

## Kinetics of Solid Waste Biodegradation in Laboratory Lysimeters

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### ABSTRACT

Solid waste biodegradation kinetics determine the time it takes to achieve stabilization of solid waste in landfills. This paper reports the results of a laboratory scale investigation aimed at evaluating the effect of different enhancement techniques on solid waste biodegradation kinetics. The experiments were carried out in a group of five lysimeters. The effect of temperature and leachate recirculation was investigated. Total Volatile Solids (TVS) and fiber content under controlled conditions of temperature and moisture were monitored for a period of nine months. The experiments were carried out under both mesophilic and thermophilic conditions. The moisture of solid waste was controlled through the process of leachate recirculation.

The results of kinetic analysis showed that solid waste degradation follows first order kinetics. The optimal conditions for solid waste biodegradation were found to be mesophilic temperature of about 38°C and moisture content of about 65%. It was concluded that leachate recirculation enhanced the biodegradation process over the whole studied range of moisture content, while the temperature influence was the maximum during mesophilic stage. The biodegradation under thermophilic conditions was decelerated as compared to control lysimeter. The results obtained by this study may be applied to a real scale bioreactor landfill.

**KEYWORDS:** Biodegradation kinetics, Solid waste, Leachate recirculation, Lysimeter, Reaction rate.

### INTRODUCTION

Landfills continued to be an integral part of many solid waste management plans (Zacharof and Butler, 2004; Al Jarrah and Abu Qdais, 2006). Once solid waste is placed in the landfill, it will be subjected to several complex biochemical and physical processes that can not be analyzed in a deterministic way. Understanding the processes that take place within a landfill is an important step toward assessing the rate of solid waste degradation and release of emissions such as leachate and landfill gases. Landfill models are useful tools that can provide

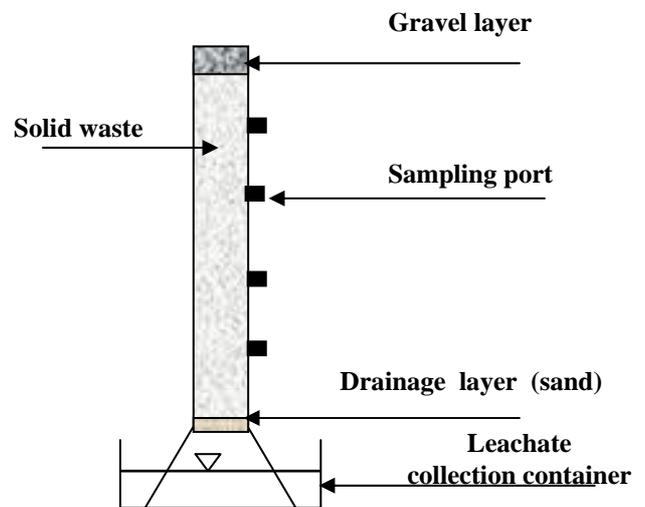
an effective methodology for organizing and assessing complex processes that take place within the landfill (White et al., 2004).

The degradation process of solid waste within the landfill is governed by several environmental factors that influence the degradation rate (Eleazer et al., 1997). Many studies were directed to evaluate the role of such environmental factors in enhancing degradation of solid waste. The role of leachate recirculation process and temperature in the enhancement and control of solid waste degradation was investigated by many researchers, such as (Francois et al., 2007; Griffith and Trois, 2006; White et al., 2004; Townsend, 2003; Shelly and Nixon, 2001; Lee et al., 2001; Lay and Noike, 1998; Reinhart and Al-Yousfi, 1996; Townsend et al., 1994; Anderson,

1986). Knowing the kinetics of biological reactions taking place within the landfill and the influencing



environmental conditions is essential to design and manage the landfilling process.



**Figure (1): Experimental set-up used in the study.**

Kouzeli (1999) developed a simple mathematical model to simulate solid waste decomposition in landfills. Two processes were taken into account; the exchange of organic matter between the solid and liquid phases and the depletion of the dissolved organic matter due to biological decomposition and flushing. The landfill was considered as a single fully mixed reactor and first order reaction kinetics apply. The model contained many kinetic parameters, the value of which has been calculated from experimental data from other investigations. It was concluded that the most important factor affecting the rate of decomposition is moisture.

Lee et al. (2001) created a model that can be used to assess the extent of landfill stabilization in terms of local mass per bulk volume of remaining refuse available for transfer. Three scenarios were applied; leachate recirculation, input of clean water and landfill control (No moisture addition). Through numerical experiments they found that the leachate recirculation provides more favorable conditions for an active anaerobic degradation of refuse.

