Determination of the remaining stabilization potential of landfilled solid waste by sludge addition

S.B. Gülec, T.T. Onay and A. Erdincler

Bogazici University, Institute of Environmental Sciences, 80815 Bebek, Istanbul, Turkey

Abstract Ultimate disposal of wastewater sludges is one of the most concerning steps of sludge management. As an alternative disposal, reuse of sludge as a soil conditioner or fertilizer has had some success. Another alternative is the addition of sludge to the solid waste landfills. Many researchers have studied the effects of sludge addition to the solid waste stabilization in landfills. However, part of the researchers found positive effects, while others found either negative effects or no effects at all. This study investigates the remaining stabilization potential of the solid waste retrieved from an operating landfill by sludge addition. Determination of the remaining stabilization potential of landfilled solid waste is an important issue in solid waste management. In this study, the further stabilization of landfilled solid waste is achieved by the addition of anaerobically digested sludge to the solid waste with different sludge to waste ratios. Four 10-litre laboratory-scale batch digesters operated under constant temperature of 34ºC are used in the experiments. One of the digesters was the control unit operated without any sludge addition. The other three digesters had different sludge to waste ratios; 1:9, 1:6, 1:4 (on wet basis) respectively, in order to find the optimum ratio for the solid waste stabilization. The comparison of gas production and quality and other indicator parameters provided an opportunity to determine the remaining stabilization potential and its significance. The results are translated in terms of conventional landfill practices, as well as emerging technologies for innovative sludge management.

Keywords Anaerobic degradation; enhancement of stabilization; landfill; sludge co-disposal; solid waste

Water Science and Technology **Vol 42 No 9 pp 269–276**

Introduction

Research activities on the innovative landfill management techniques are becoming attractive research areas in the last decades due to increasing amounts of solid waste from industrialization and urbanization. Determination of the stabilization potential of solid waste and distribution of the already completed stabilization at the site are playing important roles for the development of such innovative landfill management and control techniques. However, the mechanism and degree of this stabilization is uncertain and very difficult to determine.

Uncertainty in the rate and degree of waste stabilization prevents us making credible prediction of leachate and gas generation potential from the landfills. It also prevents us developing effective management systems for the control of these parameters. Moreover, prediction of leachate and gas generation rates is crucial for the better design of landfill bioreactors.

In this study, anaerobically digested sludge is added to the solid waste, as an alternative method of ultimate sludge disposal, to enhance the anaerobic degradation of solid wastes in the landfills. There have been many studies in the literature attempting to find out the effects of sludge addition on the solid waste degradation. Both positive and negative effects were found in these studies. Some of the researchers reported that sludge addition increases the performance of anaerobic digestion. Potential positive effects of sludge addition to solid waste were attributed to increasing water content, supply of an active anaerobic biomass and supply of readily available nutrients (Buivid *et al.*, 1981). Craft and Blakey (1988) concluded that codisposal of different kinds of sludge increases the rate of stabilization and increases the gas production. They concluded that gas generation and waste stabilization take place over a shorter period of time with sludge codisposal (Kinman *et al.*, 1987).

Leuschner (1989) examined the effect of addition of sludge, buffer, and nutrients on the solid waste degradation. He concluded that establishing a viable population of microorganisms in the reactor significantly increased the rate of methane formation. He also reported that anaerobically digested sludge exhibited a significant beneficial effect upon waste degradation. On the other hand, some researchers found that the addition of raw sludges with low pH values stimulated acid production and inhibited methane formation. Moreover, it was suggested that sewage sludge addition to solid waste may have a limiting effect on waste degradation if the anaerobic conditions are already established (Christensen and Kjeldsen, 1992).

When the environmental aspects of sludge landfilling are considered, it is important to understand the effects of sludge application on the disposed waste and the disposal site. Therefore, investigations should be carried out for the determination of these potential impacts and prevention of the adverse environmental problems.

In this study, the further stabilization of landfilled solid waste is investigated by the addition of anaerobically digested sludge to the solid waste with different sludge to waste ratios. This approach also enables us to find the conditions for optimum methane formation and determine the role of sludge addition on solid waste degradation. In other words, this study may address an alternative sludge disposal option which could accelerate solid waste stabilization in landfills. High methane concentrations resulting from this accelerated stabilization could be recovered for possible on-site utilization alternatives.

