Anaerobic Biofiltration of Landfill Gas

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ABSTRACT

This study involved the treatment (via a pilot biofilter) of landfill gas containing volatile organic compounds (including sulphur and chlorinated hydrocarbons) and determining the removal efficiency based on optimum pH, concentrations of volatile organic compounds (VOCs), base gases, pressure drop and inlet biofilter flow rates. Also measured and analysed was the reactor Empty bed residence time, and amount of nutrients added to the biofilter. The biofilter reactor was designed to mimic industrial biofilters with parameters chosen to provide optimum removal efficiencies and consisted of a two biofilters arranged in series. The ultimate focus was to design a biofilter that removes the unwanted volatile organic compounds from the high energy value of methane compound in the biofilter and thereby arriving at treated gas containing methane and oxygen for utilization in internal combustion engines. In this study, hydrogen sulfide was entirely removed, achieving a removal efficiency (RE) of 100%. The other target constituents—vinyl chloride, benzene, toluene, n-octane, and n-decane—also demonstrated significant reductions, with removal efficiencies ranging from 20% to 64%, 64% to 80%, 30% to 60%, 55% to 65%, and 45% to 66%, respectively. Biofiltration was chosen over conventional treatment methods, such as catalytic and thermal oxidation technologies, due to the biofilter's simpler construction and cost-effectiveness. The functional values of the biofilter are an Empty Bed Residence Time (EBRT) exceeding 30 seconds and a biofilter medium pH range of 4 to 11.

Keywords: Landfill gas, biogas, vinyl chloride, biofiltration, methane.

1.0. INTRODUCTION

Biogas, also known as landfill gas, is produced by the anaerobic decomposition of industrial or household waste in landfills through the action of microorganisms. This gas is primarily composed of methane, giving it considerable energy potential for use in internal combustion engines or fuel cells. However, it also contains trace amounts of chlorinated volatile organic compounds (VOCs), sulphur compounds, and BTEX (benzene, toluene, ethylbenzene, and xylene). The presence of chlorinated hydrocarbons can present challenges trace amounts of chlorinated volatile organic compounds (VOCs), sulfur compounds, and BTEX (benzene, toluene, ethylbenzene, and xylene). The presence of chlorinated hydrocarbons can present challenges, as their combustion by-products may cause corrosion in internal combustion engines. Similarly, sulfur compounds like hydrogen sulfide (H_2S) can generate toxic and corrosive by-products, such as sulfur dioxide (SO_2) when burned.

Biofiltration has proven effective in degrading persistent chlorinated hydrocarbons, such as tetrachloroethylene, in reactors simulating landfill environments (Schwarz et al., 1999). In one such study, a biofilter employed a bed of granulated activated carbon as the biomass carrier, and operated with an empty bed residence time of 8 minutes. Other studies have also demonstrated the feasibility of methane biofiltration (Nikiema et al., 2005; La et al., 2018). However, the focus has often been on reducing the energy-rich methane content in landfill gas. Before landfill gas can be harnessed effectively for energy generation, the chlorine- and sulfur-containing components must be removed. Biofiltration offers a promising method to eliminate these harmful substances, thereby enhancing the viability of landfill gas as a fuel for energy production (Schwarz, 1999; Nukunya, 2004).

In this study, data was generated over an extended period. The study also explored how biomass growth affected biofilter performance by monitoring head-loss data throughout the filtration period. Also, the nutrient solution was recycled into the filter served as the sole source of water for the biofilter bed. This approach maintained consistent water levels in the biofilter bed while preventing excess moisture from the incoming air, resulting in the biofilter functioning as a semi-biotrickling filter.

The performance of the biofilter was strongly influenced by the pH of the recycled water, which was closely controlled throughout the study. The primary objective was to investigate the biodegradation of selected chlorinated VOCs and hydrogen sulfide (H_2S) in the landfill gas under biofiltration conditions without significantly reducing the methane content. The study utilized two biofilters, initially operating with a retention time of one minute, which was later increased to two minutes to improve vinyl chloride removal. Additionally, a small amount of air was introduced into the second biofilter to enhance the removal efficiency further. The biofilter bed was composed of lava rock particles, similar to those used in previous studies (Ozis, 2007).

