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# Project Summary

# Retrospective Evaluation of the Effects of Selected Industrial Wastes on Municipal Solid Waste Stabilization in Simulated Landfills

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**This project presents a retrospective evaluation of a 10-year study on the codisposal of municipal solid waste (MSW) with selected wastes in 19 simulated landfill cells. The objective of the study was to determine the effects of additions of water, sewage sludge, buffer and industrial wastes on the progress of MSW stabilization by evaluation of leachate and gas characteristics with time. Differences between the results from most of the landfill cells were influenced by repeated operational exposure to air during leachate removal and moisture addition. However, those cells which were operated in a fashion most conducive to anaerobic methanogenesis eventually produced the highest quantities of gas and the least contaminated leachate. The overall results provide a basis for recommendations on future studies as well as design and operational strategies to maximize waste stabilization at landfill disposal sites.**

***This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

In November 1974, a study of 19 pilot-scale simulated landfill cells was initiated to evaluate the effect of selected operational variables upon the rate and ultimate degree of biologically mediated municipal solid waste (MSW) stabilization. Over a 10-year period, physical and chemical analyses on leachate and gas produced from each cell were obtained. The objective of the retrospective evaluation summarized here was to ascertain the effects of the addition of water, sewage, sludge, buffer, and industrial wastes to the MSW contained in each landfill cell

## Preliminary Considerations

Most landfills receiving MSW proceed through a series of rather predictable stabilization phases whose significance and longevity are largely determined by climatological conditions, operational variables, management options and control factors operative or being applied either internal or external to the landfill environment. These phases can be identified by certain leachate and gas analyses, selecting those parameters that best describe principal events contributing to the progress of stabilization during each phase. Moreover, to direct the choice of analyses to be used to describe a particular phase of stabilization, it is necessary to recognize that anaerobic conditions exist throughout much of the active life of a landfill. This active life normally extends over a period of years, during which time certain performance related and time dependent concepts become evident.

As with many anaerobic biological systems, landfills experience an initial lag or adjustment phase which lasts until sufficient moisture has accumulated to encourage the development of a viable microbial community. Thereafter, further manifestations of waste conversion and stabilization may be reflected by changes in leachate and gas quality as stabilization proceeds through several more or less discrete and sequential phases, each varying in intensity and longevity according to prevailing operational circumstances. Accordingly, five stabilization phases may be identified in terms of the principal events occurring during each phase:

| Phase | Principal Events |
|---|---|
| I. Initial Adjustment | Site closue, subsidence, incipient aerobic conditions |
| II. Transition | Initial leachate formation, change from aerobic to anaerobic conditions |
| III. Acid Formation | Active hydrolysis, acid fermentation, pH decrease |
| IV. Methane Fermentation | Production of $CH_4$ and $CO_2$, pH increase, nutrient consumption, metal complexation |
| V. Final Maturation | Relative dormancy, secondary fermentation, production of humic substances |

Phases III and IV are particularly significant; the latter Phase IV occurring when rapid biological stabilization (RBS) transforms intermediate products of hydrolysis and acid formation (Phase III) to $CH_4$ and $CO_2$. The facility of the associated indicator parameters to detect and describe the presence, intensity, and longevity of these phases is illustrated in Figure 1.

All of the principal events selected to describe and separate these stabilization phases are encountered at one time or another in landfills containing MSW, provided that the associated microbially mediated processes have been augmented by a sufficiency of moisture and nutrients and are not exposed to the inhibitory influences of toxic materials. However, the manifestations of these phases often overlap within the usual landfill setting, since no landfill has a single "age", but rather a family of different ages associated with the development of various sections or cells within the landfill complex and the progress of each toward stabilization. Moreover, the rate of progress through these phases may vary depending on the physical, chemical, and microbiological conditions developed within each section with time, and leachate and gas analyses often reflect the merging of conditions in each discrete section.

These concepts provided the basis for a separate interpretation of results from each of the 19 individual cells as well as a more specific comparison of groups of cells (e.g., indoor, outdoor water-only, and codisposal cells) in terms of the effects of operational variables on solid waste stabilization rates and the composition of leachates produced. In the latter analysis, comparisons are provided for peak, pre-RBS, and final concentrations of each monitoring parameter.

## Experimental Procedures

The 19 simulated landfill cells were constructed of 1.83-m diameter steel tubes, 3.6 m in height, and with an overall volume of 9.5 $m^3$. The sidewalls of the cells were coated with a coal-tar epoxy, and the bottoms were made water tight by fitting the cells with a Fiberglas liner. Each cell was placed on a concrete slab, filled to a height of 0.15 m with silica gravel, filled further with approximately 2.4 m (eight 0 3-m lifts) of MSW plus codisposal additives, and then by cover layers of 0.3-m silty clay and 0 3-m pea gravel. Gas probes were installed at three depths; two gas probes were placed above the second and sixth MSW lifts, and another in the upper pea gravel layer. Temperature probes were placed above the second, fourth, and sixth MSW lifts.

