MUNICIPAL LANDFILL BIODEGRADATION AND SETTLEMENT[a]

Discussion by G. L. Sivakumar Babu[3] and Patrick J. Fox[4]

Prediction of municipal solid waste (MSW) landfill settlement remains one of the challenging problems associated with closure of such facilities. The authors have presented the results of a laboratory study aimed at explaining the mechanisms of landfill settlement, especially with regard to the relationship to waste biodegradation. The discussers wish to comment on the authors' findings and present some of their views on this challenging problem.

Fundamentally, landfill settlement results from mechanical compression and compression due to biodegradation, each of which is temperature dependent. Recent studies have illustrated the important influence of temperature on settlement of peats and organic soils (Fox 1992; Edil and Fox 1994). To fully understand the compression of MSW, the contribution of each component to total settlement must be isolated. In the authors' study, the bioreactor cells and dry vault cells were maintained at different temperatures, 25 and 4°C, respectively. This temperature differential may have had an important effect on the measured settlement parameters. The mechanical compression component of landfill settlement can be further subdivided into immediate settlement, primary consolidation, and secondary compression. The measurement of primary consolidation settlement must be necessarily accompanied by pore pressure measurements because the settlement curve itself may or may not reveal the end of pore pressure dissipation. It would be helpful if the authors would elaborate on how primary consolidation settlement was distinguished from immediate settlement in their study.

Similar to organic soils, the secondary compression of landfills occurs at high rate due to the characteristic low density of MSW. Comparison of case studies in the literature show that this settlement may or may not be linear with the logarithm of time. In any event, the coefficient of secondary compression, C_{ae} (using the authors' notation), can be expressed as

$$C_{ae} = -2.3t\frac{d\varepsilon}{dt} \qquad (10)$$

where ε = vertical strain; t = time; and $d\varepsilon/dt$ = strain rate. Eq. (10) illustrates that the value of C_{ae} depends on the current time t, which in turn depends on the choice of the origin of the time from which t is measured. Thus, although C_{ae} is an expedient tool for use in practice, it is not considered a fundamental settlement parameter. Instead, fundamental studies might focus on the relationship of strain rate to effective stress, temperature, strain, and biodegradation of solids. Some of the conflicting data in the literature with respect to the effect of biodegradation on secondary compression might be explained in part through characterization of these factors.

Edil et al. (1990) analyzed settlement data from MSW landfills in terms of the Gibson and Lo model and a power creep law. The results show that the power creep law, which considers the total deformation response with time, better represents the settlement of MSW landfills. Similar conclusions were reached by Lee et al. (1994). These studies suggest that the division of settlement into primary and secondary components may not be realistic for landfills. Thus, methods for landfill stabilization might be better evaluated by considering total settlement behavior. This will circumvent the difficulties associated with field conditions such as heterogenous content, unsaturated conditions, varying degrees of compaction and biodegradation, and other factors. The data of Merz and Stone (1962) presenting the total settlement behavior of landfill cells treated with different stabilization methods illustrate this point (Fig. 1).

The application of the biodigester concept with addition of moisture and recirculation of leachate may be a means to accelerate landfill stabilization. As indicated by the authors as well as Tchobanglous et al. (1993), landfill settlement rates are controlled by the presence of water and a number of decomposition reactions governing gas and leachate generation that vary with environmental conditions. More information on the mechanisms controlling the MSW settlement and the relationship between gas and leachate generation and settlement is currently needed. Until such information becomes available, reliable field data on landfill settlements will continue to be necessary for the development and verification of models for settlement prediction.

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[a] March 1995, Vol. 121, No. 3, by Dean K. Wall and Chris Zeiss (Paper 5191).

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UV PILOT TESTING: INTENSITY DISTRIBUTION AND HYDRODYNAMICS[a]

Discussion by Reza Iranpour,[4] Member, ASCE, and Bill Straub,[5] Member, ASCE

The purpose of the note, as stated at the end of the introduction, was "to illustrate the relative advantages of the large-scale approach in terms of intensity distributions and fluid-flow characteristics."

Accordingly, the authors calculated the intensity distributions around three low-pressure mercury arc lamps of different lengths. The authors found that the end-effects region, where intensity is below 95% of the peak for the lamp, is 20% of

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[a] March 1995, Vol. 121, No. 3, by Ernest R. Blatchley III, William L. Wood, and Peter Shuerch (Technical Note 5434).

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the length of a lamp with an arc length of 36 cm, but only 5% of the length of a 147 cm lamp.

The authors also measured fluid velocities at different depths in a channel that contained UV lamp assemblies. One set of measurements was made for lamps in the vertical configuration and another for horizontal configuration. The measurements for the vertical configuration showed a substantial velocity decrease near the bottom because of the boundary layer. Measurements for both configurations also showed that the bulk of the lamp assemblies is sufficient to rapidly establish plug flow when upstream velocity profiles are far from uniform.

Evidently, it is easier to scale pilot test results to a full-scale system if the pilot test is done on large enough scale that one can ignore boundary effects and end effects. The results on these effects provide a quantitative assessment of influences that would be expected from basic physics and past experience.