2.0 METHODS

2.1 Site description

The selected landfill is located in Riverside, California, with site coordinates at latitude 34.00717 and longitude -117.38677. The primary types of waste deposited at this site were municipal waste and construction materials. By the time the biofiltration field study began, the landfill had been closed for several years, resulting in low gas production, around 200 scfm. The composition of the landfill gas varied, and Table 1 provides a summary of the contaminant concentrations as reported by the County. The gas is pumped by a blower through a condenser to the flare, generating a pressure of approximately 4 inches of H_2O. During the biofiltration field study, a portion of this gas was diverted through the biofilter, located about 10 meters from the flare, before being returned to the landfill line leading to the flare.

2.2 Biofilter operation

Figure 1 shows a flow sheet of the biofilter process. In designing the biofilter, it was considered that chlorinated hydrocarbons are best treated at a neutral pH and under anaerobic conditions. However, sulfur compounds are more effectively degraded in acidic conditions in the presence of oxygen. Based on this, the pH in the first biofilter was allowed to drop to around 5 to 6 in most cases, while the pH in the second biofilter was maintained at 7 to 11 using a buffer solution. The initial inlet flow rate of landfill gas was set at 180 L/min, providing an empty bed residence time of approximately one minute. This flow rate was later reduced to increase residence time and improve the degradation of vinyl chloride. The initial pressure drops in the two biofilters were 1.2 and 0.9 inches of water, respectively, and the inlet gas temperature ranged between 28 and 33°C. The inlet gas was not humidified, but water was continuously supplied to both biofilters via a pump to maintain bed moisture. Additionally, 5 gallons of nutrient solution were added to each biofilter once per month. The pH, pressure drop, and inlet and outlet concentrations in both biofilters were monitored and measured 2 to 3 times a month.

2.3 Analytical Methods

Several analytical techniques were employed to measure the concentration of compounds within the biofilter as described in section 2.3.1 below. Additionally, the pH of the recirculated nutrient solution entering the biofilter, as well as the pressure drop across each biofilter, were measured. These parameters are crucial for evaluating the biological activity inside each biofilter and understanding the prevailing experimental conditions.

2.3.1 Concentration measurements

The compounds were categorized into fixed gases (oxygen, nitrogen, methane, and carbon dioxide) and VOCs, with hydrogen sulfide also analyzed. A gas chromatograph (HP-6890) coupled with a mass spectrometric detector was used to determine their concentrations. An HP-624 column, measuring 25 m by 200 µm, was employed, with helium as the carrier gas at a flow rate of 13.3 mL/min. The oven temperature profile started at 35°C and increased to 180°C, with a ramp rate of 8°C/min and a 4-minute hold time. A split/splitless injector, set to 210°C, was used for the analysis, with a split ratio of 1:1 for VOCs and 1:20 for hydrogen sulfide.

