main problem areas. In view of the shortage of financial resources in the municipal budgets, community-based primary collection shcemes (perhaps combined with recycling and decentralized composting activities) seem to be a most promising approach for improving this situation prevailing in most cities of the developing world. This basically means that the people in low-income communities assume the responsibility of the municipality with regard to the handling of their garbage and set up of a system appropriate to their economic situation. Such types of community-based waste management schemes, involving the participation of local communities in the collection, sorting and recycling activities, have been tried out over the past few years in different places in latin America, Africa and Asia.

Many tons of municipal solid waste are generated every year in Nigeria. Land disposal (open dumps) of solid waste been practiced for centuries. Pollution from old garbage dumps and landfills is a well documented example of groundwater contamination (2). Groundwater monitoring has detected contamination at landfill sites (II). This pollution is a result of precipitation that seeps through garbage, picking up contaminants and becoming a black smelly liquid known as leachate.

Leachate may contain toxic substances from discarded household materials, for instance, materials like caustic cleaning products, used oil, batteris, paint thinner. The leachate also contains dissolved bits of food, yard waste, paper and other biodegradable products. Bacterial action makes the leachate malodorous and unsuitable for release into the envoronment. In modern landfills, a collelction system pumps leachate to a treatment center where the water is purified before being released into the ground or flow to surrounding areas, contaminating ground water supplies. In clean modern landfills, trash is dumped on site, compacted and covered with fresh soil cover prevents release of odours stops trash from belowing around and discourages disease-carry insects, rats, roaches and other vermin.

Modern landfills are ringed with monitoring wells which are regularly tested for contamination. They provide an additional safeguard by detecting any defect in the liner system which might allow leachate to contaminate the water supply.

When the landfill is full, an additional soil cover called a cap is put into place. The cap can be seeded and landscaped to improve appearance and reduce negative impact on a community, improve designed and operated, a landfill provides a method of trash disposal with minimum adverse effects.

The objective of this work is to develop an environmentally sound refuse disposal method through community participation.

STUDY SITE

COMPOSITION OF THE COMMUNITY

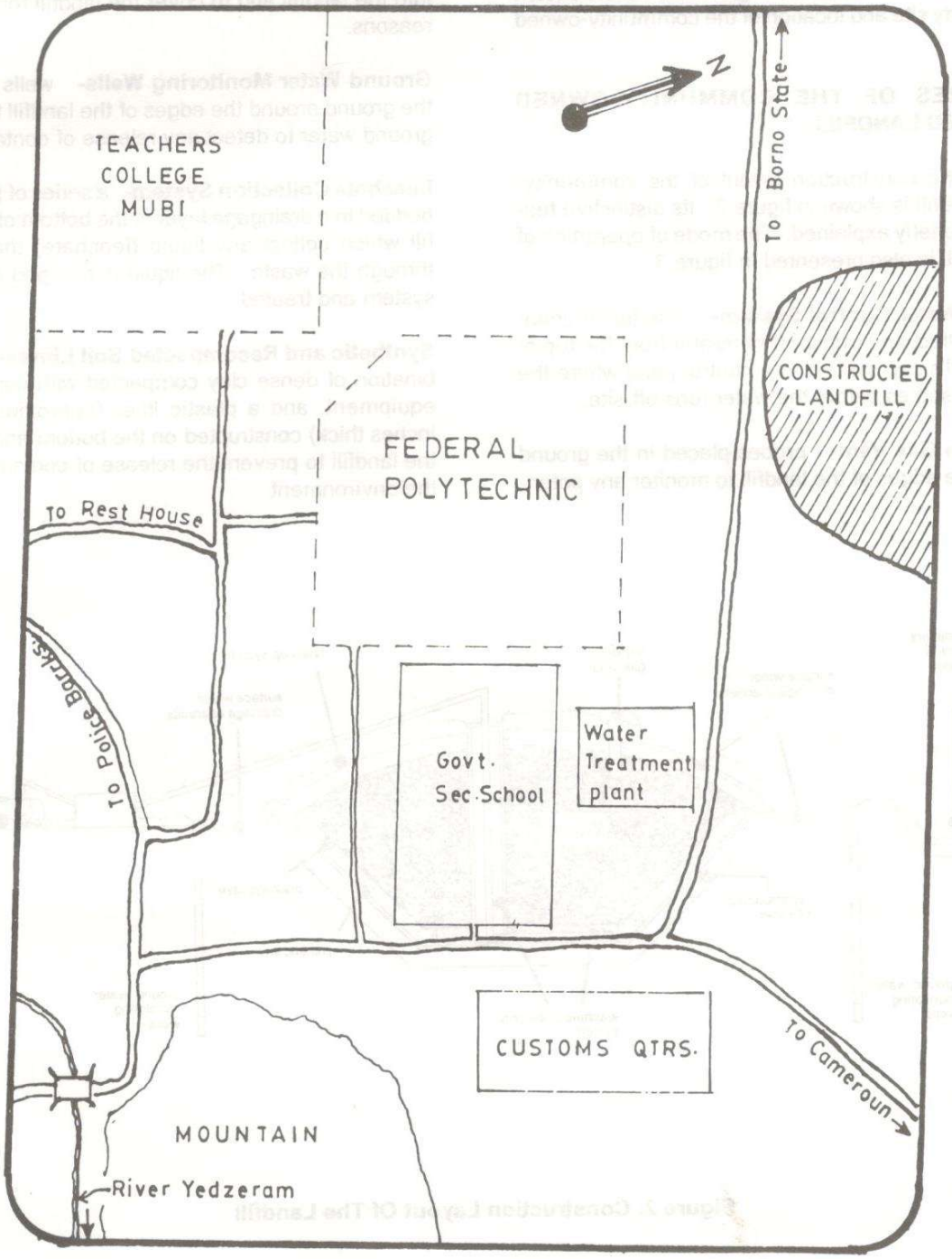
1)	Number of households	-	799
2)	Number of people	-	4,858
3)	Percent of household heads with Occupation:-		
a)	Farmers on own land	-	12
b)	Business, with Capital	-	53
c)	Skilled labourers	-	5
d)	Unskilled labourers	-	3
e)	Petty traders	-	17
f)	Civil servants (Teachers, Engineers, etc)	-	10