Shelly et al. (2001) developed a system dynamics

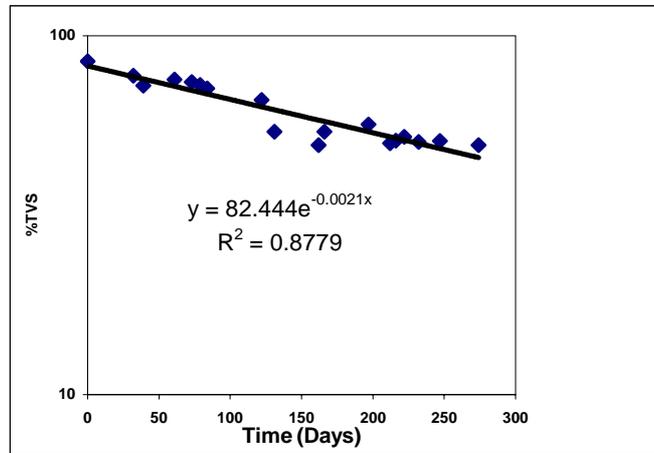
model to determine the significant processes and appropriate level of detail required to capture dynamic behavior important in managing biodegradation in landfills. Uniform spherical solid waste particles are assumed to hydrolyze from the outer surface to produce simple sugars, fermentation, acetogenesis and methanogenesis produce methane and carbon dioxide as end products. Microbial populations consume their respective substrates according to classical Monod kinetics. Experimental data were used to calibrate the model. Gurijala and Sufilta (1993) studied the effect of temperature on the biodegradation of solid waste samples. The study reported 40°C as optimum with significant inhibition of the biodegradation kinetics over 55°C.

In an attempt to simulate the landfill conditions, lysimeter studies were widely used. By conducting the study on lysimeter level, it is possible to avoid the field complexities and have better control on the operational conditions (Trankler et al., 2005).

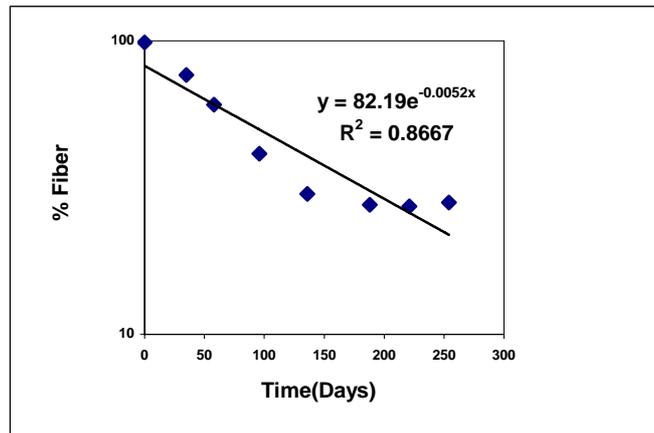
The objective of this study was to analyze the degradation kinetics of municipal solid waste and to

assess the effect of various levels of moisture content and temperature on the degradation process. To manage the control of the moisture and the temperature, the study

utilized several lysimeters which were operated under various controlled conditions in the laboratory.



a



b

Figure (2): First order biodegradation fit for the control lysimeter.

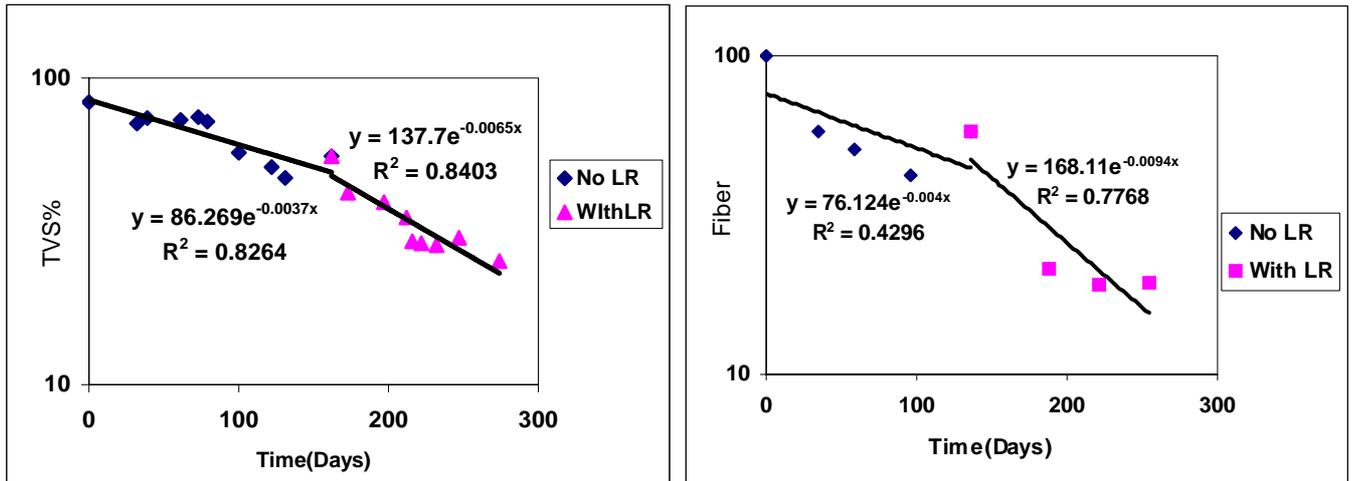
a. In terms of TVS.

