Evaluation of bioplastics degradation under simulated landfill conditions

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Introduction

Plastics are affordable, long-lasting and useful polymers and receive widespread daily life attention with their use in various applications (Thompson *et al.*, 2009; Atiwesh *et al.*, 2021). However, their degradation under ambient conditions is very difficult, they remain in the environment for many years causing severe effects on the ecosystem (Singh *et al.*, 2017).

In contrast to the impacts of conventional plastics in the environment, bioplastics have been seen as an alternative solution. Bioplastics are the polymers that comprised of renewable materials and/or can undergo biodegradation or composting (Cucina *et al.*, 2021; Rahman *et al.*, 2021). Among bioplastics, Polylactic acid (PLA) is a biodegradable and compostable polyester that can be derived from the fermentation of any sugar. Literature has a variety of studies on different types of bioplastics and their fate under different conditions. On the other hand, the literature focusing on the fate of these polymers in landfills is very limited. Although there are some studies that were conducted to assess the anaerobic digestion of bioplastics (Cho *et al.*, 2011; Kolstad *et al.*, 2012; Gomez and Michel, 2013; Batori *et al.*, 2018, Ruggero *et al.*, 2019), the behaviour of these polymers in landfills under various stabilization phases and different oxygen conditions has not been specifically investigated. Despite efforts to reduce the utilization of landfilling, it is still the most commonly used waste management method in many developing countries. Therefore, the behaviour of bioplastics in landfills must be enlightened considering their worldwide use. This study aims to evaluate the fate and biodegradability of bioplastics under real landfill conditions considering various landfill stabilization phases.

Material and Methods

Standardized laboratory-scale lysimeter system was constructed and used to determine the biodegradability of the PLA (Temizel *et al.*, 2017). Three reactors with a volume of 70 liters were used for the simulation of different phases of landfill stabilization. Each reactor was loaded with 18 kg of real municipal solid waste (MSW) samples, 1.5 L of seed sludge and two PLA cups. Biogas measurement system was used to monitor the total gas generation. The reactors were placed into the temperature control room and the experiments was started at 25-28°C which was gradually increased by time considering the stimulated phases of landfill stabilization.

All reactors (R1, R2, R3) commenced operation under aerobic conditions at 25-28°C, thus, the first stage of waste stabilization was simulated for each reactor. 500 ml of tap water was added to the reactors on a weekly basis to simulate the average 20 cm/year rainfall in İstanbul. The lids were opened for 30-45 minutes daily to get the reactors be exposed to natural aeration during aerobic phase. After 2-month operation, reactor 1 (R1) was stopped, and the condition of other two reactors (R2 and R3) was converted to semi-aerobic by closing the top lids and partial nitrogen flushing of reactors. Furthermore, the room temperature was adjusted to 35±2°C to provide mesophilic conditions for microbial waste decomposition. Approximately 50 days later, second reactor (R2) was also opened, and the experiment was continued only with the third reactor which was converted to strictly anaerobic by complete nitrogen purge on day 106. The last reactor (R3) was operated for approximately 295 days under anaerobic conditions to simulate anaerobic phase.

Leachate and gas composition analysis were conducted regularly during the experiment to understand the extend of the waste stabilization phases.

At the end of the experiment, the cups were examined using a Scanning Electron Microscope (SEM) to evaluate their ultimate condition. The images of samples were enlarged 1000 to 5000 times for each sample.

Results and Discussion

The magnified images of the surface of PLA cups before the experiment were taken by SEM in order to compare the changes that occurred after each phase. The results obtained from SEM analysis are shown in Figure 1. When the SEM images from each phase are compared, it can be concluded that most of the changes in the surfaces took place during the last phase of waste stabilization (anaerobic phase). SEM results showed that the surfaces of the cups were highly rough and damaged. Deep holes, cracks and cavities were observed on the surface. The results also indicated that PLA cups seemed to undergo biodegradation in aerobic phase more than they did in semi-aerobic phase. This can be a result of additional time given to the aerobic reactor. Initially, MSW in R1 was not unloaded, only the PLA cups were taken out of the reactor for the visual examination. Then, the cups were replaced again in R1 until the end of experiment to understand the impacts of extended aerobic conditions on bioplastics.

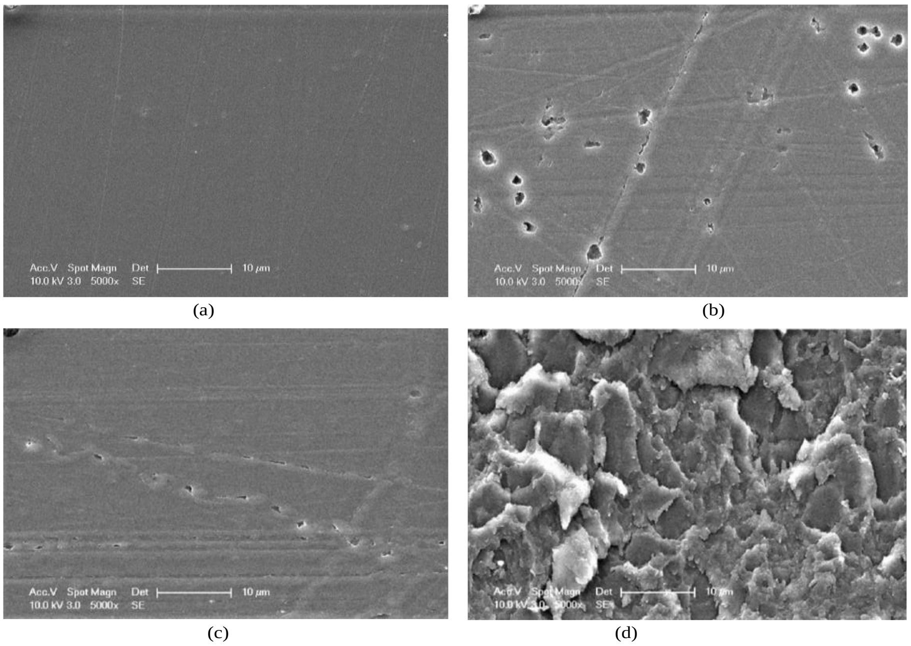

Figure 1. *(a)*PLA cup before the experiment (5000 times magnified) *(b)*PLA cup from R1, Cup1 (5000 times magnified) *(c)*PLA cup from R2, Cup3 (5000 times magnified) *(d)*PLA cup from R3, Cup5 (5000 times magnified)

Conclusions

The uncertainties about the fate of waste bioplastics ending up in landfills increased the need for research on their biodegradability. This study investigated the biodegradability of bioplastics under simulated landfill conditions. Aerobic, semi-aerobic and anaerobic conditions were provided for the appropriate simulation of oxygen levels observed in waste stabilization phases in landfills. According to the results of this study, anaerobic conditions caused visual and microscopic alteration on the surface of bioplastic cups. The cups were much softer and whiter after anaerobic phase, compared to the aerobic and semi-aerobic phases. The damaged and rough surface of the cups was observed by SEM analysis could be attributed to the partial biodegradation of PLA.

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