 ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2002)03-0303-06 **CLC number**: X705 **Document code**: A

Excavation and characterization of refuse in closed landfill

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Abstract: Refuse in landfills becomes stabilized as organic matter in refuse degrades and soluble inorganic substances dissolve during their long-term stabilization process. In this paper, this process is also referred to as mineralization process and the resultant stabilized refuse referred to as aged refuse. Aged refuse contains a wide spectrum and huge quantity of microorganisms with strong decomposition capability for refractory organic matter present in some wastewater such as leachate. In this study, aged refuse excavated from 2 to 10 years old closed landfill compartments in Shanghai Refuse Landfill is characterized in terms of particulate distribution by screening, total nitrogen, total phosphorus, biodegradable matter. The approaches for redevelopment of both land and aged refuse in the stabilized landfills are proposed.

Keywords: landfill; refuse; mineralization

Introduction

Refuse will undergo complex physical, chemical and biological changes after it is placed in a landfill (Attal, 1995; Barlaz, 1989a; 1989b; 1989c; 1987; Belevi, 1989; El-Fadel, 1996; Ham, 1982; 1987; 1993; Leckie, 1979). Consequently, leachate and landfill gas generate and refuse surface settles (Zhao, 1999; 2000). Meanwhile, in an anaerobically operated landfill, concentrations of pollutants such as COD, BOD, NH_3-N, in leachate increase sharply in 0 – 4 months and then decrease also sharply in 4 – 6 months. Leachate will be naturally attenuated in a slow but steady manner after 6 months of placement, until reaching the regulated discharged standards and surface water quality (Zhao, 2000). It would take long time for leachate to reach such a standard, in decades or hundreds of years, depending on refuse composition and moisture, local climate and geological conditions.

Shanghai Refuse Landfill, the largest landfill in China, has been long-term monitored by our laboratory (Zhao, 1999; 2000; Zhu, 1996). It was constructed in 1985 along the shore of East China Sea, which was formed by the sedimentation of silt carried by Yangtze River and put into operation at the end of 1989. It occupies around 6 km^2. The refuse is placed by area method, with a filling height of 4m. Around 2.4 million tons of municipal solid wastes (refuse), two thirds of them are being placed in the landfill (Zhao, 1999).

The landfill is separated into many landfill compartments by the clay dug in situ, with 10 hectares for each compartment. The total capacity is 13.7 million m^3. Currently, around 4000 tons of refuse, 75% of total refuse generated in Shanghai, are placed in the landfill daily. As a result, some 200 hectares of landfill compartments have been closed since 1989. The quantity of refuse placed in the landfill is being increased and 50 hectares of landfill compartments would be needed every year in the following years. It is estimated that a total area of 350 hectares of land would be made by the placement of refuse in 2003. More area would be constructed along the shore of the sea, as the shore extends for 50 – 100m every year.

Shanghai is located at the end of the Middle and Low Stream Plain of Yangtze River in China. It is absolutely difficult to look for another landfill if the old landfill is given up. Hence the refuse height at Shanghai Refuse Landfill is always 4m and more and more landfill compartments should be created towards onshore of East China Sea. Actually, Shanghai Land Making Company consecutively makes land along the shore of East China Sea except for the landfill area. According to the city planning of Shanghai, the shore

Foundation item: The National Natural Science Foundation of China (No. 29777019), and the Excellent Youth Foundation of China Education Ministry

along Shanghai Refuse Landfill, around 6 km of length, will not allowed for land making, but for landfill construction.

Obviously, Shanghai Refuse Landfill has a vast area. It should be possible for reuse after closure. Several reuse approaches are being planned. Nevertheless, a lot of work on site investigation and stabilization process of closed landfill compartments should be studied before suitable reuse means can be made. In our previous work, a large scale lysimeter with double layers was constructed in situ at Shanghai Refuse Landfill. A total weight of 10180 tones of refuse was placed during a period from 4 to 18 April 1995. The refuse height was 4m, the same height as all the other landfill compartments at the Landfill, and the filling area was 3000 m^2 (50m × 60m). The leachate was drained out of the underlying pipes which was integrated into one pipe directed to the collection well. Parameters such as pH, concentrations of Cl^-, turbidity, NH_3-N, COD_{Cr} and BOD_5 (simplified as COD and BOD respectively in the following text) in leachate in the lysimeter and closed landfill compartments at Shanghai Refuse Landfill were monitored from April 1995 through October 1998. The mathematical simulation formula between these parameters and refuse age were established based on the data obtained from the lysimeter and justified by the data obtained at the closed landfill compartments from 1989 to 1993. The long-term predictions for concentrations in leachate were made using the mathematical simulation formula established. It was predicted that COD and BOD may be reached to the strictest standard for pollution control on the municipal solid wastes landfill in China, i.e., COD < 100 mg/L and BOD < 30 mg/L, after 15 years natural attenuation. The time predicted for NH_3-N concentrations to reach the discharging standard, 15 mg/L, was found to be at least 24 – 26 years or even longer. The predictions for concentrations of Cl^-, turbidity, and pH values in the leachate are also given. The natural attenuation of Cl^- is the slowest and might be decreased to 200 mg Cl^-/L, the agricultural irrigation standard, after at least 58 years (Zhao, 2000).

