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Research article

# Kinetics of biogas production and chemical oxygen demand removal from compost leachate in an anaerobic migrating blanket reactor

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ABSTRACT

In this study, laboratory anaerobic migrating blanket reactor (AMBR) with four units was used to reduce and remove COD leachate of composting process; it was also used to determine the kinetic coefficients of COD removal and biogas and methane gas production in several different OLRs. The maximum concentration of organic matter entering the reactor was 100,000 mg/L and the reactor was under operation for 319 days. The results showed that the COD removal efficiency of AMBR in all concentrations of substrate entering the reactor was above 80%. First-order model and Stover-Kincannon were used to investigate the kinetics of COD removal via AMBR biological process; in addition, the two models of Modified Stover-Kincannon and Van der Meer and Heertjes were used to check the kinetic constants of biogas and methane gas production. The results obtained from the models showed that the experimental data on COD removal were more consistent with the results obtained from Stover-Kincannon model ($R^2 = 0.999$) rather than with the First-order model ($R^2 = 0.926$). Kinetic constants calculated via Stover-Kincannon model were as follows: saturation value constant (KB) and maximum utilization rate constants ($U_{max}$), respectively, were 208,600 mg/L d and 172,400 mg/L d. We investigated the linear relationship between the experimental data and the values predicted by the models; as compared with the values predicted by the First-order model, the values predicted by Stover-Kincannon model were closer to the values measured via experiments. Based on the results of the evaluation of kinetic coefficients of Stover-Kincannon model, with the migration of the leachate flow from unit 1 to unit 4, $U_{max}$ value has fallen significantly. The values of maximum specific biogas production rate ($G_{max}$) and proportionality constant (GB) obtained from the Stover-Kincannon model, respectively, were 35,714 ml/L d and 42.85 (dimensionless) and value of kinetic constant of Van der Meer and Heertjes (ksg) was 0.0473 ml $CH_4$/mg COD.



## 1. Introduction

The amount of waste produced globally has increased in the past decade, as the amount of waste a decade earlier was 0.68 billion tons and it already has reached about 1.3 billion tons. In addition, it is estimated that the amount of waste will have reached 2.2 billion tons by 2025 (Pellera et al., 2016). Apart from the increase in population, there are some other reasons for the increased production of waste, such as changes in lifestyle, rapid

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economic growth, industrialization, and increased rate of urbanization in many developing countries (Luo et al., 2014; Pellera et al., 2016). Increased solid waste quantities require improving and expanding the solid waste management options such as landfilling and composting. This increase in waste quantities and their management practices affect various environmental issues, posing numerous threats and creating major potential problems (El-Gohary and Kamel, 2016; Pellera et al., 2016). Composting is the microbial degradation of organic solid material that involves aerobic respiration and passes through a thermophilic stage (Finstein and Morris, 1975). The compost leachate is the liquid that leached from the bottom of the compost reactor (Zhang et al., 2007). Leachates are heavily polluted wastewaters with a complex composition containing four groups of pollutants: Dissolved organic matter, inorganic macro-components, heavy metals, and xenobiotic organic compounds with a foul odor. If the leachate enters the environment without treatment, it will have very unfavorable and irreparable effects on the environment (Amin et al., 2014b; Chen et al., 2008; Luo et al., 2014; Pellera et al., 2016). Nowadays, a lot of research is conducted to find suitable methods for the treatment of leachate (Chen et al., 2008) such as biological processes, chemical oxidation processes, coagulation, flocculation, chemical precipitation, and membrane procedures (Hashemi et al., 2016; Renou et al., 2008). To date, several anaerobic and aerobic processes and tools have been used for leachate treatment such as the followings: up-flow anaerobic sludge blanket reactor, anaerobic filter, hybrid bed reactor, and anaerobic sequencing batch reactor or aerobic processes such as aerated lagoons, conventional activated sludge processes, and sequencing batch reactors (Chen et al., 2008). Anaerobic treatment methods are very suitable for the treatment of concentrated leachate and usually have several advantages such as high organic load, low operating costs, and their capability of biogas production. However, inability to remove nitrogen and long retention time are among the disadvantages of these methods. Aerobic biological systems are suitable for the treatment of quickly biodegradable organic materials with low concentrations, but their need for aeration systems and the production of high levels of sludge are among the disadvantages of this method (Almasi et al., 2014; Amin et al., 2014a, b; Kuscu and Sponza, 2007). Anaerobic migrating blanket reactor (AMBR) system is one of the derivatives of up-flow anaerobic sludge blanket (UASB) system. This anaerobic system which has a high load capacity has several specific characteristics, for instance, it is multi-part, has a continuous flow, short hydraulic retention time, and simple design, does not require a gas-liquid separation system and multiple distribution systems, and does not have wastewater return (Angenent and Sung, 2001; Eslami et al., 2017; Kuşçu and Sponza, 2011). This system was used by the researchers for the treatment of p-nitrophenol (Kuscu and Sponza, 2007), glucose-chemical oxygen demand (Kuşçu and Sponza, 2009b), and nitrobenzene (Kuşçu and Sponza, 2009a).