A water distribution ring placed in the upper pea gravel layer provided for the application of infiltration water, and individual pipes at the bottom of each cell and connected to a central well provided for the collection of leachate Four of the cells were housed indoors where maintenance of water and gas tight seals was facilitated, and temperatures were more conducive to enhanced anaerobic biological stabilization. All of the remaining cells were outdoors and underground.

The MSW was loaded to the cells in eight lifts. Codisposal additives were evenly distributed and placed atop each of the last seven lifts. Each lift was compacted after loading with a wrecking ball; densities of in-place MSW varied from 470 to 800 kg/$m^3$ with variations arising primarily from differences in the wet weight of the codisposal additive. The weight of MSW and codisposal additives placed in each cell are listed in Table 1 along with their respective moisture contents.

Two MSW samples were obtained from each of the eight lifts in each cell and characterized with respect to the percentage (wet weight) for the 10 waste categories indicated in Table 2. Samples from each separated category were then analyzed for a number of chemical parameters.

The six industrial waste additives selected for codisposal included petroleum refinery oil/water separator sludge, neutralized lead/acid battery waste sludge, electroplating (Cr, Ni, Cd, Cu, Fe, Zn) sludge, inorganic (titanium dioxide) pigment waste, mercury cell chlorine brine sludge, and solvent-based paint sludge

Leachate and gas samples were collected monthly just prior to moisture additions and analyzed for quantity and quality. Leachate samples were analyzed for COD, TOC, TKN, total phosphorus, total volatile acids, total solids, total alkalinity, pH, specific conductivity, and a number of metals including cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. Gas samples were removed from the cells by means of a vacuum pump and drawn into sampling burets from which a representative portion was obtained with a syringe for injection into a GC. Gas volumes were measured by collecting the gas in plastic bags and pumping the gases through a wet-test meter with a vacuum pump. Gas samples were analyzed for percent $CH_4$, $CO_2$, $N_2$ and $O_2$

## Results and Discussion

Interpretations of individual simulated landfill cell behavior were based upon organic indicators, pH, specific conductivity, and metals data. Of additional importance were temperature and moisture related parameters including infiltration volumes applied, leachate volumes collected, and the moisture retained by the waste mass.

The analyses of cell behavior also include pertinent information reported during cell unloading and final disposal operations. This analysis revealed that for most of the cells, much of the solid waste was loaded while still in intact plastic and