b. In terms of fiber content.

## MATERIALS AND METHODS

The study was conducted on a laboratory scale in a group of five lysimeters. A mix of fresh solid waste samples that consisted of food waste and paper was prepared in the laboratory. The food to paper ratio in the prepared samples was 8:1, which reflected the actual ratio

in the national solid waste stream generated in Jordan. The experimental setup used in the experiments is shown in Figure 1. Five PVC lysimeters with a diameter of 15 cm and a net height of 120 cm were used. A wire mesh and a drainage layer of sand were installed at the bottom of each lysimeter to prevent the loss of solid waste and to drain the produced leachate.



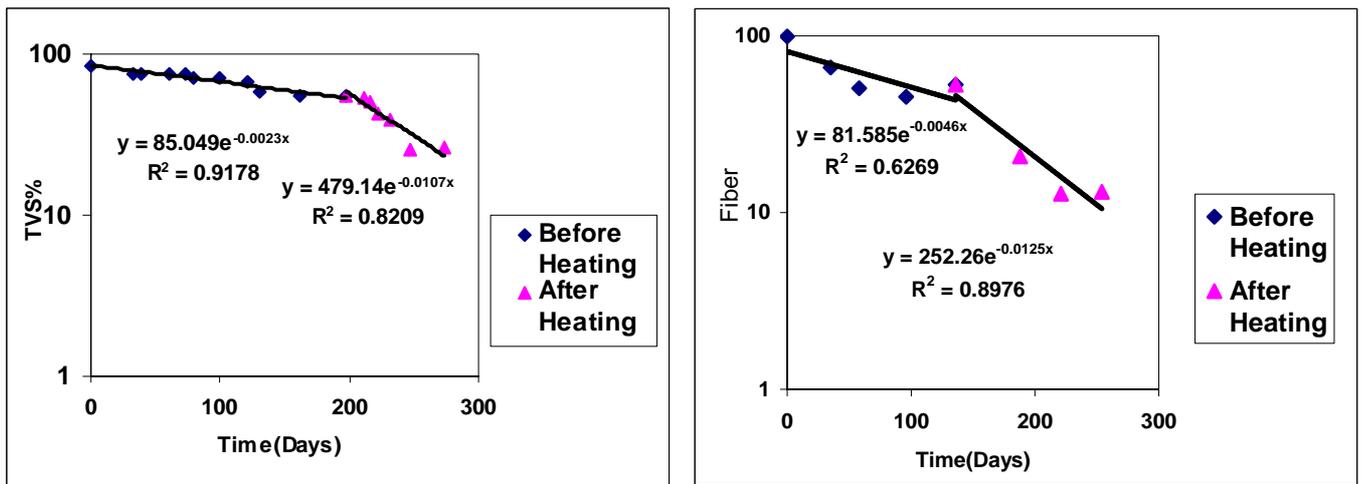
a

b

Figure (3): The impact of leachate recirculation on the solid waste biodegradation rate.

a. In terms of TVS.

b. In terms of fiber contents.



a

b

Figure (4): The solid waste biodegradation kinetics under mesophilic temperature of 40°C.

a. In terms of TVS.

b. In terms of fiber contents.

