EFFECT OF LANDFILL OPERATIONS ON THE QUALITY OF MUNICIPAL SOLID WASTE LEACHATE

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SUMMARY: The change in leachate quantity and characteristics during landfill development is examined with respect to data from a large Ontario (Canada) landfill. The data suggests that when fresh waste lifts are placed on older waste, the older waste acts as a bioreactor with respect to the fresh waste leachate. The attenuation effect on both leachate volume and quality through older waste shown by other researchers in lysimeter tests appears to be relevant to this large active landfill site. These results suggest that planned waste placement and fluid addition (natural or irrigation) may play major roles in the treatment of leachate before removal from the landfill and hence reduction of the landfill contaminating lifespan.

1. INTRODUCTION

A natural result of landfilling is the production of leachate, containing contaminants from the decomposing waste. Fluid addition and waste filling procedures are the two parameters influencing leachate quantity and quality over which landfill operators have some control. Natural fluid addition may be increased or reduced by cover design and the selection of various types of intermediate and final cover materials. Natural fluid addition may be augmented by irrigation or leachate recycling. Waste filling operations allow control over the degree of waste compaction, precomposting, sorting, filling location, and daily or intermediate cover construction. In the present case, the factors that will be considered are precipitation and the location of waste filling operations relative to the leachate sampling point.

2. FACTORS AFFECTING LEACHATE CHARACTERISTICS

Leachate characteristics depend upon several factors including: waste composition; age of waste; degree of compaction; decomposition phase; waste filling procedures; waste moisture content; rate of water movement; and temperature (Qasim & Chiang, 1994).

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2.1 Solid Waste Decomposition and Age of Waste

It is well recognized that there are three general phases of waste decomposition (McBean et al., 1995; Qasim & Chiang, 1994). The aerobic phase immediately after waste placement is dominated by aerobic bacteria present in the waste at placement. During this phase the amount of leachate reaching the base of the landfill (i.e. reaching the collection system) is limited since the waste has not yet reached field capacity and much of the water infiltrating the waste is taken up by the waste, which serves to increase the water content of the waste.

After oxygen has been depleted, facultative anaerobes tend to dominate the decomposition process (McBean et al., 1995; Qasim & Chiang, 1994). This phase that is marked by high concentrations of volatile fatty acids (VFA's) and high biochemical and chemical oxygen demand (BOD and COD). The pH is typically reported to be between pH 5 and 6 (Farquhar 1989). Typically this phase occurs up to five years after waste placement (Farquhar, 1989).

The third phase of decomposition occurs when anaerobic methanogenic bacteria become dominant (McBean et al., 1994). The consumption of VFA's, produced during the acid anaerobic phase, increases the pH to between pH 7 and 8 (Farquhar, 1989), and reduces the BOD/COD ratio. The early methanogenic phase typically falls within five to ten years after waste placement (Farquhar, 1989).

2.2 Fluid Addition

The rate of fluid addition (infiltration) is dependant on several factors including but not limited to: rate of precipitation; presence of landfill cover; type materials used in landfill cover; fluid losses due to runoff, evapotranspiration and storage (Qasim & Chiang, 1994). The rate of infiltration affects initial production of leachate, rate of leachate generated, and the rate of decomposition within the waste. The rate of waste decomposition is partially dependant on the water moisture content and infiltration rate (Palmisano & Barlaz, 1995; Qasim & Chiang, 1994). For example, a study of fluid addition within experimental landfill cells (Blakey et al., 1997) showed that increasing the rate of fluid addition decreased the time to initial leachate production and increased the rate at which organic material was consumed within the waste.

2.3 Landfill Operations

Waste is landfilled over a period of time that may last as long as 20 years or more. Considering the decomposition processes with respect to time, it is expected that separate cells of the same landfill will be at different stages of decomposition. Typical landfill operations have waste placed and compacted in lifts typically of between 2 – 5 m thick (McBean et al., 1995). As operations continue, new lifts of waste are placed upon existing waste that may be well along in its decomposition. Ham & Bookter (1982) studied the effect of placing a second lift (1.2m thick) of MSW upon an initial lift (1.2 m thick) that had decomposed over several years. Two lysimeter cells (Cell 3 and Cell 4) were constructed for this portion of the study. Cell 3 had a soil cover over the initial waste lift, while Cell 4 was left uncovered. The initial lift of waste generated a peak COD of about 30,000 mg/L, in both Cell 3 and 4, after approximately 4 to 5 months of operation, which corresponded to the regular production of significant amounts of leachate. After leachate COD had remained steady for a significant period of time (approximately 3 years), an additional 100 tonnes of waste (1.2 m thick) was placed on top of the initial lift. In Cell 3, the second waste lift was placed directly on the cover over the first lift and then the second lift was covered as well. The second lift in Cell 4 was placed directly over the first lift and it was left uncovered. Six months after the second waste lift placement, COD rose sharply in Cell 4 (to approximately 15,000 mg/L) but Cell 3 did not, which suggests that the intermediate (Lift 1) soil cover played a role in leachate attenuation. Cell 4's second COD peak was about half of the original peak, and this suggests that the lower lift served to "treat" the leachate generated by the second lift before it was collected.