A community in Mubi of Adamawa State is playing a key role in municipal waste management-collection and disposal.

A primary collection schemes was set up in 1991. The household refuse is collected daily by local collection system, which subscribed families to the primary collection system, which comprised several refuse barrels located in all neighbourhoods, reduced the walking distance to less than 30m to each house. Households were motivated to throw their refuse into those refuse drums. The collection teams used two-wheeled barrows to transport the full barrels to the nearest communal collection point and transferred into container skips of about 6 and 14m3 capacity. Finally, these are transported in a truck to the landfill site. Financing of solid waste collection services is an important factor. Although most people are willing to pay for the removal of the refuse from their immediate environment, they are generally not concerned with its ultimate disposal.

Fig: I.

Sketch of Study Site Showing Location of the Landfill at Mubi Town Outskirt



The landfill site is therefore located at a reasonable distance (10km) from the collection area but in such a way that it will not result in additional investment in the infrastructure of the road and transportation. In this manner, financial burden on the community as a result of collection, transporting and disposal of the refuse is minimized. Figure I shows the sketch of the study site and location of the community-owned landfill.

FEATURES OF THE COMMUNITY-OWNED IMPROVED LANDFILL

The construction layout of the community-based landfill is shown in figure 2. Its distinctive features are briefly explained. The mode of operartion of this landfill is also presented in figure 3.

Surface Water Control System- a series of channels to collect and transport rainwater from the top of the landfill's cap system to a control pond where the sediment settles before the water runs off-site.

Explosive Gas Vent- probes placed in the ground around the edges of the landfill to monitor any potential explosive (methane) gas migration off-site. This landfill has explosive gas extraction system which removes gas in a controlled manner.

Final Cap System- a barrier consisting of vegetation, soil and clay to prevent infiltration of rainwater into the landfill and to cover the landfill for aesthetic reasons.

Ground Water Monitoring Wells- wells placed in the ground around the edges of the landfill to sample ground water to detect any release of contaminants.

Leachate Collection System- a series of pipes embedded in a draingage layer at the bottom of the landfill which collect any liquid (leachate) that travels through the waste. The liquid is pumped out of the system and treated.

Synthetic and Recompacted Soil Liners- a combination of dense clay compacted with construction equipment, and a plastic liner (approximately 1/6 inches thick) constructed on the bottom and sides of the landfill to prevent the release of contaminants to the environment.