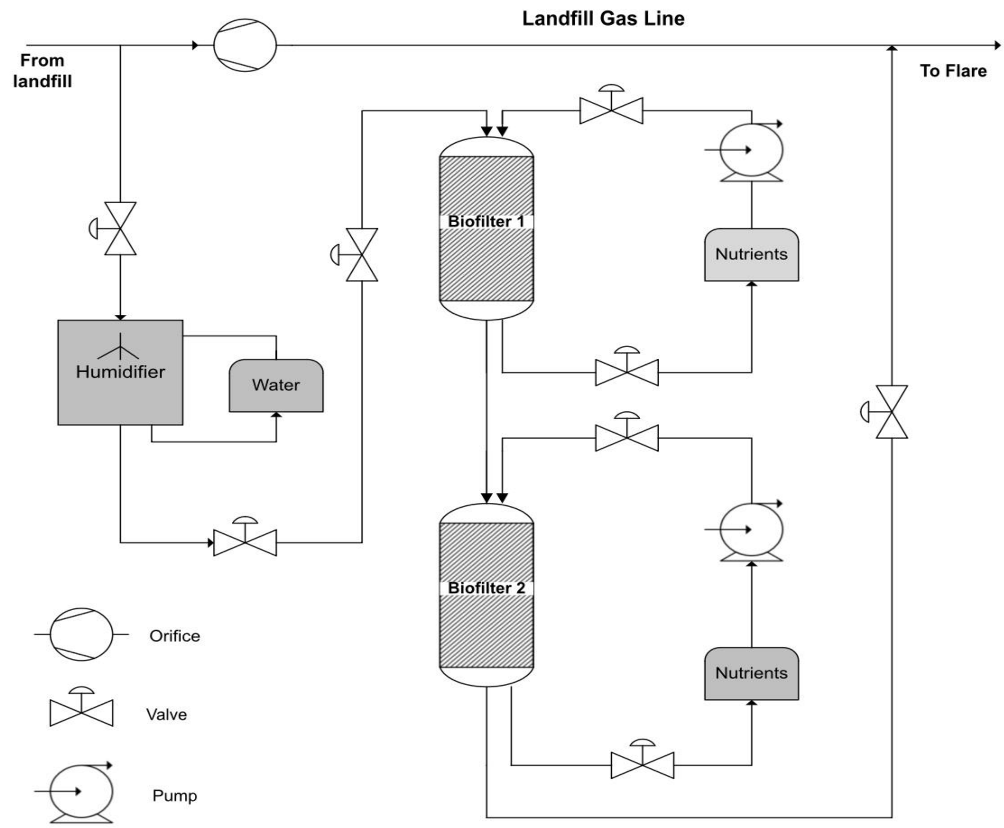

Figure 1: Flow sheet of the biofilter system for the treatment of landfill gas

2.3.2 Back-pressure measurements

The pressure-drops developed across each biofilter were measured by a water manometers attached to the respective biofilter (BF-1 and BF-2). This represented the pressure drop.

2.3.3 pH measurements

A 100 ml sample of water was collected from the reservoir, and its pH was measured using a Cole Palmer pH meter (model 1986-60) and recorded.

Compound	Concentration
1,1,1-trichloroethane 1	3.25 ppb
1,1-dichloroethane	14.2 ppb
1,2-dichlorocthane	8.18 ppb
acetonitrile	8.12 ppb
benzene	166 ppb
benzyl chloride	20 ppb
carbon dioxide	33.2%
carbon tetrachloride	3 ppb
chlorobenzene	20 ppb
chlorofonn	4 ppb
dichlorobenzene	35.3 ppb
dichloromethane	11.3 ppb
hydrogen sulfide	15.4 ppb
methane	44.3%
nitrogen	21.3%
oxygen	0.81%
tetrachloroethane	52.9 ppb
toluene	1710 ppb
trichloroethane	67.7 ppb
vinyl chloride	4200 ppb
xylene	1782 ppb

Table 5.1: Typical Concentration of landfill gas at the West Riverside Landfill

3.0 RESULTS AND DISCUSSIONS

The landfill gas was initially passed through two biofilters with an Empty Bed Residence Time (EBRT) of 60 seconds, and later increased to 120 seconds to enhance the removal efficiency of volatile organic compounds (VOCs). The flow rate entering the biofilters was monitored using the pressure difference measured across an orifice meter and displayed on a U-tube manometer. As shown in Figure 2, fluctuations in EBRT are observed, attributed to the non-uniform production and flow rate of landfill gas.The removal efficiencies (RE) of VOCs and hydrogen sulfide were calculated using the following formula:

$$\mathrm{RE} = \frac{c_{in} - c_{out}}{c_{in}} \quad (1)$$

Figure 3 illustrates the Removal Efficiency (RE) of the fixed gases, including oxygen, nitrogen, methane, and carbon dioxide. It is evident that methane, carbon dioxide, and nitrogen were not significantly removed, while oxygen exhibited a higher RE (between 33% and 71%), indicating aerobic biodegradation of VOCs. The removal efficiency of hydrogen sulfide was excellent, as depicted in Figure 4, with complete removal in the first biofilter. This high removal rate is likely due to the preference of microorganisms to degrade hydrogen sulfide in the limited presence of oxygen, rather than methane.The maximum RE for other VOCs ranged from 61% for n-decane (Figure 6), 57% for toluene (Figure 5), and up to 83% for benzene (Figure 5). Favorably high biodegradation of vinyl chloride is known to occur in the presence of methane and has been observed to peak at 61% in our work.

The higher RE of benzene compared to toluene and n-decane can be attributed to the lower initial concentration of benzene, as toluene concentrations were approximately ten times higher (Table 1). This means that a larger population of microorganisms is required to degrade toluene. Overall, the relatively low RE for VOCs was linked to the low EBRT and limited oxygen concentration. To address this, after 45 days, the EBRT was increased, and additional oxygen was supplied to the second biofilter after 60 days of operation. These changes led to a significant improvement in RE, including achieving a 61% RE for vinyl chloride. Figure 7 shows a steady increase in relative pressure drop as biodegradation proceeded, with biomass accumulation in the pores of the lava rock biofilter causing increased head loss. Figure 8 demonstrates the pH decline over time, starting neutral in both biofilters but becoming more acidic, particularly in the first biofilter where hydrogen sulfide removal primarily occurs.