Nowadays, process modeling methods are widely used to control and predict the performance of anaerobic treatment systems (Abtahi et al., 2013; Alavi et al., 2011). Being familiar with biokinetics is necessary for the design and optimization of biological treatment systems (Hamza et al., 2009). In the present study, AMBR system was used for the treatment of leachate of composting; in addition, to evaluate the kinetics of COD removal by AMBR biological process we used First-order model and Stover-Kincannon model. Moreover, in order to check the kinetic constants of biogas and methane gas production, we used two models including Modified Stover-Kincannon model and Van der Meer and Heertjes model.

## 2. Materials and methods

### 2.1. Experimental set-up and seed

A powered Plexiglas AMBR reactor was used to conduct the experiments. The inflow sample entering the AMBR was real compost leachate with different concentrations. Table 1 presents the characteristics of the examined leachate. We used a rectangular AMBR reactor with internal length, width, and height of 43, 10, and 23.5 cm, respectively, with an efficient capacity of 10 L. Using three vertical Plexiglas plates attached to the bottom of the reactor, the AMBR was divided into four equal units. Keeping a centimeter away from the plates, three Plexiglas plates were hung, so that the hung baffles were 8 inches away from the floor of the reactor; it helped to create a rising and falling flow in various parts of the reactor. In order to mix the materials in the reactor, four mixers (LANDA) equipped with adjustable timer with a rotation of 80 rpm, with a functioning time of 10 s, and a 15-min time-off were used. The mixer installed in the end chamber was off so that to prevent the exit of biomass flocs. The reactor was fed through taking leachate from the reservoir using a peristaltic pump (ETATRON, Italy) with a flow of 1 L within 24 h. Using a tube installed at the top of the reactor, the gas produced from biological interactions was moved outside and was connected to a gas meter to quantitatively analyze the biogas. We used a wet gas meter (Elster, AMCO, Germany).

In order to seed the AMBR reactor, we used anaerobic digester sludge collected from an urban wastewater treatment plant and produced at a temperature of 35 °C. First, using a 2 mm sieve, rubbish and large seeds were separated and then the leachate was injected into the reactor. The amount of TSS and VSS of the sludge were 35,500 mg/L and 26,650 mg/L, respectively.

### 2.2. Reactor start-up

As the organic loading of the leachate was high, first it was diluted extent, and then over time, the amount of dilution was reduced. The maximum level of dilution was performed during the launch of the reactor. The AMBR reactor launch was performed over a period of 40 days and in the first 20 days the mean loading was 500 mg COD/L d while in the second 20 days it was 750 mg COD/L d. At the end of the desired period of time, COD removal efficiency reached 75%.

### 2.3. Operation condition

After launching the reactor and achieving an appropriate COD removal efficiency, the reactor was operated with a load of 1000 mg COD/L d. The flow rate injected into the reactor was 1 L per 24 h. The dilution was decreased over the time and during the 9th round of operation the leachate samples were injected into the reactor without dilution. In the 10th and 11th rounds the input flow was increased to 2 L and the reactor performance was evaluated. Table 2

**Table 1**
Leachate characterization that was collected from compost manufacturer.

| Raw leachate | Range | Average | SD |
|---|---|---|---|
| $BOD_5$ (g/l) | 49–69.5 | 55.2 | 22.76 |
| COD (g/l) | 80–110 | 95.5 | 37.2 |
| TSS (g/l) | 14–17 | 15.5 | 6.3 |
| TDS (g/l) | 28–31.5 | 29.6 | 11.48 |
| TP (g/l) | 0.25–0.35 | 0.28 | 0.01 |
| TKN (g/l) | 1.8–2.8 | 2.3 | 0.07 |
| pH | 3.5–5.5 | 4.4 | 0.33 |
| EC (ms/cm) | 30–37.5 | 33.5 | 13.52 |