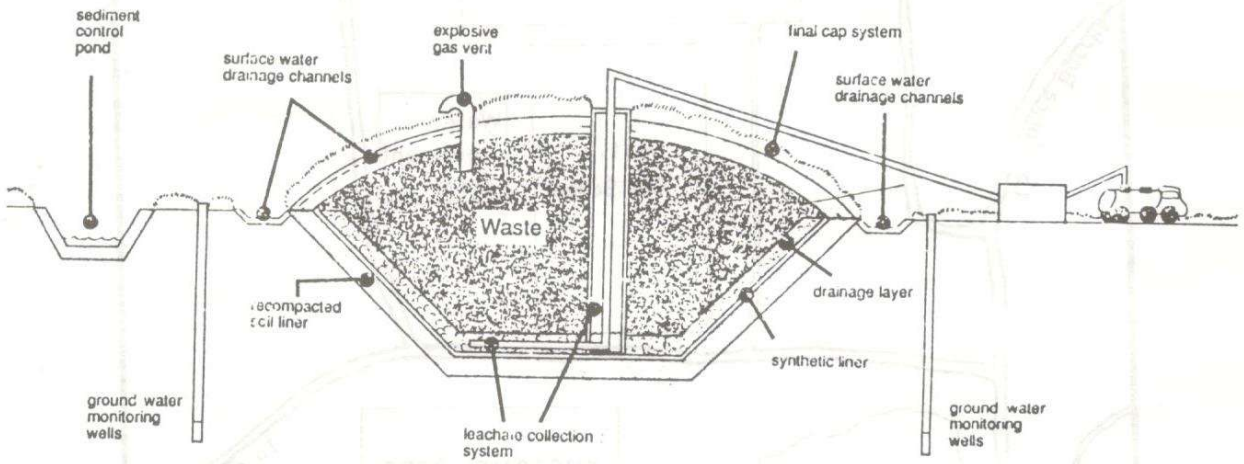
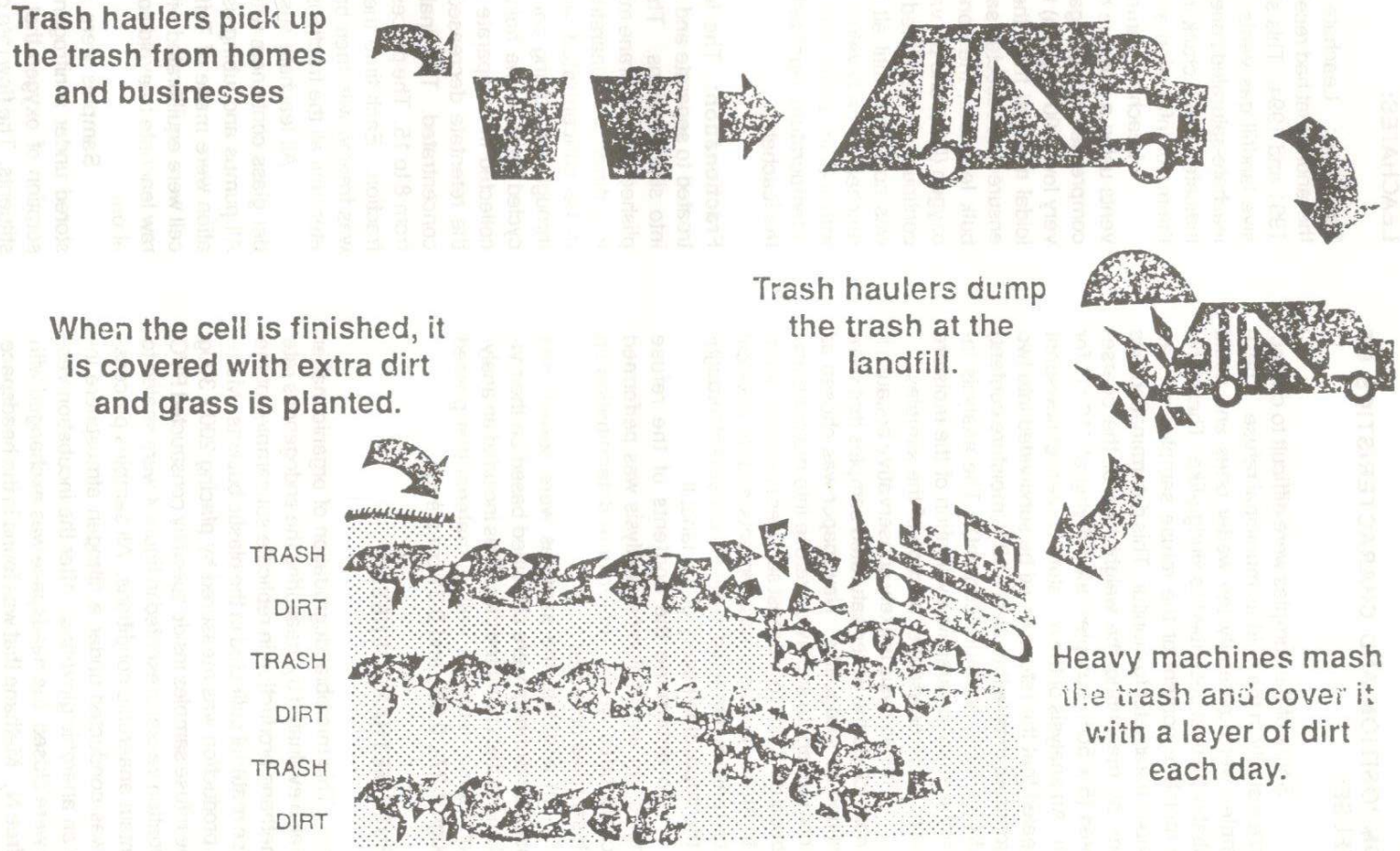