3. CASE STUDY

The landfill being examined is located near Toronto, Canada and covers an area of 99 hectares. It has a design capacity of approximately 33,000,000 m^3 and has been developed in four stages, with Stage 1 commencing operation 1983. At the present time, the landfill is still in operation, thus the leachate is produced from waste of different ages (up to 15 years old). The leachate generated has been monitored on a regular basis since landfilling began.

3.1 Leachate Characteristics

Figure 1 shows the leachate COD, calcium, chloride and pH plotted against time. The data shows considerable scatter that is characteristic of landfill leachate data (Rowe, 1995; Ham & Bookter, 1982). The COD and calcium concentrations seem to be proportional to one another (i.e. when COD increases calcium also increases). This trend is correlated to the change in pH with time, especially during 1994 –1995 when the pH peaked at about 8 and the COD and Ca dropped to 1,500 and 100 mg/L respectively. At this time the leachate characteristics are similar to that expected of older waste/leachate (Farquhar, 1989). The increase in COD and calcium, and drop in pH in 1995 suggest that leachate from younger waste had augmented the leachate being collected. The chloride concentration varies but not in a manner that can be easily correlated with COD or calcium concentration. For example all three (COD, Ca^{2+}, and Cl^-) are high in late 1991 but in mid to late 1994 chloride is at a peak while COD and calcium are low.

The mean annual leachate parameters from 1983 to 1997 are summarised in Table 1. The values for the parameters listed have generally increased with time but not monotonically (Rowe, 1995). It appears that the BOD, COD and sulphate reached peak values in 1996, while chloride was at its highest point in 1997 (and may still be rising). The calcium concentration peaked in 1991, and has decreased subsequently although high values were evident in 1992 and 1996. There has been a gradual increase in leachate pH (from 6.1 to 7.1) between 1992 and 1997. Both TKN and NH_3 continue to rise in 1997, suggesting that degradation processes are producing organic nitrogen and ammonia in solution. The BOD/COD ratio is a measure of the degradability of the organic contaminants within the leachate. Research has shown that the BOD/COD ratio tends to decrease with age (Qasim & Chiang, 1994). Here the BOD/COD ratio has typically ranged between 0.5 and 1.0, with an average of 0.67 and no clear trend although it might be argued that it is decreasing from a peak of 0.78 in 1993 to about 0.6 in 1997. The BOD/COD ratio and pH indicate that after 14 years of operation the leachate mix (which includes leachate from different parts of the landfill developed at different times) is acetogenic (Rowe, 1995). The COD/DOC ratio tends to decrease as waste ages and the lower ratio is said to represent a more oxidised state of organic carbon that is less readily available as a energy source (Qasim & Chiang, 1994). The COD/DOC ratio remains relatively constant between 3 and 4 with no decreasing trend. This suggests that continuing waste filling operations are providing sources of reduced carbon available for microbial growth. The SO_4/Cl ratio appears to peak in 1996 which indicates that younger waste may be increasing the sulphate concentration. These results suggest between 1994 and 1997 leachate from young waste had augmenting the leachate from older waste.