Although the authors made no effort to address costs, these must be considered in plans for a pilot test, and there are good reasons for believing that tests on the scale used by the authors could be greater than many small plants could afford. Perhaps even large plants would want to use smaller tests in an era of tight budgets.

The authors used a channel 61 cm (24 in.) wide, 152.4 cm (60 in.) deep, and 6.1 m (20 ft) long. For the vertical lamp test 80 lamps were used with a flow of 87.6 L/s (2 mgd), and for the horizontal test 64 lamps were used, and a flow of 70.1 L/s (1.6 mgd). For comparison, we note that a 1992 U.S. Environmental Protection Agency (USEPA) study of 30 plants in the United States mentions that 12 of the plants had peak flows less than or equal to 87.6 L/s (2 mgd), and 16 had average flows less or equal than 87.6 L/s (2 mgd) (USEPA 1992). (For 1.6 mgd the numbers are 11 and 14, respectively.) Thus, the authors' pilot test was equivalent to full-scale operation for these plants.

A recent plan for smaller-scale pilot tests of UV disinfection at three of the treatment plants of the Los Angeles Bureau of Sanitation (Research 1995) and similar studies (Fisher 1993; Brown 1993) includes estimates of lower costs than the tests of the authors. The Los Angeles tests would involve 12 lamps and a flow of 8.76 L/s (0.2 mgd) through 15.2 cm (6 in.) by 22.8 (9 in.) stainless-steel channels that would be supplied with the test unit, with plant personnel installing pipes to and from the test area.

The following table of the respective additional costs of a large-scale test compared to the Los Angeles plan is based on estimates of the cost of a concrete channel, the size used by the authors, and of the additional cost of the larger pipes; assuming that pumping power cost is proportional to the flow, that lamp power is proportional to the number of lamps; and that the costs of hydraulic testing and cleaning are proportional to the sizes of the lamp arrays. Since all tests assume 147 cm lamps emitting 26.7 W of UV energy, these size-dependent costs also are proportional to the numbers of lamps.

Table 2 shows additional costs of large-scale tests. Evidently, these are rough estimates, but since the cost per plant of the present Los Angeles plan is in the neighborhood of $100,000, or less if the cost of virological testing can be reduced, additional costs of $25,000–$30,000 are significant.

We believe that additional use of computational simulation and more detailed measurements could allow using smaller pilot tests facilities, with an overall reduction of costs. This approach would assess boundary and end contributions to pilot test results, so that they could be properly scaled to a full-scale system, instead of trying to reduce them to negligibility.

In particular, the UV intensity calculations by the authors can be extended to determine the intensity distribution around lamp arrays of different sizes. One can assume cylindrical symmetry for each lamp, as they did; the measured absorbance at the wastewater site; and the fact that mechanical support and electrical connections are in assemblies at the ends of the lamps, where the intensity is low. Then the intensity in the disinfection area of strong irradiation can be evaluated at any point necessary by code implementing the formula that they used for each lamp in the array, incorporating this as a routine called by fluid dynamics software built with a product such as PDease.

TABLE 2. Additional Costs of Large-Scale Tests

Parameter (1)	Vertical (80 lamps) ($) (2)	Horizontal (64 lamps) ($) (3)
Channel	10,000	10,000
Hydraulics test	17,000	13,000
Pump power	1,620	1,260
Lamp power	1,020	780
Cleaning	570	430
Piping, etc.	1,000	1,000
Total	31,210	26,470

This product provides sophisticated support for evaluating technologically important partial differential equations used in a wide variety of engineering and scientific applications. It includes not only graphical display of results but provides substantial assistance in constructing finite-element models. Given a region in which the solution of a partial differential equation (PDE) is to be evaluated, PDease can generate a finite-element decomposition on its own or it assists the user in building one interactively, and it provides other services like error analysis and adaptive selection of time steps. Considering that arrays of cylindrical lamps in rectangular channels allow repetition of portions of the decomposition, these capabilities promise to provide models for the flow at a small fraction of the cost of coding them by hand.

With the capabilities of its companion product, Macsyma, a well-established integrated symbolic mathematics package, it would be possible to refine the calculation by, for example, partitioning the region of the calculation into maximum-intensity and end-zone regions for the UV irradiation, and bulk-flow and boundary-layer regions for the flow, to deal with the fact that some of these regions scale with the areas of wetted surface, and others scale with the volume of the irradiation region. Conversely, since the time needed for the calculation is strongly dependent on the grid spacing needed to resolve flow variation, the calculations would be simplified because the arrays create plug flow.

Macsyma and PDease are available in a combined package for the Windows environment on personal computers for about $1,200, or sometimes slightly less from discount dealers like SciTech International, Inc., Chicago. Other mathematical software packages, such as MapleTM and MathematicaTM, with similar capabilities, are available at similar prices, often from the same dealers. Some of these packages can be used on engineering workstations, such as those in the RS-6000 line, that have much higher numerical calculation capacity than personal computers. Allowing another approximately $10,000 for the cost of coding and evaluating a model of the channel and lamp array would still provide savings of approximately $15,000 or more over the kind of test advocated by the authors.