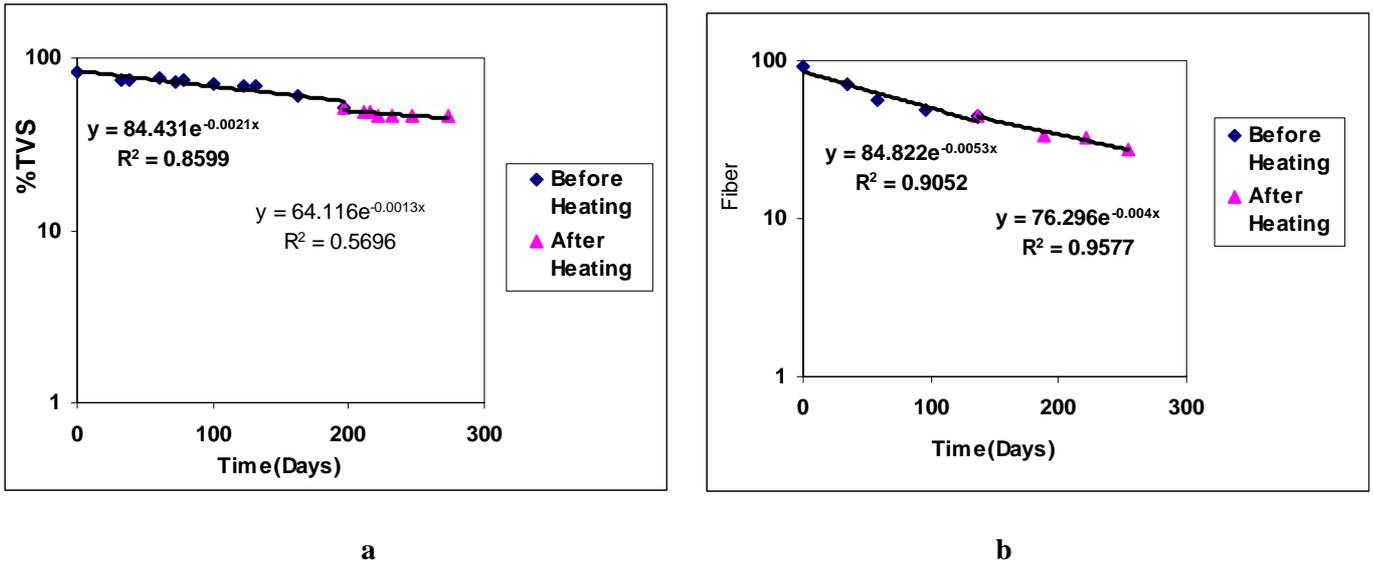


Figure (5): The solid waste biodegradation kinetics under thermophilic temperature of 60°C.

a. In terms of TVS.

b. In terms of fiber contents.

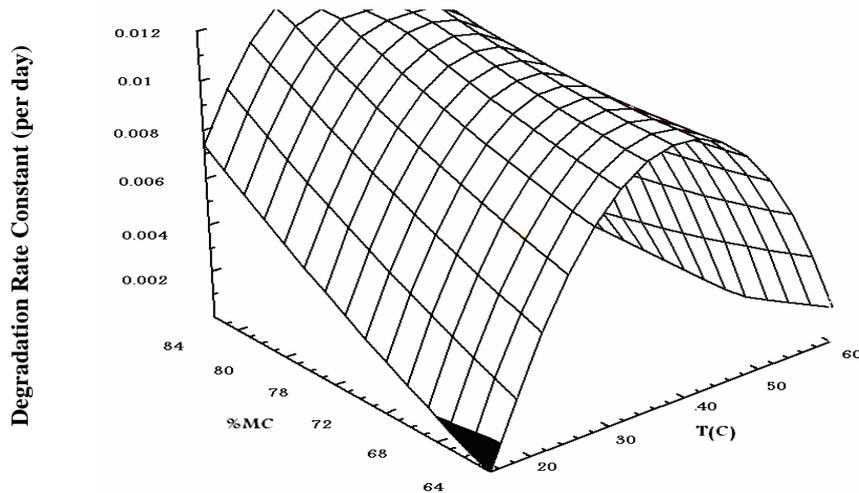


Figure (6): Combined effect of the temperature and moisture content on the reaction rate constant in terms of TVS.

A gravel layer was spread at the top of the lysimeter to homogeneously infiltrate the recirculated liquid (Leachate). Leachate collection was accomplished using a plastic container that was put under the lysimeters. The temperature management was accomplished by

incubating the lysimeters in water baths. The temperature of the baths was controlled using electric heaters inserted in water and set to the required temperature which was maintained during the experiments by utilizing a thermostat.

Composite samples were taken from four sampling ports distributed along the depth of the lysimeter. Total Volatile Solids (TVS) and fiber content degradation of the samples were monitored for a period of nine months and analyzed following Standard Methods for Examination of Water and Wastewater (APHA, 1995) for TVS analysis and Weende method (Offner, 1999) for fiber content analysis.