Table 1: Annual Leachate Parameters

	Year (Years of Operation)													
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
(mg/L)*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
BOD[1]		10,064	7,151			8,587	4,711		9,273	11,845	3,042	2,851	12,141	7,777
COD[1]	9,387	9,814	15,127	8,960	6,519	13,857	8,507	15,635	11,948	15,922	5,226	4,449	17,795	12,971
DOC[1]	2,358	2,178	4,125	2,862	2,610	4,580	2,772	5,129	4,014	5,084	1,886	1,536	5,882	4,353
TKN[1]	21	26	39	187	33	300	164	183	266	609	622	357	1,047	1,087
NH_3 as N[1]	90	131	241	149	159	265	120	161	225	501	546	305	945	952
Calcium[1]	989	1,030	1,521	985	737	1,379	934	1,539	1,239	969	327	399	1,263	588
Chloride[1]	487	573	982	489	857	1,598	1,339	1,800	1,251	2,205	2,376	1,211	2,556	2,979
Sulphate[1]				9		9			1	2	8	11	207	148
pH[2]	6.3	6.0	5.8	6.1	6.5	6.1	6.3	6.3	6.1	6.5	7.4	7.1	6.9	7.1
BOD/COD	-	1.03	0.47	-	-	0.62	0.55	-	0.78	0.74	0.58	0.64	0.68	0.60
COD/DOC	3.98	4.51	3.67	3.13	2.50	3.03	3.07	3.05	2.98	3.13	2.77	2.90	3.03	2.98
SO_4/Cl	-	-	-	0.019	-	0.006	-	-	0.001	0.001	0.003	0.009	0.081	0.050
Max. Data Points	3	7	7	6	9	10	14	12	12	13	11	12	11	13
Min. Data Points	2	3	3	3	7	3	14	12	3	3	3	3	11	13
Leachate Collected[3]									53,291	123,975	31,069[4]	154,819	19,503[5]	66,314[6]
Recirculated Fluid[3]									124,096	22,201	0	0	0	0

* except pH, BOD/COD, and SO_4/Cl; [1] geometric mean; [2] arithmetic mean; [3] cubic metres per annum (m^3/a); [4] flow after drop in precipitation and discontinuing fluid recirculation operations; [5] October to December 1996; [6] January to September 1997.