Settlement and changes in refuse composition for total sugar, raw cellulose, biological degradable matter, volatile solid, organic carbon, were also monitored in this lysimeter and closed landfill compartments (Zhao, 2000; 2001). Mathematical simulation formulae between these parameters and refuse age were developed based on the data obtained from the lysimeter and validated by data from landfill compartments closed in April of 1991, 1992, 1993 and 1994. Long-term predictions for these parameters for the landfill were made using these formulae. It was predicted that the refuse might be fully aged and cumulative settlement might be over 30% of the initial height after around 22 – 30 years of placement (Zhao, 1999; 2000).

Based on the investigation mentioned above, a planning for redevelopment of Shanghai Refuse Landfill is made. One of priorities is to use the relatively stabilized landfill compartments as cultivation of plants. Many types of plants and crops were tested. It was found that heavy metals and toxic organic matters in crops exceed the food standard and such action was given up. Plantation of plants used for green construction in city is completely possible and is practicing in the Landfill. Nearly all the shallow root plants can be developed on the 30 – 60 cm cover soil. As refuse age extends, more and more types of plants can be cultivated.

The second priority for reuse of stabilized refuse is to use it as organic fertilizer for non-crop cultivation. The third one is to use it as filling materials in biofilter for treatment of leachate and high strength organic waste waters, as reported elsewhere(Zhao, 2001). It was found that in the initial stage, refuse taken from the landfill was odorous and the color seemed to be grey and voluminous, and the samples dried very slowly at room temperature and leachate generated while drying. After around two years, the refuse became black and could be dried quickly at room temperature. The odor was slight. Remarkable differences in the appearance could be found for the refuse taken before and after 23 months. Nevertheless, at least 7 – 8 years of degradation seem necessary for refuse to reach some stability for uses.

In this work, refuse and top soil taken at Shanghai Refuse Landfill was characterized and compared, and their possible uses are discussed.

1 Experimental

1.1 Excavation of refuse from the landfill

Quantity and components of refuse and placement time are well recorded for every compartment in Shanghai Refuse Landfill. All the refuse placed in the landfill was collected from the downtown area in Shanghai, where natural or coal gas are used. The components of refuse placed in the landfill are thus considered to be nearly consistent in these years, though changes considerably in general in refuse collected in Great Shanghai Area. The contents of refuse are shown in Table 1.

Table 1 Characterization of the excavated refuse in closed landfill compartments

Age of refuse in the landfill, years	Weight percentages based on particles distribution, %				Glass and plastics in the excavated or fresh refuse	
	Diameter > 40 mm	Diameter 15 – 40 mm	Diameter < 15 mm	Total	Glass	Plastics
Fresh refuse	77.97	12.02	10.01	100	0.69	3.41
2	70.57	16.60	12.83	100		
4	66.45	14.87	18.68	100		
6	40.16	30.12	29.72	100	0.87	3.93
8	29.50	32.85	37.65	100		
9	25.45	29.24	45.31	100	0.81	4.19

Refuse was excavated in April 1999 from the landfill compartments which had been closed and covered over a period of 2, 4, 6, 8 and 9 years. At least 200 – 400 kg of samples for each compartment was taken. The refuse samples were naturally dried. The larger non-degradable matters such as stones, glass bottles, plastic films (bags), rubber, etc., were removed and weighted. For analysis, the finer fractions was broken into small pieces by hammer, ball miller and grinder if necessary, until the particles were smaller than 100 μm. Sometimes, big woods pieces (such as the used furniture) could be found in the samples in the initial period, after the refuse was placed. In this case, the wood was removed before weighting and drying. It was considered that such a preliminary treatment for large wood was acceptable because they may be rarely available.

For biofilter material uses, the finer fractions with diameter less than 5 cm was selected from the refuse with age of 9 years.

1.2 Analysis of refuse samples (EPA of China, 1989; Zhao, 1999)

After the dried refuse samples were broken down into small particles (powder), raw cellulose, biological degradable matter (expressed as cellulose, BDM respectively), organic carbon, volatile solid, total nitrogen (TN) and total phosphorus (TP) in the refuse samples were analyzed. TN and TP were analyzed by conventional methods and the other parameters by the following procedures (Zhao, 1999).