This hypothesized $10,000 is likely to be an upper bound, since the computations can be done on computers that are likely to be available already in many offices, and hiring a consultant in numerical analysis is not expected to be necessary. Moreover, the vendor of a pilot test unit like the Trojan

Systems UV2000 could purchase the software once and model each of its pilot test units and standard full-scale configurations once, leaving only parameters like turbidity to be specified for a particular installation. Then modeling calculations would be part of the service provided to potential customers during pilot testing, and the cost would be amortized over multiple customers.

Thus, computational studies would complement the laboratory investigations of microscale mixing in lamp arrays, called for by the authors. As the price of computations continue to decrease, unlike the costs of building and operating a 44 L/s (1,000,000 gpd) laboratory test, it is reasonable to hope that complementing laboratory measurements with computation can cut the costs and improve the quality of results needed to plan full-scale UV disinfection systems.

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Closure by Ernest R. Blatchley III,[6] Member, ASCE, William L. Wood,[7] Member, ASCE, and Peter Shuerch[8]

The comments of the discussers provide a valuable perspective of the problems associated with pilot testing. Their comments point out several of the practical as well as theoretical issues associated with (UV) pilot testing and the extrapolation of test results to full scale.

The central theme of the discussion is that large-scale UV pilot testing may not be justified. Their first argument is that the pilot test system described in the note is of a size similar to that of many full-scale systems. The commenters should recognize that the term "large-scale" is relative; in the case of facilities with flows less than 43.8 L/s (1 mgd) or so, a conventional pilot system with a small number of lamps will probably suffice. As of 1992, approximately 50% of the existing UV facilities were those associated with medium- [43.8 L/s (1 mgd) $< Q <$ 876 L/s (20 mgd)] to large-sized [$Q >$ 876 L/s (20 mgd)] plants (USEPA 1992). Many of the new facilities being designed and built also fall into these categories. It is these facilities which stand to gain the most from pilot-testing at a scale similar to the system described in our paper.

The second argument posed by the discussers relates to the justification of additional costs associated with the large-scale tests. It is true that the large-scale tests are likely to be more expensive than those associated with conventional small-scale testing. However, cost estimates of this type are susceptible to large errors due to the number of assumptions that are required (Blatchley et al. 1996). Under the assumption that the tabulated costs presented by the discussers are representative of the actual additional costs associated with large-scale pilot testing, it is important to put these costs into their proper context. Clearly these costs are not justifiable for small systems —under some circumstances it may be difficult to justify any level of pilot testing for small systems. However, in the design of medium- to large-scale systems, it is important that physically meaningful pilot test data be available. The summary document provided by USEPA (1992) provides an indication of the importance of accurate pilot test results. Specifically, it is pointed out that system sizing has varied between 0.5 and 1.7 mgd/kW, with no obvious deviation from this range as system size increases. While some of this variability is attributable to differences in water quality among wastewater treatment facilities, it is also clear that some fraction of this variability is attributable to differences in interpretation of pilot test data and varying levels of conservatism applied in process design. Accurate pilot test data can help to minimize this variation. When implementation of UV is considered at a medium- to large-scale facility, these differences can represent substantial capital and operational costs. Therefore, while the costs of large-scale pilot testing are likely to be greater than those of their small-scale analog, large-scale tests could yield financial benefits in the design and sizing of the corresponding full-scale system that can more than offset these costs.

Pilot tests are a necessary component of the design process for medium- to large-scale systems because a reliable, theoretically sound, predictive design tool (i.e., a numerical model) does not yet exist for UV disinfection systems. The currently available process models for UV systems are unable to yield predictions of process performance that are sufficiently accurate to be used as the primary or sole basis of design. This is largely the result of their empirical nature and their inability to represent the distribution of UV "doses" that are actually delivered in continuous-flow UV systems (Blatchley and Hunt 1994). As is correctly pointed out by the discussers, research should be directed toward a more fundamentally-based design model, one that incorporates turbulent fluid motions and the three-dimensional nature of the UV intensity field. Work in this area is currently underway, though it is likely to take several years to develop this tool to a useable form for the general engineering community. For this work to be carried out correctly, it will require considerably more than the $10,000 suggested by the writers. Our current estimates are that another two to three years of research will be necessary to bring our model to a useable form. When we are finished with this model, we anticipate that it will allow for accurate predictions of process performance, such that the need for pilot tests is minimized, but probably not eliminated.

The facilities in Los Angeles that are referred to in the discussion are likely to be on the large end of the spectrum of facility sizes. Therefore, these facilities are exactly the type of facility that could benefit from large-scale pilot testing. Until a predictive numerical modeling approach is developed, design engineers will need to continue to rely on pilot testing for the selection of system characteristics. The selection of appropriate pilot equipment is arguably the most important decision to be made in this process.

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