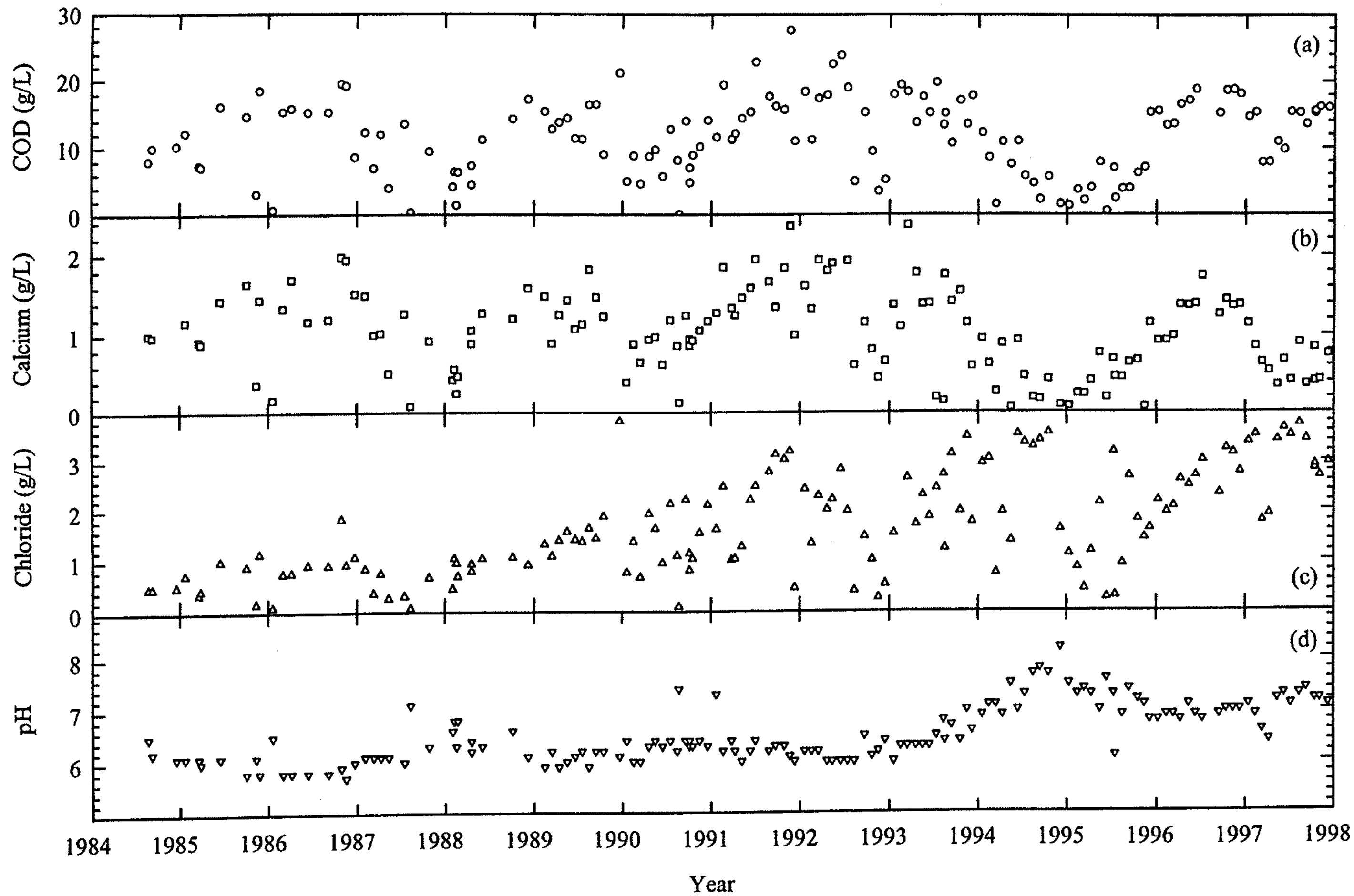

Figure 1. Leachate characteristics with respect to time, (a) COD, (b) Calcium, (c) Chloride, and (d) pH.

3.2 Waste Placement

This landfill was constructed in stages beginning with Stage 1 in 1983. Construction of the liner proceeded in a southern direction towards the southern limit of the landfill footprint, and the leachate pumping station, with the final sections of Stages 3 and 4 being completed in 1994. Waste filling operations continued in Stages 1 and 2, and the northern portions of Stages 3 and 4, while engineered barrier was constructed. To monitor the waste filling operations, the landfill is subdivided into a grid consisting of 117 cells (typical size is 100 x 100 m or 1 hectare). The grid is orientated on the north compass heading with the grid cells numbered from west to east, north to south. The cells in which landfilling has occurred on a given day are recorded daily by landfill staff. The horizontal drainage distance from the cell where waste was placed on a given day to the leachate pumping station (measured along the leachate collection system drainage path to the leachate pumping station) was calculated for each cell. From this data the most frequently filled cell was evaluated on a weekly basis and the resulting horizontal drainage distance is plotted with respect to time in Figure 2.

The rapid drop in COD and calcium in 1994 and the subsequent increase in 1995 does not fit with overall leachate quality trends shown in Figure 1 and Table 1. To try and explain this, consider Figure 2a, which shows how the horizontal drainage distance from the working face to the leachate pumping station with respect to time. In late summer and early fall of 1993, filling operations were principally occurring within 200 to 400 m of the leachate pumping station (the southern most portions of stages 3 and 4) where construction of that year's liner had been completed. Filling proceeded north away from the pumping station until late fall 1994 when filling was occurring stages 1 and 2 (1,100 – 1,300 m from the pumping station) as waste lifts were placed upon older waste (up to 10 years old). Coincident with the shift in waste placement position, the total precipitation (Figure 2b) falling on site dropped between 1992 and 1994 (977 mm to 759 mm). Fluid recirculation operations were discontinued in early 1993. Subsequently, the leachate generated dropped from 30,000 m^3/month in January 1993 to a minimum of 890 m^3/month in May 1994.

The effect on the leachate composition is threefold. First, the waste placed in stages 1 and 2 during 1994 was on top of older waste, with a depth of between 30 to 40 m. Leachate generated by this new waste lift would percolate through the older waste, which has an established microbial population that effectively attenuates the increased leachate strength associated with young waste (Palmisano & Barlaz, 1995; Ham & Bookter, 1982; Farquhar, 1989). Secondly, the decrease in total precipitation between 1992 and 1994 increased the length of time required for fresh waste to reach field capacity. Discontinuing fluid recirculation operations in 1993 also reduced the volume of fluid addition to the landfill, which also increased the time to field capacity. These two variables increased the length of time for initial leachate production. Thus, the fresh waste placed in the southern most portions of Stages 3 and 4 in late 1993 appears to have had little affect on the COD or calcium concentrations and pH during 1994. The leachate collected at this time is more representative of the leachate generated from the "older" waste.