1.2.1 Raw cellulose

To 1g of refuse, add 100 ml of acidic solution (dissolving 20g of cetyl-trimethyl ammonium bromide in 1000 ml of 1 M sulfuric acid solution), heat for 70 min. Filter. The cake, i.e., raw cellulose, is dried in 105 ℃ and weighed, after washing with water and acetone.

1.2.2 Biological degradable matter (BDM)

Analysis of BDM is similar to that of COD for wastewater. Nevertheless, BDM is determined at room temperature.

1.2.3 Volatile solid (VS)

VS is determined by burning the samples at 650℃ for 1h.

1.2.4 Organic carbon

The content of organic carbon (OC) in refuse was evaluated based on the assumption that it is around 47% of the volatile solid.

2 Results and discussions

2.1 Variation of composition in refuse with refuse age

Table 1 shows the particle distribution of the excavated refuse at SRL. The proportions of finer fractions increase as the age of refuse at the landfill increases. Meanwhile, the longer refuse age, the slighter smell. Strong odor and leachate generate from the refuse with an age of lower 2 – 3 years. Refuse with an age of 10 years of placement can be dried naturally at ambient temperature and no leachate would be observed to generate. Around 45% of the excavated refuse with 10 years old may be used for the feed materials of the biofilter, in which nearly all the plastics, larger stone, glass, etc, are absent.

2.2 Chemical properties and stabilization of refuse

It is shown in Tables 2 and 3 that moisture in refuse is always higher than that in soil and quite consistent at different age (from 30% to 36%). BDM in refuse is much higher than that in the soil, indicating that the refuse has not fully aged (Table 3).

Table 2 Comparison of chemical composition of the refuse with different age (in weight percent, dry basis) and top cover soil

Refuse age, years	2	4	6	8	10
Refuse					
Moisture, %	31	30	31	33	36
Cd, ppm	10.7	1.1	2.7	6.6	5.6
Cr, ppm	120.6	73.5	174.6	252.1	169.3
Pb, ppm	171.3	134.2	141.0	372.2	77.9
The soil used as top cover materials (0 – 15 cm)					
Moisture, %	13.5	12.1	17.3	13.7	14.8
BDM, %	2.997	2.585	2.025	3.513	3.676

Heavy metal contents in refuse vary with refuse age, but always much higher than those in the soil (Tables 2 and 3). For the contents in soil for specific metal, the deeper towards the refuse mass, the higher contents. Among these metals, zinc contents are the highest. Those phenomena explain why a refuse landfill would be impossible for agricultural uses, especially uses for crop plantation. Analysis of heavy metals contents in the crops such as peanut and water melon tentatively planted on the 60 cm top soil in the 10 years landfill compartments shows that mercury is far higher than the EU standard for human uses.

Contents of BDM in the refuse placed in 1991, 1992, 1993 and 1994 are shown in Fig.1. The data seem to fluctuate with refuse age. Nevertheless, the parameters apparently decline in general as refuse age extends. It is easy to get an appropriate equation from BDM dependence on refuse age (Fig.1) as

$$\text{BDM (wt \%)} = -2.2623\ln(t, \text{day}) + 25.394.$$

Table 3 Contents of heavy metals in the top soil with different depth at the 10-years placement compartments

Depth of the soil from top, cm	Metals	Content of sample 1, ppm	Contents of sample 2, ppm
0 – 15	Cd	0.030	0.010
	Cu	19.377	21.500
	Pb	12.118	12.888
	Zn	69.658	68.939
15 – 30	Cd	0.031	0.031
	Cu	23.974	23.350
	Pb	16.024	13.872
	Zn	82.994	76.895
> 30	Cd	0.320	0.901
	Cu	166.260	327.845
	Pb	79.627	134.238
	Zn	537.617	885.933

The average value of BDM in soil in Table 2 is 2.26%. Supposing that BDM in refuse would approach to that in soil when refuse is fully stabilized, then

$$2.76 = -2.2623\ln(t, \text{day}) + 25.394,$$

$$t = 22026 \text{ days (60 years)}.$$

Though it is just a rough evaluation, the result simply imply that it would take long time for refuse to fully be aged and stabilized.