Figure 2: Construction Layout Of The Landfill

Figure 3

Landfill Operation



EXPERIMENTAL SECTION

COMPOSITION AND CHARACTERISTICS OF REFUSE:

Some of the samples were difficult to characterize visually in the field as municipal refuse. These samples were generally the wetter ones and could probably be best described as sludge-like. Therefore, the moisture content of the refuse samples was an obvious parameter to monitor. This determination was made by measuring the weight loss of the coarse-sieved (5 x 5cm) samples upon drying at 110 oC for 48 h. An analysis of the moisture content of newsprint revealed that the refuse could be subdivided into two major groupings; either wet (> 50 % moisture content) or dry (< 50 % Moisture content). The analysis included a quantile-quantile evaluation of the moisture content in the newspaper fraction of the samples.

This analysis is likely conservative because it did not include the water-saturated samples that were identified as sludge-like. Newspaper was chosen as the component to subdivide refuse into moisture levels because it was found most samples is enough quantity to make reliable measurements and its physical characteristics remained relatively consistent throughout the deposition history of the landfill.

To determine the contents of the refuse samples, an archaeological analysis was performed which included weight and volume determination on each samples collected.

In addition, the samples were sorted, and refuse components were classified based on their visual and tactile characteristics. This included an analysis of coarse debris as well as material that passed through 1.27-, 0.63-, and 0.31-cm sieves.

REFUSE METHANOGENESIS:

This microbial degradation of organic matter was also evaluated by measuring the endogenous rate of methane production in replicate subsamples of the refuse material collected in the plastic buckets. Methane production was measured by placing 200 - 300g of the refuse samples inside specially constructed PVC incubation vessel presented in figure 4 were sealed to maintain anaerobic conditions. All samples processing was conducted under a nitrogen atmosphere inside an anerobic glovebag. After the incubation vessels were closed, the headspace was exchanged with O_2-free N_2. Methane that was found in the headspace of the incubation vessels was monitored by gas chromatography.

SAMPLING, FRACTIONATION, AND ANALYSIS OF LEACHATES:

Sampling: Leachate samples were collected from the landfill that had received municipal refuse between 1991 and 1994. This site contains a network of passive landfill gas vents, many of which extend to the leachate-saturated zone. A previous confidential study indicated that a crack in clay cover of the landfill was the major infiltration area.

Leachate samples were withdrawn from the vents using a positive displacement pump driven by compressed nitrogen gas. The pumping rate was kept very low (100 mL/min) to prevent detachment of colloidal material from the surrounding refuse (8). To ensure that collected samples were representative of bulk leachate, the conductivity, turbidity, dissolved oxygen (DO), and pH value of the pump effluent were continuously monitored during sampling. No sample was collected until all these index parameters had reached a steady value. The samples were preserved with sodium azide (1 g/L) and stored under nitrogen at a temperature slight below the in situ temperature of the leachate.

Fractionation: The leachate samples were than treated to separate and concentrate leachate colloids into size fractions. This fractionation was accomplished by membrane microfiltration and ultrafiltration in a stirred cell apparatus (Figure 5). The suspension to be concentrated was pumped under pressure through the stirring cell with the retentate being recycled back to the holding reservoir and the filtrate collected in a separate reservoir. As the volume of the retentate decreased, the rejected colloids were concentrated. The final concentration ratios ranged from 8 to 15. The process was repeated for each size fraction. Each time the filtrate of the previous step was treated with membranes of smaller cutoff diameter until all the fractions were obtain.

All leachate suspensions were stored in amber glass containers with air-tight, Teflon-lined caps. All pumps and tubing used in sampling and fractionation were made of Teflon. The walls of the stirred cell were equilibrated with the dissolved phase of the raw leachate to avoid sorptive losses during fractionation.

Samples were collected, fractionated, and stored under a nitrogen atmosphere to prevent absorption of oxygen that could oxidize leachate constituents. The flow rate of the nitrogen gas steam was kept to minimum to prevent excessive stripping of dissolved CO_2.