The five lysimeters were initially allowed to degrade naturally for about four months without controlling any of the operational parameters. Then the lysimeters were operated under various controlled conditions of moisture content and temperature; leachate recirculation process was applied to lysimeters 1 and 2, while temperature control was applied to lysimeter 3 and 4; lysimeter 3 was operated under mesophilic conditions, while lysimeter 4 was operated under thermophilic conditions. Lysimeter 5 was used as the control.

## RESULTS AND DISCUSSION

Data on Total Volatile Solids (TVS) and fiber content were continuously collected from the five lysimeters during the whole study period (9 months). The collected data were fitted to find out the degradation rate kinetics and which order it follows. The fitted data were found to be following the first order kinetics in terms of TVS as well as fiber contents. Figure 2 (a and b) shows the first order kinetics fit for the control lysimeter (lysimeter 5). As it can be seen, the first order kinetics simulates the TVS and fiber degradation very well with a coefficient of determination ( $R^2$ ) of 0.88 and 0.80 for TVS and fiber content, respectively.

### Effect of Leachate Recirculation

The effect of leachate recirculation on the biodegradation rate is presented in Figure 3 (a and b). The biodegradation kinetics fit for TVS and fiber content for lysimeter 1 before and after leachate recirculation indicate that leachate recirculation has increased the biodegradation rate. The first order reaction constant for both TVS and fiber content has increased nearly by 2

fold as compared to the rate before leachate recirculation. This is in agreement with the result reached by Francois et al (2007), who reported that leachate recirculation has accelerated the waste degradation and reduced the required duration necessary for waste to reach a stabilized state.

### Effect of Temperature

Lysimeter 3 was operated under mesophilic conditions. Figure 4 (a and b) shows the TVS and fiber content first order fit for this lysimeter before and after temperature control at 40°C. As it can be observed from the figure, increasing the temperature has led to the enhancement of the solid waste biodegradation process. The biodegradation rate constants of both TVS and fibers were increased by about 4.5 and 2.5 times, respectively.

The impact of thermophilic conditions was tested on lysimeter 4, which was operated at a temperature of 60°C. Figure 5 (a and b) shows TVS and fiber content before and after heating to a thermophilic level. Contrary to the case of mesophilic biodegradation, the thermophilic conditions have led to a deceleration of the biodegradation process. The first order biodegradation rate constants were decelerated by 35% and 25% for both TVS and fiber contents, respectively. This may be attributed to the fact that such relatively high temperature could not be tolerated by the microbial population involved in the solid waste biodegradation process. Consequently, the microbial activity has been declined. The above results indicate that the mesophilic conditions are optimal for the biodegradation enhancement of solid waste. This is in agreement with what was concluded by Gurijala and Sufilta (1993) and by Khattabi et al. (2002).

The combined effect of both leachate recirculation and temperature on the solid waste biodegradation is presented by Figure 6 which reflects the impact of the two operational parameters (temperature and moisture content) on the first order reaction constant. It is obvious that the maximum value of the constant was achieved under a temperature of 38°C and a moisture content of 65%. This suggests that for the enhancement of solid waste biodegradation in the landfills, the operational

conditions should be controlled around these values. Under conventional landfill conditions, this control is not possible. However, with the introduction of the bioreactor landfill, controlling temperature and moisture content became a feasible option.

Despite the fact that the biodegradation of solid waste can be described by first order kinetics, the rate of solid waste biodegradation is slower than that of the wastewater. This is expected, since the degradation of solid waste in landfills is taking place in a solid state, while wastewater treatment takes place in liquid form, where the hydrolysis rate is faster.

### CONCLUSIONS AND RECOMMENDATIONS

As for all biological processes, the reaction rate can be influenced by various factors during solid waste biodegradation. Moisture content and temperature are among those factors which should be considered when selecting enhancement techniques of solid waste stabilization. As judged by the biodegradation trend of

solid waste in this study, the solid waste biodegradation can be described by first order kinetics.

The kinetics analysis conducted in this study revealed that leachate recirculation enhanced the biodegradation rate. Furthermore, mesophilic temperature was found to be the optimal temperature that enhanced the biodegradation rate of solid waste by many folds. On the other hand, during the thermophilic stage the degradation rate was decelerated. The optimal temperature that gave the maximum degradation rate was 38°C.

Since in the landfills the biodegradation of solid waste takes place as a solid substrate, the reaction rate constants are lower than those reported for liquid waste. The optimal biodegradation conditions reported by this study can be applied on a real scale bioreactor landfill to enhance biodegradation and biogas recovery and minimize the afterclosure liability period. It is recommended that future lysimeter studies consider wider range of moisture content and new parameters such as solid waste particle size.

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