Materials and method

The experimental part of this study consisted of anaerobic digestion of landfilled municipal solid waste with sludge addition. Four 10 L Plexiglas reactors were placed into a constant temperature bath in which the temperature is adjusted to 34ºC. Reactors were operated with different sludge to waste ratios in order to find the optimum ratio for methane gas formation and also determine the effects of sludge addition on solid waste degradation.

Solid waste samples used in the reactors were taken from 1.5–2.0 m depth at an operating landfill site. The retrieved solid waste samples were 2-years old. The anaerobically digested sludge that was used for the enhancement of stabilization was obtained from the anaerobic wastewater treatment plant of a liquor factory. Physical and chemical solid waste and sludge characterization were performed prior to the commencement of reactor operations.

Different sludge to waste ratios were selected for the reactors prior to loading of the system. Other operational parameters were kept constant for each reactor. However, the composition of solid waste loaded to each reactor was not the same due to the heterogeneity of the landfill environment. The moisture content of each reactor was adjusted to 85%, the optimum value based on the literature, for the activity and the better performance of methanogens (Pohland *et al.*, 1992). The amount of water to be added to each reactor was calculated based on the initial moisture contents of sludge and solid waste. The sludge to waste ratios were selected according to the design considerations for codisposal operations given in the Environmental Protection Agency (EPA) manual on municipal sludge landfills (EPA, 1978). One of the reactors was loaded only with solid waste without any sludge addition and this reactor was called a "Control Reactor". The highest sludge to waste ratio was selected as 4 kg of refuse to1 kg wet sludge (EPA,1978). Moreover, Craft and Blakey (1988) gave the highest sludge to waste ratio to be adopted in operational practices as 1:4.1. The loading conditions of the reactors are given in Table 1.

After the loading, each reactor was carefully stirred, sealed, and then purged with helium gas to displace air from reactor headspaces to initiate the anaerobic conditions. All reactors were operated in the batch mode without leachate recirculation in a bath with a constant temperature of 34ºC.

Table 1 Loading conditions of the reactors

Reactor	Sludge: waste ratio	Moisture content	Solid waste added-wet (g)	Sludge added-wet (g)	Water added (L)
1	0	85%	1500	–	4
2	1:9	85%	1500	166	4.054
3	1:6	85%	1500	250	4.083
4	1:4	85%	1500	375	4.125

Analysis of the leachate from the reactors

Leachate samples collected from the reactors were analyzed for pH, ORP (Oxidation-Reduction Potential), COD (Chemical Oxygen Demand), orthophosphate, ammonia nitrogen, chlorine and alkalinity. All these analyses were performed according to "Standard Methods for the Examination of Water and Wastewaters"(1989).

Analysis of the gas from the reactors

The gas generated in the reactors was monitored for the understanding and identification of the stabilization phase of the solid waste in the system. The volume of daily gas production and the gas composition were the monitored parameters throughout the study. The gas production was measured daily by observing the displacement of the confining solution at every gas collection unit.

The generated gas composition was analyzed once in ten days. The gas composition analysis was performed with HP 5890A Gas Chromatograph by using nitrogen as a carrier gas. Carbon dioxide (CO_2) and methane (CH_4) concentrations were measured.

Results and discussion

Initial analysis

The overall moisture content of solid waste was found to be 45% and the total solid content of sludge was determined as 20%. The results of leachate analysis showed very low heavy metal concentrations. Therefore, heavy metal inhibition was not expected in the reactors. Several pH measurements were made for the anaerobically digested sludge taken from the liquor factory. The average pH value was 6.9.