The dependence of total nitrogen and total phosphorus in refuse and cover soil sample at the same location on the refuse age is given in Fig. 2. Contents of total nitrogen regularly decrease as refuse age extends while those of total phosphorus slightly fluctuate with time. The average value of TN in soil is 0.66. The linear equation of TN with time in refuse is obtained as

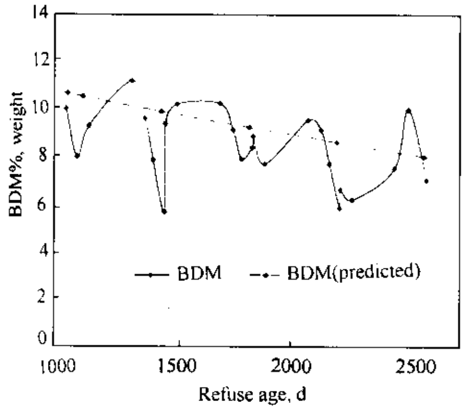

Fig.1 BDM contents in refuse excavated in the closed landfill compartments of Shanghai Refuse Landfill

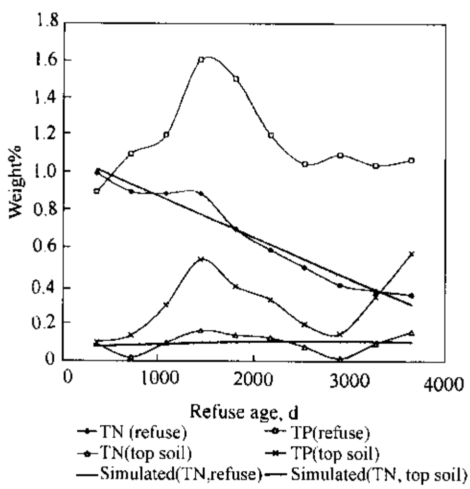

Fig.2 Comparison of total N and total P contents in refuse and top cover soil

$$TN\ (refuse) = -0.0002t + 1.098,\ R^2 = 0.9566$$

let TN (refuse) = 0.66

then t = 8790 days (24 years).

Disparity is obvious for evaluation of stabilization time of refuse based on the comparison of TN and BDM in refuse with those in cover soil. Nevertheless, it may be considered that long time would be taken for refuse in landfill to reach full stability and mineralization. In our previous work it has been found that around 23 – 30 years of stabilization may be needed for Shanghai Refuse Landfill based on leachate attenuation and settlement dependence on refuse time (Zhao, 1999; 2000; Zhu, 1996).

2.3 Practical significance of aged refuse excavation

After the refuse in the closed landfill compartments is excavated, fresh refuse can be re-placed in the emptied space. Nevertheless, the economy of this practice depends on the refuse age, i.e., mineralization state of refuse. Big articles such as stone, brick can not be reused and should be certainly re-placed. From Table 5 it can be seen that more space will be available for fresh refuse placement in landfill compartments with longer refuse age. In general, bigger articles will have to be re-placed into the original compartments and all the finer fractions can be recycled effectively. In this case, around 57% of initial space can be used for placement of fresh refuse in a 10 years old landfill compartment, while this percentage decreases to 20% in a 4 years old landfill compartment.

From Table 1 it can be also seen that the plastic and glass contents in refuse in the 10 years old landfill compartments are 4.19% and 0.81% respectively. So far around 8 million tons of refuse has been placed in the landfill. According to our previous research, around 80% of refuse would become decomposed residues and the other fractions become leachate and gases, when refuse is stabilized to a great extent after 20 years of placement. Hence, there would be some 6.4 millions of refuse residues that would remain in the landfill in the future. This quantity will certainly increase year by year. That means some 0.26 million tons of plastic, 51840 tons of glass and 3.2 million tons of finer fractions of compost that could be recovered, when these refuse is excavated after full stabilization. Shanghai Refuse Landfill is planning such an ambitious practice.

Table 5 Space available after excavation of aged refuse

Refuse age, years	Space needed for the re-placement of the non-recoverable materials v, %	Space available for re-placement of fresh refuse v, %
10	42.60	57.40
8	43.87	56.13
6	49.93	50.07
4	79.02	20.98
2	82.10	17.90

Perhaps stabilization process is different in different regions and locations of landfills. According to this study, around 8-10 years of placement may be sufficient to make the refuse fully be mineralized, at least suitable for use as feed materials of biofilter described in this paper, in Shanghai Refuse Landfill. In dry and cold area in northern China, the stabilization time for refuse in landfill is much longer.

3 Conclusions

Mineralization degree of refuse placed in Shanghai Refuse Landfill was characterized. Longer placement time will lead to availability of a greater fraction of fine materials and recoverable wastes such as plastic and bottles. Refuse is considered to be stabilized to a remarkable extent after 8 - 10 years of placement.

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(Received for review June 25, 2001. Accepted August 20, 2001)