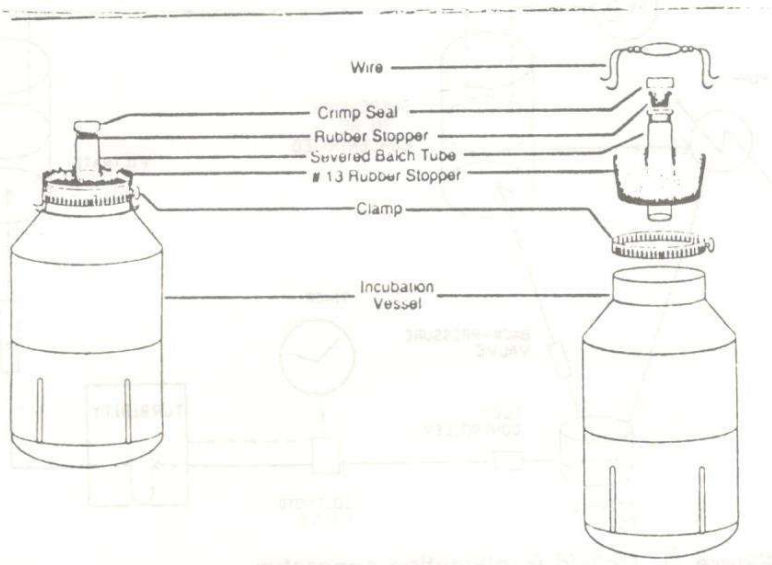


Figure 4 Schematic representation of the vessel constructed for refuse incubations.

Both the filtrate and retentate (fraction) of each filtration step were analyzed for total and fixed solids, total organic carbon (TOC), and selected metals and organic pollutants. Enrichment of any of these parameters in a fraction was attributed to the colloids concentrated in that fraction. A mass balance was performed over each step to quantify colloidal components and to check for sorptive losses.

The filter membranes used proved sharp separation, with minimum sorptive losses and/or leachate of filter material.

Extensive testing of various alternative filtration media included hollow-fiber cartridges, polysulfone plates, and polycarbonate plates with model colloids, dissolved pollutants, and actual landfill leachate. Based on these tests, four polycarbonate membranes (nominal pore sizes of 10000, 1000, 100, and 10nm) and a polysulfone membrane (1.3nm) were selected to define the boundaries of the fractions.

Because these membranes were sensitive to clogging, intermittent filtration had to be applied with suitable filtration/stirring cycles. The flow rate and turbidity of filtrate were continuously monitored to detect clogging and assure proper operation. A solenoid value controlled by a timer and a turbidimeter were used to turn the process on and off as needed.

Analysis: All the colloidal fractions and filtrates of the samples collected were scanned by proton-induced x-ray emission analysis to identify elements that were associated with colloids. Further analysis by atomic absorption (Perkin Elmer 1100B spectrophotometer) quantified selected elements in subsequent samples. Prior to analyses, these suspensions were acidified (to pH < 1).

The amounts to total (TS) and fixed solids (FS) were measured by weighing the residue of 5mL of suspension dried at 103 and 550°C, respectively. TOC was obtained by taking the difference between total and inorganic carbon measured by a total carbon analyzer (Dohrman DC-80).

RESULTS AND DISCUSSION

Studies conducted on the municipal solid waste stream of Mubi town in 1990 showed the waste composition to be similar to what obtains in most of the Nigerian urban area. The results are presented in figure 6 on the basis of weight and volume determinations.

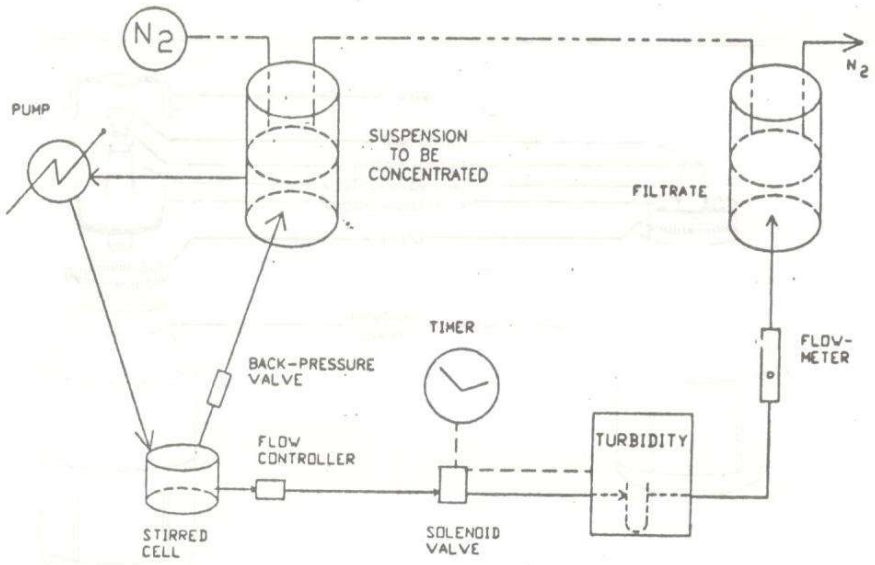


Figure 5 Colloid fractionation apparatus.