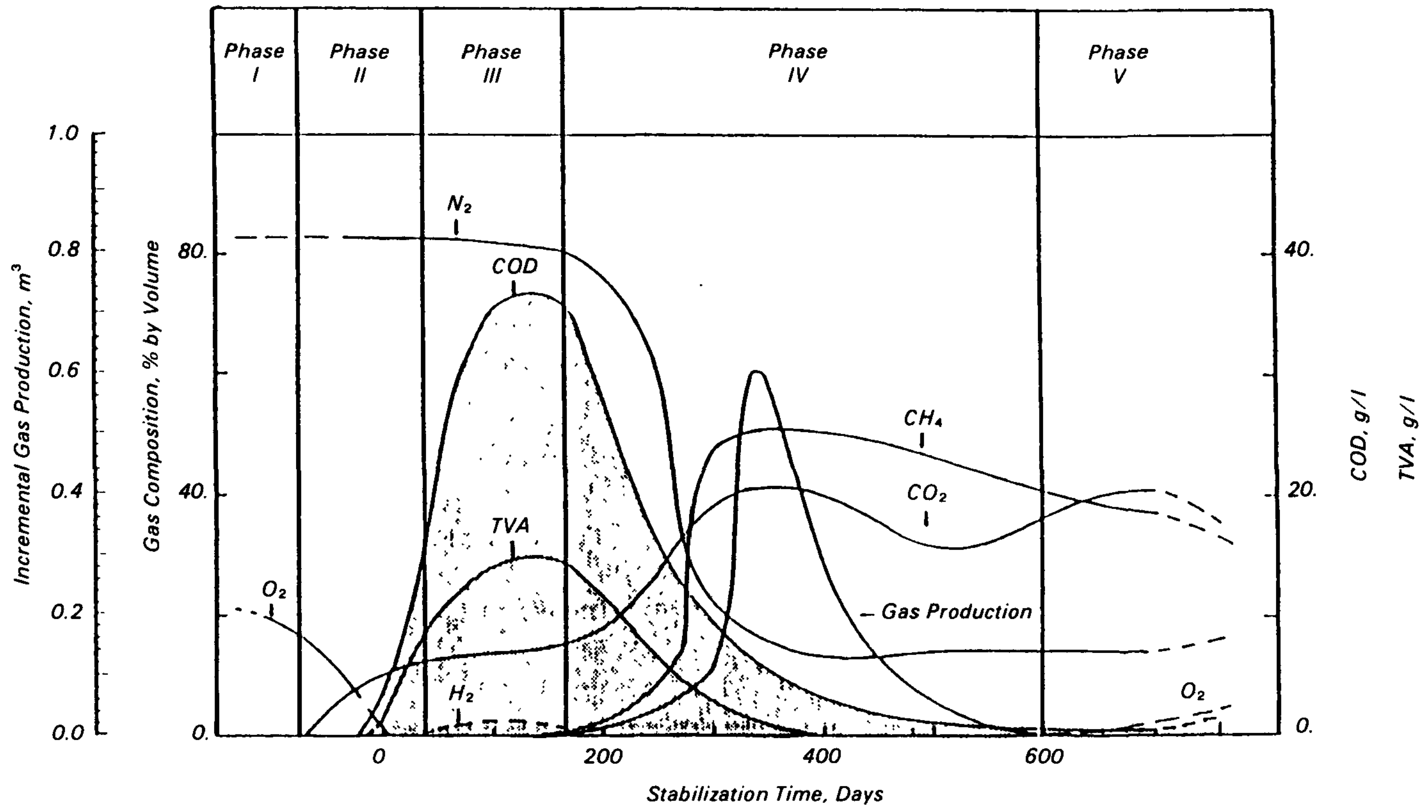


***Figure 1.*** *Changes in selected indicator parameters during the phases of landfill stabilization.*

paper bags. Therefore, much of the waste, including the garbage and vegetative matter, was protected and remained relatively unaltered even after 10 years residence in the test cells. Although the contents of the landfill cells appeared as a black, tar-like mass, many recognizable articles remained intact.

Some of the research objectives originally conceived for the research proved unattainable, primarily because of operational differences between sealed and vented cells which obscured the effects of the codisposal variables intended for study. In particular, the failure of gas seals and the intentional placement of gas vents atop some of the outdoor cells led to the regular introduction of air into most cells during leachate drainage and water addition operations. This prevented or delayed the establishment and maintenance of anaerobic conditions necessary for methanogenesis and rapid biological stabilization (RBS) and, thereby, retarded the stabilization of the waste mass and the associated reduction in leachate strength over time. Accordingly, the majority of change in leachate characteristics for many of the cells was caused by solubilization and washout of high concentrations of waste constituents. This transfer of waste constituents without biologically mediated stabilization is undesirable because it would result in greater leachate treatment requirements and potential for leachate migration and environmental impairment.

The indoor cells, which were kept more anaerobic and at warmer temperatures, stabilized fastest and, therefore, eventually produced the least quantities of leachate-transported contaminants. Conversely, the outdoor air-exposed cells took longer to approach or reach rapid biological stabilization (RBS) or methanogenesis and, therefore, produced higher quantities and more dramatic washout of leachate contaminants

## Conclusions

The importance of rapidly establishing and maintaining stable anaerobic biological conditions (i.e., RBS) was clearly illustrated by the results of this study. The cells which were operated in a fashion most conducive to methanogenesis produced the highest amounts of methane, while also yielding the most stabilized and lowest strength leachates The effects of the codisposal variables were directly manifested in the characteristics of the leachates produced in the absence of biological activity.

Simulated landfill cell design and operation were the major variables influencing the relative contributions of biological and physical waste stabilization mechanisms and the understanding of how they are affected by codisposed industrial wastes Since anaerobic biological activity was inhibited in many of the test cells, it was not possible from this study to clearly distinguish the effects of the codisposed wastes on