Leachate analysis

The pH values of all reactors exhibited a similar trend throughout the study (Figure 1). The pH values of all reactors stayed in the range of 7.0–8.5. However, a sudden decrease in pH

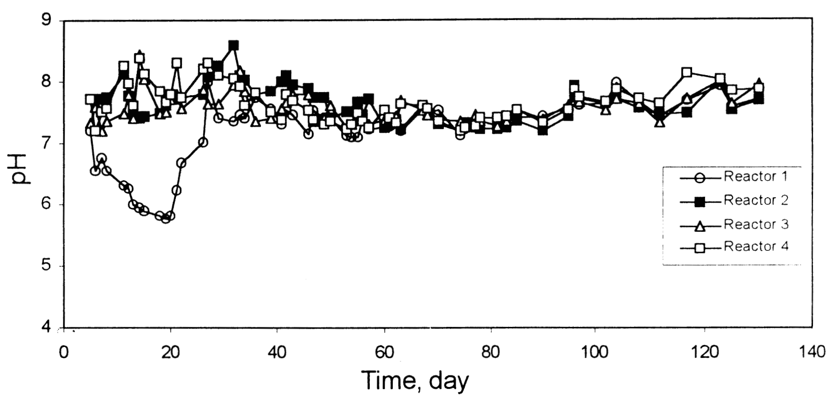

Figure 1 The pH of the leachate from the reactors

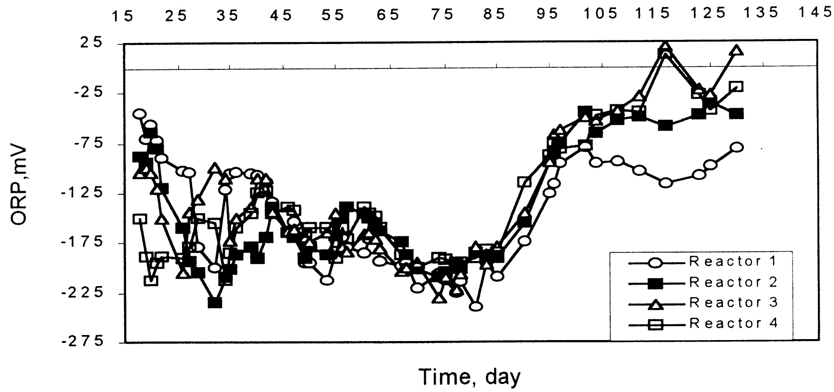

Figure 2 The ORP of the leachate from the reactors

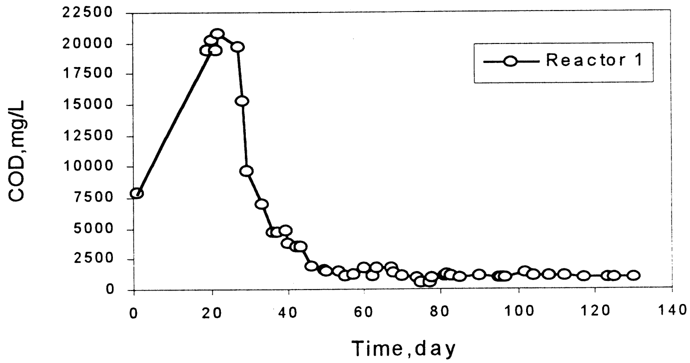

Figure 3 The COD of the leachate from the reactor 1

was observed at the control reactor during the first 30 days of the research. The decrease in pH to a value of 5.8 was attributed to the release of organics in the leachate, and generation and build-up of volatile organic acids in the reactor. However, water addition performed on Day 20 created dilution and the increase in pH occurred. On the other hand, the pH of leachates from reactors receiving digested sludge did not show any significant change. This may be explained by the buffer capacity of sludges. The pH range observed throughout the research, was suitable for the onset and continuity of anaerobic conditions and the activity of methanogens as indicated in the literature (Emcon.,1980).

The initial leachate ORP values of all the reactors were negative indicating the presence of highly reducing environments. As indicated in Figure 2, right after the start-up of the reactors, the ORP values continued to drop and reached a minimum of –230 mV indicating a complete anaerobic environment and favorable conditions for methane generation and anaerobic degradation of organic material. Increase in organic material removal was also supported by COD data obtained during this period. The findings were also in accordance with the literature, explaining the necessity of highly reducing conditions for the maintenance and efficiency of methanogenic activity (Rachdawong, 1994). A similar trend was observed for each reactor, the time required to reach a minimum ORP value was shorter for reactors with high sludge to waste ratios, indicating the positive effect of sludge addition for the onset of the anaerobic conditions. After Day 80, the ORP values started to increase and reached their initial values, indicating the completion of the stabilization of readily biodegradable substances. This was also supported by low COD removal and gas production rates.