4. CONCLUSIONS

Leachate composition data from this landfill demonstrates several trends and shows the variability expected of MSW leachate. The leachate characteristics are generally consistent when compared to other published leachate data. The COD and calcium concentrations tend to be proportional, and inversely proportional to leachate pH. The variation in chloride

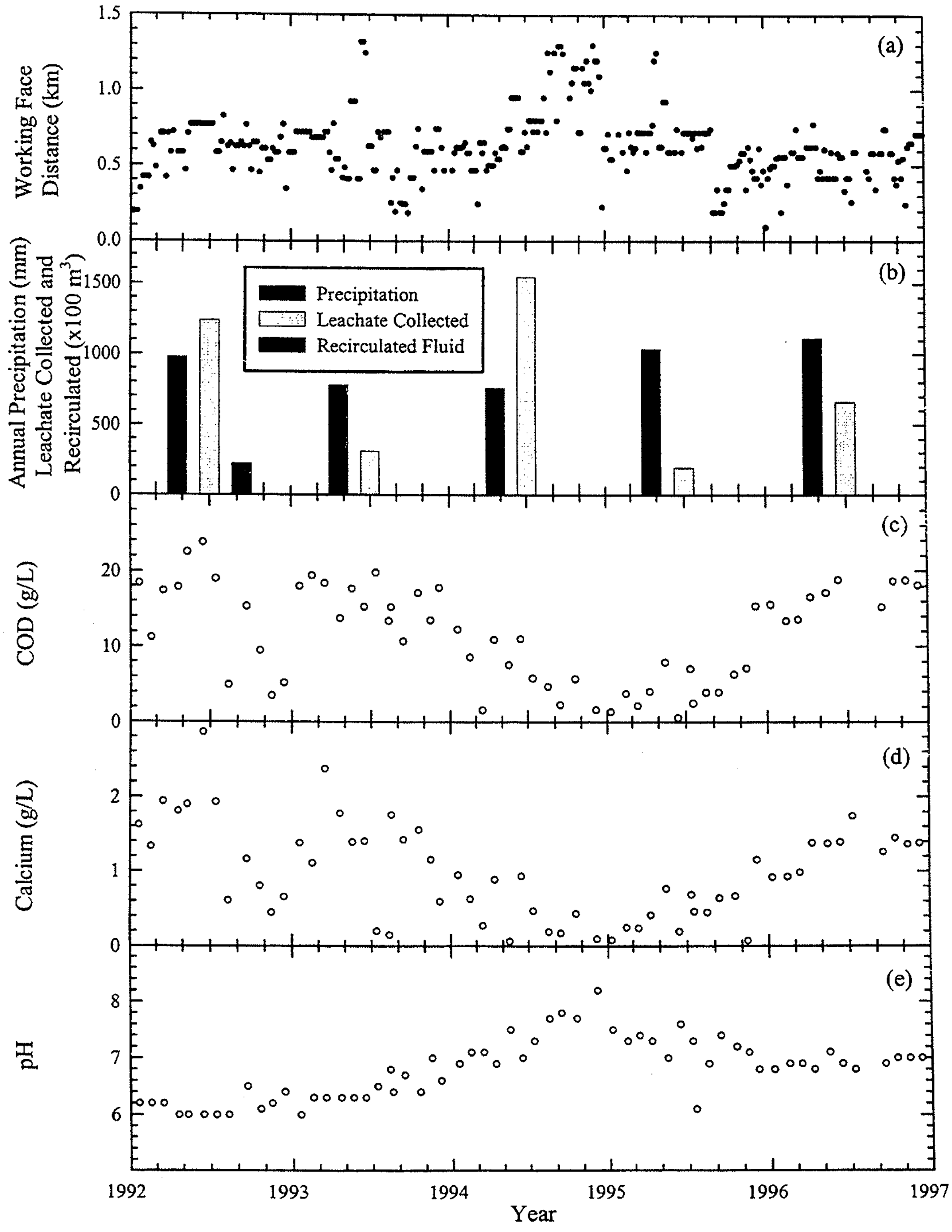

Figure 2. Waste filling position, precipitation data, leachate generation, and leachate characteristics with respect to time, (a) distance of working face from leachate pumping station, (b) annual precipitation, volume of leachate collected, and volume of fluid recirculated, (c) COD, (d) calcium, and (e) pH.

concentration does not appear to correlate well with other leachate parameters (e.g. COD, calcium, and pH), and may still be increasing after 14 years of operation.

An examination of the data demonstrates the effect of waste placement and total precipitation on the composition of the leachate produced. The data suggests that when fresh waste lifts are placed on older waste, the older waste acts as a bioreactor that seems to "treat" the leachate generated by the newer waste. Thus the effect of leachate percolation through older waste shown by Ham & Bookter (1982) in a relatively small cell appears to be relevant to this large landfill site. These results suggest that planned waste placement and fluid addition (natural or irrigation) can play major roles in the treatment of leachate before removal from the landfill and hence reduction of the landfill contaminating lifespan.

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