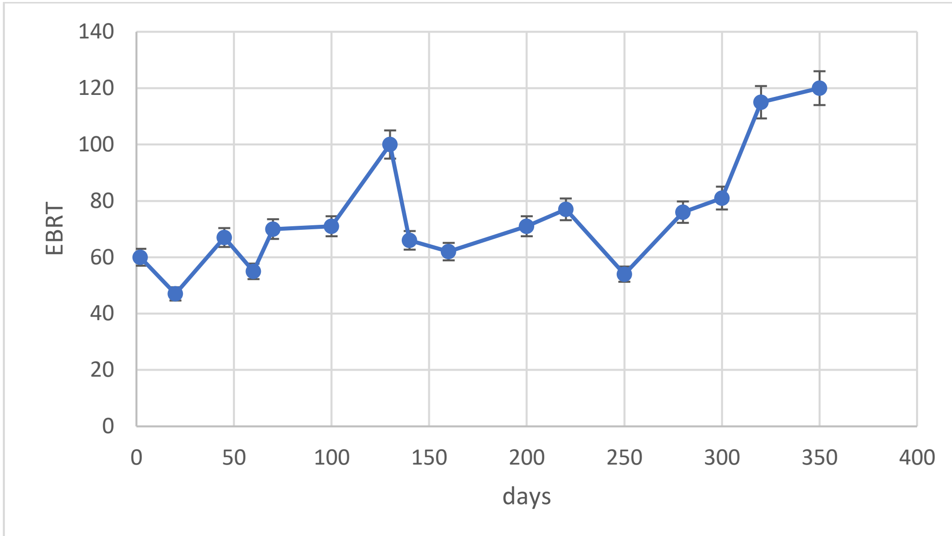

Figure 2: The empty bed residence time during the run

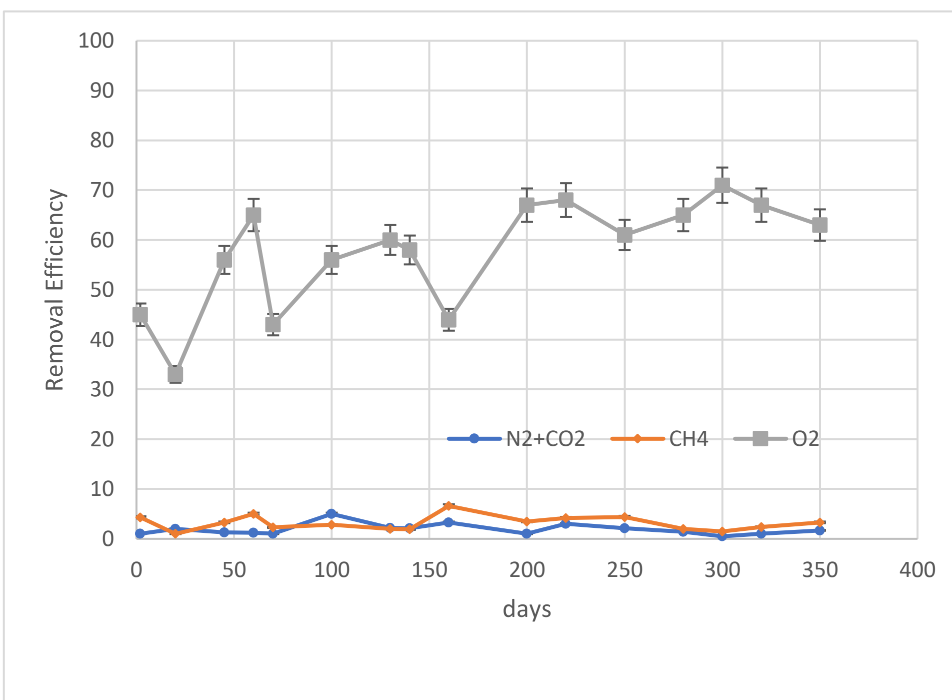

Figure 3: Removal efficiencies of fixed gases

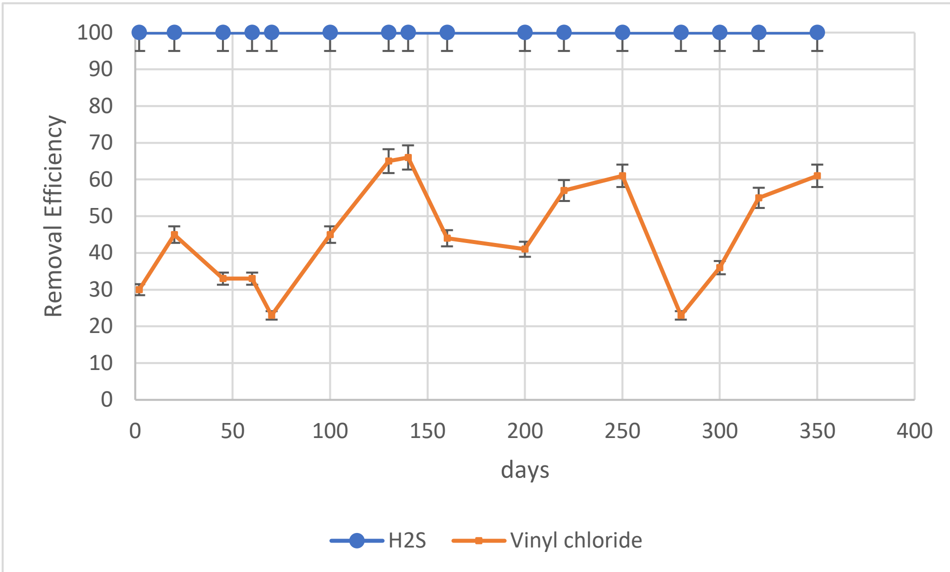

Figure 4: Removal efficiency of vinyl chloride and hydrogen sulfide

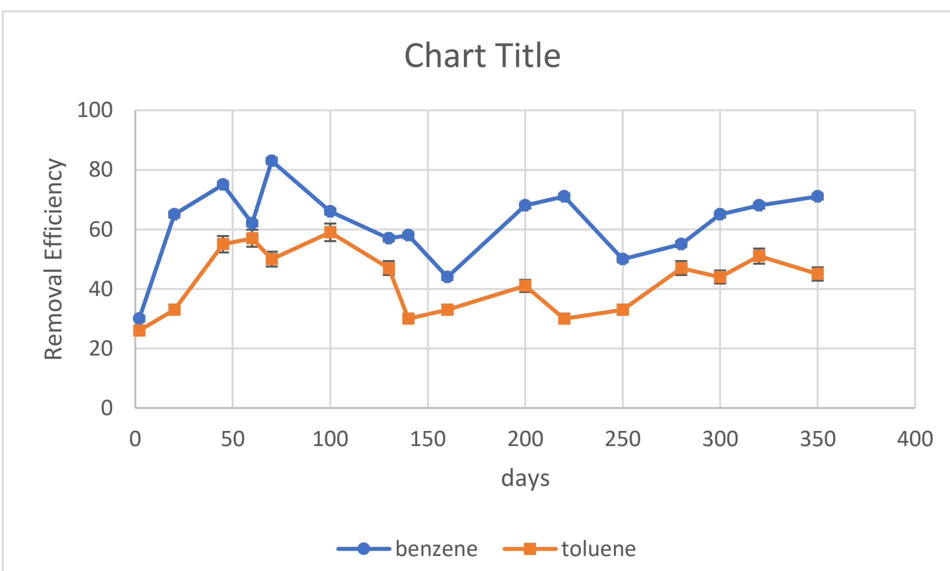

Figure 5: Removal efficiency of benzene and toluene