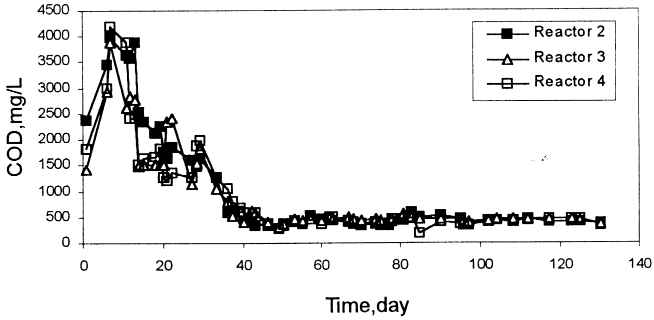

Figure 4 The COD of the leachate from the reactors 2, 3, 4

When all reactors were compared, it was observed that the initial leachate COD concentrations were different for each reactor due to the diverse organic loadings. The difference in COD values was also a result of the use of real solid waste, retrieved from a very heterogeneous environment instead of preparing synthetic solid waste for the operation of reactors. Figure 4 shows that the reactors with sludge addition (Reactor 2, 3 and 4) followed a similar COD removal trend throughout the study. The hydrolysis of organic material in the solid waste yielded high initial COD concentrations in leachate, followed by the decrease in concentration due to the conversion of volatile organic acids to methane and carbon dioxide. By Day 45, most of the degradation of biodegradable organic matter was achieved for Reactors 2, 3, and 4. The existence of residual COD concentrations was attributed to the presence of refractory humic like substances (Rachdawong, 1994). Similar to the ORP data, the time required to reach minimum leachate COD concentrations was shorter for high sludge to waste ratios. Although the similar release and conversion patterns were observed in the control reactor, the time required for the release and removal of the organic content of solid waste was much longer then the reactors operated with sludge addition. This was due to the higher organic content of solid waste loaded to the control reactor and also the initial built-up of volatile organic acids in the reactor (Figure 4).

Leachate ammonia and orthophosphate concentrations were also monitored throughout the study to assure the availability of macro-nutrients for bacterial assimilation. Ammonia concentrations were high in all of the reactors due to the decomposition of organic material containing nitrogen. The highest ammonia concentration of 450 mg/L resulted from the control reactor having high initial organic content. Leachate ammonia concentrations decreased by bacterial assimilation and stayed constant at 250 mg/L until the end of the study indicating sufficient nitrogen concentrations for the microbial activity. On the other hand, leachate orthophosphate concentrations ranged from 1 to 5 mg/L for all reactors.

Alkalinity was monitored in the leachate samples to measure the system buffer capacity. The alkalinity concentration was in the range of 2000 to 6000 mg $CaCO_3$/L throughout the study. Initially, an increase in leachate alkalinity concentrations was observed due to the formation of volatile organic acids. However, after the conversion of VOAs to methane, alkalinity concentrations gradually decreased through to the end of the study.

Gas analysis

Gas volume and composition were determined as indications of the progression of solid waste stabilization in the reactors. Cumulative gas volumes produced in the reactors are shown in Figure 5. The overall volume of gas produced was much higher in the reactors with high sludge to waste ratios. The total gas production in the reactors was 51 L, 40 L, 44 L and 51.5 L for Reactors 1, 2, 3, and 4, respectively. The maximum volume of gas produced during the initial two-week period was also greatest for Reactor 4 indicating that the