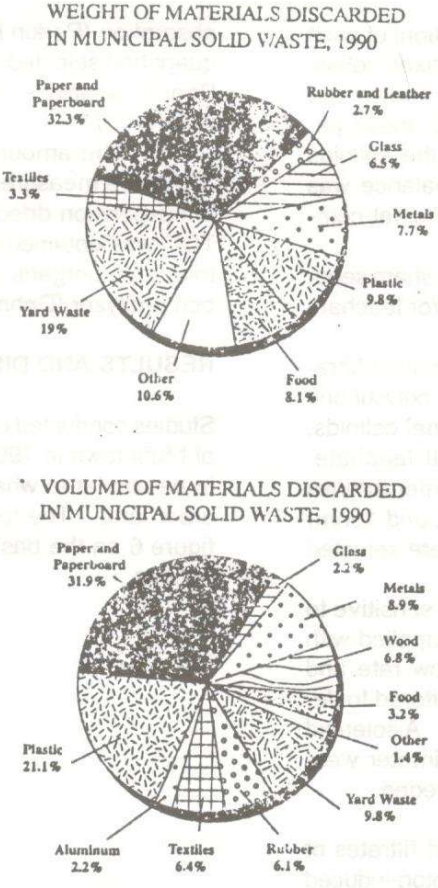


Figure 6 Showing Composition Of Refuse Generated in Mubi.

RESOURCE RECOVERY OPERATION: CASE OF ENERGY FROM THE LANDFILL LEACHATE:

Recirculating the leachate through the landfill enhanced biological activity, which accelerated methane production and waste decomposition. Moreover, the leachate itself became less of a groundwater contaminant. Stepping up the biogas production made it economical to use the methane as fuel. (Unused, it is a more potent greenhouse gas than carbon dioxide). In addition, recirculating the leachate instead of transporting it to a sewage treatment plant eliminate costs associated with transporting and treating leachate.

Methane is a flammable gas that is created naturally when large amount of trash decay. The gas will be pumped to a central unit from extraction wells that have been drilled deep into the buried landfill waste. The methane will be burned by engines which will drive several electrical generators. It is estimated that the electric power to be generated will be sufficient to light approximately 20 homes. Results of the methanogenesis (Methane Formation) are shown in table I.

FACTORS INFLUENCING SUBSURFACE MOVEMENT AND TREATABILITY OF LANDFILL LEACHATE:

Evaluation of a series of samples collected from this landfill revealed stable colloids in the leachate. Colloid stability, attributed to an organic coating, implies a high degree of mobility and persistence. High concentrations of organic macromolecular species were isolated from the 1.3-10nm fraction.

Although total metal concentrations were low, portions of several heavy metals were found in the colloidal phase of the leachate. The same might be true for other metals that have significant concentratiions in leachates from other methanogenic landfills.

The organic content of certain colloidal fractions (>0.1 um) can sorb significant amounts of hydrophobic organic pollutants. The performance of unit processes treating landfill leachate can be strongly influenced by their efficiency in removing those colloids. It is unlikely, however that these colloids can significantly mobilize organic pollutants in contaminated aquifers.

To study the impact of leachate evolution on colloidal solids, most of the samples were collected from two vents during selected seasons (Table 2). One vent (DV-12) was used to sample the lowest measurable leachate elevation in the landfill.

In this study, deep leachate (DV-12) samples had more colloidal and dissolved solids than did leachate samples from the recharge area (DV-3).

Among the elements detected in the leachate, three (zinc, lead, and chromium) were heavy metals. Significant fractions of these pollutants were associated with colloids in the landfill leachate (Table 3). Zinc was found in all colloids fractions and in the dissolved phase. Lead was either dissolved or part of the colloids in the 1-10um fraction, while chromium was split between the dissolved phase and the humic fraction (1.3-10). The actual concentrations of all these heavy metals, however, were very low, limiting their environmental significance.

The presence of colloidal lead was supported by the equilibrium speciation simulation. The model results indicated that Pb5(P04) Cl(s) would be present in the system. Although precipitation of zinc was not predicted by the model, this may be because we have no data on the sulfide concentration in the leachate. Sulfide, which is commonly formed in landfill leachate by reduction of sulfide, is removed by forming precipitates with iron and heavy metals. Due to the low solubility of these precipitates and the presence of metals, sulphide is normally depleted and does not reach significant levels in landfill leachates (13-15). Because the sulfide concentration in this leachate was not measured, colloidal sulphide precipitates (of iron, zinc, or lead) could be present.