**Table 1.** *General Loading Characteristics of Municipal Solid Waste and Codisposal Additives Placed in the Test Cells*

| Test Cell Number | Type of Cell | Codisposal Additive | Codisposal Additive: Wet Weight, kg | Codisposal Additive: Moisture Content, % | Codisposal Additive: Dry Weight, kg | MSW: Wet Weight, kg | MSW: Moisture Content, % | MSW: Dry Weight, kg |
|---|---|---|---|---|---|---|---|---|
| 1 | OS | Water, 200 mm/yr | - | - | - | 3025 | 38.2 | 1870 |
| 2 | OS | Water, 400 mm/yr | - | - | - | 2989 | 38.2 | 1847 |
| 3 | OS | Water, 600 mm/yr | - | - | - | 3007 | 38.2 | 1858 |
| 4 | OS | Water, 800 mm/yr | - | - | - | 3002 | 38.2 | 1855 |
| 5 | OS | Sewage Sludge | 68 | 88.8 | 8 | 3001 | 38.2 | 1855 |
| 6 | OS | Sewage Sludge | 204 | 88.0 | 24 | 2919 | 38.2 | 1804 |
| 7 | OS | Sewage Sludge | 680 | 88.0 | 82 | 2964 | 38.2 | 1832 |
| 8 | OV | Calcium Carbonate | 91 | 10.0 | 82 | 2994 | 38.2 | 1850 |
| 9* | OV | Petroleum Sludge | 1518 | 79.0 | 319 | 3001 | 30.4 | 2089 |
| 10* | OV | Battery Waste Sludge | 1291 | 89.3 | 138 | 2998 | 30.4 | 2087 |
| 11 | OS | Prewetting Water | 1293 | 100.0 | 0 | 2924 | 38.2 | 1807 |
| 12 | OV | Electroplating Sludge | 1190 | 79.5 | 244 | 3048 | 38.2 | 1883 |
| 13 | OV | Inorganic Pigment Waste | 1421 | 51.7 | 686 | 3006 | 38.2 | 1858 |
| 14 | OV | Chlorine Brine Sludge | 2039 | 24.1 | 492 | 3015 | 38.2 | 1863 |
| 15* | OV | Polio Virus | - | - | - | 3010 | 30.4 | 2041 |
| 16 | IS | Water, 400 mm/yr | - | - | - | 2996 | 38.2 | 1852 |
| 17 | IS | Solvent-Based Paint Sludge | 1604 | 24.7 | 1208 | 2998 | 38.2 | 1853 |
| 18* | IS | Water, 400 mm/yr | - | - | - | 3000 | 30.4 | 2088 |
| 19* | IS | Water, 400 mm/yr | - | - | - | 3012 | 30.4 | 2096 |

*OS = outdoor, initially sealed.*
*OV = outdoor with vented or poorly fitted top.*
*IS = well sealed indoor.*
** Cells were loaded April 1975, all others in November 1974.*

biological degradation patterns Nor was it possible to provide a clear indication of the leachate characteristics expected from the codisposal cells under conditions more favorable to methanogenesis, where leachate organic strength is drastically reduced by conversion to methane and carbon dioxide, and metals are more successfully attenuated by increased levels of sulfides and other precipitation mechanisms prevalent at more neutral pH values. Therefore, determination of acceptable codisposal loadings in terms of attenuation and absence of inhibition could not be made.

Since the potential influences of the industrial wastes on biological activity were obscured by operational practices detrimental to methanogenesis, most of the apparent waste mass "conversion" in the outdoor industrial waste cells was by washout. On the other hand, the results from the indoor cells serve to demonstrate the benefits of enhanced biological activity toward reducing potential environmental impact associated with leachate migration and ultimate leachate treatment and disposal costs, and improving the recovery of energy as biogas. The simulated landfill cells which attained rapid biological stabilization (RBS) most quickly produced less than half the quantities of leachate organic contaminants than did cells which did not reach RBS

## Recommendations

To minimize the quantities of organic and inorganic contaminants transported from the waste mass via leachate, emphasis should be placed on promoting anaerobic biological activity in MSW and codisposal landfills. This would involve efforts to provide anaerobic conditions, temperature insulation, a sufficient and uniform moisture environment, and the minimization of isolation or restricting layers which protect wastes from microbial and moisture contact

To promote anaerobic conditions, landfills should be designed to be as contained and aa homogeneous as possible, with the development of individual cells and the selection and maintenance of the containment system receiving particular attention In addition, MSW placement should be scheduled such that this process is enhanced in each landfill.

Since the results from this study did not conclusively reveal the expected influences of codisposed industrial wastes, sewage sludge, and buffer, additional studies are recommended to more fully elucidate the potential effects of these variables. Any future studies should be undertaken using well controlled landfill cells operated in a fashion conducive to promoting rapid biological stabilization (RBS), so that the effects of industrial waste loadings on biologically mediated MSW stabilization and the associated attenuation capacity for these loadings can be established.