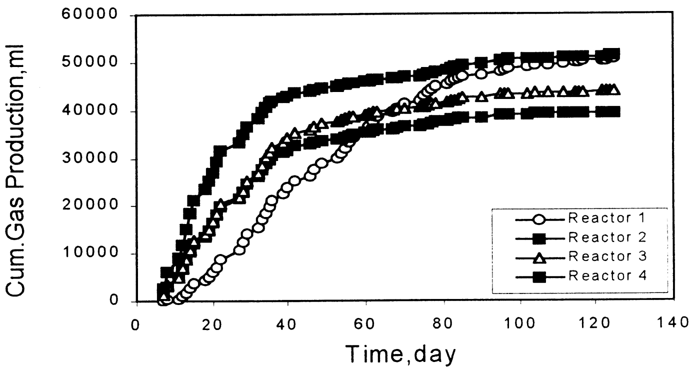

Figure 5 Cumulative gas production of the reactors

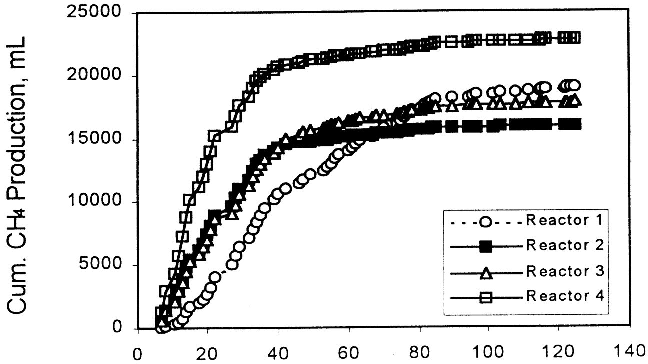

Figure 6 Cumulative methane production of the reactors

stabilization of solid waste proceeded more rapidly and thoroughly in the reactor having the highest amount of sludge. The higher degree of stabilization observed in the Reactor 4 can be directly attributed to the application of high amount of digested sludge which served as the seed of microorganisms as well as the source of nutrients. Due to its higher organic content, the total amount of gas produced from the control reactor was also significant. The times required to reach the maximum gas production for Reactor 1 and 4 were found to be 95 and 53 days, revealing clearly that the addition of sludge decreased the time of solid waste stabilization.

Methane and carbon dioxide, the primary end products of the anaerobic waste degradation process, were also monitored throughout the experimental study as indicators of the rate of biological activity and the extent of organic material conversion. The initial gas composition data indicated 40% of methane concentrations in the reactor head spaces suggesting that all four reactors were in the active methane formation phase. This early methane production in the reactors was possibly a consequence of the age of the solid waste samples retrieved from the landfill. The initiated methane formation in the landfill continued to proceed in the reactors under a more controlled environment. The methane production in Reactor 4 ceased earlier than the other reactors due to the faster depletion of organic compounds with sludge addition. However, methane production in the other reactors, especially in the control reactor was distributed over a longer period of time due to the slow progressing biological activities.

Cumulative methane production data for all reactors is presented in Figure 6. The total volume of methane produced was 19 L, 15.9 L, 17.8 L and 22.8 L, for Reactors 1, 2, 3 and 4, respectively. It was again observed that the higher sludge to waste ratio yielded higher methane recovery rates. This is due to the fact that the decomposable organic material such as the volatile organic acids, a principal substrate for methanogens, was removed faster while increasing the gas production and the methane concentration.

Conclusions

In this study, the remaining stabilization potential of solid waste retrieved from an operating landfill site was investigated by means of the anaerobic digestion of the waste with sludge addition. The conclusions are given as follows.

1. The addition of anaerobically digested sludge was found beneficial for the initiation, rate and the extent of solid waste stabilization.
2. Four reactors were loaded with sludge to waste ratios of 0:0 (Control Reactor), 1:9, 1:6, 1:4, respectively. Among these, Reactor 4 with the highest sludge to waste ratio of 1:4 was found to be efficient for the faster removal of the organic fraction of the solid waste.
3. The sludge addition was beneficial for obtaining increased amounts of methane production. The optimum sludge to waste ratio for the highest methane production rate was 1:4. This approach could also be considered for the sites operated for methane recovery and utilization.
4. Due to the beneficial effects of sludge addition on waste stabilization, the codisposal of anaerobically digested sludge with solid waste was evaluated to be a possible disposal option of the sludge. For this disposal option the sludge to waste ratio of 1:4 was found to be satisfactory for the acceleration of the waste stabilization rates. However, prior to deciding the optimal ratio for such disposal alternative, field-scale determinations should be made on a site-by-site basis (EPA,1978). Moreover, it was stated in the literature that the anaerobically digested sludges are classified as "marginally suitable" in terms of their suitability for site application due to operational problems encountered while mixing sludges with solid waste (EPA,1978).