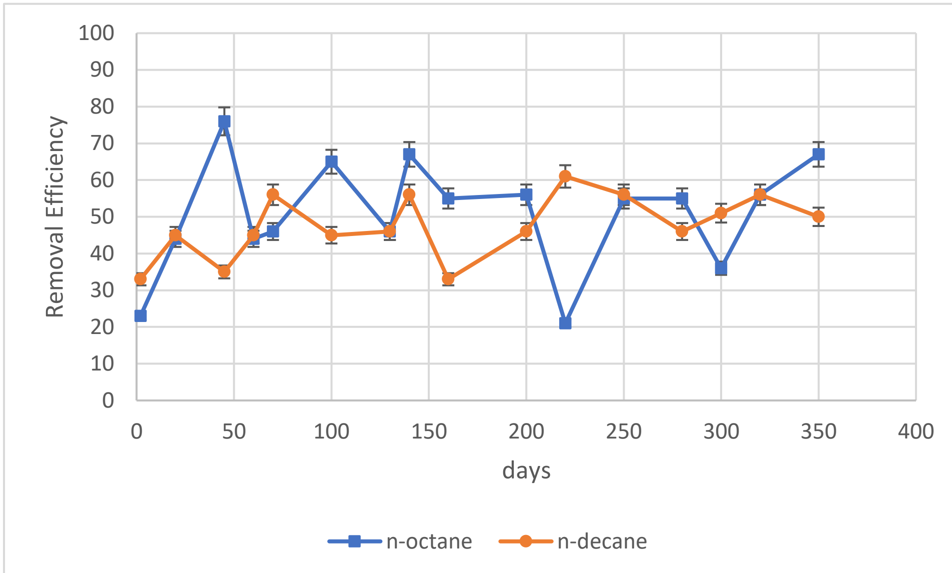

Figure 6: Removal efficiency of n-octane and n-decane

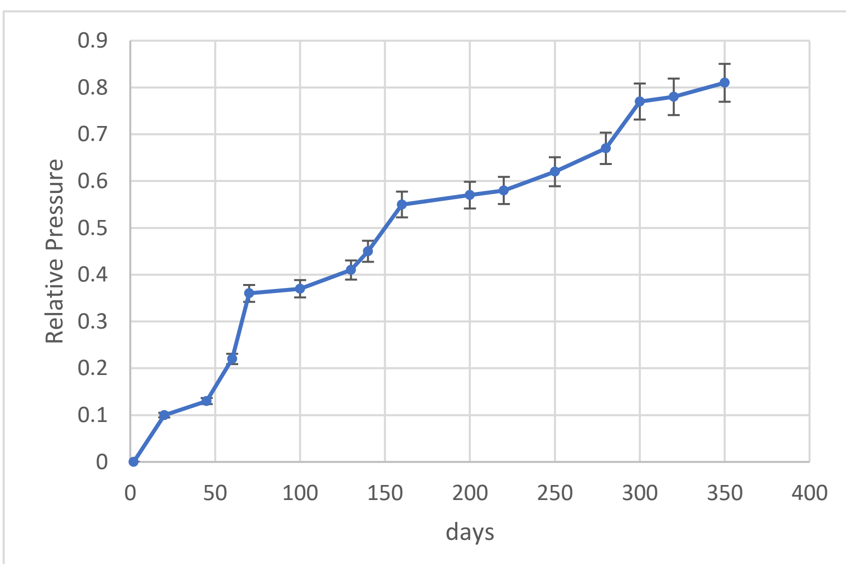

Figure 7: Overall pressure drop developed in biofilter 1 and 2

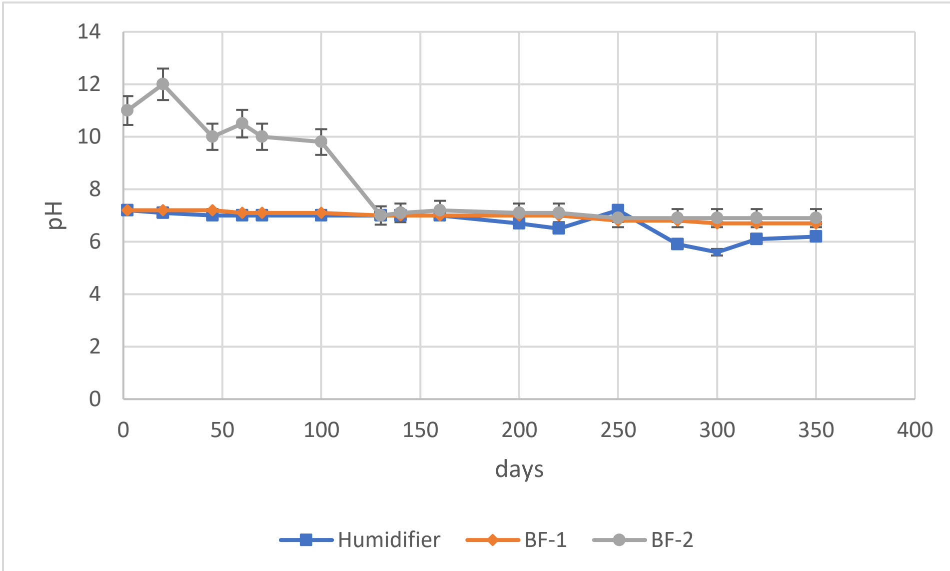

Figure 8: pH changes in recycle water to biofilter- and biofilter-

4.0 CONCLUSIONS

Hydrogen Sulfide and benzene were degraded successfully. It can also be concluded that addition of oxygen and an increase in EBRT improves the RE, which indicates that with the right choice of EBRT, the removal efficiencies of the other VOC may be improved. Because methane is not degraded significantly, biofiltration of landfill gas shows promise as a clean-up technology for its use as a fuel.

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