The relationship between dissolved and colloidal species can be described by distribution coefficients (K's) that are defined as the ratio of the solid concentration of each metal (in the colloidal form) to the metal concentration in the dissolved phase. Average values and standard deviations of the water-colloid (by fraction) log K_d values for all metals studies are shown in Table 5. The affinity of each metal for the colloids of each fraction did not change dramatically over time and location. As noted above, however, some of these metals could have been present as precipitates.

Colloidal stability is a necessary but not sufficient requirement for colloid-facilitated transport. The other important characteristic is the relative affinity of the contaminant for the colloid. For the metals in the leachate, it seems reasonable that the in-situ water-colloid K_d values (Table 5) would be similar to those characterizing sorption of metals onto soils. Under these conditions there would be partitioning of metals to both colloids and the surrounding aquifer solids so that, whenever stable collioid are present, increased mobilization of metals should be expected. Hydrophobic orgainic pollutants, which partition into organic material (1,11,12) are even more likely to be mobilized with the leachate. This enhanced mobilization would result from landfill leachate colloids with high organic matter content competing with low organic content aquifer solids for those pollutants.

In contract with ground water systems, typical treatent processes provide limited contact time that may be insufficient for equilibrium conditions to be reached. As result, rate limitations could prevent complete desorption of pollutants from the colloids. Additionally, the 1-10-um colloids that are good sorbents and may reach high concentrations are not likely to be strained out by the media of artificial unit. Finally, removal of the colloids greater than 0.1 um will provide significant removal of hydrophobic organic pollutants. Therefore, the impact of landfill leachate colloids on the efficiency of treatment processes for the removal of organic pollutants can be far more significant than the mobility enhancement of pollutants in aquifers.

The effect of leachate colloids on treatment processes is supported by Chian and De-Walle (13), who found that the efficiencies of most physicochemical processes were reduced when treating landfill leachate. In contrast, membrane processes (which remove colloids) such as reverse osmosis were effective. More information about the kinetics of pollutant desorption from landfill leachate colloids is needed to quantitatively evaluate the impact of those colloids on individual treatment units.

SUMMARY AND CONCLUSION

Local resource person has conducted a study on landfill leachate and upgrading of a landfill through the involvement of a community. This study revealed that community organizations can fund projects aimed at the development of cost-effective solid waste management system. If properly designed and operated, a landfill provides a method of trash disposal with minimum adverse effects.

Indigenous technical experts - (Engineers and Scientists) are capable of finding sustainable solutions to environmental problems in Nigeria.

Federal, State and Local agencies should combine today to outlaw open dumping and close the clean up existing open dumps, though old habits are hard to break.

Urban SWM is one of the most serious environmental problems confronting the Nigerian Government. Inadequate collection and disposal of solid waste are major reasons for the environmental degradation and health risks in the fast growing urban areas.

The most promising approach to improve the collection coverage is the introduction of community-based waste management schemes which involve the local communities in the collection, sorting and recycling activities. Research is needed to determine how such schemes can be implementned under different kinds of condition. Operational efficiency of SW (solid waste) services can be improved by increasing the participation of the private sector. However, future research should not only address the question of what should be the role of private sector in SWM, but also how the performance of public enterprises can be improved and what should be the role of the public (government) sector vis-a-vis the private sector.

In order to improve the present situation of final disposal, three basic measures are suggested: (a) institutional and financial models for waste disposal activities as an integral part of SWM have to be found and applied; (b) appropriate guidelines for the operation of landfills have to be developed; and (c) recycling of the large organic putrescible municipal solid waste fraction needs to be encouraged.

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Table 1: Selected Characteristics of Municipal Refuse Samples Collected from the Landfill

SAMPLE NO.	SAMPLING DEPTH (M)	TEMP (°C)	RATE OF METHANOGENESIS [umol(dry kg)$^{-1}$day^{-1}]	MOISTURE (%wt/wt)	SULPHATE (mmol/kg)	pH
1.	3.08	29.4	0	19.0	10.06	6.2
2.	6.15	42.2	262.5	27.8	6.45	6.7
3.	9.23	ND	0	16.0	23.54	6.3
4.	13.45	37.2	335.2	37.6	15.9	7.4
5.	15.69	37.7	272.3	31.2	10.06	7.1
6.	4.62	ND	0	21.4	30.7	5.8
7.	10.15	ND	1.6	17.9	6.06	6.4
8.	4.31	22.2	520.3	73.4	8.60	6.9
9.	6.77	25	435.1	42	13.43	7.5
10.	9.23	14.4	124.9	35.6	12.89	7.4
11.	9.23	14.4	297.5	33.6	7.61	7.0
12.	3.38	16.1	219.3	43.5	10.39	6.8
13.	3.38	22.2	371.8	41.1	11.38	6.9
14.	3.38	22.2	302	21.5	6.22	6.8
15.	6.76	18.3	274.9	43.4	4.96	7.2
16.	3.08	21.1	0	37.0	25.69	6.3
17.	6.15	28.9	0	32.6	14.39	7.2
18.	9.85	27.8	302	52.1	4.41	7.4
19.	3.08	21.1	0	35.8	31.94	6.2
20.	3.08	ND	79.9	37.9	12.23	7.4
21.	6.76	43.3	56.8	40.1	16.08	7.3
22.	9.23	40.5	149.8	32.2	11.92	6.9