   For instance, if 100 tons of sludges resulting from a municipal wastewater treatment plant are planned to be codisposed with municipal solid waste in a landfill with a predetermined sludge to solid waste ratio of 1:4, it would be mixed with 80 tons of solid waste in case that the sludge was dewatered up to 20% solids content. If 500 lb/yd^3 solid waste density is applicable and 3 m of lift height is assumed, the area required for the disposal of the sludge would be calculated as 90 m^2.
5. The average methane generation was calculated as 12.61 L CH_4/kg solid waste. Based on comparison of the experimental yield of 12.61 L CH_4/kg solid waste with the theoretical yield of 185 L CH_4/kg solid waste, it is concluded that only a total stabilization potential of 7% remained in the solid waste retrieved from the landfill site. A low stabilization potential was expected due to the low initial leachate COD concentrations resulting from the solid waste. This information explains why the retrieved solid waste was partially stabilized prior to its use in the laboratory.

As a conclusion, the remaining stabilization potential of the solid waste was found to be less than 10%. However, this stabilization potential could not be generalized for the whole site. Even when the waste was taken from one location mainly, two different ranges of initial COD values of 2000 and 7000 mg/L were obtained due to the heterogeneity of the landfill. In order to determine the stabilization potential of the whole site, this study should be enlarged and the same analysis should be performed for different locations and depths of solid waste until the whole picture of the site is obtained.

The scope of the study was limited to specify the technique to be used for the determination of the remaining stabilization potential of the solid waste in landfill. Studying different types of wastewater sludges and various sludge to waste ratios could be beneficial for understanding the extent of stabilization and alternative sludge disposal options. Overall, this technique proved the suitability of sludge codisposal in landfills. An integrated solid waste management approach should be adopted in order to operate landfills as controlled landfill bioreactors while developing alternative methods for sludge disposal.

Acknowledgements

The authors acknowledge the financial support provided by Bogaziçi University Research Fund for the realization of this research project BU-97 HY101.

References

Buivid, M.A., Boyd, W.F. and Pacey, J.G. (1981). Fuel gas enhancement by controlled landfilling of municipal solid waste. *Resources and conservation*, **6**, 3–20.

Christensen, T.H. and Kjeldsen (1992). Effects of landfill management procedures on landfill stabilization and leachate and gas quality. *Landfilling of Waste: Leachate,* T.H. Christensen *et al.* (eds.), Elsevier Applied Science, London, pp. 1–33.

Craft, D.G. and Blakey, N.C. (1988). Codisposal of sewage sludge and domestic waste in landfills. *ISWA Proceedings*, **1**, 161–168, Academic Press, London, UK.

Emcon Associates (1980). *Methane Generation and Recovery from Landfills.* Ann Arbor Sciences, Michigan, USA.

Kinman, R.N., Nutini, D.L. and Walsh, J. (1987). Gas enhancement techniques in landfill simulators. *Waste Management and Research*, **5**, 13–25.

Leuschner, A.P. (1989). Enhancement of degradation: laboratory scale experiments. T.H. Christensen, R. Cossu and R. Stegmann (eds.), *Sanitary Landfilling: Process, Technology and Environmental Impact*. 61–82, London, UK.

Pohland, F.G., Onay, T.T., Al-Yousfi, A.B., Hanaki, K. and Vasuki, N.C. (1992). Post-stabilization characteristics of landfilled solid waste after exposure to leachate recirculation. Research in the University of Pittsburgh, Pittsburgh, USA.

Rachdawong, P. (1994). *Use of Recycled Carpets During Landfill Management of Solid Wastes.* M.S. Thesis, Department of Civil and Environmental Engineering, University of Pittsburgh.

Standard Methods for the Examination of Water and Wastewaters (1989). 17th Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

U.S. Environmental Protection Agency (1978). *Municipal Sludge Landfills; Process, Design, Manual*, EPA-625/1-78-010 SW-705, Office of Solid Waste, Washington D.C.,USA.