In light of the Resource Conservation and Recovery Act Amendments leading to the banning of liquids and hazardous wastes from landfills, and the shortage of approved hazardous waste land disposal sites, the industrial wastes chosen for additional codisposal studies should be selected in cognizance of both the total production quantities of these wastes as well as the quantities which may permit safe disposal in MSW landfills

**Table 2.** *Compositional Analyses of Municipal Solid Waste Placed in Each of the Nineteen Test Cells*

| Test Cell Number | Loading Variable | Waste Component, % by wet weight: Paper | Garden Wastes | Metals | Food | Glass | Plastics, Rubber, Leather, Textiles | Fines | Ash, Rock, Dirt | Diapers | Wood |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Water, 200 mm/yr | 37.1 | 13.8 | 12.2 | 9.5 | 9.3 | 11.2 | 4.0 | 3.3 | 2.5 | 1.4 |
| 2 | Water, 400 mm/yr | 41.5 | 21.5 | 8.5 | 6.3 | 9.9 | 9.9 | 3.5 | 3.3 | 1.2 | 2.2 |
| 3 | Water, 600 mm/yr | 36.5 | 25.9 | 8.1 | 6.1 | 9.4 | 6.7 | 3.0 | 3.5 | 1.5 | 1.4 |
| 4 | Water, 800 mm/yr | 37.8 | 22.6 | 5.9 | 5.9 | 8.8 | 10.5 | 3.5 | 1.4 | 3.2 | 2.0 |
| 5 | Sewage Sludge | 41.2 | 16.6 | 8.0 | 11.3 | 7.1 | 14.9 | 2.9 | 1.6 | 1.8 | 1.1 |
| 6 | Sewage Sludge | 34.9 | 30.2 | 8.6 | 11.0 | 5.9 | 11.6 | 2.4 | 3.4 | 2.3 | 0.3 |
| 7 | Sewage Sludge | 43.6 | 20.3 | 9.0 | 5.3 | 6.4 | 9.8 | 2.8 | 2.9 | 2.4 | 1.7 |
| 8 | Calcium Carbonate | 53.1 | 11.1 | 5.8 | 6.6 | 6.4 | 12.2 | 1.7 | 1.6 | 1.6 | 1.1 |
| 9 | Petroleum Sludge | 41.3 | 17.0 | 8.9 | 7.6 | 5.3 | 14.0 | 2.1 | 2.8 | 0.9 | 1.9 |
| 10 | Battery Waste Sludge | 44.0 | 8.2 | 8.8 | 11.2 | 7.2 | 10.1 | 3.3 | 4.7 | 2.9 | 4.4 |
| 11 | Prewetting Water | 39.8 | 16.2 | 8.4 | 8.7 | 9.0 | 11.1 | 3.4 | 2.0 | 2.4 | 1.6 |
| 12 | Electroplating Sludge | 46.5 | 9.5 | 7.7 | 8.2 | 8.8 | 8.0 | 4.2 | 6.1 | 1.5 | 1.2 |
| 13 | Inorganic Pigment Waste | 39.1 | 20.7 | 8.3 | 6.3 | 7.8 | 10.1 | 2.9 | 1.8 | 3.7 | 1.4 |
| 14 | Chlorine Brine Sludge | 37.1 | 11.1 | 9.9 | 9.0 | 8.2 | 12.4 | 4.1 | 4.1 | 4.8 | 1.5 |
| 16 | Water, 400 mm/yr | 41.8 | 16.3 | 8.9 | 7.3 | 6.0 | 13.9 | 2.8 | 1.3 | 2.7 | 0.8 |
| 17 | Solvent-Based Paint Sludge | 45.7 | 15.6 | 7.7 | 6.0 | 6.6 | 11.3 | 2.8 | 2.7 | 1.6 | 1.4 |
| 18 | Water, 400 mm/yr | 48.3 | 9.8 | 9.3 | 6.2 | 8.4 | 9.4 | 3.4 | 3.0 | 2.9 | 3.9 |
| 19 | Water, 400 mm/yr | 43.2 | 11.9 | 7.4 | 8.5 | 10.0 | 10.2 | 3.6 | 1.9 | 3.0 | 1.9 |
| | Mean* | 41.8 | 16.6 | 8.4 | 7.9 | 7.8 | 11.1 | 3.1 | 2.9 | 2.4 | 1.7 |
| | Standard Deviation | 4.6 | 6.0 | 1.4 | 1.9 | 1.5 | 1.8 | 0.7 | 1.3 | 1.0 | 1.0 |

* The mean is based on 18 rather than 19 cells since the Compositional Analysis for Cell No. 15 was not available

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*The complete report, entitled "Retrospective Evaluation of the Effects of Selected Industrial Wastes on Municipal Solid Waste Stabilization in Simulated Landfills," (Order No. PB 87-198 701/AS; Cost: $24.95, subject to change) will be available only from:*
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