23.	15.38	ND	26.3	25.0	15.55	7.1
24.	4.62	21.7	702.5	74.7	28.1	7.1
25.	3.08	21.7	17.2	29.8	5.76	6.8
26.	4.92	21.7	52.2	54.2	79.69	6.8
27.	5.23	21.7	148.1	23.9	8.98	6.9
28.	8.62	31.7	377.8	32.3	7.40	6.9
29.	9.80	10.5	316.3	52.4	45.97	7.9
30.	13.85	57.8	109.4	22.5	15.43	7.2
31.	20.31	45.5	24.1	32.8	17.86	7.1
32.	12.31	62.8	0	10.1	2.27	7.2
33.	21.53	45.5	298.3	50.6	21.38	8.1

ND = not determined

Table 2: Landfill Leachate Sample Identification:

Sample	Location	Temp(°C)	Turbidity (NTU)	Date
1.	Vent DV-13	24	18.1	Dec 22, 1992
2.	Vent DV-3	18	10.5	Mar 8, 1992
3.	Vent DV-12	30	550	June 8, 1993
4.	Vent DV-3	31	7.2	Sept. 1, 1993
5.	Vent DV-12	34	58.0	Nov. 2, 1993

* Temperature and turbidity data represent steady- state condition

Table 3: Reported Leachate composition

Component	Concentration	Component	Concentration
chloride	3100	cadmium	0.03
COD	2510	calcium	224
cyanide, total	< 0.01	chromium, total	0.21
floride	2.6	iron	68
nitrogen, ammonia	639	Lead	1.32
nitrogen, nitrate	< 0.25	Magnesium	468
nitrogen, nitrite	< 0.05	Manganese	1.07
pH	7.45	Mercury	<0.0001
phosphere, total	41.1	nickel	0.17
dissolved solids	8900	Potassium	864
specific conductance (umhos/cm)	14700	selentium	< 0.002
sulfate	< 10	silver	0.01
total organic carbon	563	sodium	842
arsenic	0.01	zinc	0.548
barium	1.08		

* All unit except pH and conductivity are milligram per liter.

Table 4: Range in Concentration of Collodial Constituents Expressed (as mg/L) in Raw Leachate

constituent	<1.3nm	1.3-10nm	10nm-0.1um	0.1-1um	1-10um
total solids	$6.9x10^3$-$1.45x10^4$	227-387	10-112	34-85	6-617
fixed solids	$5.85x10^3$-$1.29x10^4$	53-76	3-60	4.5-45	3-184
TOC	$2.77x10^2$-$7.27x10^2$	87-195	3-21	7.26	0.3-22(
Fe	1.0-2.2	1.2-3.6	1.18-1.6	0.5-6.02	0.13-4.8
Mg	50-241		<0.3-7.7	<0.2-0.53	<0.1-2.2
Ca	11-74	1.0-2.0	0.23-3.4	0.1-20	0.47-82
Zn	0.06-14	0.01-0.03	<0.01-0.03	<0.03-0.15	0.01-1.0
Pb	0.1-0.25	<0.01-0.01	<0.01	<0.01-0.04	<0.01-0.1(
Cr	0.07	<0.01-0.05	z0.01	<0.01	<0.01-0.02

Table 5: Calculated log K_d (Mean Standard Deviation) for Methal. Associated with Colloids in Leachate.

	1.3-10nm		10nm-0.1um		0.1-1um		1-10um	
Metal	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Fe	3.66	0.18	4.00	0.59	4.12	0.67	3.92	0.39
Mg	2.29	0.22	2.20	0.39	1.30	0.20	1.13	0.09
Ca	2.44	0.29	2.81	0.55	3.79	0.68	3.85	
Zn	2.58	0.35	3.75	0.63	4.01	0.34	4.24	0.44
Pb	2.32	0.15	1.99	0.05	3.20	0.04	3.18	0.17
Cr	3/17	0.08	2.68	0.51	2.91	0.35	3.14	0.79

* Three samples were used for Pb and Cr; all other values are based or four samples.